National Association of Broadcasters

ENGINEERING HANDBOOK

SIXTH EDITION

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Vice President for Engineering

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TO THE PROFESSIONAL BROADCAST ENGINEER

Whose adherence to sound engineering principles has created a superb broadcast system in the United States of America

"The electromagnetic spectrum is as vital to our national prosperity—and our ultimate survival—as any other natural resource. In trying to capture in one volume the expertise and know-how necessary to understand the countless applications of radio energy in today's ever-changing world, the NAB *Engineering Handbook* provides a unique challenge for broadcast engineers to continue to explore the vast potential of radio and television for public service while encouraging creative technical innovations that will give scope to the almost inconceivable variety that characterizes broadcasting in America."

VINCENT T. WASILEWSKI
President, National Association of Broadcasters

Foreword

Modern engineering has been expanding explosively. This has been evident in all fields, particularly in communication, including broadcast engineering. Cut and try experimentation, so productive in the early period of development, has now been replaced by designs of antennas, transmitters, associated equipment, and interconnections based upon a thorough understanding of the principles involved. During the past two decades, the usable spectrum has been expanded to include a portion of the needs for frequency modulation and television, but these needs have expanded even faster than the available bands. Whenever needs increase faster than resources, advanced engineering must be applied to insure the most adequate service available within the limitations imposed by nature (or man).

In order to serve the wide range of modern technology, engineers must be educated first in fundamentals common to many applications. This is the primary function of the engineering school. But as society demands ever more sophisticated and elaborate systems to meet its needs, each segment of our complex economy must develop means for continuing the education of practicing engineers into the more advanced principles and specialized applications peculiar to that section of industry. I want to congratulate the broadcasting industry on the fact that, through its organization, The National Association of Broadcasters, it is providing a most convenient means for keeping its own practicing engineers abreast of the latest developments by the publication of this new edition of the *NAB Engineering Handbook*. The several sections have been written by outstanding authoritative leaders in each appropriate field. It should go far toward insuring that the best engineering practices are put into effect throughout the industry.

I know of no other group where cooperation in the technical field has been more general. It is a record of which the industry should be proud. This handbook is another milestone in technical cooperation and in the literature of its field.

W. L. Everitt
Dean of Engineering
University of Illinois

Preface

The fundamental purpose of this *Handbook* is to present in one volume a logical treatment of the broadcast system, both radio and television, stressing the practical aspect and the type of information that often is passed along from person to person with no concrete basis for evaluation. In addition, there is great need for authoritative information on the application of more recently developed methods and techniques. Much of the basis for the contents of this *Handbook* was provided by many years of correspondence with broadcast engineers relative to their problems in the field. Although theory and mathematics have been included where necessary, the practical, operational aspects have received greatest attention. Theoretical treatment of the various subjects can be found in numerous textbooks readily available. Although this *Handbook* has been prepared primarily in the interests of the member stations of the National Association of Broadcasters, it will be available to everyone. The many peculiar engineering problems encountered in foreign countries have been taken into account insofar as possible, without specifically delineating them.

To obtain maximum uniformity, emphasis, and coherence, the *Handbook* treats subjects in a logical sequence beginning with the Antenna, Wave Propagation, and Field-strength Measurements, then proceeding to the Tower Structure, Transmission Lines, Transmitters, Studio-Transmitter Links, Studios and Equipment, Remote Pickup Facilities, Networking Facilities, and Recent Techniques. Obviously, a complete volume could be written on any one of these topics. Consequently, the treatment was designed to cover the type of problem and situation that is both fundamental in nature and unusual in circumstances. It has been paramount throughout this Handbook to avoid the type of information contained in equipment technical manuals.

Any attempt to deal with a broadcast system for both radio and television inevitably omits certain information that some engineers would like to have covered. This was considered and resulted in the conclusion that certain limitations had to be accepted: It was also impossible to include complete information on certain subjects because of the current status of development and standardization. There has been no vigorous scrutiny to avoid duplication, but very little occurs throughout the Handbook. In any manuscript and its processing into a Handbook, errors inevitably occur, although every attempt has been made to eliminate them. The editor will appreciate having them called to his attention when noticed.

To all the contributing authors and organizations, the NAB extends its sincere thanks and at the same time apologies for often demanding a great deal in a short period of time. Their patience, cooperation, and willingness to prepare their material while performing their regular duties deserves high praise and appreciation.

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FCC Administrative Procedures for AM, FM, TV, and Related Services

GENERAL

Any qualified citizen, firm, or group may apply to the Federal Communications Commission for authority to construct a standard (AM), frequency modulation (FM), or television (TV) broadcast station.

Licensing of these facilities is prescribed by the Communications Act of 1934, as amended, which sets up certain basic requirements. In general, applicants must satisfy the Commission that they are legally, technically, and financially qualified, and that the operation of the proposed station would be in the public interest.

The licensing procedure is detailed in Part 1 of the Commission's rules, "Practice and Procedure." Station operation is covered by Part 73 "Radio Broadcast Services." This includes technical standards for AM, FM, and TV stations, and TV and FM channel (frequency) assignments by states and committees. Copies of these rules are available from the Government Printing Office, Washington, D.C.

Most applicants employ engineering and legal services in preparing their applications. The Commission does not make technical or other special studies for prospective applicants nor does it recommend individual lawyers or engineers. However, names of firms and individuals practicing before the Commission may be found in various trade publications.

The following is a summary of the consecutive steps to be followed in applying for authorization to build and operate a broadcast station. The application procedure is substantially the same whether the facility sought is AM, FM, or TV.

SELECTING A FACILITY

An AM applicant must make his own search for a frequency on which he can operate without causing or receiving interference from existing stations and stations for which applications are pending. AM broadcast stations operate on "local," "regional," or "clear" channels. Stations of 250-watt power for nighttime broadcasting and up to 1-kilowatt daytime broadcasting serve small communities; stations of 500-watt to 5-kilowatt power cover centers of population and surrounding areas; stations of 10- to 50-kilowatt power are for large area coverage, particularly at night.

An FM station applicant must request an FM channel assigned to the community in which he proposes to operate, or a place within a 10-mile radius (for Class A FM stations) or a 15-mile radius (for Class B or Class C FM stations), which has no FM channel assignment. Power, antenna height, and station separation are governed by the zone in which the station is located.

There are three classes of commercial FM stations and three zones. Class A stations use power from 100 watts to 3 kilowatts to cover a radius of about 15 miles; Class B stations, 5 kilowatts to 50 kilowatts for 40-mile service and Class C, 25 kilowatts to 100 kilowatts for 65-mile range.

Noncommercial educational FM stations are in a separate category and may operate with power as low as 10 watts. Commercial and educational FM stations may apply for a "Subsidiary Communications Authorization" (Form 318) to furnish certain supplemental services. FM stations may engage in stereophonic broadcasting, for which no special application is required.

An applicant for a TV station must request a VHF (Very High Frequency) or a UHF (Ultra High Frequency) channel assignment to the community in which he proposes to operate, or a place having no channel assignment within 15 miles of that community. Power depends upon the kind of channel used (VHF or UHF), and station separation is determined by three zones. TV "translator" stations serve remote communities by picking up and rebroadcasting the programs of outside stations, with the latter's permission. They operate on any VHF channel or on any unassigned UHF channel between 55 and 69, or on any assigned channel. Certain channels are assigned for noncommercial educational TV operation. There is a "Community Antenna Relay Service" for noncommon carrier microwave facilities to relay TV signals to community antenna (CATV) systems.

APPLYING FOR A CONSTRUCTION PERMIT

After a prospective broadcaster has decided upon the type of station he desires and the place where it would be located, he should ascertain the programming needs of the locality he intends to serve and devise plans to meet these needs. The next step is to apply for a construction permit. This is done on FCC Form 301, "Application for Authority to Construct a New Broadcast Station or Make Changes in an Existing Station," which covers AM, FM, or TV broadcast, except educational applications which use FCC Form 340, FM and TV translators (Form 346), and FM booster stations (Form 349P). These forms require information about the citizenship and character of the applicant, as well as his financial, technical, and other qualifications, plus details about the transmitting apparatus to be used, antenna, and studio locations, and the service proposed. Commercial broadcast applicants are required to show their financial ability to operate for one year after construction of the station. Triplicate copies are required. Nonprofit educational institutions apply for new or changed instructional TV fixed stations on Form 330-P.

APPLICANTS MUST GIVE LOCAL NOTICE

Applicants for new broadcast stations, license renewals, station sales, or major changes in existing stations must give local public notice of their plans and also of any subsequent designation of their applications for hearing. This is done over the applicant's local station (if any) and by advertising in the local newspaper. It affords interested persons an opportunity to comment on these applications to the Commission. Applicants and stations must also maintain public reference files in their respective localities.

APPLICATION PROCESSING

All broadcast applications (except translators) are reported twice by the Commission—first when the application is received and, again, when the application is formally accepted for filing. An application is not acted upon until at least 30 days after the Commission gives public notice of its acceptance. During that time objecting petitions may be filed.

Competing AM applications may be filed up to a date in a notice of AM applications ready for processing. It usually is about 30 days following that notice. Competing FM and TV applications may be filed up to the day the initial application is ready for Commission consideration.

Applications are, in general, processed in the order in which accepted. They are reviewed for engineering, legal, and financial data by the Broadcast Bureau which, under delegated authority from FCC, acts on routine applications and reports to the Commission applications involving policy or other particular considerations. If an application has no engineering or other conflicts and no valid protests have been received, the applicant is found qualified. Assuming all other requirements are met, the application may be granted without hearing and a construction permit issued. All such grants are announced by the Commission. Petitions for reconsideration of grants made without hearing can be filed within 30 days after the grant is made, however, petitioners must give valid reasons why these objections were not raised before the grant was made.

HEARING PROCEDURE

Where it appears that an application does not conform to the Commission's rules and regulations, that serious interference would be caused to another station or if other serious questions of a technical, legal, or financial character develop, a hearing is usually required. The Commission must accord a hearing if two or more competing applicants seek the same frequency or immediately adjacent frequency which could cause interference, before the Commission renders its decision.

In designating an application for hearing, the Commission gives public notice of the issues for the information of the applicant and others concerned. The hearing notice generally allows the applicant 60 days or more in which to prepare. Even after the hearing has been set, an applicant may amend his application to resolve engineering or other problems. (Commission approval is required for all mergers or situations in which a competing applicant withdraws on payment of expenses.)

Hearings on competing applications are normally held at the Commission's Washington offices. Hearings on license revocations and renewals are held in the communities affected.

Hearings are customarily conducted by an examiner. He has authority to administer oaths, examine witnesses, and rule upon the admission of evidence. A prehearing conference is held to reach agreement on procedural matters.

Within 20 days after the close of a record by the hearing examiner, each party and the Chief of the Broadcast Bureau of the Commission can file proposed findings of fact and conclusions to support their contentions. After review of the evidence and statements, the hearing examiner issues an initial decision.

If the applicant wishes to contest the initial decision, he or any other interested party has 30 days from the date on which the initial decision was issued to file exceptions. In all cases heard by an examiner, the Commission, or its Review Board may hear oral argument on timely request of any party. After oral argument, the Commission or the Review Board may adopt, modify, or reverse the hearing examiner's initial decision. In cases where the Review Board has acted on the exceptions, an appeal of the Board's decision may be taken to the Commission within 30 days. The Commission may, however, deny an appeal for review without stating reasons for such action.

Court appeals can be taken within 30 days following release of the final decision, in which case the Commission's action is stayed pending court determination.

CONSTRUCTION PERMIT

When an application is granted, a construction permit is issued. The new permittee may then request call letters which, if available and conforming to the rules, are issued. A period of 60 days from date of the construction permit is provided in which construction shall begin, and a maximum of six months thereafter as the time for completion (or eight months in all). Application to make changes in an existing station is made on the same form used in seeking initial construction authorization (Form 301). Application to modify a broadcast construction authorization or to modify a license is made on Form 301-A "Request for Modification of Broadcast Station Authorization." If the permittee is unable to build his station within the time specified, he must apply for extension of time on Form 701 ("Application for Additional Time to Construct a Radio Station"), giving reasons. Upon completion of construction the permittee conducts equipment (not program) tests.

LICENSE

Original

The final step in obtaining permission to operate a station is to apply for the actual license on Form 302 ("Application for New Broadcast Station License"), or Form 341 (for Noncommercial Educational FM stations), Form 347 (for TV and FM translators), or Form 349L (for FM boosters). Applicants must show compliance with all terms, conditions, and obligations set forth in the original application and the construction permit. Not until he applies for a license can the holder of a construction permit request authority to conduct program tests. The license application form provides a space for program test requests, or it can be made separately. A station license and program test authority are issued if no new cause or circumstance has come to the attention of the Commission that would make operation of the station contrary to public interest.

Renewal

Applicants for renewal of station license must show that they have operated according to the terms of their original authorizations and the promises they made in obtaining them. Most renewal applications are made on Form 303 ("Application for Renewal of Broadcast Station License"). Noncommercial educational licensees, however, use Form 342; TV and FM translators Form 348 and FM boosters Form 349R. Pending the disposition of any Commission hearing or other proceeding involving license renewal or revocation considerations, the station continues to operate even though its license term may have expired.

SALES AND TRANSFERS

If the holder of a construction permit or license desires to assign it to someone else, he makes application on Form 314 ("Application for Consent to Assignment of Radio Broadcast Station Construction Permit or License"). Should the permittee or licensee wish to transfer corporate control, he applies on Form 315 ("Application for Consent to Transfer Control of Corporation Holding Radio Broadcast Station Construction Permit or License"). Form 316 ("Application for Assignment or Transfer—Short Form") may be used when the transfer or assignment involves no substantial change in interest. Sales of stations held less than three years are subject to hearing except in cases of death, hardship, or other mitigating circumstances beyond the licensee's control.

CONSTRUCTION CHANGES

Applicants for authority to make construction changes in existing stations apply on the same form used for a construction permit for the type of station involved.

APPLICATION FEES[1]

Since March 17, 1964, the Commission has charged fees for most application filings in order to comply with government policy to charge for certain federal services. On July 1, 1970, a new fee schedule was adopted for broadcast stations, which includes three types of charges: (1) a filing fee (the only type of fee previously charged) payable when the application is tendered; (2) a

[1] The fee schedule is continually revised. See the Commission's rules for the current schedule.

grant fee, payable when the application is granted; and (3) an annual operating fee, paid by all commercial AM, FM, and TV stations, in lieu of the renewal application fee previously charged. Application filing fees for construction permits, generally considerably higher than those previously charged, vary with the type of station, from $25 for a daytime-only 250-watt nondirectional AM station permit and $100 for a Class A FM, to $5,000 for a VHF TV permit in the top-50 markets (in TV, though not in radio, fees vary with market size; top 50, next 50, and other; and there is also a VHF-UHF difference). An extra filing fee of $50 is charged for a directional antenna application. Applications for major changes are charged the same fee as those for new stations. The grant fee is charged on the same scale, nine times the amount of the application fee. For assignments of licenses and transfers of control (other than involuntary transfers), the filing fee is $1,000 (per license) and the grant fee is two percent of the consideration (selling price) for the assignment or transfer, payable on consummation. The annual operating fee is based on a station's highest commercial announcement rate: in AM and FM, the highest one-minute rate multiplied by 24 and in TV the highest 30-second rate multiplied by 12, with a minimum of $52 in radio and $144 in television. Most "other" applications, such as for covering licenses and minor changes, entail a filing fee of $50 and no grant fee; requests for important Special Temporary Authorizations (STAs) or waiver of the rules in the broadcast services require a filing fee of $50 and a grant fee of $25; involuntary assignments or transfers of control require a filing fee of $250 (per station where more than one is involved) and no grant fee; and applications for subscription television authorizations entail a $1,000 filing fee but no grant fee.

Translators and noncommercial educational stations are exempt from fees. In adopting the new fee schedule, the Commission recognized that the amont of fee for assignment/transfer grants—two percent of consideration—may be difficult to determine where the consideration includes elements other than cash or property with an ascertainable market value. The Commission stated that a rule of reason would be followed. In difficult cases, parties are invited to consult with Commission personnel with respect to the value to be attributed.

August 1, 1970, was the generally effective date of the new schedule. Grant fees were not charged where the application was on file before July 1, 1970. The annual operating fee for broadcast stations is due each year on the anniversary of the station's license expiration date. For the first year, the fee will be a *pro rata* share of the annual fee from August 1, 1970.

The fee schedule will be subject to continuing review, to determine whether changes in overall or comparative levels are in order.

PRINTED RULES

FCC rules may be obtained only through the Government Printing Office, Washington, D.C. 20402. The rules on FCC practice and procedure are contained in Volume I, which is available for $8.00 per copy; the broadcast rules are contained in Volume III, for $18.50. Orders should be sent to the Government Printing Office direct (not through the FCC). The printed rules are sold on a subscription basis, which entitles the purchaser to receive subsequent amendments to the rule part purchased until an overall revised issue is printed.

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Frequencies Used by the Broadcast Service

STANDARD BROADCAST (AM) STATIONS

Classes and Power of Standard Broadcast Stations[1]

(a) *Clear channel.* A clear channel is one on which the dominant station or stations render service over wide areas, and which are cleared of objectionable interference within their primary service areas and over all or a substantial portion of their secondary service areas. Stations operating on these channels are classified as follows:

(1) *Class I station.* A Class I station is a dominant station operating on a clear channel and designed to render primary and secondary service over an extended area and at relatively long distances. Its primary service area is free from objectionable interference from other stations on the same and adjacent channels, and its secondary service area free from interference except from stations on adjacent channels, and from stations on the same channel in accordance with the channel designation in Sections 73.25 or 73.182 FCC Rules and Regulations. The operating power shall not be less than 10 kilowatts nor more than 50 kilowatts.

(2) *Class II station.* A Class II station is a secondary station which operates on a clear channel (see Section 73.25) and is designed to render service over a primary service area which is limited by and subject to such interference as may be received from Class I stations. Whenever necessary a Class II station shall use a directional antenna or other means to avoid interference with Class I stations and with other Class II stations, in accordance with Section 73.182 (and Section 73.22 in the case of Class II-A stations). Class II stations are divided into three groups:

(i) *Class II-A station.* A Class II-A station is an unlimited time Class II station operating on one of the clear channels listed in Section 73.22 and assigned to a community within a state specified in the Table contained in that section. A Class II-A station shall operate with power of not less than 10 kilowatts nighttime nor more than 50 kilowatts at any time.

(ii) *Class II-B station.* A Class II-B station is an unlimited time Class II station other than those included in Class II-A. A Class II-B station shall operate with power not less than 0.25 kilowatts nor more than 50 kilowatts.

(iii) *Class II-D station.* A Class II-D station is a Class II station operating daytime or limited time. A Class II-D station shall operate with power not less than 0.25 kilowatts nor more than 50 kilowatts.

(b) *Regional channel.* A regional channel is one on which several stations may operate with powers not in excess of 5 kilowatts. The primary service area of a station operating on any such channel may be limited to a given field intensity contour as a consequence of interference.

(1) *Class III station.* A Class III station is a station which operates on a regional channel and is designed to render service primarily to a principal center of population and the rural area contiguous thereto. Class III stations are subdivided into two classes.

(i) *Class III-A station.* A Class III-A station is a Class III station which operates with power not less than 1 kilowatt nor more than 5 kilowatts and the service area of which is subject to interference in accordance with Section 73.182.

(ii) *Class III-B station.* A Class III-B station is a Class III station which operates with power not less than 0.5 kilowatt nor more than 1 kilowatt night and 5 kilowatts daytime, and the service area of which is subject to interference in accordance with Section 73.182.

(c) *Local channel.* A local channel is one on which several stations operate with powers no greater than provided in this paragraph. The primary service area of a station operating on any such channel may be limited to a given field intensity contour as a consequence of interference. Such stations operate with power no greater than 250 watts nighttime, and no greater than 1 kilowatt daytime (except that for stations in an area in the State of Florida south of the parallel 28° north latitude, and between the

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[1] All section numbers refer to the FCC Rules and Regulations used by the Broadcast Services.

meridians 80° and 82° west longitude, power is limited to 250 watts, daytime and nighttime).

(1) *Class IV station.* A Class IV station is a station operating on a local channel and designed to render service primarily to a city or town and the suburban and rural areas contiguous thereto. The power of a station of this class shall not be less than 0.25 kilowatt, and not more than 0.25 kilowatt nighttime and 1 kilowatt daytime, and its service area is subject to interference in accordance with Section 73.182. Stations which are licensed to operate with 100 watts day or night may continue to do so.

Assignment of Class II-A Stations

(a) *Table of assignments.* One Class II-A station may be assigned on each channel listed in the following table within the designated State or States:

Channel (kHz)	Location of existing Class I station	State(s) in which Class II-A assignment may be applied for
670. . .	Chicago, Ill.	Idaho.
720. . .	Chicago, Ill.	Nevada or Idaho.
780. . .	Chicago, Ill.	Nevada.
880. . .	New York, N.Y. .	North Dakota, South Dakota, or Nebraska.
890. . .	Chicago, Ill.	Utah.
1020. .	Pittsburgh, Pa. . . .	New Mexico.
1030. .	Boston, Mass. . . .	Wyoming.
1100. .	Cleveland, Ohio . .	Colorado.
1120. .	St. Louis, Mo. . . .	California or Oregon.
1180. .	Rochester, N.Y. .	Montana.
1210. .	Philadelphia, Pa. .	Kansas, Nebraska, or Oklahoma.

(b) *Minimum service to "white" areas.* No Class II-A station shall be assigned unless at least 25 percent of its nighttime interference-free service area or at least 25 percent of the population residing therein receives no other interference-free nighttime primary service.

(c) *Power.* Class II-A stations shall operate with not less than 10-kilowatt power nighttime.

(d) *Protection.* (1) *Protection by Class II-A stations to other stations.* The co-channel Class I-A station shall be protected by the Class II-A station to its 0.1 mv/m contour daytime and its 0.5 mv/m 50 percent skywave contour nighttime. All other stations of any class authorized on or before October 30, 1961, shall normally receive protection from objectionable interference from Class II-A stations as provided in Section 73.182.

(2) *Protection to Class II-A stations.* A Class II-A station shall normally receive daytime protection to its 0.5 mv/m groundwave contour and nighttime protection to the contour to which it is limited by the co-channel Class I-A station.

(e) *Applications not complying with this section.* Applications for Class II-A stations which do not meet the requirements stated under Minimum Service and Power sections will be returned without further consideration.

Time of Operation of Standard Broadcast Stations

The several classes of standard broadcast stations may be licensed to operate in accordance with the following:

(a) Unlimited time permits operation without a maximum limit as to time.

(b) Limited time is applicable to Class II (secondary) stations operating on a clear channel with facilities authorized before November 30, 1959. It permits operation of the secondary station during daytime, and until local sunset if located west of the dominant station on the channel, or if located east thereof, until sunset at the dominant station, and in addition during night hours, if any, not used by the dominant station or stations on the channel.

(c) Daytime permits operation during the hours between average monthly local sunrise and average monthly local sunset.

(d) Sharing time permits operation during hours which are so restricted by the station license as to require a division of time with one or more other stations using the same channel.

(e) Specified hours means that the exact operating hours are specified in the license. Specified hours stations operating on local channels, except those sharing time with other stations may operate at hours beyond those specified in their licenses to carry special events programming. To the extent that such operation is conducted during the nighttime hours, the station's authorized nighttime facilities must be used.

Minimum Operating Schedule

(a) All standard broadcast stations are required to maintain an operating schedule of not less than two-thirds of the total hours they are authorized to operate between 6 a.m. and 6 p.m., local time, and two-thirds of the total hours they are authorized to operate between 6 p.m. and midnight, local time, each day of the week except Sunday: *Provided, however,* that stations authorized for daytime operation only need to comply with the minimum requirement for operation between 6 a.m. and 6 p.m.

AM/FM SECTION

Frequencies Used for Standard Broadcast Stations

The band 535-1605 kHz is used for standard broadcasting. It is divided into 107 channels of 10 kHz each. Following is a list of standard broadcast channels and the conditions under which each may be used in the United States. For further reference and additional information, see FCC Rules, and the 1950 North American Regional Broadcast Agreement.

Channel	*Classification*	*NARBA Class I Priority*	*Use Under FCC Rules*	*See Footnotes*
540	Clear	Canada (I-A) Mexico (I-A)	II	(2) (3) (12) (14) (21)
550	Regional	Cuba (I-C)	III-A, III-B	(4) (5) (11)
560	Regional		III-A, III-B	(4) (11)
570	Regional	Cuba (I-D)	III-A, III-B	(4) (7) (11)
580	Regional		III-A, III-B	(4) (11)
590	Regional	Cuba (I-D)	III-A, III-B	(4) (7) (11)
600	Regional		III-A, III-B	(4) (11)
610	Regional		III-A, III-B	(4) (11)
620	Regional	Dominican Republic (I-C)	III-A, III-B	(4) (5) (11)
630	Regional	Cuba (I-D)	III-A, III-B	(4) (7) (11)
640	Clear	USA (I-A) Canada (I-B) Cuba (I-C)	I, II	(5) (6) (8) (9) (10) (19) (22) (26)
650	Clear	USA (I-A)	I, II	(6) (8) (9) (10) (19) (22)
660	Clear	USA (I-A)	I, II	(6) (8) (9) (10) (19) (22)
670	Clear	USA (I-A)	I, II	(6) (8) (9) (10) (19) (23)
680	Clear	USA (I-B)	I, II	(10) (11) (13) (19) (26)
690	Clear	Canada (I-A) Cuba (I-C) Mexico (I-B)	II	(1) (3) (5)
700	Clear	USA (I-A)	I, II	(6) (8) (9) (10) (19) (22)
710	Clear	USA (I-B)	I, II	(10) (11) (13) (19) (26)
720	Clear	USA (I-A)	I, II	(6) (8) (9) (10) (19) (23)
730	Clear	Mexico (I-A)	II	(14) (21) (25)
740	Clear	Canada (I-A) Cuba (I-D)	II	(1) (3) (7)
750	Clear	USA (I-A)	I, II	(6) (8) (9) (10) (19) (22)
760	Clear	USA (I-A)	I, II	(6) (8) (9) (10) (19) (22)
770	Clear	USA (I-A)	I, II	(6) (8) (9) (20)
780	Clear	USA (I-A)	I, II	(6) (8) (9) (10) (19) (23)
790	Regional		III-A, III-B	(4) (11)
800	Clear	Mexico (I-A)	II	(14) (21) (25)
810	Clear	USA (I-B)	I, II	(10) (13) (19) (26)
820	Clear	USA (I-A)	I, II	(6) (8) (9) (10) (19) (22)
830	Clear	USA (I-A)	I, II	(6) (8) (9) (10) (19) (22)
840	Clear	USA (I-A)	I, II	(6) (8) (9) (10) (19) (22)
850	Clear	USA (I-B) Mexico (I-B)	I, II	(10) (13) (19) (26)
860	Clear	Canada (I-A) Cuba (I-C)	II	(1) (3) (5)
870	Clear	USA (I-A)	I, II	(6) (8) (9) (10) (19) (22)
880	Clear	USA (I-A)	I, II	(6) (8) (9) (10) (19) (23)
890	Clear	USA (I-A)	I, II	(6) (8) (9) (10) (19) (23)
900	Clear	Mexico (I-A)	II	(14) (21) (25)
910	Regional		III-A, III-B	(4) (11)
920	Regional	Cuba (I-D)	III-A, III-B	(4) (7) (11)
930	Regional		III-A, III-B	(4) (11)
940	Clear	Canada & Mexico (I-B)	I, II	(19) (26)
950	Regional	Cuba (I-D)	III-A, III-B	(4) (7) (11)
960	Regional		III-A, III-B	(4) (11)
970	Regional		III-A, III-B	(4) (11)
980	Regional	Cuba (I-D)	III-A, III-B	(4) (7) (11)

Channel	*Classification*	*NARBA Class I Priority*	*Use Under FCC Rules*	*See Footnotes*
990	Clear	Canada (I-A)	II	(1) (3)
1000	Clear	Mexico & USA (I-B)	I, II	(10) (13) (19) (26)
1010	Clear	Canada (I-A) Cuba (I-B)	II	(1) (3) (15)
1020	Clear	USA (I-A)	I, II	(6) (8) (9) (10) (19) (23)
1030	Clear	USA (I-A)	I, II	(6) (11) (13) (16) (20) (23)
1040	Clear	USA (I-A)	I, II	(6) (8) (9) (10) (19) (22)
1050	Clear	Mexico (I-A)	II	(14) (17) (21) (25)
1060	Clear	Mexico & USA (I-B)	I, II	(10) (13) (19) (26)
1070	Clear	Canada & USA (I-B)	I, II	(10) (13) (19) (26)
1080	Clear	USA (I-B)	I, II	(10) (13) (19) (26)
1090	Clear	Mexico & USA (I-B)	I, II	(10) (13) (19) (26)
1100	Clear	USA (I-A)	I, II	(6) (8) (9) (10) (19) (23)
1110	Clear	USA (I-B)	I, II	(10) (13) (19) (26)
1120	Clear	USA (I-A)	I, II	(6) (8) (9) (10) (19) (23)
1130	Clear	Canada & USA (I-B)	I, II	(10) (13) (19) (26)
1140	Clear	Mexico & USA (I-B)	I, II	(10) (13) (19) (26)
1150	Regional		III-A, III-B	(4) (11)
1160	Clear	USA (I-A)	I, II	(6) (8) (9) (10) (19) (22)
1170	Clear	USA (I-B)	I, II	(10) (13) (19) (26)
1180	Clear	USA (I-A)	I, II	(6) (8) (9) (10) (19) (23)
1190	Clear	Mexico & USA (I-B)	I, II	(10) (13) (19) (26)
1200	Clear	USA (I-A)	I, II	(6) (8) (9) (10) (19) (22)
1210	Clear	USA (I-A)	I, II	(6) (8) (9) (10) (19) (23)
1220	Clear	Mexico (I-A)	II	(14) (18) (21) (25)
1230	Local		IV	
1240	Local		IV	
1250	Regional		III-A, III-B	(4) (11)
1260	Regional		III-A, III-B	(4) (11)
1270	Regional		III-A, III-B	(4) (11)
1280	Regional		III-A, III-B	(4) (11)
1290	Regional		III-A, III-B	(4) (11)
1300	Regional		III-A, III-B	(4) (11)
1310	Regional		III-A, III-B	(4) (11)
1320	Regional		III-A, III-B	(4) (11)
1330	Regional		III-A, III-B	(4) (11)
1340	Local		IV	
1350	Regional		III-A, III-B	(4) (11)
1360	Regional		III-A, III-B	(4) (11)
1370	Regional		III-A, III-B	(4) (11)
1380	Regional		III-A, III-B	(4) (11)
1390	Regional		III-A, III-B	(4) (11)
1400	Local		IV	
1410	Regional		III-A, III-B	(4) (11)
1420	Regional		III-A, III-B	(4) (11)
1430	Regional		III-A, III-B	(4) (11)
1440	Regional		III-A, III-B	(4) (11)
1450	Local		IV	
1460	Regional		III-A, III-B	(4) (11)
1470	Regional		III-A, III-B	(4) (11)
1480	Regional		III-A, III-B	(4) (11)
1490	Local		IV	
1500	Clear	USA (I-B)	I, II	(13) (19) (26)
1510	Clear	USA (I-B)	I, II	(13) (19) (26)
1520	Clear	USA (I-B)	I, II	(13) (19) (26)
1530	Clear	USA (I-B)	I, II	(13) (19) (26)
1540	Clear	Bahamas (I-A) USA (I-B)	II	(19) (24)
1550	Clear	Canada & Mexico (I-B)	I, II	(19) (26)

Channel	Classification	NARBA Class I Priority	Use Under FCC Rules	See Footnotes
1560	Clear	USA & Cuba (I-B)	I, II	(13) (19) (26)
1570	Clear	Mexico (I-A)	II	(14) (21) (25)
1580	Clear	Canada (I-A)	II	(1) (3)
1590	Regional		III-A, III-B	(4) (11)
1600	Regional		III-A, III-B	(4) (11)

Note:

1. For Class II stations which will not deliver over 5 microvolts per meter groundwave or 25 microvolts per meter 10 percent time skywave at any point on the Canadian border and provided that such stations operating nighttime (i.e., sunset to sunrise at the location of the Class II station) are located not less than 650 miles from the nearest Canadian border.

2. Subject to the condition that no harmful interference be caused to services operating on 500 kHz and in the band 510-535 kHz.

3. Proposed rule making in Docket 10453 provides for certain assignments on this channel to be submitted to the Canadian government for comments, taking into account daytime skywave. No applications are being granted at this time which are not in conformity with the proposals contained in Docket 10453.

4. Class IV stations presently operating on this channel are allowed to continue operation, but are not protected against interference from Class III stations. No new Class IV stations will be assigned to the channel.

5. New assignments may not deliver over 25 microvolts per meter 10 percent time skywave at any point on the border of the country having priority for a Class I-C station on this channel. For definition of this class of station and requirements for daytime protection, see 1950 North American Regional Broadcasting Agreement.

6. Class II stations may operate presunrise with a power not in excess of 500 watts from 6 a.m. local time to sunrise where such stations are located west of the Class I-A station.

7. New assignments may not deliver over 50 microvolts per meter 10 percent time skywave at any point on the border of the country having priority for a Class I-D station on this channel. For definition of this class of station and requirements for daytime protection, see 1950 North American Regional Broadcasting Agreement.

8. One Class I and one or more Class II stations may be assigned on this channel. Class II stations are restricted to limited time or daytime only operation in the continental limits of the United States. There may be assigned to this frequency Class II stations operating unlimited time in Alaska, Hawaii, Virgin Islands, and Puerto Rico which will not deliver over 5 microvolts per meter groundwave day or night or 25 microvolts per meter 10 percent time skywave at night at any point within the continental limits of the United States.

9. Power shall not be less than 50 kilowatts for Class I stations on this channel.

10. Pending finalization of Docket 6741, action is being withheld on applications for new daytime or limited time assignments, changes in frequency to operate on this channel, or applications for modification of facilities which would increase radiation or change stations location.

11. Class III station may commence operation with their daytime antenna systems at 6 a.m. local time, and continue such operation until local sunrise provided that the presunrise power not exceed 500 watts or such lesser power as may be determined.

12. Class II stations shall not deliver a signal of more than 5 microvolts per meter groundwave or 25 microvolts per meter 10 percent skywave at any point on the Canadian border, nor more than 10 microvolts per meter daytime or 50 microvolts per meter nighttime at any point on the Mexican border provided that stations operating at night shall be located within the continental United States including Alaska and not less than 650 miles from the nearest point on the Canadian border and north of the parallel 35 degrees north if west of the meridian 93 degrees west or north of the parallel 30 degrees north if east of said meridian.

13. One or more Class I stations may be assigned to this channel. Class II applications are subject to the same provisions as stated in Footnote 10.

14. In continental U.S., for Class II stations which operate daytime only with power not in excess of 1 kilowatt and which will not deliver over 5 microvolts per meter groundwave at any point on the Mexican border, and in Alaska, Hawaii, Puerto Rico, and the Virgin Islands, for Class II stations which will not deliver over 5 microvolts per meter groundwave or 25 microvolts per meter 10 percent time skywave at any point on said border.

15. A station on 1010 kHz shall also protect a Class I-B station at Havana, Cuba.

16. Under terms of the 1950 North American Regional Broadcasting Agreement, Class I-A priority on this channel is assigned to USA, however, FCC Rules continue to classify 1030 kHz as Class I-B, pending ratification of the 1950 Agreement.

17. The U.S. is permitted under the "Gentlemen's Agreement" to continue operation of one 50 kilowatt full-time Class II station with directional pattern that will direct the signal to the northeast and protect the Mexican station's signal in the U.S. as much as possible.

18. The U.S. is permitted under the "Gentlemen's Agreement" to assign a station in the Detroit, Michigan, area with a directional antenna that will direct the signal to the northward and protect the Mexican station's coverage in the U.S. as much as possible.

19. All new assignments on this channel must be in accordance with Section 73.187.

20. Two Class I stations will be assigned this frequency.

21. The United States may assign stations to operate with powers not in excess of 5 kilowatts daytime on this frequency. Stations with powers in excess of 1 kilowatt may not be assigned in areas within the following distances of the locations specified:

800 kHz–820 miles from Ciudad Juarez, Chihuahua
1050 kHz–620 miles from Monterrey, Nuevo Leon
1570 kHz–620 miles from Ciudad Acuma, Coahuila

22. Docket 6741 proposes no action at this time but introduces subject of increased power.

23. Unlimited Class II-A stations will be assigned in underserved areas.

24. Class I and II stations on 1540 kHz shall deliver not over 5 microvolts per meter groundwave or 25 microvolts per meter 10 percent skywave at any point of land in the Bahama Islands and such station operating nighttime (i.e., sunset to sunrise at the location of the Class II station shall be located not less than 650 miles from the nearest point of land in the Bahama Islands.

25. Class II stations are permitted to operate on Mexican Class I-A clear channels commencing at 6 a.m. local time with their daytime antenna system and to continue such operation until the sunrise time specified in their basic instrument of authorization provided that the power not exceed 500 watts.

26. Presunrise operation is permitted on this frequency provided a special showing is made.

FM STATIONS

Classes and Power of FM Stations

Class A station. A Class A station is a station that operates on a Class A channel and is designed to render service to a relatively small community, city, or town, and the surrounding rural area. A Class A station will not be authorized to operate with effective radiated power (ERP) greater than 3 kilowatts, and the coverage of a Class A station may not exceed that obtained from 3 kilowatts effective radiated power and antenna height of 300 feet above average terrain. A Class A station will not be licensed with more than 3 kilowatts effective radiated power or less than 100 watts effective radiated power.

Class B station. A Class B station is a station that operates on a Class B-C channel in Zone 1 or Zone I-A and is designed to render service to a sizable community, city, or town, or to the principal city or cities of an urbanized area, and to the surrounding area. No Class B station will be authorized with effective radiated power (ERP) greater than 50 kilowatts and the coverage of a Class B station must not exceed that obtained from 50 kilowatts effective radiated power and 500-foot antenna height above average terrain. A Class B station will not be licensed with more than 50 kilowatts effective radiated power or less than 5 kilowatts effective radiated power.

Class C station. A Class C station is a station that operates on a Class B-C channel in Zone II and is designed to render service to a community, city, or town, and large surrounding areas. No such station will be authorized with an effective radiated power (ERP) greater than 100 kilowatts, and the coverage of a Class C station may not exceed that obtained from 100 kilowatts effective radiated power and antenna height of 2000 feet above average terrain. A Class C station will not be licensed with more than 100 kilowatts effective radiated power or less than 25 kilowatts effective radiated power.

Time of Operation

(a) All FM broadcast stations will be licensed for unlimited time operation. All FM stations are required to maintain an operating schedule of not less than 8 hours between 6 a.m. and 6 p.m., local time, and not less than 4 hours between 6 p.m. and midnight, local time, each day of the week except Sunday.

(b) In the event that causes beyond the control of a permittee or licensee make it impossible to adhere to the operating schedule in paragraph (a) of this section or to continue operating, the station may limit or discontinue operation for a period of not more than 10 days, without further authority of the Commission. If causes beyond the control of the permittee or licensee make it impossible to comply within the allowed period, informal written request shall be made to the Commission in Washington, D.C. no later than the 10th day for such additional time as may be deemed necessary.

Subsidiary Communications Authorizations (SCA)

FM broadcast stations may engage in "functional (background) music" operations in addition to their regular FM broadcast service. The SCA will run concurrently with the FM broadcast license, and may not be renewed unless the FM broadcast license is also renewed.

Stereophonic Broadcasting

FM broadcast stations may, without further authority, transmit stereophonic programs in accordance with the Commission's technical standards provided that the Commission is notified within 10 days of the installation of accepted stereophonic transmission equipment or any change therein.

Frequencies Used for FM Broadcast Stations

The band 88-108 MHz is reserved for the FM Broadcast Service. These are 100 channels of 200 kHz each (80 for commercial broadcasting and 20 for educational broadcasting). Educational channels are in the 88-92 MHz portion of the FM band, and commercial broadcasting is alloted the remainder, 92-108 MHz.

Channel No.	*Frequency (in MHz)*	*For Class*
221	92.1	A
222	92.3	B-C
223	92.5	B-C
224	92.7	A
225	92.9	B-C
226	93.1	B-C
227	93.3	B-C
228	93.5	A
229	93.7	B-C
230	93.9	B-C
231	94.1	B-C
232	94.3	A
233	94.5	B-C
234	94.7	B-C
235	94.9	B-C
236	95.1	B-C
237	95.3	A
238	95.5	B-C
239	95.7	B-C
240	95.9	A
241	96.1	B-C
242	96.3	B-C
243	96.5	B-C
244	96.7	A
245	96.9	B-C
246	97.1	B-C
247	97.3	B-C
248	97.5	B-C
249	97.7	A
250	97.9	B-C
251	98.1	B-C
252	98.3	A
253	98.5	B-C
254	98.7	B-C
255	98.9	B-C
256	99.1	B-C
257	99.3	A
258	99.5	B-C
259	99.7	B-C
260	99.9	B-C
261	100.1	A
262	100.3	B-C
263	100.5	B-C
264	100.7	B-C
265	100.9	A
266	101.1	B-C
267	101.3	B-C
268	101.5	B-C
269	101.7	A
270	101.9	B-C
271	102.1	B-C
272	102.3	A
273	102.5	B-C
274	102.7	B-C
275	102.9	B-C
276	103.1	A
277	103.3	B-C
278	103.5	B-C
279	103.7	B-C
280	103.9	A
281	104.1	B-C
282	104.3	B-C
283	104.5	B-C
284	104.7	B-C
285	104.9	A
286	105.1	B-C
287	105.3	B-C
288	105.5	A
289	105.7	B-C
290	105.9	B-C
291	106.1	B-C
292	106.3	A
293	106.5	B-C
294	106.7	B-C
295	106.9	B-C
296	107.1	A
297	107.3	B-C
298	107.5	B-C
299	107.7	B-C
300	107.9	B-C

Note: In Hawaii, the frequency band 98-108 MHz is allocated for nonbroadcast use. The frequencies 98.1 through 107.9 MHz will not be assigned in Hawaii for broadcast use.

In Alaska, the frequency band 88-100 MHz is allocated exclusively to government radio services and nongovernment fixed service. The frequencies 88.1 through 99.9 MHz will not be assigned in Alaska for use by FM broadcast stations.

The frequency 89.1 MHz is reserved in the New York area for the use of the United Nations.

TELEVISION STATIONS

Minimum and Maximum Visual Effective Radiated Power (ERP)

Minimum

Applications will not be accepted for filing if they specify less than—10 dbk (100 watts) visual effective radiated power in any horizontal direction. No minimum antenna height above average terrain is specified.

Maximum[1]

Channel Nos.	*Maximum Visual ERP*
2-6	20 dbk (100 Kw)
7-13	25 dbk (316 Kw)
14-83	37 dbk (5000 Kw)

[1]The maximum visual effective radiated power of television broadcast stations operating on Channels 14-83 within 250 miles of the Canadian-USA border may not be in excess of 30 dbk (1000 kilowatts).

Time of Operation

All television broadcast stations are licensed for unlimited time operation. Each station must maintain a regular program operating schedule as follows:

First 18 months of operation: Not less than 2 hours daily in any five broadcast days per week, and not less than a total of 12 hours per week.

Each successive 6-month period. Not less than 2 hours daily in any five broadcast days per week, and not less than a total of 16 hours, 20 hours, and 24 hours per week, respectively.

Third year of operation and thereafter: Not less than 2 hours in each of the seven days of the week, and not less than a total of 28 hours per week.

Frequencies Used for Television Stations

There are 82 channels in the Television Broadcast Service, 12 for VHF television and 70 for UHF television. Each channel has a bandwidth of 6 MHz.

Assignment of a channel to an applicant is made in accordance with the Table of Assignments given in FCC Rules.

The channel numbers and frequency bands for television stations are as follows:

Channel No.	*Frequency Band (in MHz)*	*Channel No.*	*Frequency Band (in MHz)*
2	54-60	43	644-650
3	60-66	44	650-656
4	66-72	45	656-662
5[1]	76-82	46	662-668
6[1]	82-88	47	668-674
7	174-180	48	674-680
8	180-186	49	680-686
9	186-192	50	686-692
10	192-198	51	692-698
11	198-204	52	698-704
12	204-210	53	704-710
13	210-216	54	710-716
14	470-476	55	716-722
15	476-482	56	722-728
16	482-488	57	728-734
17	488-494	58	734-740
18	494-500	59	740-746
19	500-506	60	746-752
20	506-512	61	752-758
21	512-518	62	758-764
22	518-524	63	764-770
23	524-530	64	770-776
24	530-536	65	776-782
25	536-542	66	782-788
26	542-548	67	788-794
27	548-554	68	794-800
28	554-560	69	800-806
29	560-566	70[2]	806-812

Channel No.	*Frequency Band (in MHz)*	*Channel No.*	*Frequency Band (in MHz)*
30	566-572	71[2]	812-818
31	572-578	72[2]	818-824
32	578-584	73[2]	824-830
33	584-590	74[2]	830-836
34	590-596	75[2]	836-842
35	596-602	76[2]	842-848
36	602-608	77[2]	848-854
37	608-614	78[2]	854-860
38	614-620	79[2]	860-866
39	620-626	80[2]	866-872
40	626-632	81[2]	872-878
41	632-638	82[2]	878-884
42	638-644	83[2]	884-890

[1] In Alaska and Hawaii, the frequency bands 76-82 MHz and 82-88 MHz are allocated for nonbroadcast use. These frequency bands (Channels 5 and 6) will not be assigned in Alaska or Hawaii for use by television broadcast stations.

[2] No new translator authorizations are being issued on channels 70 through 83.

Frequency Selection

Service	*Choice*
AM Broadcasting	Applicant must specify frequency. Search must be made for an available frequency by applicant.
FM Broadcasting	Applicant must select any unassigned channel from table of assignments.
TV Broadcasting	Applicant must select any unassigned channel from table of assignments.

TRANSLATOR STATIONS

Definition

A television translator is a station in the broadcasting service operated solely for the purpost of retransmitting the signals of a television broadcast station or another television broadcast translator station, by means of direct frequency conversion and amplification of the incoming signals and without significantly altering any characteristic of the incoming signal other than its frequency and amplitude, for the purpose of providing television reception to the general public.

Power

A television broadcast translator station will not be authorized to operate with a transmitter power output in excess of the rated power output of the transmitter and in no event shall the rated peak visual power output of the transmitter be in excess of 100 watts.

Frequencies Used for Translator Stations

Any one of the 12 standard VHF channels may be assigned to a VHF translator on the condition that no interference is caused to the direct reception by the public of any television broadcast station.

Any one of the 15 UHF channels from 55-69 inclusive with a power up to 100 watts with restrictions.

Any one of the UHF channels from 14-54 provided a showing is made that the translator may not be accommodated on the 15 channels from 55-69.

AUXILIARY BROADCAST SERVICES

Introduction

FCC Rules provide for the use of radio transmitting apparatus to supply certain auxiliary services in connection with broadcasting. These services fall into four general categories:

1. *Portable or mobile stations* which may be used to relay programs from places of origination other than a studio.
2. *Base stations,* usually located at the studio or transmitter of a broadcast station, and used to coordinate the activities of portable or mobile stations.
3. *Fixed stations (STL)* which may be used to provide a program circuit between the main or auxiliary studios to the transmitter of a broadcast station.
4. *Fixed stations (Intercity Relay)* which may be used to relay programs from one broadcast station to other broadcast stations for network programming.

Category 1 includes two classes of stations, i.e., *Remote Pickup Broadcast Mobile Stations* which may be used for relaying aural broadcast program material or the aural portion of television programs and are available to AM, FM, and TV broadcast station licensees; and *Television Pickup Stations* which may be used for relaying television program material, either visual alone or the combined visual and aural program material by means of multiplexing. Television pickup stations are available only to television broadcast stations.

Category 2 contains a class of station called a *Remote Pickup Broadcast Base Station.* From the standpoint of equipment, frequency assignments, technical operation, and availability, they are identical with Remote Pickup Broadcast Mobile Stations. A differentiation is made because they are permanently installed at a fixed location and do not normally carry program material. The primary purpose of such base stations is to provide communication with remote mobile stations or television pickup stations, however, other uses are permitted under special circumstances.

Category 3 includes three classes of stations; *Standard Broadcast STL Stations, FM Broadcast STL Stations,* and *Television STL Stations.* STLs (studio-transmitter links) are used to provide a program circuit between the studio and the transmitter of a broadcast station. They are available to AM, FM, and TV broadcast stations. AM, FM, and TV STLs which are used to carry only the aural portion of TV programs, operate in the same general portion of the spectrum and the same type of transmitting equipment is used in all three services. Television STLs which are used to carry the visual portion of television programs operate in the so-called "microwave" portion of the spectrum. Some equipment is designed to simultaneously carry the aural portion of the program material on the same carrier by means of multiplexing, and such use is permitted if it can be accomplished without degrading the visual and aural signal to a point where the overall performance of the television system cannot meet the minimum requirements of the Rules Governing Television Broadcast Stations.

Category 4 includes two classes of stations; *FM Broadcast Intercity Relay Stations and TV Intercity Relay Stations.* (There is no AM Intercity Relay Service.) Intercity relay stations are used for the interexchange of programs between broadcast stations for network operation. Circuits for the interexchange of broadcast programs are normally operated by communications common carriers, however, in the case of FM broadcasting, where high-quality aural circuits are required and in the case of television, where special video circuits as well as high-quality aural circuits are required, the telephone company serving a certain area may not be able to supply the desired service due to lack of adequate facilities. Under such circumstances, intercity relay stations are available to FM and TV broadcasters. No provision is made for intercity relay stations to be used in conjunction with AM broadcast stations since telephone circuits of suitable broadcast quality are generally available or can be made available on short notice. FM intercity relay stations and TV intercity relay stations which carry only the aural portion of the television program operate in the same general portion of the spectrum as AM, FM, and TV STL stations. TV intercity relay stations used for the visual portion of television programs operate in the microwave bands used by TV pickup and TV STL stations. As in the case of TV STLs, the aural portion of the TV program may be transmitted on the same carrier as the visual program material by means of multiplexing. Quality standards for intercity relay stations are left to the discretion of the individual broadcaster.

Remote pickup broadcast stations are required to monitor for EBS Radio Alerts and go off the air until the Radio All Clear. They may obtain the Radio Alert by monitoring any standard, FM, or TV station. Since the remote personnel would naturally be in communication with the mother station, and monitoring its transmissions in any case, no special receiver is required.

All of the material in this section is intended to be an explanation of the FCC Rules relating to the operation of auxiliary broadcast stations. It does not replace the need for reference to the full text of Part 74 of the FCC Rules which covers the services. The material in this article is arranged according to classes of broadcasting stations which may use auxiliary stations, and reference is made throughout to the pertinent sections of Part 74 for further study.

AM/FM SECTION[1]

Remote Pickup Broadcast Stations

Broadcasters may use remote pickup broadcast stations at their discretion, and the choice between radio and wire lines does not depend on whether or not wire lines are available.

Remote pickup broadcast stations may be used for:

1. Transmission of AM, FM, or the aural portion of TV program material originating outside a regular studio. (Normally, only Mobile stations are used.)
2. Orders and related communications directly concerning such transmissions, but *may not be used* to provide private mobile telephone systems to station personnel. (Both Base and Mobile stations may be so used.)
3. Emergency program or order circuits from studios in the event of failure of regular wire circuits, *may not be used* for such purposes on a regular basis. (Both Base and Mobile stations may be so used.)
4. In Alaska, Hawaii, Puerto Rico, and Virgin Islands for intercity relays and STLs, provided such transmissions are not intended to be received directly by the public. Such use is not authorized in the continental limits of the U.S. (Both Base and Mobile stations may be so used.)
5. Under STA for mobile communications in connection with adjustment and maintenance of antenna system, or in connection with field intensity surveys. (Both Base and Mobile stations may be so used.)
6. Coordination of the activities of portable or mobile stations.
7. Two-way communication between the studio and transmitter of a broadcast station which has a radio STL. (Base stations only.)

[1]FCC Docket No. 20189 proposes to substantially amend these rules.

Wire lines may be used to complete remote pickup circuits, if necessary.

Remote pickup broadcast stations will not be granted exclusive frequency assignments, and the same frequency or frequencies may be assigned to other licensees in the same area. (In the television section, it will be noted that some exclusive assignments of auxiliary frequencies are made for television purposes.)

Applicants may request information about the existing remote pickup assignments in a particular area, and apply for unassigned frequencies to the extent permitted by the FCC rules. The Commission is unable to supply information regarding existing assignments to the Industrial Radio Stations in the band shared by remote pickup stations with the service.

Where a frequency is shared by two or more remote pickup stations and simultaneous operation is contemplated, the transmission of actual program material has first priority, the transmission of cues and orders including preparatory communications has second priority, and the use of the remote pickup station for other authorized communication has the lowest priority.

The following groups of frequencies are allocated for assignment to remote pickup broadcast stations. A licensee may have one or more frequencies assigned for operation in the same area, but is limited within each "division" to assignments from a single "group."

Division	*Group*	*Frequencies (in kHz)*	*Type of Emission*	*Notes*
1	A	1606[1] 1622 1646	A-3	Not shared with other services.
		(in MHz)		
2	D	25.87[1] 26.15 26.25		

Division	*Group*	*Frequencies (in MHz)*	*Type of Emission*	*Notes*
		26.35		
2	E	25.91[1] 26.17 26.27 26.37		
2	F	25.95[1] 26.19 26.29 26.39	A-3 or 40-F-3	Not shared with other services. See Note
2	G	25.99[1] 26.21 26.31 26.41		
2	H	26.03[1] 26.23 26.33 26.43		
3	I	26.07[1] 26.11 26.45	A-3 or 20-F-3	Not shared with other services. See Note
3	J	26.09[1] 26.13 26.47		
4	K	152.87 152.93 152.99 153.05 153.11 153.17 153.23 153.29 153.35	A-3 or 60-F-3	Shared with Industrial Radio Services which have first priority on the frequencies.
		161.64 161.67 161.70 161.73 161.76	A-3 or 30-F-3	These frequencies may not be used by remote pickup stations in Puerto Rico or the Virgin Islands. In other areas, certain existing stations in the Public Safety and Land Transportation Radio Service have been permitted to continue operation on these frequencies on conditions that no harmful interference is caused to remote pickup broadcast stations.
		160.89 160.95 161.01 161.07 161.13 161.19 161.25 161.31 161.37	A-3 or 60-A-3	These frequencies are allocated for assignment to remote pickup and base stations in Puerto Rico and the Virgin Islands only. They are shared with the Land Transportation Radio Service.

Division	Group	Frequencies (in MHz)	Type of Emission	Notes
5	L	166.25	A-3 or 60-A-3	Operation on these frequencies not authorized (1) within the area bounded on the west by the Mississippi River, on the north by the parallel of latitude 37°30′ N and on the east and south by that arc of the circle with center at Springfield, Ill. and radius equal to the airline distance between Springfield, Ill. and Montgomery, Alabama, subtended between the foregoing west and north boundaries; (2) within 150 miles of New York City; and (3) in Alaska or outside the continental United States and is subject to the condition that no harmful interference is caused to government radio stations in the band 162-174 MHz.
5	M	170.15		
6	N	450.05[2] 450.15[2] 450.25[2] 450.35[2] 450.45[2] 450.55[2] 450.65[2] 450.75[2] 450.85[2] 450.95[2] 455.05[2] 455.15[2] 455.25[2] 455.35[2] 455.45[2] 455.55[2] 455.65[2] 455.75[2] 455.85[2] 455.95[2]	A-3 or 100-F-3	Not shared with other services. See Note

Note: The operation of studio cueing transmitters and wireless microphones will be authorized in the bands 26.10 through 26.48 MHz and 450 through 451 MHz. Transmitting units may be operated on any frequency within these bands provided that emissions are confined to the authorized band.

[1] Use is subject to the condition that no harmful interference is caused to the reception of broadcast stations.

[2] FCC Docket #2189 proposes to charge this allocation plan.

AM/FM Studio-Transmitter Link Stations

STL stations are available to the licensees of both AM and FM broadcast stations and are used to relay programs from the studio to the transmitter of the station. Where the licensee of an AM station is also the licensee of an FM station, the same STL may be used for both stations. The STL may also be used for the purpose of providing communication between studio and transmitter when no programs are being transmitted, or if multiplexing is employed, may be used for communication during program transmission.

Broadcasters may use radio STLs at their discretion, and the choice between radio STL and wire line (common carrier) STL does not depend on whether or not wire lines are available.

Any AM or FM station employing a radio STL may also use remote pickup base stations to provide an "order circuit" for communication of information concerning program service. Radio circuits may be used for this purpose *only* when the broadcast station uses a radio STL.

Exclusive assignments will be made to STL stations providing the program circuit from the main studio to the transmitter of FM broadcast stations. In the case of AM STL stations, and FM STL stations at secondary studios, exclusive assignments will be made wherever practicable.

The following frequencies are available for the transmission of aural program material between a studio and the transmitter and for the transmission of aural program material between stations (intercity):

Frequency (in MHz)	*Type of Emission*	*Notes*
947.0	400-F-3	Not shared with other services.
947.5		
948.0		
948.5		
949.0		
949.5		
950.0		
950.5		
951.0		
951.5		

Note: If a single licensee requires more than one aural program channel between the same point of origin or destination (stereo) more than one transmitter may be authorized to operate within a single 500 kHz channel employing carrier frequencies above and below the center frequency listed above.

No new stations will be authorized in the band 942—947 MHz. All stations presently authorized to operate on frequencies in the band 942—947 MHz may continue to operate pursuant to the provisions of their existing authorizations until the termination of such authorizations. Renewal of authorizations for such stations will be issued only on the condition (1) that they accept any harmful interference that may be experienced from either ISM equipment or from the radio-positioning service in the band 890—942 MHz and (2) that they do not cause harmful interference to the radio-positioning service.

Radio Order Circuits

Remote pickup base stations may be authorized to provide two-way communication between the studio and transmitter of a broadcast station which has a radio STL.

The following frequencies may be assigned for radio order circuits. They are licensed for unlimited time operation, but their use is secondary to other need for the same frequency(s).

Group	*Frequency (in MHz)*	*Type of Emission*
I	26.07[1]	20-A-3
	26.09[1]	or
	26.11	20-F-3
	26.45	
J	26.13	20-A-3
	26.47	or
		20-F-3

[1]Use is subject to the condition that no harmful interference is caused to the reception of high frequency broadcast stations.

FM Intercity Relay Stations

The operation of FM intercity relay stations is subject to the condition that no harmful interference is caused to other radio stations, present or future, operating in accordance with the Table of Frequency Allocations.

Wire lines may be used to complete circuits for FM intercity relays. Intercity relay stations may be used for communication of program information when no programs are being transmitted, or if multiplexing is employed, may be used for communication during program transmission.

Relay stations will be authorized only when suitable common carrier facilities are not available. Each application for a new FM intercity relay system, or for renewal of an existing system must be accompanied by verified statements showing:

1. Why the facilities are needed, including reasons why common carrier facilities are not available.
2. That the applicant has requested such facilities from the common carrier serving the area, and including copies of such request(s) and reply(s).

Frequencies available for FM intercity relay stations are the same as those used for broadcast STLs.

As in the case of STLs, they are licensed for unlimited time operation, directional antennas are required, and they may be operated by remote control.

TELEVISION SECTION

Television Pickup Stations

Television pickup stations may be used for:

1. Transmission of program material originating outside a regular studio. These channels are primarily used for the transmission of the video portion of the pickup, but the aural portion may be multiplexed on the same channel. Applications must clearly state the nature of any multiplexing proposed. If only the video portion is transmitted on the television pickup channel, the aural portion may be transmitted by wire line, or on one of the frequencies designated for remote pickup broadcast stations.
2. To provide temporary studio-transmitter links (without further authority of the FCC provided the installation of the antenna does not increase the height of any existing structure by more than 20 feet. Authority for increase of more than 20 feet may be obtained from FCC if necessary).

3. Orders and related communications concerning such transmissions. They *may not be used solely* for this purpose.

Television STL Stations

The TV STL may be used for communications relating to program continuity during periods when no programs are being transmitted, or by multiplexing at any time.

The aural signal may be multiplexed on the STL, but broadcasters contemplating the use of multiplexing should assure themselves that the equipment proposed to be used has sufficient performance quality to enable them to meet the requirements of the FCC Rules.

The television broadcaster may elect to have a communications common carrier provide television pickup or television STL service, and in this case, the common carrier may use the same channels which would normally be assigned to the television station.

When the television station uses a television channel STL, it may also use remote pickup base stations to provide an "order circuit" for communication of information concerning program service. Radio circuits may be used for this purpose *only* when a television channel STL is used.

Television Intercity Relay Stations

Television intercity relay stations provide a means whereby television broadcast licenses may provide their own intercity television transmission services in connection with the operation of their television broadcast stations.

The use of channels for television intercity relay stations is on a secondary basis and is subject to the condition that no harmful interference is caused to stations operating in accordance with the Table of Frequency Allocations.

No standards are specified in either FCC Rules or in any existing proposed rulemaking concerning the quality of television intercity relay stations. Intercity relay stations may be used for communication of program information either by multiplexing, or by simplex during periods of nonuse for program transmission.

Assignment of Channels for the Television Auxiliary Services

The television auxiliary frequencies are assigned interchangeably for television pickups, STLs, or intercity relay stations.

Television stations may request the assignment of one channel in Band A or Band B, and one channel in Band D, or the following list of channels for use on an exclusive basis. In addition, they may request the assignment of additional channels which will be assigned, if available in the area, on a nonexclusive basis. The nonexclusive channels may be withdrawn any time they are needed to provide exclusive channels for other television stations in the same area.

If two television stations in the same area are so located that they may share a single STL, they may by mutual agreement request the same assignment of the exclusive channel and, in addition, may be granted a second exclusive channel for each station from either Band A or Band B and a third exclusive channel from Band D.

Where only one exclusive channel is assigned, it is normally assigned to the main studio STL (where the television station employs a television channel STL); additional STLs may be operated at the broadcaster's discretion. Operation of the STL on a nonexclusive channel is subject to the condition that no harmful interference is caused to the operation of television pickup stations.

Any suitable type of emission may be used for the frequencies above 1500 MHz. Identification of the emission may be by whatever means the emission is authorized for, except that a visual-only transmitter may be identified by means of a keyed signal, either interrupting the carrier or by means of modulation impressed on the carrier, giving the call sign of the station.

Directional antennas are not required, but are usually employed at these frequencies.

Assignment of Channels for the Television Auxiliary Services

The following frequencies are available for assignment to television pickup, television studio-to-transmitter links, and television intercity relay stations:[1]

BAND A (in MHz)	*BAND B (in MHz)*
1990-2008	6875-6900
2008-2025	6900-6925
2025-2042	6925-6950
2042-2059	6950-6975
2059-2076	6975-7000
2076-2093	7000-7025
2093-2110	7025-7050
2450-2467[2]	7050-7075
2467-2484[2]	7075-7100
2484-2500[2]	7100-7125

[1]Frequencies in the bands 17700-19300 MHz, 19400-19700 MHz, 27525-31300 MHz, and 38600-40000 MHz are available for assignment on a case-by-case basis for television pickups, STL, and intercity relay purposes.

[2]Channels are allocated to accommodate the incidental radiations of industrial, scientific, and medical equipment,

BAND D (in MHz)

12700-12725[3]	12975-13000
12725-12750[3]	13000-13025
12750-12775[3]	13025-13050
12775-12800[3]	13050-13075
12800-12825[3]	13075-13100
12825-12850[3]	13100-13125
12850-12875[3]	13125-13150
12875-12900[3]	13150-13175
12900-12925[3]	13175-13200
12925-12950[3]	13200-13225
12950-12975	13225-13250

and stations operating therein must accept any interference that may be caused by the operation of such equipment. These frequencies are also shared with other communications services and exclusive channel assignments will not be made, nor is the channeling shown necessarily that which will be employed by such other services.

[3]The use of channels between 12700 and 12950 MHz by television pickup stations is subject to the condition that no harmful interference is caused to community antenna relay, television STL, and television intercity relay stations.

Radio Order Circuits

Remote pickup base stations may be authorized to provide two-way communication between the studio and transmitter of a television station which has a television channel STL.

The following frequencies may be assigned for radio order circuits. They are licensed for unlimited time operation, but their use is secondary to other need for the same frequency(s).

Group	*Frequency (in MHz)*	*Type of Emission*
I	26.07[1]	20-A-3
	26.09[1]	or
	26.11	20-F-3
	26.45	
J	26.13	20-A-3
	26.47	or
		20-F-3

[1]Use is subject to the condition that no harmful interference is caused to the reception of high-frequency broadcast stations.

OTHER FREQUENCIES OF INTEREST TO BROADCASTERS

Motion Picture Radio Service

Of all the types of industrial enterprises, only the Motion Picture Radio Service seems to be applicable to use by broadcasters, and this service may only be used by broadcasters while they are engaged in the production or filming of motion pictures (newsreels, documentaries, features, etc.). Since other services are both more practicable and more economical for general use as auxiliary broadcast stations, the Motion Picture Radio Service should be considered only by television stations that employ full-time motion picture crews, or by companies engaged in the business of making motion pictures for use either by theaters or television stations.

Frequencies Used for Motion Picture Radio Service Stations

All assignments of frequencies to base and mobile stations in the Motion Picture Radio Service are on ***a shared basis with other services.***

Certain other frequencies are available to the Motion Picture Radio Service for use in developmental operations for the service, but only the frequencies available for assignment without this limitation are shown below. For lists of developmental operations frequencies, see Section 91.404 of the FCC rules.

Base and Mobile Stations[1]

Frequency (in kHz)	*Type of Emission*	*Notes*
1628		
1652		
2292	A-3	All shared with
2398	or	other services
4637.5	40-F-3	

Base, Mobile and Fixed

(in MHz)		
27.235		
27.245		No protection
27.255		from ISM
27.265		
27.275		

Base and Mobile Stations

152.87		
152.90		
152.93		Shared with the
152.96		Industrial Radio
152.99		Service
153.02		
173.225		
173.275		Shared with the
173.325		Relay Press
173.375		Radio Service

[1]Also paired frequencies in the 952-960 MHz and on certain frequencies between 1427 and 40000 MHz.

Operational Fixed Stations

Subject to the condition that no harmful interference will be caused to reception of television channel numbers 4 or 5, the following frequencies are available for assignment to operational fixed stations in the Motion Picture Radio Service *on a shared basis* with other services.

The type of emission employed for these stations is either A-3 or 40-F-3.

MHz	*MHz*	*MHz*	*MHz*
72.02	72.82	73.66	74.50
72.06	72.86	73.70	75.54
72.10	72.90	73.74	74.58
72.14	72.94	73.78	75.42
72.18	73.02	73.82	75.46
72.22	73.06	73.90	75.50
72.26	73.10	73.94	75.54
72.30	73.14	73.98	75.58
72.34	73.18	74.02	75.62
72.38	73.22	74.06	75.66
72.42	73.26	74.10	75.70
72.46	73.30	74.14	75.74
72.50	73.34	74.18	75.78
72.54	73.38	74.22	75.82
72.58	73.42	74.26	75.86
72.62	73.46	74.30	75.90
72.66	73.50	74.34	75.94
72.70	73.54	74.38	75.98
72.74	73.58	74.42	
72.78	73.62	74.46	

BROADCASTING SATELLITES

In 1971 the ITU Word Administrative Radio Conference for Space Telecommunications (WARC-ST) held a meeting in Geneva during which several allocations to accommodate the Broadcasting-Satellite service were adopted. On November 14, 1973, the Federal Communications Commission amended its Rules and Regulations to conform with the actions taken during the WARC-ST meeting and in so provided for the following:

620-790 MHz Band. No provisions were made for accommodating the broadcasting-satellite service in this band.

2500-2690 MHz Band. This band was allocated for the broadcasting-satellite service (shared with the fixed and the fixed-satellite services) with the proviso that "the use of (this band) by the broadcasting-satellite service is limited to domestic and regional systems for community reception of educational television programming and public service information."

11.7-12.2 GHz Band. This band was allocated to the broadcasting-satellite service and the fixed-satellite service on a primary shared basis (with mobile service on a secondary shared basis). However, because the Commission was unable to determine at this time how the broadcasting-satellite service and the fixed-satellite service would share this band, no specific rules for sharing were adopted, but, a footnote was included which originally would permit the authorization of systems in either service on a case-by-case basis. Subsequently, because of objections raised by the broadcasting industry, this footnote was amended in November 1973 to provide for the authorization of systems only in the fixed-satellite service on a case-by-case basis.

41-43 GHz and 84-86 GHz Bands. These bands were allocated on an exclusive basis to the broadcasting-satellite service.

CITIZENS RADIO SERVICE

The following frequencies are available for assignment to the Citizens Radio Service:

Base and Mobile (in MHz)	*Mobile (in MHz)*
462.550	467.550
462.575	467.575
462.600	467.600
462.625	467.625
462.650	467.650
462.675	467.675
462.700	467.700
462.725	467.725

Signaling and Control (in MHz)

72.08	72.24	72.40	72.96
72.16	72.32	72.64	

Mobile Stations (in MHz)

26.965	27.035	27.115	27.185
26.975	27.055	27.125	27.205
26.985	27.065	27.135	27.215
27.005	27.075	27.155	27.225
27.015	27.085	27.165	27.255
27.025	27.105	27.175	

Note–All Citizen frequencies are shared by other services. For details see Section 95 of the Commission's Rules. These rules and allocations are presently under review by the FCC.

SUMMARY OF FREQUENCIES ALLOCATED TO THE BROADCAST SERVICES

Frequency or Band	*Use*	*Exclusive to Broadcast Service*
535-1605 kHz	107 AM Channels	Yes
1606-1646 kHz	3 Remote Pickup B/c Channels	Yes
25.87-26.47 MHz	26 Remote Pickup B/c Channels	Yes
54-72 MHz	TV Channels 2-4	Yes
76-88 MHz	TV Channels 5 & 6	Yes
88-92 MHz	20 Noncommercial FM Channels	Yes
92-108 MHz	80 Commercial FM Channels	Yes–except in Hawaii & Alaska
152.87-153.35 MHz	9 Remote Pickup B/c Channels	No–shared with Industrial Services which have first priority of use.
160.89-161.37 MHz	9 Remote Pickup B/c Channels	For assignment in Puerto Rico & the Virgin Islands. Shared with Land Transportation Radio Service.
161.64-161.76 MHz	5 Remote Pickup B/c Channels	Yes
166.25 MHz 170.15 MHz	2 Remote Pickup B/c Channels	No–Government stations operating on these two frequencies must be protected.
174-216 MHz	TV Channels 7-13	Yes
450-451 MHz 455-456 MHz	20 Remote Pickup B/c Channels	Yes
470-890 MHz	TV Channels 14-83	No–some geographical sharing with Land Mobile Service.
947.0-951.5 MHz	10 Aural STL & Intercity Relay Channels	Yes
1990-2110 MHz	7 TV Pickup/STL/Intercity Relay Channels	Yes
2450-2500 MHz	3 TV Pickup/STL/Intercity	No–must accept interference from I-S-M services. Also used by Fixed and Mobile Services.
2500-2690 MHz	Broadcasting-Satellite	No–shared with Fixed Instructional TV
6875-7125 MHz	10 TV Pickup/STL/Intercity Relay Channels	Yes
11700-12200 MHz	Broadcasting-Satellite	No–shared with Land Mobile and Aeronautical
12700-13250 MHz	22 TV Pickup/STL/Intercity Relay Channels	No–shared with Community Antenna Relay Service.
17700-19300 MHz	TV Pickup/STL/Intercity Relay Channels	
19400-19700 MHz	TV Pickup/STL/Intercity Relay Channels	
27525-31300 MHz	TV Pickup/STL/Intercity Relay Channels	
38600-40000 MHz	TV Pickup/STL/Intercity Relay Channels	
40000-41000 MHz	Broadcasting-Satellite	Yes
84000-86000 MHz	Broadcasting-Satellite	Yes

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4

Major Standards of Interest to Broadcast Engineers

Standards relating to various areas of communications engineering and equipment are sponsored and developed through the efforts of many organizations. The principal organizations are the National Association of Broadcasters (NAB), the International Radio Consultative Committee (CCIR), the American National Standards Institute (ANSI), the Institute of Electrical and Electronics Engineers (IEEE), Electronic Industries Association (EIA), and the Society of Motion Picture and Television Engineers (SMPTE).

The standards organizations listed above are not intended to be all inclusive but only to represent those which are of general interest to the broadcaster. In addition to the above referenced organization standards are developed by the British Standards Institution (BSI), Deutscher Normenausschus (German Standards Committee, DNA); International Electrotechnical Commission (IEC); Record Industry Association of America (RIAA); Union Technique de l'Electricité; Japanese Standards Association, and the United States Government.

ELECTRONIC INDUSTRIES ASSOCIATION

2001 Eye Street, N.W.
Washington, D. C. 20006

The EIA has available numerous recommended standards and engineering publications. The following test devices are of interest to the broadcast industry. For a listing of available standards and further information contact the EIA.

Standard Color Chips

Twenty-eight nominal and limit chips.

Resolution Chart

The Resolution Chart is used to help measure the resolving power of a television system or of a part of it, such as a television camera chain. The chart is televised by the studio facility, under test, and reproduced on a suitable picture monitor. Horizontal and vertical resolution wedges cover the range from 200 to 800 lines.

Gray Scale Overlay Strips for Resolution Chart

These strips are intended to be pasted over the corresponding sections of the Resolution Chart. These highly accurate gray scales will then provide the correct logarithmic reflectance relationship for the scales on the chart.

Linearity (Ball) Chart

This Chart is used to help test geometric distortion of a television camera chain. This is done by comparing on a suitable picture monitor two superimposed patterns; one generated by an electrical pattern generator, the other by televising a chart with the equipment to be checked. The electrical pattern grating frequencies required to match the chart pattern are 315 kHz for horizontal, 900 Hertz for vertical linearity tests.

Color Registration Chart

The Color Registration Chart is used to aid in the alignment and test of the accuracy of registration of triple-pickup color television cameras. The fine black horizontal and vertical lines on a white background permit accurate alignment of the optical and electrical systems of three-pickup cameras.

Linear Reflectance Chart

The Linear Reflectance Chart with the steps of gray scales in linear relationship is used in the alignment and measurement of the transfer characteristic of television camera systems. This is of particular importance in color television, where departure from the correct characteristics may result in color error.

Logarithmic Reflectance Chart

This Chart is similar to the Linear Reflectance Chart with the exception that the steps of reflectance difference follow a logarithmic, instead of a linear relationship. It is highly useful in the alignment and measurement of the transfer characteristic of television camera systems, particularly those for color.

Facsimile Test Chart

The Facsimile Test Chart consists of a variety of patterns intended to facilitate the checking of modulation characteristics, square wave testing, power supply regulation and clamping, definition, halftone characteristics, index of cooperation, readability, jitter, and other parameters of transmitted facsimile copy.

SOCIETY OF MOTION PICTURE AND TELEVISION ENGINEERS (SMPTE)

862 Scarsdale Avenue
Scarsdale, N.Y. 10583

The SMPTE has available numerous test films which are widely used by the television industry as yardsticks for setting performance objectives of new and operational equipment. The test films are planned by the Technical Committee of the Society after considerable research and consultation. In addition, the Society has sponsored many standards and recommended practices which have been adopted by the American National Standards Association and are identified by the ANSA designation Ph. The following test devices are available from the Society:

Sound Test Films

(Sound Only)

35-mm Magnetic Four-Track Projection Sound

Azimuth Alignment
Flutter
Signal Level
Multifrequency
Channel-Four
Loudspeaker Balance

35-mm Magnetic Three-Track Sound
(Not for use in theater projectors)

Azimuth Alignment
Flutter
Signal Level
Multifrequency

16-mm Magnetic Sound

Azimuth Alignment
Flutter
Signal Level
Multifrequency

35-mm Photographic Sound

Buzz Track
Scanning Beam
Sound Focus and Alignment, Type A
Sound Focus and Alignment, Type B
Flutter
Signal Level
Multifrequency, Type A (Laboratory)
Multifrequency, Type B (Service)

16-mm Photographic Sound

Buzz Track
Scanning Beam
Sound Focus and Alignment, Type A
Sound Focus and Alignment, Type B
Flutter
Signal Level
Multifrequency

Picture-with-Sound Test Films

Photographic Sound—Music and Dialogue

16-mm Projector Performance

Projector Performance Test Films

(Picture Only)

Projector Alignment and Registration

70-mm All-Purpose Projector Alignment
35-mm Projector Alignment—Anamorphic
35-mm Projector Alignment & Image Quality
  35-mm Projector Alignment (section)
16-mm Registration
Super-8 Registration
8-mm Registration

Projector Performance

35-mm Subjective Picture
35-mm Visual
  35-mm Focus and Alignment (section)
  35-mm Travel Ghost (section)
  35-mm Jump and Weave (section)
16-mm Travel Ghost

Film Leader Master Positives

35-mm Universal Leader
16-mm Universal Leader

Television Test Films & Slides

(Picture Only)

Monochrome Performance

35-mm Operating Performance
16-mm Operating Performance
  35-mm Alignment and Resolution (section)
  16-mm Alignment and Resolution (section)
2 x 2-in. Alignment and Resolution Slide

Operational Alignment

35-mm Television Operational Alignment
16-mm Television Operational Alignment
8 x 10-in. Operational Alignment Transparency
2 x 2-in. Operational Alignment Slide

Color Subjective Reference

35-mm Color Subjective Reference
16-mm Color Subjective Reference
2 x 2-in. Television Color Reference Slide Set

INSTITUTE OF ELECTRICAL AND ELECTRONICS ENGINEERS

345 East 47th Street
New York, N.Y. 10017

The IEEE has a number of standards pertaining basically to methods of measurement as they relate to the broadcasting industry. The number of standards which have been developed are too numerous to list and the reader is requested to contact the IEEE directly. Listed below are some of the published standards that are available and of primary interest:

Definitions of Terms for Antennas, Modulation Systems, and Transmitters.
Definitions of Terms for Antennas and Waveguides.
Definitions of Terms for Waveguide Components.
Measurement of Waveguides and Components.
Test Procedure for Antennas.
Methods of Measurement of Gain, Amplification, Loss, Attenuation, and Amplitude-Frequency Response on Audio Systems and Components.
Definitions of Terms for Audio.
Recommended Practice for Volume Measurements of Electrical Speech and Program Waves.
Definitions of Terms in Electroacoustics.
Test Procedure for Facsimile.
Definitions of Terms for Facsimile.
Definitions of Terms for Modulation Systems.
Measurements of Piezoelectric Ceramics.
Definitions of Ferroelectric Crystal Terms.
Methods of Measurement of Pulse Quantities.
Definitions of Terms for Radio Transmitters.
Methods of Testing Frequency Modulation Broadcast Receivers.
Methods of Testing Amplitude Modulation Broadcast Receivers.
Open Field Method of Measurement of Spurious Radioation from Frequency Modulation and Television Broadcast Receivers.
Methods of Testing Receivers Employing Ferrite Core Loop Antennas.
Methods of Testing Monochrome Television Broadcast Receivers.
Methods of Measurement of Noise.
Methods of Calibration of Mechanically Recorded Lateral Frequency Records.
Methods of Determining Flutter Content in Sound Recorders and Reproducers.
Definitions of Terms, Pulses.
Abbreviations of Radio-Electronic Terms.
Letter Symbols and Mathematical Signs.
Definitions of Color Television Terms.
Methods of Measurement of Television Aspect Ratio and Geometric Distortion.
Definitions of Terms Relating to Television.
Measurement of Luminance Signal Levels.
Measurement of Television Differential Gain and Differential Phase.
Methods of Measurement of Television Time of Rise, Pulse Width, and Pulse Timing of Video Pulse.
Measurement of Resolution of Camera Systems.
Methods of Measurement of Television Electronically Regulated Power Supplies.
Definitions of Terms Relating to Guided Waves.
Definitions of Terms, Wave Propagation.
Graphical and Letter Symbols for Feedback Control Systems.
Methods of Measurement of Conducted Interference Output to the Power Line from FM and Television Broadcast Receivers in the Range of 300 Kc to 25Mc/s.
Construction Drawings of Line Impedance Network.
Definitions of Semiconductor Terms.
Definitions of Terms of Superconductive Electronics.
Methods of Testing Transistors for Large Signal Applications.

NATIONAL ASSOCIATION OF BROADCASTERS

1771 N Street, N.W.
Washington, D.C. 20036

The NAB Recording and Reproducing Standards are for the benefit and welfare of the broadcasting industry, and represent the contributions of more than 100 of the Nation's authorities on the various phases of recording as used by the industry. Close liaison has been maintained with other organizations (as well as foreign countries) to insure the maximum degree of coordinated understanding and recommended standardization, to permit interchangeability and, at the same time, to embrace the latest technological advances of the art. Standards available from NAB are as follows:

1. Cartridge Tape Recording and Reproducing (October 1964).
2. Disc Recording and Reproducing (March 1964).
3. Magnetic Tape Recording and Reproducing (Reel-to-reel) (April 1965).
4. Cassette Tape Recording and Reproducing (January 1973).

LATERAL MONOPHONIC AND STEREOPHONIC DISC RECORDING AND REPRODUCING STANDARDS[1]

Turntable Specifications

Turntable Speed (RPM)[2]

1.05 It shall be standard that the mean speed of the recording turntable be either 33-1/3 or 45 RPM ± 0.1%, and the mean speed of the reproducing turntable be either 33-1/3 or 45 RPM ± 0.3%.

1.05.01 This measurement shall be made by means of a stroboscopic disc illuminated by a neon lamp or equivalent operated from a standard frequency source. The stroboscopic disc for 33-1/3 RPM speed measurements shall have 216 spots in 360 degrees and for 45 RPM shall have 160 spots in 360 degrees.

At either 33-1/3 or 45 RPM not more than 7 dots per minute in either direction may pass or drift by a reference point for the recorder and 21 dots per minute in either direction for the reproducer.

Turntable and Disc Rotation

1.10 It shall be standard that discs intended for broadcasting application be rotated in a clockwise direction as viewed from the side being reproduced and that the direction of feed shall be outside-in.

Wow and Flutter Factor (Recording)[3]

1.15 It shall be standard that the average deviation (measured over the range 0.5-200 Hz) from the mean speed of the recording turntable, when making the recording, shall not exceed 0.04% of the mean speed. The average deviation above shall be measured by a meter the dynamics of which shall be the same as those of the VU meter as specified in ASA Standard C16.5-1961.

Wow and Flutter Factor (Reproducing)[3]

1.20 It shall be standard that the average deviation from the mean speed of the reproducing turntable when reproducing shall not exceed 0.1% of the mean speed.

Turntable Starting Time (Reproducing)

1.25 It shall be standard that the turntable platen shall attain its mean speed as defined in Section 1.05 in not more than 120 degrees rotation.

Turntable Height (Reproducing)

1.30 It is considered good practice that the vertical distance between the floor and the top of the platen be 28 inches.

Turntable Platen (Reproducing)

1.35 It is considered good practice that the diameter of the reproducing turntable platen be substantially the same as that of the largest diameter disc for which the turntable is intended.

1.35.01 Turntables for 45 RPM shall be recessed a minimum of 0.030 inches to a diameter of 3-7/8 inches ± 1/32 inches from the center pin.

1.40 It shall be standard that the diameter of the center pin of a turntable be 0.2830 inches + 0.000 inches — 0.0005 inches for 33-1/3 RPM discs. The diameter of the center pin for 45 RPM discs shall be 1.500 inches + 0 — 0.002 inches.

Disc Specifications

Outer Diameters[4]

2.05 It shall be standard that the outer disc diameter fall within the limits specified in the following table:

Nominal	*Finished Discs* (Pressings or Instantaneous)
12 in.	11-7/8 ± 1/32 in.
10 in.	9-7/8 ± 1/32 in.
7 in.	6-7/8 ± 1/32 in.

Center Hole Diameter

2.10 It shall be standard that the disc center hold diameter be 0.286 in. + 0.001 — 0.002 inches for 33-1/3 RPM discs and 1.504 inches ± 0.002 in. for 45 RPM discs.

[1] The term disc is used throughout these standards to indicate both types of mechanical recording commonly referred to separately as transcriptions and phonograph records.

[2] It is recognized that 78.26 RPM discs are still in existence but this speed is no longer considered a standard.

[3] The term average as used in this section shall refer to the measurement device characteristic rather than the period of time over which the observation is made.

[4] It is recognized that 16 inch transcriptions are still in limited use but this size disc is no longer considered a standard.

Concentricity of Center Hole

2.15 It shall be standard that the disc center hole be concentric with the recorded groove spiral within 0.005 in.

Disc Warp

2.20 It shall be standard that the variation of the total indicator reading (TIR) of the surface of the disc because of warping shall not be in excess of 1/16 in. and that within any 45° segment the total indicator reading (TIR) shall not exceed 1/32 in.

Outer Modulated Groove Diameter

2.25 It shall be standard that the diameter of the outermost modulated groove be within the limits specified in the following table:

12 in.—outside start—11-7/16 in. maximum
10 in.—outside start— 9-7/16 in. maximum
7 in.—outside start— 6-9/16 in. maximum

Innermost Groove Diameter

2.30 It shall be standard that the diameter of the innermost modulated groove shall be not less than 4-3/4 in. in the case of 33-1/3 RPM discs, and not less than 4-1/4 in. for 45 RPM discs.

Number of Blank Grooves

2.35 It shall be standard that there shall be at least one unmodulated groove at recording pitch before and after modulation.

Stopping Groove

2.40 It shall be standard that following the termination of the innermost recording groove, a leadout spiral and a locked concentric stopping groove shall be provided.

Minimum Label Information

2.45 It shall be standard that the label of a disc contain at least the following technical information:

a. Monophonic or Stereophonic
b. Speed—(45 or 33-1/3 RPM)
c. Recommended playback characteristic
d. Recommended type of playback stylus

Groove Shape—Monophonic[5]

2.50 It shall be standard that the groove shape for finished monophonic discs shall have an included angle of 90° ± 5°; a top width of not less than 0.0022 in. and a bottom radius not greater than 0.00025 in. (It is recommended that discs with these groove shape characteristics be reproduced with a stylus having a tip radius of 0.001 in. +0.0001 in. — 0.0002 in. and an included angle of 40-55°).

Groove Shape—Stereophonic[5]

2.55 It shall be standard that the groove shape for finished stereophonic discs shall have an included angle of 90° ± 2°; a top width of not less than 0.001 in. and a bottom radius of not greater than 0.0002 in. (It is recommended that discs with these groove shape characteristics be reproduced with a stylus having a tip radius of 0.0005 to 0.0007 in. and an included angle of 40-55°.)

Electrical Specifications

Frequency Characteristics for Monophonic and Stereophonic Discs[6]

3.05 It shall be standard that the reproduce system frequency response characteristic for monophonic and stereophonic discs shall be as shown in Fig. 1 and Table 1.

Reproducing characteristic with constant velocity of the reproducing stylus tip the curve of voltage output of the reproducing system versus frequency shall be that which results from the combination of three curves as follows:

one falling with increasing frequency in conformity with the impedance of a parallel combination of a capacitance and a resistance having a time constant of t_1; (75 μsec.)

one falling with increasing frequency in conformity with the impedance of a series com-

[5] It has been concluded that groove shaped standards should apply to the finished disc rather than to the recording stylus. It is recognized that in some cases disc groove dimensions depart slightly from those of the recording stylus, but such deviations should be anticipated in the recording operation and controlled in the processing plant. In actual practice, standards covering reproducer stylus contour have no significance unless the groove standards refer to the finished disc. In the event that it is necessary to play both monophonic and stereophonic discs with the same reproducer, the use of a 0.0007 inch stylus is recommended.

[6] In disc recording, it is the generally accepted practice to evaluate sound quality and musical balance of a disc on a reproducer which has a specified response—frequency characteristic. This characteristic, which has become an international standard, is essentially the inverse of the NAB recording characteristic originally introduced in the NARTB Recording and Reproducing Standards (June 1953). It is considered appropriate, therefore, that NAB specify the reproducing characteristic rather than the recording characteristic in its disc standards. It should be recognized, however, that in so doing, the *basic* disc recording characteristic is implied and defined.

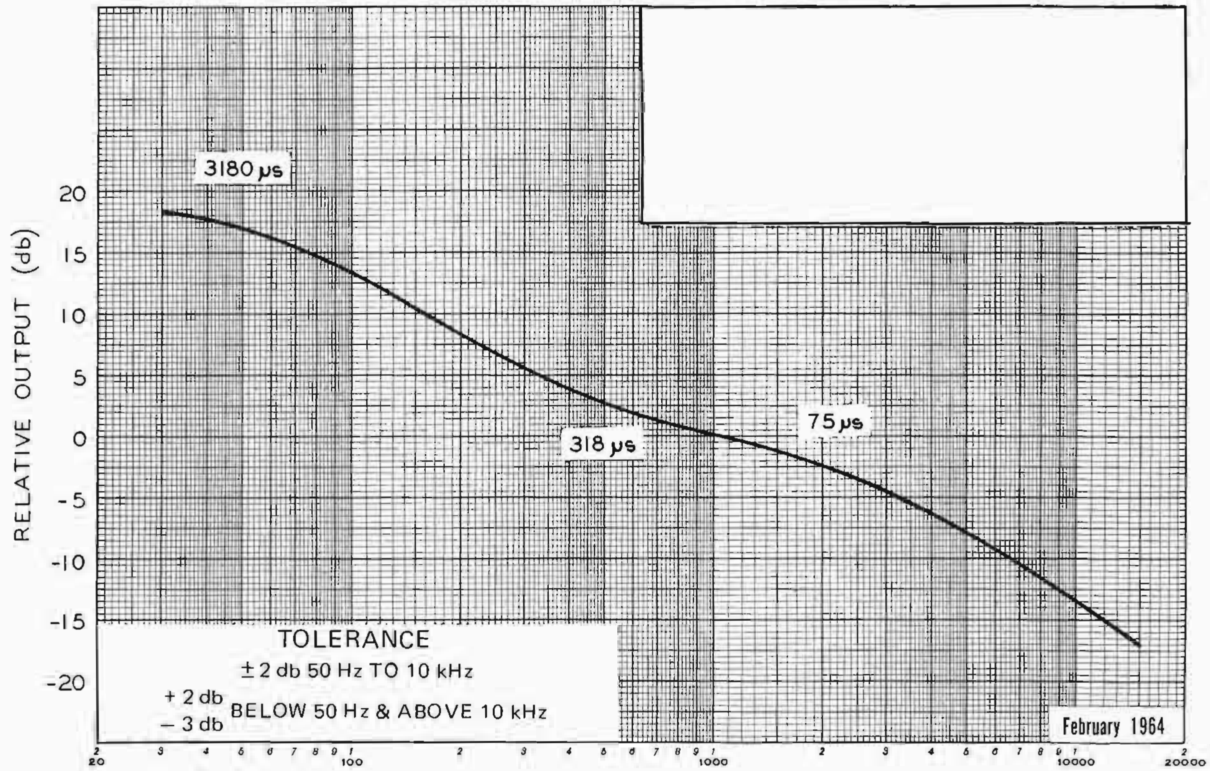

Fig. 1. NAB Standard Disc reproducing characteristic: relative output versus frequency for constant velocity input.

TABLE 1

Frequency versus NAB Monophonic and Stereophonic Reproducing Characteristic

Frequency Hz	Reproducing Characteristic dB
15,000	− 17.17
14,000	− 16.64
13,000	− 15.95
12,000	− 15.28
11,000	− 14.55
10,000	− 13.75
9,000	− 12.88
8,000	− 11.91
7,000	− 10.85
6,000	− 9.62
5,000	− 8.23
4,000	− 6.64
3,000	− 4.76
2,000	− 2.61
1,000	0
700	+ 1.23
400	+ 3.81
300	+ 5.53
200	+ 8.22
100	+ 13.11
70	+ 15.31
50	+ 16.96
30	+ 18.61

bination of a capacitance and a resistance having a time constant of t_2; (318 µsec.)

one rising with increasing frequency in conformity with the admittance of a series combination of a capacitance and a resistance having a constant of t_3; (3180 µsec.)

The combined curve is defined by:

$$N\text{(dB)} = 10 \log \left(1 + \frac{1}{4\pi^2 f^2 t_2^{\,2}}\right) - 10 \log \left(1 + 4\pi^2 f^2 t_1^{\,2}\right) - 10 \log \left(1 + \frac{1}{4\pi^2 f^2 t_3^{\,2}}\right)$$

f = frequency in Hz.

It is recommended that the system response below 30 Hz and above 15,000 Hz be attenuated at least 6 dB per octave with the 3 dB points at 20 Hz and 16 Hz.

Reference Recorded Program Level—Monophonic[7]

3.10 It shall be standard that the reference recorded program level shall produce the same reference deflection on a standard volume indicator (ASA Standard C16.5—1961) as that produced by a 1000 Hz tone recorded at a peak velocity of 7 centimeters per second.

[7]It is well established that at least a 10 dB margin is required between the sine wave load handling capacity of a system and the level of program material measured by a

Reference Recorded Program Level—Stereophonic[7]

3.15 It shall be standard that the reference recorded program level for each channel in its plane of modulation shall produce the same reference deflection on a standard volume indicator (ASA Standard C16.5—1961) as that produced by a 1000 Hz tone recorded at a peak velocity of 5.0 centimeters per second. (Approximately 3 dB below the monophonic Reference Recorded Program Level.)

Reproducing System Noise—Monophonic

3.20 *Low frequency noise* (*rumble*): It shall be standard that for a monophonic disc reproducing system the low frequency noise voltage generated by the turntable, its associated pickup and equalizer or equalized preamplifier when playing an essentially rumble-free silent groove, shall be at least 40 dB below a reference level of 1.4 centimeters per second peak velocity at 100 Hz.

The response of the pickup and equalizer or equalized preamplifier shall conform to the NAB standard reproducing curve; the amplifier and indicating meter shall have uniform response, within ± 1 dB, between 10 and 250 Hz with 500 Hz response 3 dB below the 100 Hz response, and an attenuation at the rate of at least 12 dB per octave at frequencies above 500 Hz. The amplifier and indicating meter response shall decrease at the rate of at least 6 dB per octave below 10 Hz. The meter used shall have the same dynamic characteristics as the standard VU meter (ASA Standard C16.5—1961). If the meter reading fluctuates, maximum values shall conform to this requirement. It should be recognized that in making these measurements, the arm resonance should fall outside of the prescribed pass-band or be sufficiently damped so as not to affect the results.

This measurement is intended to give a measure of the electrical effect of the low-frequency noise output of a turntable pickup combination. Since the result depends on the equalizer, pickup and arm characteristics as much as on the turntable itself, it is not feasible to standardize the turntable alone.

The measurement reflects the electrical effect, not the aural annoyance value, of low-frequency noise. It has been found that strong low-frequency noise at a frequency and intensity below audibility may create severe intermodulation distortion in an audio system, and that in modern systems with extended low frequency response, this may be more serious than the audibility of the low frequency.

The reference level of 1.4 centimeters per second peak velocity approximates the expected program level at 100 Hz and corresponds in amplitude to 7 centimeters per second peak velocity at 500 Hz.

3.25 *High frequency noise:* [8] It shall be standard that the noise level measured with a standard volume indicator (ASA Standard C16.5—1961) when reproducing a disc on a flat velocity basis over a frequency range between 500 and 15,000 Hz shall be at least 55 dB below the level obtained under the same conditions of reproduction using a 1,000 Hz tone recorded at a peak velocity of 7 centimeters per second. Response of the system at 500 Hz shall be 3 dB below the response at 1,000 Hz, and the response shall fall at the rate of at least 12 dB per octave below 500 Hz. Response of the system at 15,000 Hz shall be 3 dB below the response at 1,000 Hz, and the response shall fall at the rate of at least 12 dB per octave above 15,000 Hz.

Reproducing System Noise—Stereophonic

3.30 *Low frequency noise* (*rumble*): It shall be standard that for a stereophonic reproducing system, the low frequency noise voltage in each channel generated by the turntable, its associated pickup and equalizer, or equalized preamplifier when playing an essentially rumble-free silent groove shall be at least 35 dB below a reference level of 1 centimeter per second peak velocity at 100 Hz in the plane of modulation.[9]

The response of the pickup, and equalizer or equalized preamplifier shall conform to the NAB standard reproducing curve; the amplifier and indicating meter shall have uniform response, within ± 1 dB, between 10 and 250 Hz, with 500 Hz response 3 dB below the 100 Hz response, and an attenuation at the rate of at least 12 dB per octave at frequencies above 500 Hz. The amplifier and indicating meter response shall decrease at the rate of at least 6 dB per octave below 10 Hz. The meter used shall have the same dynamic characteristics as the standard VU meter (ASA Standard C16.5—1961). If the meter reading fluctuates, maximum values shall conform to this

standard volume indicator. This standard would then contemplate program peaks running as high as a velocity of approximately 21 centimeters per second. This is believed to be approximately the maximum velocity which can be traced without excessive distortion at groove speeds encountered at the inner radius of a 33-1/3 RPM disc. This has also been substantiated by practical experience.

[8]This measurement is intended to give a measure of noise in terms of a fixed reference. In this way, it becomes a true figure of merit for comparisons of variations in surface noise of discs. It does not, however, take into account the program level which may happen to be recorded on a particular disc nor the dynamic range of the program material. NAB preemphasis will improve the signal-to-noise ratio by approximately 8 dB, thus resulting in an effective signal-to-noise ratio under minimum conditions of 63 dB.

[9]A 100 Hz 1.4 centimeters per second peak reference lateral signal may also be used for this measurement.

requirement. It should be recognized that in making these measurements, the arm resonance should fall outside of the prescribed pass-band or be sufficiently damped so as not to affect the results.

This measurement is intended to give a measure of the electrical effect of the low-frequency noise output of the turntable-pickup combination. Since the result depends on the equalizer, pickup, and arm characteristics as much as on the turntable itself, it is not feasible to standardize the turntable alone.

The measurement reflects the electrical effect, not the aural annoyance value, of low frequency noise. It has been found that strong low-frequency noise at a frequency and intensity below audibility may create severe intermodulation distortion in an audio system, and that in modern systems with extended low frequency response, this may be more serious than the audibility of the low frequency.

The reference level of 1 centimeter per second peak velocity at 100 Hz corresponds in amplitude to 5 centimeters per second peak velocity at 500 Hz since we are then operating on the constant amplitude portion of the recording characteristic.

3.35 *High frequency noise:*[10] It shall be standard that the noise level in each channel measured with a standard volume meter (ASA Standard C16.5—1961) when reproducing a disc on a flat velocity basis over a frequency range between 500 and 15,000 Hz shall be at least 50 dB below the level obtained under the same conditions of reproduction using a 1,000 Hz tone recorded at a peak velocity of 5 centimeters per second. Response of the system at 500 Hz shall be 3 dB below the response at 1,000 Hz, and the response shall fall at the rate of at least 12 dB per octave below 500 Hz. Response of the system at 15,000 Hz shall be 3 dB below the response at 1,000 Hz, and the response shall fall at the rate of at least 12 dB per octave above 15,000 Hz.

Stereophonic Groove Characteristics—(45°—45° system)

3.40 *Planes of modulation:* It shall be standard that in a 45°—45° stereophonic disc the groove shall have orthogonal modulation planes inclined at 45° to a radial line on the surface of the disc and the intersection of the modulation planes shall be normal to said radial lines.

3.45 *Channel orientation:* It shall be standard that the outer groove wall of the disc shall contain the right-hand channel information and the inner wall shall contain the left-hand channel information.

3.50 *Phase:* It shall be standard that the phase relationship between channels shall be such as to result in lateral groove displacement when the stereo recording system is driven with equal amplitude and in-phase signals and the groove displacement shall be vertical when the stereophonic recording system is driven by equal amplitude signals in anti-phase (180°).

Channel Separation—Stereophonic[11]

3.55 It shall be standard that the separation between recorded and unrecorded channels measured at the output of the pickup and equalizer or equalized preamplifier shall be at least 26 dB over the range between 100—7,500 Hz and above 7,500 Hz separation shall not degenerate at a rate greater than 6 dB per octave.

Channel Balance Stereophonic[12]

3.60 It shall be standard that with equal groove modulations and with the outputs of the two complete channels adjusted to be equal within 1/4 dB at 1000 Hz the frequency characteristic of each channel shall agree with the standard reproduce curve of Fig. 1 within ± 1 dB between 100 and 7,500 Hz and within ± 2 dB above and below these frequencies.

Channel Phasing—Stereophonic

3.65 *Recording:* It shall be standard that equal in-phase signals applied to the left and right channel inputs of a stereo disc recorder result in lateral modulation of the stereo groove. Conversely, equal anti-phase signals produce vertical modulation.

3.70 *Reproducing:* It shall be standard that lateral modulation of a disc groove will produce equal in-phase voltages at the output of the turntable and conversely that vertical modulation will produce equal anti-phase voltages.

Test Record Specifications

The NAB Test Record shall consist of a 12-inch double-face disc, side A of which is *Monophonic*

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[10] This measurement is intended to give a measure of noise in terms of a fixed reference. In this way, it becomes a true figure of merit for comparisons of variations in surface noise of discs. It does not, however, take into account the program level which may happen to be recorded on a particular disc nor the dynamic range of the program material. NAB pre-emphasis will improve the signal-to-noise ratio by approximately 8 dB, thus resulting in an effective signal-to-noise ratio under minimum conditions of 58 dB.

[11] It is recognized that the values specified herein are of a magnitude that may in certain cases be subject to noise influences. The measurement of separation is best accomplished by the use of tuned voltmeter.

[12] For measurement purposes it may be assumed that equal modulations are obtained by reproducing a lateral monophonic test record.

and side B *Stereophonic*, recorded at a speed of 33-1/3 RPM, with a fast spiral between bands of radial distance 3/32 inches and containing the following information.[15]

4.05 *Side A, Monophonic:*

Band 1—Level Check: A 1000 Hz tone of 20 seconds duration recorded at the NAB Standard Reference Level of 7 centimeters per second peak velocity.

Band 2—Wow and Flutter: A 3000 Hz tone recorded at 7 centimeters per second peak velocity for a duration of 2 minutes.

Band 3—Frequency Response:

1. Frequency run containing frequencies as tabulated in Table 1 of the Standards with the duration of each tone being 10 seconds except for 100, 1000, 10,000 Hz which shall be 15 seconds.
2. The recorded characteristic shall be the inverse of the NAB curve at 14 dB below the reference level of 7 centimeters per second peak velocity at 1000 Hz.
3. Between tones there shall be a fast spiral of radial distance 1/32 in., except between 100, 1000 and 10,000 Hz where the radial distance shall be 1/16 in.

Band 4—Rumble Reference Level: A 100 Hz tone recorded at 1.4 centimeters per second peak velocity for a duration of 20 seconds.

4.10 *Side B, Stereophonic:*

Band 1—Phase and Balance Test:

1. 1 kHz lateral recording at 7 centimeters per second peak velocity for 20 seconds duration.
2. Fast spiral 1/16-in. radial distance.
3. 1 kHz right channel recorded at 5 centimeters per second peak velocity for 10 seconds duration.
4. Fast spiral 1/16-in. radial distance.
5. 1 kHz left channel recorded at 5 centimeters per second peak velocity for 10 seconds duration.
6. Fast spiral 1/16-in. radial distance.
7. 1 kHz vertical recording at 7 centimeters per second peak velocity for 20 seconds duration.

Band 2—Spot Frequency Test: A series of 3 second tones as follows: Lateral recording of 100 Hz, 1 kHz, 10 kHz, 1 kHz, 100 Hz, 1 kHz, 10 kHz, 1 kHz, etc., with a total duration of 60 seconds with no interval between tones, and with levels adjusted for constant output on a reproducing system using the NAB Standard.

Band 3—Separation Test:

1. 10 kHz right channel recorded at 5 centimeters per second peak velocity for 10 seconds duration.
2. Fast spiral of 1/32 inch radial distance.
3. 10 kHz left channel recorded at 5 centimeters per second peak velocity for 10 seconds duration.
4. Fast spiral of 1/16 inch radial distance.
5. Repeat 1 through 4 at 7.5 kHz, 3 kHz, 1 kHz, 100 and 50 Hz.

Band 4—Level Check: 1 kHz lateral recording at 7 centimeters per second peak velocity ending at 5-1/4 in.

[15] A 4-inch label shall be used which contains a 33-1/3 and 45 RPM strobe.

Glossary of Disc Recording and Reproducing Terms and Definitions

Acetate Disc—An acetate disc is a recording disc consisting of a solid substrate coated with a plasticized cellulose nitrate lacquer.

Advan · Ball—An advance ball is a rounded support (often sapphire) attached to a cutter which rides on the surface of the recording medium so as to maintain a uniform mean depth of cut and correct for small irregularities of the disc surface.

Background Noise—Background noise is the total system noise output of a reproducer in the absence of signal when the system is in normal operation.

Binder—A binder is a resinous material which causes the various materials of a disc compound to adhere.

Biscuit—A biscuit is a small slab of plastic material as it is prepared for use in the presses.

Burnishing Facet (surface)—A burnishing facet in disc recording is the portion of the cutting stylus directly behind the cutting edge and which smooths the groove.

Chip—The chip, in disc recording, is the material removed from the recording medium by the recording stylus while cutting the groove.

Compression Molding—Compression molding is the process of forming a disc by means of compressing a charge of suitable plastic in a cavity.

Constant-Amplitude Recording—Constant-amplitude recording indicates a mechanical recording characteristic wherein, for a fixed amplitude of a sinusoidal signal, the resulting recorded amplitude is independent of frequency.

Constant-Velocity Recording—Constant-velocity recording indicates a mechanical recording characteristic wherein, for a fixed amplitude of a sinusoidal signal, the resulting recorded amplitude is inversely proportional to frequency.

Crystal Cutter—A crystal cutter is a cutter in which the mechanical displacements of the recording stylus are derived from the deformations of a piezoelectric material.

Cutter (mechanical recording head)—A cutter is an electromechanical transducer which transforms an electric input into mechanical motions of a cutting stylus.

Cutting Stylus—A cutting stylus is a stylus having its cutting edge at a plane substantially different from the cutting facet for the purpose of cutting and polishing the groove in an acetate disc.

Disc Recorder—A disc recorder is a mechanical device consisting of a record head with cutting stylus and a properly driven turntable to inscribe a signal on a recording disc.

Drive Pin—A drive pin is a pin similar to the center pin, but located to one side thereof, which is used to prevent a disc from slipping on the recording turntable.

Eccentricity—Eccentricity is the displacement of the center of the recording groove spiral, with respect to the disc center hole.

Equalization (corrective equalization)—Equalization is the effect of intentionally introduced electrical correction employed in the recording and reproducing process to obtain a desired overall response.

Equalization (diameter)—Diameter equalization is the increasing of the high frequency record level with respect to the decreasing groove speed (velocity) in recording to compensate for reproducing losses (see translation loss).

Fast Spiral—A fast spiral is an unmodulated groove on a disc having a spacing that is much greater than that of the modulated grooves.

Feedback Cutter—A feedback cutter is an electro-mechanical transducer which performs the same function as a "cutter." It is equipped with an auxiliary coil mechanically coupled to the driver coil in the magnetic field. Signals exciting the "cutter" are induced into the feedback coil and in turn are fed back to the input circuit of the cutter amplifier resulting in reduced distortion and substantially constant velocity response.

Flash—Flash is the excess compound generated at the edge of a disc during the compression molding operation.

Flutter (wow)—In recording or reproducing, flutter is the deviation in frequency or pitch which results from minor periodic or random changes in the motion of the medium. (*Note:* The term "flutter" usually refers to cyclic deviations occurring at a relatively high rate, as, for example, 10 cycles per second. The term "wow" usually refers to cyclic deviations occurring at a relatively low rate as, for example, a once-per-revolution speed variation of a turntable. The term "drift" usually refers to a random rate close to zero cycles per second.)

Flutter Rate—Flutter rate is the number of cyclical variations per second of the flutter.

Forty-five Disc—A "45" disc is one recorded for reproduction at 45 revolutions per minute. It is normally a seven-inch disc with a raised label area and a center hole 1.5 inches in diameter.

Frequency Record—A frequency record is a disc containing various sine-wave frequencies recorded at known amplitudes, for the purpose of measuring reproducing system frequency response characteristics.

Groove—A groove is the track inscribed in a disc by a cutting or embossing stylus including modulations caused by the vibrations of the stylus.

Groove Angle—Groove angle is the angle between the two side walls of a groove measured in a radial plane perpendicular to the disc surface.

Groove, Concentric or Stopping—A concentric groove is a locked circular groove the center of which is coincident with the center of the recording spiral.

Groove Depth—Groove depth is the vertical distance from the plane at the surface of the disc to the bottom of the groove.

Groove Depth, Variable—Variable groove depth is the technique of varying the average groove depth in relation to the vertical modulation displacement.

Groove, Fast (fast spiral)—A fast groove is an unmodulated spiral groove with groove spacing much greater than normally used for modulated grooves.

Groove, Lead-in (lead-in spiral)—A lead-in groove is an unmodulated fast spiral groove from the edge of the disc to the start of the modulated groove area.

Groove, Lead-over (crossover spiral)—A lead-over groove is a fast groove connecting two modulated sections or bands on a disc.

Groove, Lead-out—A lead-out groove is an unmodulated spiral groove at the end of a recording connecting the last groove at normal modulated groove pitch to a locked concentric or eccentric stopping groove.

Groove, Locked (concentric groove)—A locked groove is a circular continuous groove following a modulated groove section for the purpose of preventing further inward or outward travel of the pickup.

Groove Pitch, Variable—Variable groove pitch is the technique of varying the groove spacing in relation to the lateral modulation displacement of the cutting stylus.

Groove Shape—Groove shape is the contour of a disc groove in a radial plane perpendicular to the disc surface, usually specified in terms of top width, included angle, and bottom radius.

Groove Speed (linear velocity)—Groove speed is the linear speed of a disc groove with respect to a fixed point such as a stylus tip.

Groove, Unmodulated—An unmodulated groove is a groove in a disc which has been recorded with no signal applied to the cutter.

Groove Width—Groove width is the radial distance between the intersections of the groove side walls and the surface plane of the disc.

Grouping—Grouping is nonuniformity in spacing between grooves of a disc caused by irregular motion on the recording lathe feed screw.

Injection Molding—Injection molding is the process of forming a disc by injecting a liquefied plastic material into a die cavity.

Instantaneous Recording—An instantaneous recording is a disc which is intended for direct playback without further processing.

Lacquer Disc—A lacquer disc is a recording disc consisting of plasticized cellulose nitrate lacquer coated on a rigid substrate such as aluminum or glass.

Lacquer Original (*lacquer master*)—A lacquer original is an instantaneous recording on a lacquer disc made for the purpose of generating an original master by an electroforming process.

Land—Land is the flat surface of a disc between adjacent grooves.

Lateral Recording (*monophonic*)—A lateral recording is a disc containing groove modulation caused by radial recorder stylus motion in the plane of the disc surface.

Long Playing—Long playing refers to a disc having a playing time substantially greater than 5 minutes. This normally refers to a 10 or 12 in. 33-1/3 RPM disc recorded with approximately 150 to 300 grooves per inch.

Master (*master original*) (*master negative*)—A master in disc recording is a metal part generated from a Lacquer Original. It may be used to generate metal molds by electroforming or to press discs.

Master No. 2, No. 3, etc.—A No. 2 master in disc recording is a metal part generated from a No. 1 mold by electroforming; a No. 3 master is a similar part generated from a No. 2 mold, etc.

Microgroove—Microgroove is a disc groove having a nominal top width of 3 mils suitable for reproducing with a 1/2 to 1 mil stylus.

Mixer—A mixer, in a sound recording or reproducing system, is a device having two or more inputs, usually adjustable, and a common output, which operates to combine linearly the separate input signals to produce an output signal.

Modulation Noise—Modulation noise is that component of noise which exists only in the presence of a recorded signal.

Mold (*mother*) (*metal positive*)—A mold in disc recording is a metal part derived from a master by electroforming. It has grooves similar to those on a disc and thus may be played as a disc.

Mold No. 1—A No. 1 mold in disc recording is a metal disc derived from a No. 1 Master by electroforming. It may be used to generate a No. 2 master or stampers for pressing discs.

Offset Angle—In lateral disc reproduction, the offset angle is the smaller of the two angles between the projections into the plane of the disc of the vibration axis of the pickup stylus and the line connecting the vertical pivot (assuming a horizontal disc) of the pickup arm with the stylus point.

Optical Pattern (*light pattern*)—An optical pattern is a light pattern which can be observed when the surface of a recorded disc is illuminated radially by a collimated beam of light. The outline of the envelope or pattern is the function of the maximum modulation slope or recorded stylus velocity inscribed in the groove wall.

Overcutting—In disc recording, overcutting is the effect of excessive level characterized by one groove cutting into an adjacent one.

Pickup—A pickup is an electromechanical transducer which is actuated by modulations present in the groove of the recording medium and which transforms this mechanical input into an electric output.

Pickup Arm (*tone arm*)—A pickup arm is a pivoted arm arranged to hold a pickup.

Pickup, Capacitor—A capacitor pickup is a reproducer which depends for its operation upon the variation of its electrical capitance.

Pickup, Cartridge—A pickup cartridge is the removable portion of a pickup containing the electromechanical translating elements and the reproducing stylus.

Pickup, Crystal—A crystal pickup is a reproducer which depends for its operation on the piezoelectric effect of crystals.

Pickup (*variable-reluctance magnetic pickup*)—A variable reluctance magnetic pickup is a reproducer which depends for its operation on the variations in the reluctance of a magnetic circuit.

Pickup, Moving Coil (*dynamic reproducer*)—A moving-coil pickup is a reproducer, the electric output of which results from the motion of a coil in a magnetic field.

Pinch Effect—In disc recording, the pinch effect is a pinching of the reproducing stylus tip twice each cycle in the reproduction of lateral recordings, due to a decrease in angle measured in a plane perpendicular to the modulation slope at any given instant.

Pitch—Pitch is commonly used to express the number of grooves per inch.

Playback—Playback is an expression used to denote reproduction of a disc.

Plastic—Plastic is a resin or polymer suitable for molding discs by the application of heat and pressure in a mold (die) cavity.

Poid—A poid is the curve traced by the center of a sphere when it rolls or slides over a surface having a sinusoidal profile.

Postemphasis (*de-emphasis*) (*playback equalization*)—Postemphasis is the reproducing system equalization conforming to a standard response curve. (See NAB Reproducing System Characteristics.)

Pre-Emphasis (*pre-equalization*) (*record equalization*)—Pre-emphasis in recording is the pre-equalization of a recording system where the system response is the reciprocal of a standard reproduce characteristic.

Pressing—A pressing is a disc produced in a molding press from a master or stamper.

Recording Loss—Recording loss is the loss in level whereby the amplitude of the wave in the medium differs from the amplitude executed by the stylus.

Re-recording—Re-recording is the process of reproducing a recorded sound source and recording this reproduction.

Rumble (*turntable rumble*)—Rumble is low-frequency vibration mechanically transmitted to the recording or reproducing turntable and superimposed on the reproduction.

Separation—Separation is the ratio of signal in the recorded channel to the signal in the unrecorded channel of a stereophonic disc groove.

Side Thrust—Side thrust in disc reproduction is the radial component of force on a pickup arm caused by the stylus drag.

Silvering—Silvering is a process wherein the lacquer original is metalized by precipitating on to this surface the metallic silver in ammoniated silver nitrate.

Silver Spraying—Silver spraying is metalizing the Lacquer Original using a dual spray nozzle wherein the ammoniated silver nitrate and reducer are combined in an atomized spray to precipitate the metallic silver.

Sputtering (*cathode sputtering*)—Sputtering is a process sometimes used in the production of the metal master wherein the original is coated with an electric conducting layer by means of an electric discharge in a vacuum. *Note:* Obsolete.

Stamper—A stamper is a metal negative made by electro-forming from which finished pressings are molded.

Stereophonic Recording—Stereophonic recording in discs is a system where two channels are recorded in a single groove.

Stylus Drag (*needle drag*)—Stylus drag is an expression used to denote the force resulting from friction between the surface of the recording medium and the reproducing stylus.

Stylus, Embossing—An embossing stylus is a recording stylus with a rounded tip which displaces the material in the recording medium to form a groove.

Stylus Force (*static stylus force*) (*vertical stylus force*) (*needle force*)—The stylus force is the vertical force exerted by the stylus on the groove. *Note:* For convenience of measurement the stylus force may be considered equivalent to the vertical force required to just lift the stylus clear of the groove.

Stylus, Recording—A recording stylus is the tool which inscribes the grooves into the disc medium. Tips may be designed for either cutting or embossing the groove.

Stylus, Reproducing—A reproducing stylus is a mechanical transmission element consisting of a suitable tip to follow the modulation of a recorded groove and a means for transferring the resultant vibration to the transducer element of the pickup. *Note:* In many modern pickups the term "stylus" may refer to a sub-assembly comprising the entire moving system of the pickup cartridge.

Surface Noise—Surface noise is the noise component in the electric output of a pickup due to irregularities in the surfaces of the groove walls at or close to the points of stylus contact.

Tracing Distortion—Tracing distortion is the non-linear distortion introduced in the reproduction of discs, because the curve traced by the motion of the spherical tip stylus is limited to a function of the tip radius and its instantaneous acceleration in the groove. *Note:* For example, in the case of a sine-wave modulation in vertical recording the curve traced by the center of the tip of a stylus is a poid.

Tracing Angle Error (*lateral*)—Lateral tracking angle error is the angle, projected to the plane of the disc, between the vibration axis of the mechanical system of the pickup and a tangent to an unmodulated groove at the point of stylus contact.

Tracking Angle Error (*vertical*)—Vertical tracking angle error is the angle between the mechanical axis of the pickup, projected on a plane perpendicular to the disc surface and containing the tangent to the groove at the point of contact, and the effective axis of the vertical modulation of the groove.

Translation Loss (*playback loss*)—Translation loss is the loss in the reproduction of a mechanical recording whereby the amplitude of motion of the reproducing stylus differs from the recorded amplitude in the medium.

Vertical Recording (*hill and dale recording*)—A vertical recording is a mechanical recording in which the groove modulation is in a direction essentially perpendicular to the surface of the recording medium. *Note:* Obsolete.

Wax—In mechanical recording, wax refers to a blend of waxes with metallic soaps. *Note:* Obsolete.

Wax, Cake—Cake wax is a thick disc of wax upon which an original mechanical disc recording may be inscribed. *Note:* Obsolete.

Wax, Flowed—Flowed wax is a mechanical recording medium, in disc form, prepared by melting and flowing wax onto a metal base. *Note:* Obsolete.

Wax Original (*wax master*)—A wax original is an original recording on a was surface for the purpose of making a master. *Note:* Obsolete.

NAB MAGNETIC TAPE RECORDING AND REPRODUCING STANDARDS: REEL-TO-REEL

Physical and Mechanical Specifications

Magnetic Tape Dimensions

1.01 Width. It shall be standard that magnetic tape width shall be 0.246 in. ± 0.002 in. for nominal 1/4-in. sound recording tape.

1.02 Thickness. It shall be standard that the thickness of magnetic tape shall not exceed 0.0022 in.

1.03 Length. It shall be standard that magnetic tape be supplied in the following minimum lengths:

Nominal Reel Dia.	*Nominal Hub*	*1.5 mil base*	*1.0 mil base*	*0.5 mil base*
3 in.	1.75 in.	125 ft.	200 ft.	300 ft.
5 in.	1.75 in.	600 ft.	900 ft.	[14]
7 in.	2.25 in.	1200 ft.	1800 ft.	[14]
10.5 in.	NAB 4.5 in.	2500 ft.	3600 ft.	[14]
14 in.	NAB 4.5 in.	5000 ft.	7200 ft.	[14]

Magnetic Tape Wind

1.04 It shall be standard that tape shall be wound with the oxide coated surface facing toward the hub of the reel.

1.04.01 Recorded tape normally should be wound so that the start of the program material is at the outside of the reel.

1.04.02 It is good engineering practice when storing recorded tapes for long periods of time that the start of the program material be at the inside next to the hub. Tapes so stored or shipped shall be clearly marked to prevent accidental playing in the reverse direction.[15]

Magnetic Tape Level and Uniformity

1.05 It shall be standard that magnetic tape shall have an average output level at 400 Hz at a tape speed of 7-1/2 ips which is uniform within ± 0.5 dB throughout a given reel.

[14]Not recommended.

[15]Tapes stored with the end of the program toward the outside of the reel will have slightly less preprint than postprint. This is generally desirable because postprint tends to be masked by the program material and reverberation effects. Also, rewinding a tape immediately before playing tends to reduce print-through. Another advantage of rewinding before playing is that stresses are relieved and any adhesion of adjacent layers of tape will be eliminated. A further advantage is that tape wound on the take-up reel in the play mode of operation usually is wound more smoothly than when wound at high speed. Therefore, there is less chance of damage during storage or shipment or due to temperature and humidity changes.

1.05.01 This measurement is to be made at the NAB Standard Reference Level and read on a Standard Volume Indicator (ASA Standard C16.5-1961) with bias adjusted for maximum output for the tape under test.

1.06 It shall be standard that magnetic tapes of any specified type shall have an average output at 400 Hz at a tape speed of 7-1/2 ips which is uniform within ± 1 dB from reel to reel.

1.06.01 This measurement is to be made at the NAB Standard Reference Level and read on a Standard Volume Indicator (ASA Standard C16.5-1961) with bias adjusted for maximum output for the tape under test.

Magnetic Track Designations

1.07 It shall be standard that in multitrack recordings, Track One shall be the top track when the tape is moving from left to right with the coated side facing away from the observer and with the leader to the right. The next lower track is designated Track Two, and so on.

Magnetic Track Dimensions

1.08 It shall be standard that the recorded magnetic track for full track recordings be 0.238 in. + 0.010 — 0.004 in. in width.

1.09 It shall be standard that the recorded tracks for two track monophonic or stereophonic recordings be 0.082 ± 0.002 in. in width with a center-to-center spacing of 0.156 ± 0.004 in.

1.10 It shall be standard that the recorded tracks for four track recordings shall be 0.043 + 0.000 — 0.004 in. in width. The center-to-center distances between Tracks 1 and 3, and between Tracks 2 and 4 shall be 0.134 + 0.002 — 0.000 in. The four tracks shall be equally disposed across the tape with a tape width of 0.244 in. and the outer edges of Tracks 1 and 4 coincident with the edges of the tape.

Two Track Stereophonic Recordings

1.11 It shall be standard that for two track stereophonic recordings, Track 1 shall carry the recording for the left-hand channel as viewed from the audience, and Track 2 shall carry the recording for the right-hand channel.

1.12 It shall be standard that for two track stereophonic recordings, the tracks shall be recorded with head gaps in line and phased for reproduction on equipment so connected that when a full track tape is reproduced, it produces in-phase signals in the two channel outputs.

Four Track Monophonic Recordings

1.13 It shall be standard that for four track monophonic recordings, the track recording sequence shall be 1-4-3-2.

Four Track Stereophonic Recordings

1.14 It shall be standard that Tracks 1 and 3 shall be used simultaneously for one direction of tape travel and Tracks 2 and 4 for the other direction. Tracks 1 and 3 shall be used first as the tape is unwound from the supply reel.

1.15 It shall be standard that Tracks 1 and 4 shall carry the recording for the left-hand channel as viewed from the audience, and Tracks 2 and 3 shall carry the recording for the right-hand channel.

1.16 It shall be standard in four track stereophonic recordings that Tracks 1 and 3 and Tracks 2 and 4 shall be recorded with the head gaps in line and shall be phased for reproduction on equipment so connected that when a full-track tape is reproduced it produces in-phase signals at the two channel outputs.

Magnetic Tape Reel Dimensions (1/4 in. tape)

1.17 It shall be standard that NAB magnetic tape reels for 1/4 in. tape be identified as Type A or Type B reels.

1.17.01 It shall be standard that NAB Type A reels shall include 10-1/2- or 14-in. metal or filled plastic reels with a nominal 3-in. center hole and shall conform to the dimensions and specifications of Fig. 2 and Table 2.

1.17.02 It shall be standard that NAB Type B reels shall include all filled or unfilled plastic reels with a nominal 5/16-in. center hole and shall conform to the dimensions and specifications of Fig. 3 and Table 3.

Specifications for Standard Systems

The following systems specifications apply to all high quality magnetic recording and reproducing equipment used for music and speech programs where superior performance is of primary importance.

Magnetic Tape Speeds

2.01 *Preferred speed.* It shall be standard that the preferred tape speed be 7-1/2 in. per second ± 0.2%.

2.01.01 The tolerance on tape speed shall apply to any portion of the reel of tape in use and shall be measured by the method described in Annex A.

2.02 *Supplementary Tape Speeds.* It shall be standard that 15 and 3-3/4 in. per second ± 0.2% be supplementary tape speeds.

2.02.01 The tolerance on tape speed shall apply to any portion of the reel of tape in use and shall be measured by the method described in Annex A.

Standard Reference Level

2.03 It shall be standard that the NAB Standard Reference Level shall be that 400 Hz level which is equal to the recorded level on the NAB Primary Reference Tape.[16]

Standard Recorded Program Level[17]

2.04 It shall be standard that recorded program material shall produce the same reference deflection on a Standard Volume Indicator (ASA Standard C16.5—1961) as that produced by a 400 Hz sine wave signal recorded at the NAB Standard Reference Level.

Standard Reproducing System Response[18]

2.05 It shall be standard that the Reproduce System Response at 7-1/2 in. per second from a 7-1/2 NAB 65 Test Tape shall be within the tolerance limits shown in Fig. 4a, between 30 Hz and 15 kHz. The positive tolerance shall not be exceeded beyond these frequency limits.

2.06 It shall be standard that the Reproduce System Response at 15 in. per second from a 15 NAB 65 Test Tape shall be within the tolerance

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[16]The NAB Primary Reference Tape is a tape of the normal general purpose type which has been selected for average characteristics of output, sensitivity, and distortion. The 400 Hz recording on it was made at 7-1/2 ips with bias adjusted for maximum output, at an output level 8 dB below that which produced 3% third harmonic distortion. This does not imply a failure to meet the 10 dB overload margin of Footnote 17. It is rather, a practical convenient method of specification consistent with the magnetic recording and reproducing process. Since neither the tape nor the measurement conditions can be duplicated exactly in the field, all NAB Standard Test Tapes contain a 400 Hz recording at the NAB Standard Reference Level within ± 0.25 dB as a means for making this level available.

[17]It is well established that at least a 10 dB margin is required between the sine wave load handling capacity of a system and the level of program material as measured by a Standard Volume Indicator (ASA Standard C16.5—1961). These peak levels are believed to be approximately the maximum flux which can be recorded on presently available tapes without excessive distortion. This is also substantiated by practical experience.

[18]It is recommended that the Standard Reproducing System response roll off at the rate of at least 6 dB per octave beyond the frequency limits specified.

Basic Reproducing Characteristics are defined in Annex B. The curves are shown in Fig. 6 and the values listed in Tables 4 and 5. Precise methods of measuring and calibrating a reproducing system are discussed in Annex C. A reproducer calibrated by these methods and meeting all of the specifications of this Standard is considered suitable for measuring and calibrating Standard Test Tapes.

Since NAB Standard Test Tapes are recorded across the full width of the tape, per Section 4.02, a low frequency boost may be expected when the test tape is reproduced on a head of less than full-track width. Refer to the instructions supplied with the test tape for further details.

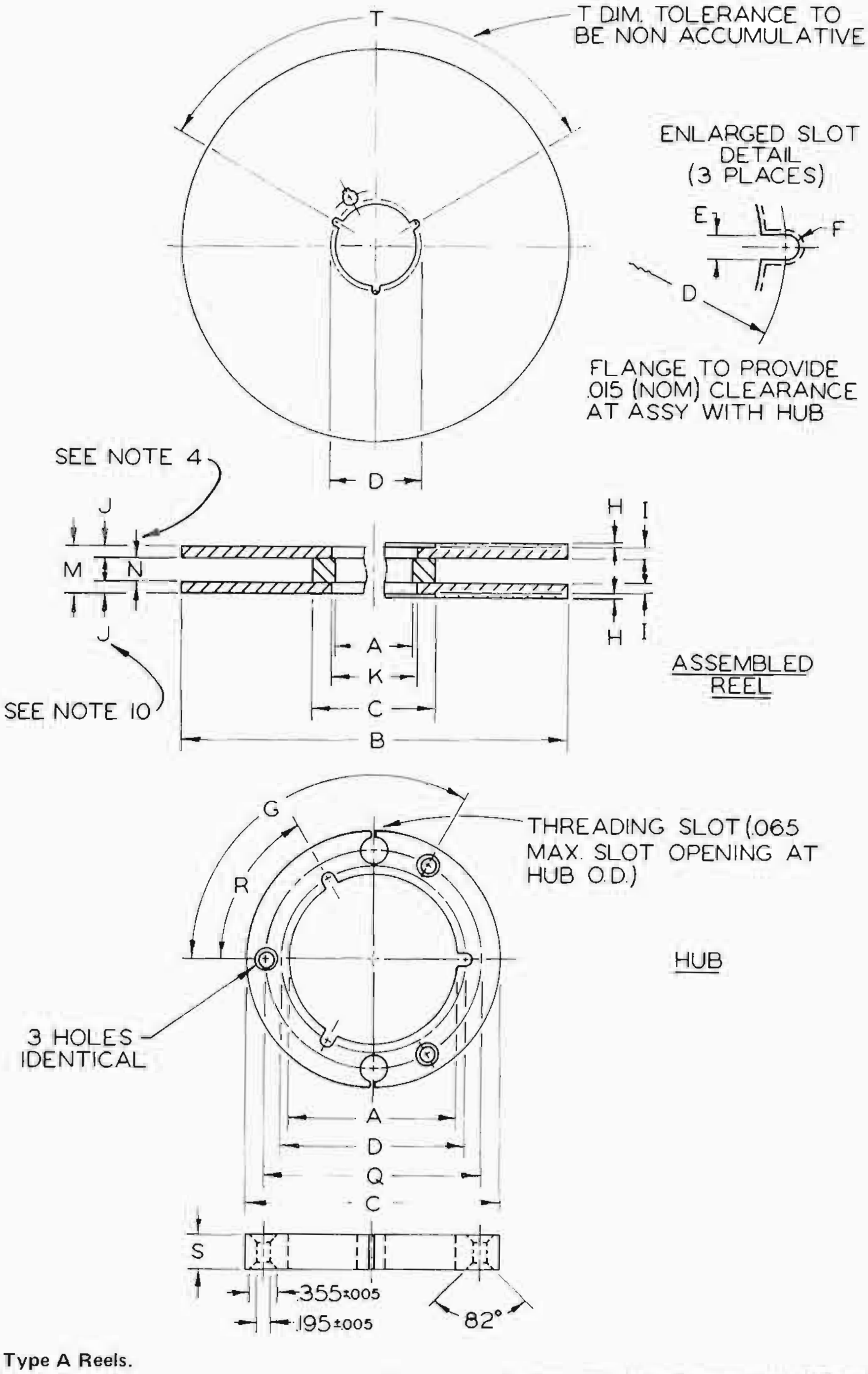

Fig. 2. NAB Type A Reels.

1. Reels shall have dimensions in inches as shown in above and Table 2.

2. Flanges may have cut outs of random shape. The flange open area shall not exceed 50% of the total flange area.

3. Threading slots are shown on the figure but are optional.

4. Dimension N is the distance between flanges at the hub and shall not vary more than ± 0.050 in. when measured from the hub to the periphery of the flanges. Flange wobble shall not extend beyond the hatched areas.

5. The outside cylindrical hub surface (Dimension C) shall be concentric to the center diameter (Dimension A) within 0.010 in. total indicator reading (TIR), and the flange rim (Dimension B) shall be concentric to the center hole within 0.050 in. TIR.

6. The real lateral mounting surfaces in the area of Dimension C of both sides of the reel shall be parallel to each other within 0.010 in. at the C diameter when machinist's flats are put in firm contact with each side. The distance between the two machinist's flats is Dimension M.

7. The outside cylindrical hub surface (Dimension C) shall have a taper no greater than 0.002 in. for metal reels and 0.003 in. for plastic reels.

8. Reels shall be symmetrical in that they shall mount and be functional when mounted on either lateral mounting surface.

9. The flanges shall be fastened to the hub with three or more fasteners which shall not protrude above the lateral mounting surface.

10. Dimension J represents flange thickness only for the NAB Type A metal reel.

TABLE 2

Dimensions for NAB Type A Reels Metal or Filled Plastic Three-Inch Center Hole

	Metal	Plastic
A	3.002 + 0.006 – 0.000	3.010 + 0.015 – 0.000
B	10.500 or 14.000 + 0.020 – 0.010	10.500 ± 0.020
C	4.500 ± 0.010	4.500 ± 0.015
D	3.250 + 0.008 – 0.002	3.250 + 0.020 – 0.000
E	0.219 + 0.010 – 0.000	0.219 + 0.013 – 0.000
F	0.109 + 0.005 – 0.000	0.109 + 0.007 – 0.000
G	120 degrees ± 0.25 degrees	Not applicable
H	0.025 maximum	0.060 maximum
I	0.080 maximum	0.115 maximum
J	0.055 maximum	Not applicable
K	3.031 + 0.006 – 0.000	Not applicable
M	0.462 ± 0.020	0.485 + 0.040 – 0.000
N	0.350 ± 0.005[a]	0.285 ± 0.015
Q	3.875 ± 0.002	Not applicable
R	60 degrees ± 0.25 degrees	Not applicable
S	0.350 ± 0.005	Not applicable
T	120 degrees ± 1/4 degrees	120 degrees ± 1/4 degrees

[a]See figure caption Part 4 of Fig. 2.

TABLE 3

Dimensions for NAB Type B Reels Plastic with Nominal 5/16-in. Center Hole

Nominal size	3	5	5	7	7	Tolerance	10-1/2	Tolerance
B	2.938	5.000	5.000	7.000	7.000	+ 0.031 – 0.000	10.500	± 0.020
C	1.750	1.750	3.000	2.250	4.000	± 0.010	4.500	± 0.015
G	120°	120°	120°	120°	120°	± 0.5°	120°	± 0.5°
H	0.050	0.050	0.050	0.050	0.050	Maximum	0.060	Maximum
I	0.115	0.115	0.115	0.115	0.115	Maximum	0.115	Maximum
M[a]	0.485	0.485	0.485	0.485	0.485	+ .040 – 0.000	0.485	+ 0.040 – 0.000
P	1.750	1.750	2.250	2.250	2.250	Minimum	4.500	Minimum
U	0.319	0.319	0.319	0.319	0.319	± 0.003	0.319	± 0.003
V	0.063	0.063	0.063	0.063	0.063	± 0.005	0.063	± 0.005
W	0.625	0.625	0.625	0.625	0.625	± 0.005	0.625	± 0.005
X[b]								
Y[b]								
Z[b]								

[a]See figure caption Part 9 of Fig. 3.
[b]See figure caption Part 3 of Fig. 3.

limits shown in Fig. 4b, between 30 Hz and 15 kHz. The positive tolerance shall not be exceeded beyond these frequency limits.

2.07 It shall be standard that the Reproduce System Response at 3-3/4 in. per second from a 3-3/4 NAB 65 Test Tape shall be within the tolerance limits shown in Fig. 4c, between 50 Hz and 10 kHz. The positive tolerance shall not be exceeded beyond these frequency limits.[19]

Standard Recorded Response

2.08 It shall be standard that the Standard Recorded Response shall be within the tolerance limits shown in Fig. 5a, 5b, or 5c, depending upon the tape speed.

[19]It should be noted that full-track operation at the lower tape speeds may cause some difficulty in consistently meeting the frequency response standards due to possible tape skew and the resultant azimuth errors.

2.08.01 The recorded response is defined as the difference between the overall record-reproduce response and the reproduce response from an NAB Standard Test Tape of the same speed.[20]

2.08.02 The measurement of recorded response shall be made at the same level as that on the NAB Standard Test Tape. Normal operating bias shall be used.

[20]The recording equalization of a recorder/reproducer should be adjusted for an overall response which matches as nearly as possible the response of the reproducer from the NAB Standard Test Tape. This response is standardized, rather than the simple overall record-reproduce response, in order to assure better interchangeability of recorded tapes.

An alternate definition of a Recorded Characteristic could be in terms of measured surface induction or remanent flux in free space. However, since such measurements are of limited value, particularly when used with ferromagnetic heads at short wavelengths, the definition in 2.08.01 has been accepted as more useful for the purpose of this Standard.

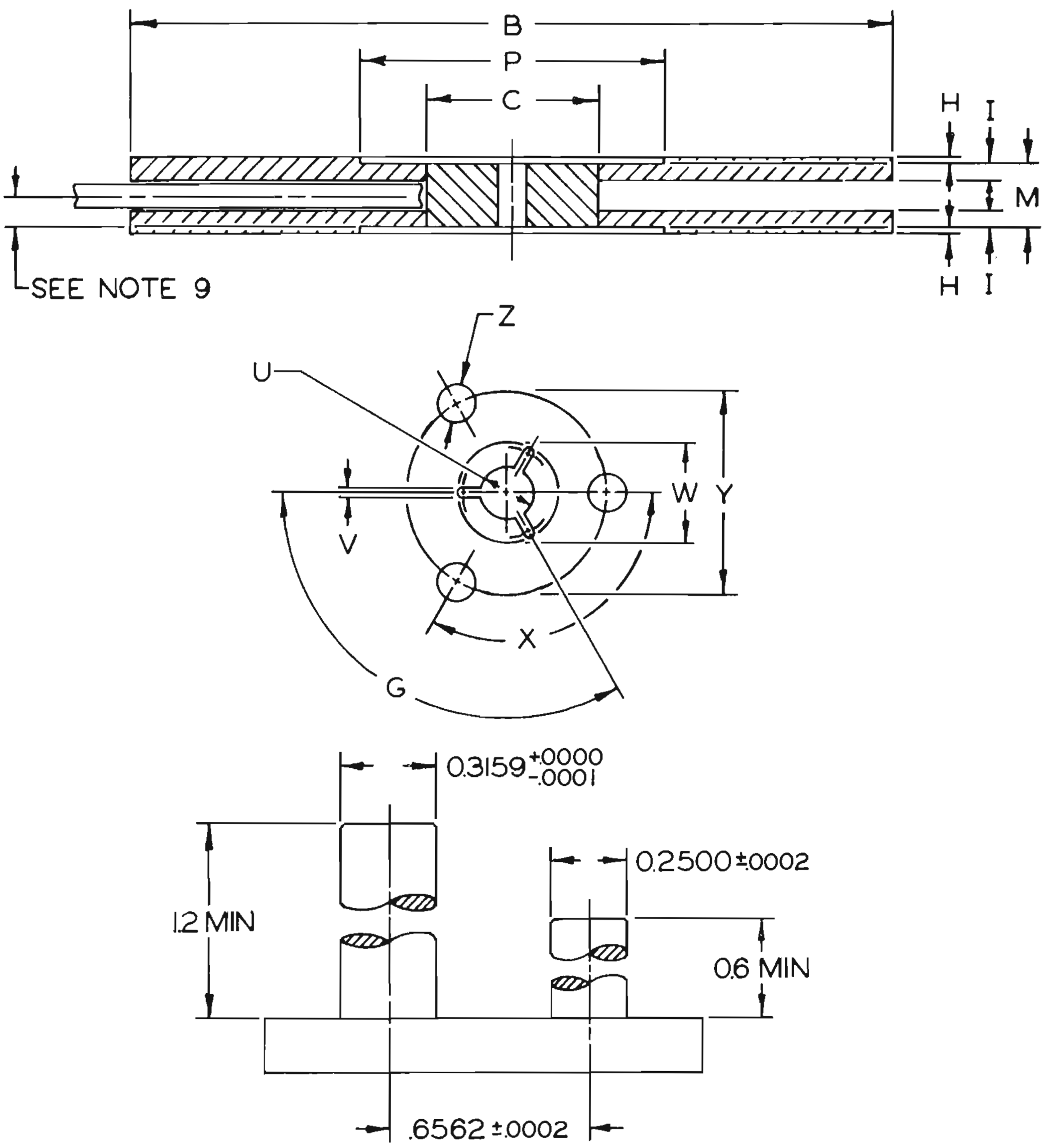

Fig. 3. NAB Type B reel and drive hole gauge.

1. Reels shall have dimensions in inches as shown in the above and Table 3.

2. Flanges may have cut outs of random shape and size, however, flange open area must not exceed 50% of the area between Dimensions B and C.

3. Reels may have one, two or three drive holes and must fit on the gauge shown on Fig. 3. If more than one drive hole is used, they shall be symmetrically spaced around the center hole.

4. Reels are to be constructed so that any profile section taken through the center axis of the reel will fall within the hatched envelope shown above. This includes warpage and lateral run out of the flanges. Bosses, ribs or other raised designs are permitted on the outside of the flange surfaces but they shall not extend beyond the envelope when the reel is rotated on its center axis.

5. The reel hub should be provided with a suitable method of tape attachment. Threading slots are optional, but, if used, shall not be wider than 0.065 in. at the hub surface.

6. The outside cylindrical hub surface (Dimension C) shall be concentric to the center diameter (Dimension U) within 0.010 in. total indicator reading (TIR), and the flange rim (Dimension B) shall be concentric to the center diameter within 0.020 in. TIR.

7. The outside cylindrical hub surface (Dimension C) shall have a taper in relation to either lateral mounting surface no greater than 0.003 in.

8. Reels shall be symmetrical in that they shall mount and be functional when mounted on either lateral mounting surface.

9. The intent of this standard is to accept all plastic reels with an M dimension between 0.485 in. and 0.525 in. With guides set for a nominal tape path center line of 0.243 in. above the reel mounting surface there will be no flange interference with the tape with the I dimension held at 0.115 in. or less and the M dimension at a minimum. A larger M dimension will merely raise the upper flange further away from the upper edge of the tape.

TABLE 4
NAB Standard Reproducing Characteristic
7-1/2 and 15 ips (3180 and 50 μs)

Reproducing amplifier output for constant flux in the core of an ideal reproducing head

Frequency (in Hz)	Response (in dB)	Frequency (in kHz)	Response (in dB)
20	− 8.6	1.5	+ 0.9
25	7.0	2	1.45
30	5.8	2.5	2.1
40	4.1	3	2.75
50	3.0	4	4.1
60	2.3	5	5.4
70	1.8	6	6.6
75	1.6	7	7.7
80	1.4	7.5	8.2
90	1.2	8	8.6
100	1.0	9	9.5
150	0.45	10	10.35
200	0.2	11	11.1
250	0.1	12	11.8
300	− 0.1	13	12.5
400	±0	14	13.1
500	+ 0.1	15	13.6
600	0.1	16	14.2
700	0.2	17	14.7
750	0.2	18	15.2
800	0.2	19	15.6
900	0.3	20	16.1
1 kHz	+ 0.4		

TABLE 5
NAB Standard Reproducing Characteristic
1-7/8 and 3-3/4 ips (3180 and 90 μs)

Reproducing amplifier output for constant flux in the core of an ideal reproducing head

Frequency (in Hz)	Response (in dB)	Frequency (in kHz)	Response (in dB)
20	− 8.8	1.5	+ 2.2
25	7.2	2	3.4
30	5.9	2.5	4.6
40	4.2	3	5.7
50	3.2	4	7.7
60	2.4	5	9.4
70	1.9	6	10.8
75	1.7	7	12.1
80	1.6	7.5	12.6
90	1.3	8	13.2
100	1.1	9	14.15
150	0.6	10	15.0
200	0.4	11	15.8
250	0.2	12	16.6
300	0.15	13	17.2
400	±0	14	17.9
500	+ 0.1	15	18.5
600	0.3	16	19.0
700	0.5	17	19.6
750	0.55	18	20.0
800	0.6	19	20.5
900	0.8	20	21.0
1 kHz	+ 1.0		

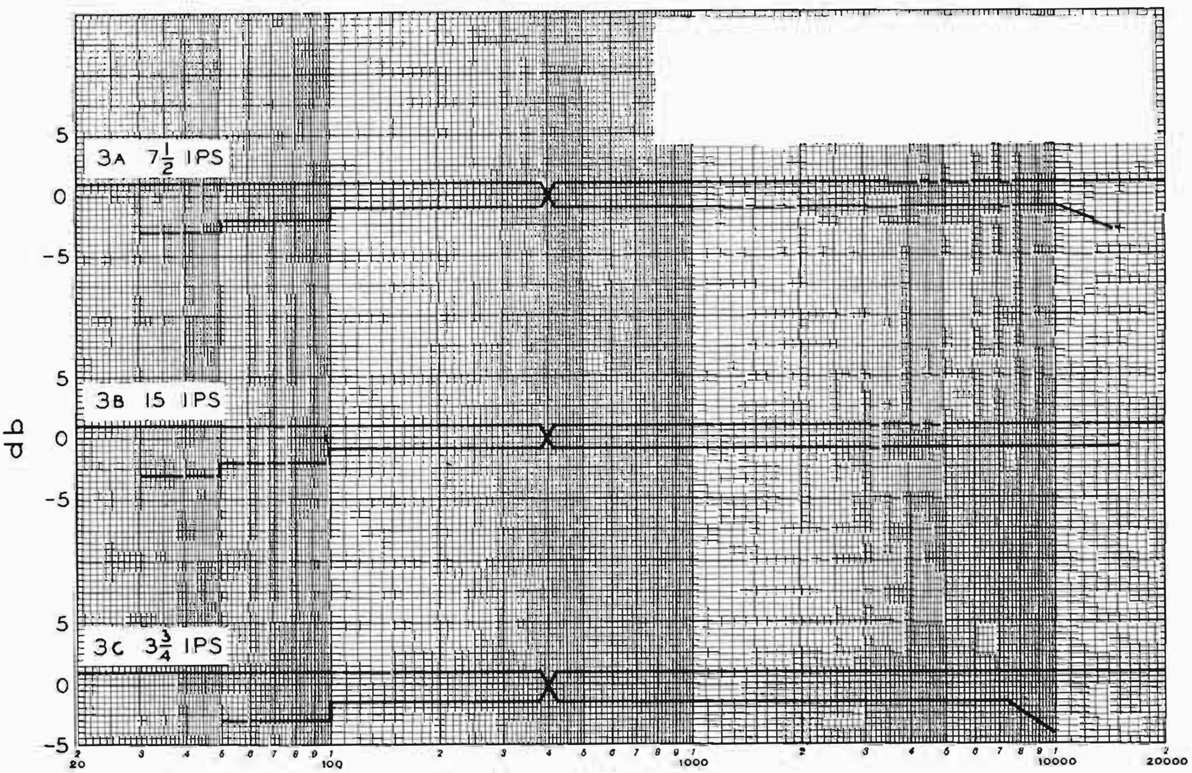

Fig. 4. NAB standard reproducing systems response limits.

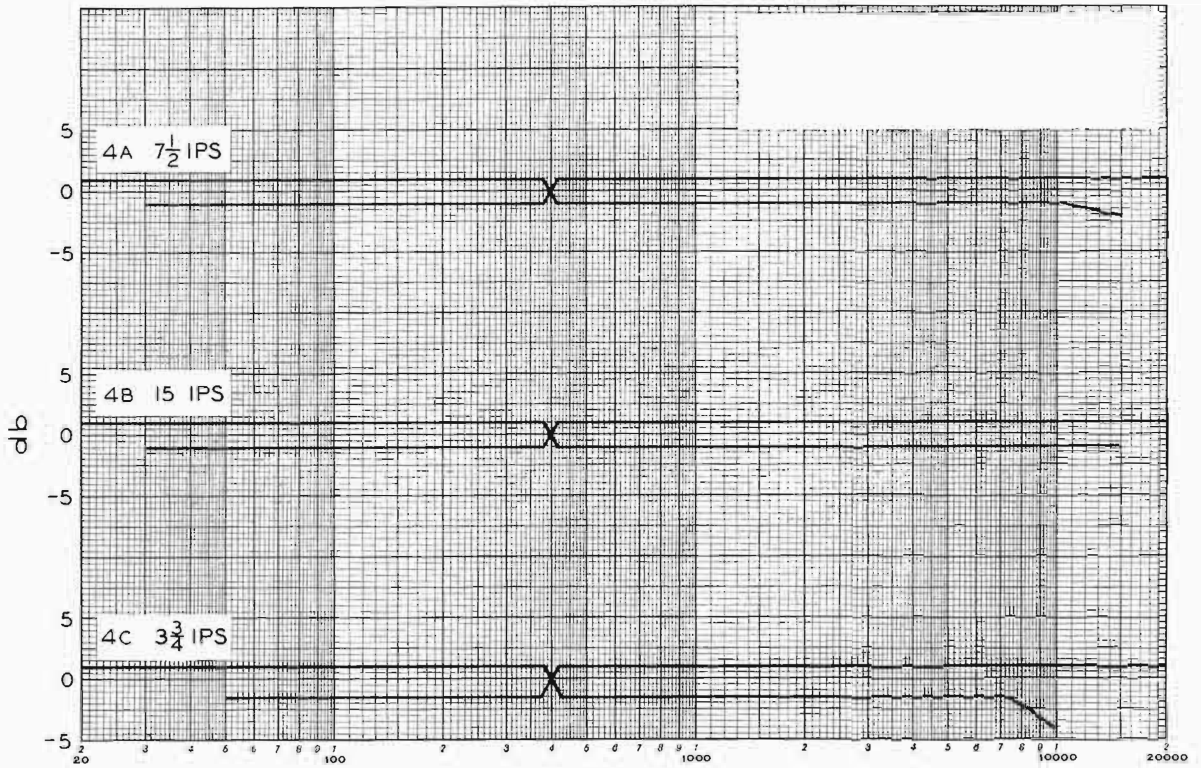

Fig. 5. NAB standard recorded response limits.

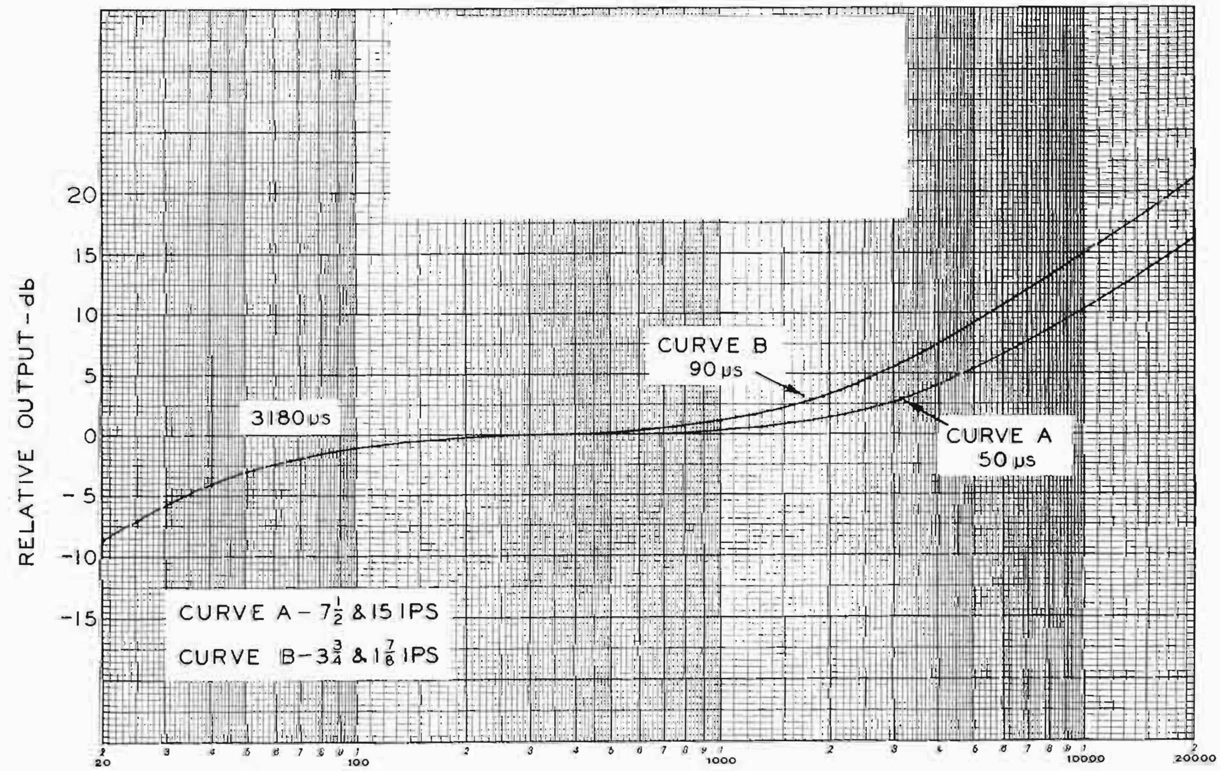

Fig. 6. NAB standard reproducing characteristic reproducing amplifier output for constant flux in the core of an ideal reproducing head.

Signal-to-Noise Ratio[21]

2.09 It shall be standard that the unweighted signal-to-noise ratio shall be not less than the following:

Tape Speed	*Full Track*	*Two Track*	*Four Track*
15 ips	50 dB	45 dB	not used
7-1/2 ips	50 dB	45 dB	45 dB
3-3/4 ips	46 dB	46 dB	45 dB

2.09.01 Unweighted noise shall be measured over the frequency range of 20 Hz to 20 kHz. The response of the measuring system shall be uniform ± 0.3 dB from 30 to 15,000 Hz. Response at 20,000 Hz shall be 3 dB below the 400 Hz value, falling at the rate of at least 12 dB per octave above 20 kHz. The noise measurement shall be made using a tape previously recorded with bias but with no signal. The reference signal level shall be the 400 Hz NAB Standard Reference Level and the indicating meter shall have the dynamics of the Standard Volume Indicator (ASA Standard C16.5—1961). The measuring system shall have a full-wave rectified average measurement law.

2.10 It shall be standard that the weighted signal-to-noise ratio shall be not less than the following:[22]

Tape Speed	*Full Track*	*Two Track*	*Four Track*
15 ips	58 dB	53 dB	not used
7-1/2 ips	60 dB	55 dB	52 dB
3-3/4 ips	57 dB	54 dB	52 dB

2.10.01 Weighted noise shall be measured using the weighting curve of Fig. 7 in the measuring circuit. This curve is based on the ASA "A" curve (ASA Standard S1.4-1961). The noise measurement shall be made using a tape previously recorded with bias but with no signal. Calibration is made (with the weighting network inserted) at 1000 Hz using the 1000 Hz Standard Level which is included for this purpose on the NAB Standard Test Tape. The indicator meter shall have the dynamics of the Standard Volume Indicator (ASA Standard C16.5-1961) and the measuring system shall have a full-wave rectified average measurement law.

Distortion[23]

2.11 It shall be standard that the overall record reproduce system total harmonic distortion including tape shall be less than 3% rms for a 400 Hz sine wave signal recorded to achieve a reproduce level 6 dB above the NAB Standard Reference Level.

Flutter

2.12 It shall be standard that in the reproduce mode the unweighted flutter content when reproducing an essentially flutter-free recording of 3 kHz at any portion of the reel of tape in use shall not exceed the following:

Tape Speed	*Flutter (rms)*
15 ips	0.15%
7-1/2 ips	0.20%
3-3/4 ips	0.25%

2.12.01 Unweighted flutter content shall be measured over the frequency range of 0.5 Hz to 200 Hz. The response of the measuring system shall be 3 dB down at 0.5 Hz and 200 Hz, and falling at a rate of at least 6 dB per octave below and above these frequencies, respectively. At low frequencies where the meter pointer follows the wave form, the maximum deflection shall indicate the rms value. The indicating meter shall have the dynamics of the Standard Volume Indicator (ASA C16.5-1961), a full-wave rectified average measurement law, and shall be calibrated to read the rms value of a sinusoidal frequency variation.

2.12.02 It shall be standard that the meter be read for random periods throughout the length of the tape, noting the average of the peak readings, but excluding random peaks which do not recur more than three times in any 10-second period.

2.13 It shall be standard that in the reproduce mode the weighted flutter content when reproduc-

[21]These measurements are intended to give a measure of noise in terms of the NAB Standard Reference Level; they are therefore figures of merit for comparisons of system noise. They do not, however, take into account the program level which may be recorded on a particular tape without excessive distortion. It should be borne in mind that the peak signal-to-noise ratio may be approximately 10 dB better than the figures given when the NAB Standard Recorded Program Level is used on general purpose tape.

[22]The use of 3-3/4 ips full-track recordings may present practical difficulties in maintaining azimuth.

See Footnote 21.

The weighted noise measurement employs a frequency response similar to that of the ear at low volume levels and is intended to give a more useful indication of the subjective signal-to-noise ratio than the unweighted measurement. The noise measurement is approximately comparable to that obtained by the use of a 500 to 15,000 Hz filter in disc noise measurements.

Note that the weighted signal-to-noise ratio is poorer at 15 ips than at 7-1/2 ips. This is due to the fact that the reproduce amplifier equalizations remains the same for both speeds while the tape noise increases with tape speed.

[23]The recording amplifier should not overload with high frequency input signals equal in level to the maximum expected low frequency levels. In practice, this means that the recording high frequency pre-emphasis may place an additional demand on the undistorted amplifier output. Distortion of this type is not normally detected by harmonic distortion measurements. Bias leakage into the record or reproduce amplifier circuits may be a source of additional distortion.

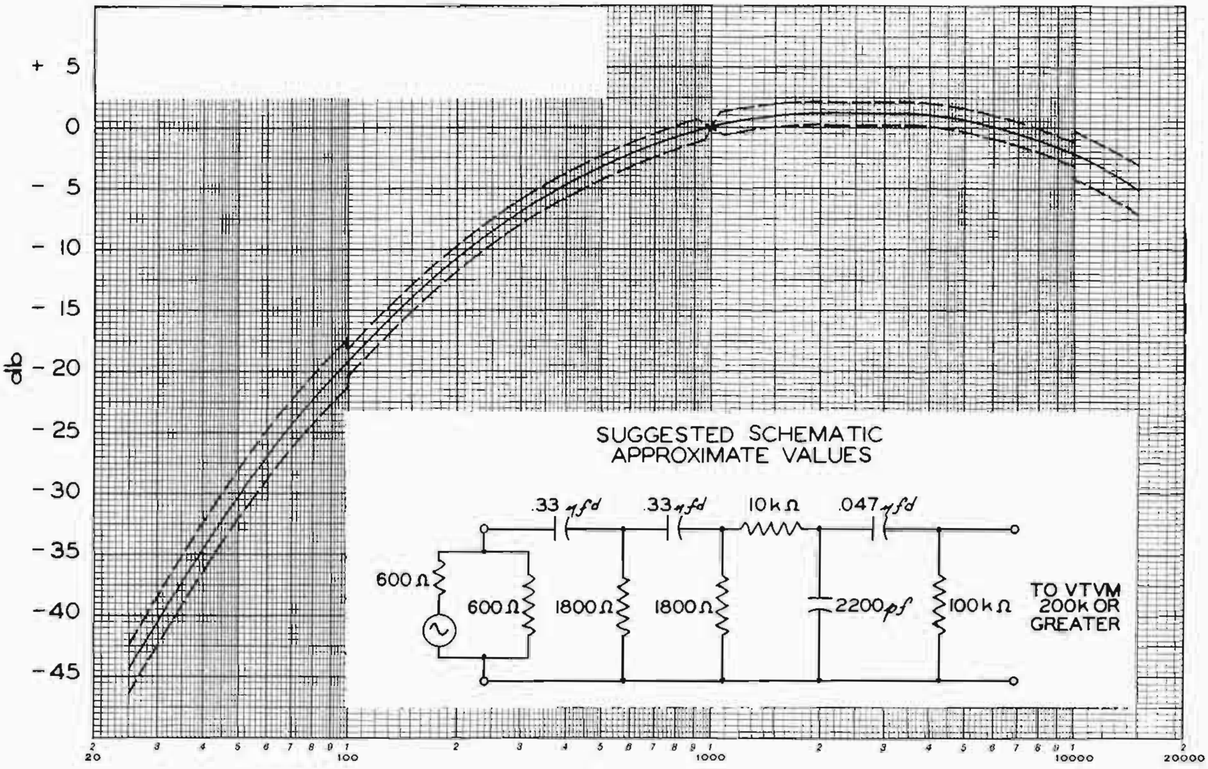

Fig. 7. Weighting curve for weighted noise measurements.

ing an essentially flutter-free recording at 3 kHz at any portion of the reel of tape in use shall not exceed the following:[24]

Tape Speed	*Flutter (rms)*
15 ips	0.05%
7-1/2 ips	0.07%
3-3/4 ips	0.10%

2.13.01 Weighted flutter shall be measured over the frequency range of 0.5 to 200 Hz. The response of the measuring system shall be as specified in Fig. 8. At low frequencies where the pointer follows the waveform, the maximum deflection shall indicate the rms value. The indicating meter shall have the dynamics of the Standard Volume Indicator (ASA C16.5-1961), a full-wave rectified average measurement law, and shall be calibrated to read the rms value of a sinusoidal frequency variation.

2.13.02 It shall be standard that the meter be read for random periods throughout the length of the tape, noting the average of the peak readings, but excluding random peaks which do not recur more than three times in any 10-second period.

Crosstalk[25]

2.14 It shall be standard that for two or four track monophonic systems and for four track stereophonic systems, the adjacent track signal-to-crosstalk ratio shall be not less than 60 dB in the range from 200 Hz to 10 kHz.[26]

2.14.01 For these measurements, bias shall not be applied to the unrecorded tracks.

Stereophonic Channel Separation

2.15 It shall be standard that with stereophonic systems channel separation shall be not less than 40 dB between the frequencies of 100 Hz and 10 kHz.

2.15.01 For measurements of stereophonic systems, bias shall be applied to both tracks.

[24]The weighted flutter measurement employs a frequency response similar to the sensitivity of the ear to frequency variations versus the frequency of these variations ("flutter rate") and is intended to give a more useful indication of the subjective effect of flutter than the unweighted measurement.

[25]These measurements shall be made at the recorded level of the frequency response portion of the NAB Standard Test Tape, and must be made with a tuned voltmeter in order to eliminate the effect of noise. The reference level shall be the 400 Hz tone in the frequency response portion of the NAB Test Tape.

[26]It should be recognized that two-track monophonic tapes which are duplicated on stereophonic equipment will have the crosstalk characteristics of a stereophonic system and therefore may not meet this crosstalk specification.

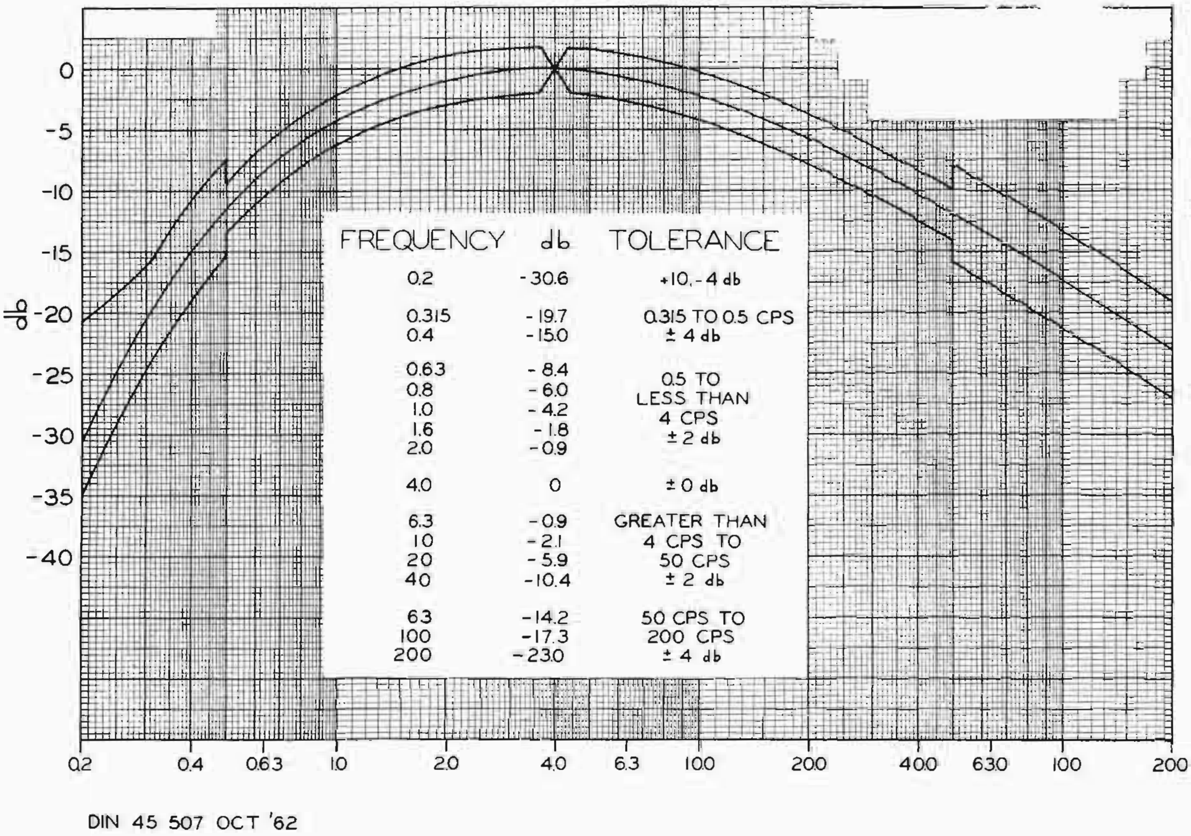

Fig. 8. Weighting curve for weighted flutter measurements.

Specifications for Special Purpose Limited Performance Systems

The use of lightweight portable magnetic recorders is recognized in this section of the Standard. It presents what are considered to be the minimum acceptable performance requirements where adequate voice intelligibility and interchangeability of recorded tapes are of primary importance. Systems meeting these specifications are not suitable for maximum fidelity recording of speech or music.

Tape Speeds

3.01 It shall be standard that tape speeds for Special Purpose Magnetic Recording and Reproducing Systems be 7-1/2, 3-3/4, or 1-7/8 in. per second, ± 2% as measured at any portion of the reel of tape in use, and shall be measured by the method described in Annex A.

Flutter

3.02 It shall be standard that in the reproduce mode, unweighted flutter content, when reproducing an essentially flutter-free recording of 3 kHz, shall not exceed 0.5% rms at any portion of the reel of tape in use.

3.02.01 Unweighted flutter content shall be measured over the frequency range of 0.5 Hz to 200 Hz. The response of the measuring system shall be 3 dB down at 0.5 Hz and 200 Hz, and falling at a rate of at least 6 dB per octave below and above these frequencies, respectively. At low frequencies where the meter pointer follows the waveform, the maximum deflection shall indicate the rms value. The indicating meter shall have the dynamics of the Standard Volume Indicator (ASA C16.5-1961), a full-wave rectified average measurement law, and shall be calibrated to read the rms value of a sinusoidal frequency variation.

3.02.02 It shall be standard that the meter be read for random periods throughout the length of the tape, noting the average of the peak readings, but excluding random peaks which do not recur more than three times in any 10-second period.

Standard Recorded Program Level[27]

3.03 It shall be standard that recorded program material shall produce the same reference

[27]It is well established that at least a 10-dB margin is required between the sine wave load handling capacity of a

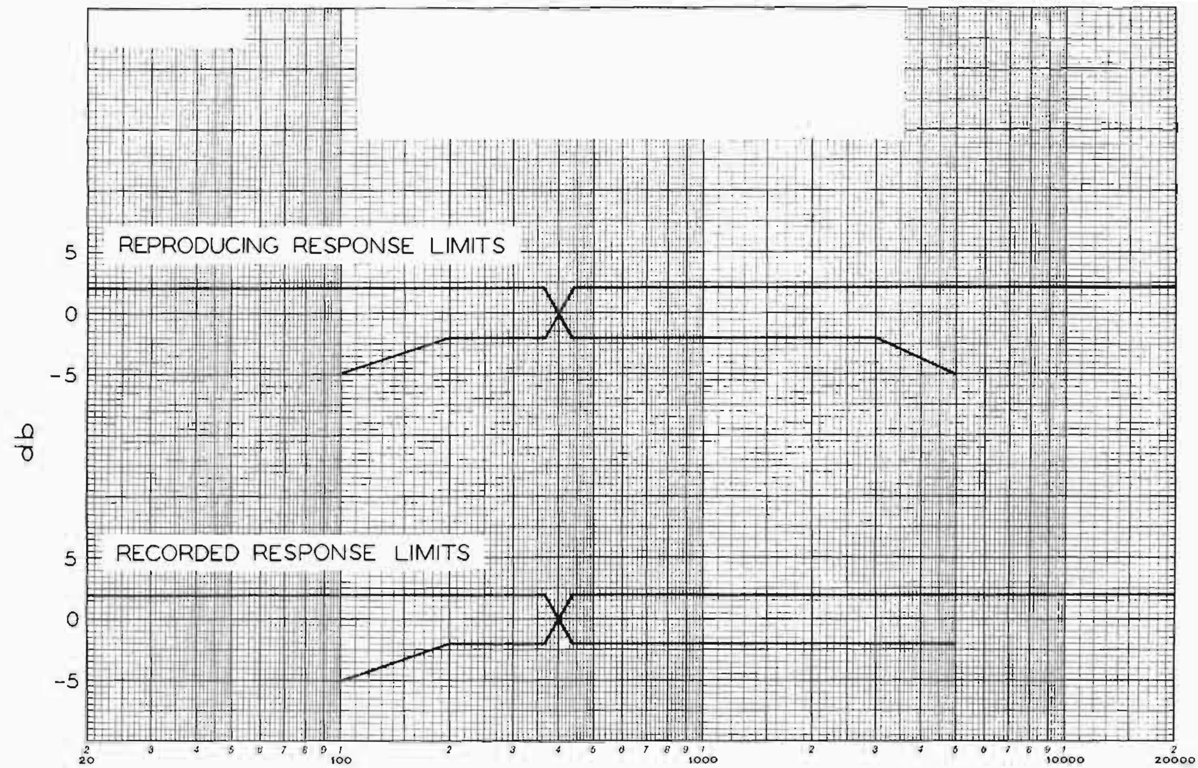

Fig. 9. NAB reproducing system and recorded response limits. Special purpose limited performance systems applicable to 7-1/2, 3-3/4, and 1-7/8 ips.

deflection on a Standard Volume Indicator (ASA Standard C16.5-1961) as that produced by a 400 Hz sine wave signal recorded at the NAB Standard Reference Level.

Reproducing System Response[28]

3.04 It shall be standard that the Reproduce System Response from an appropriate NAB Test Tape shall be within the tolerance limits shown in Fig. 9.

3.04.01 This specification represents the minimum acceptable limits, and is not intended to restrict the frequency range of voice recording systems which have the inherent capability of wide-range recording, without distortion. It is, however, often considered desirable to limit the extreme low frequency response for improved speech intelligibility.

system and the level of program material as measured by a Standard Volume Indicator (ASA Standard C16.5-1961). These peak levels are believed to be approximately the maximum flux which can be recorded on presently available tapes without excessive distortion. This is also substantiated by practical experience.

At a speed of 1-7/8 ips, it may be advisable to record certain types of program material at a lower level to avoid distortion.

[28]Basic Reproducing Characteristics are defined in Annex B. The curves are shown in Fig. 6 and the values listed in Tables 4 and 5.

Recorded Response

3.05 It shall be standard that the Recorded Response shall be within the tolerance limits shown in Fig. 9.

3.05.01 The recorded response is defined as the difference between the overall record—reproduce response and the reproduce response from an NAB Standard Test Tape of the same speed.

3.05.02 The measurement of Recorded Response must be made at the same level as that on the Standard Test Tape. Normal operating bias shall be used.

3.05.03 It is recommended that the Recorded Response be attenuated below 100 Hz at the rate of approximately 6 dB per octave in order to improve speech intelligibility. A similar attenuation above 5 kHz is recommended in order to reduce the chance of high frequency tape overload at the lower tape speeds.

Signal-to-Noise Ratio

3.06 It shall be standard that the unweighted signal-to-noise ratio shall be not less than the following:

Full Track	46 dB
Two Track	43 dB
Four Track	40 dB

3.06.01 Unweighted noise shall be measured over the frequency range of 20 Hz to 20 kHz. The response of the measuring system shall be uniform ± 0.3 dB from 30 to 15,000 Hz. Response at 20,000 Hz shall be 3 dB below the 400 Hz value, falling at the rate of at least 12 dB per octave above 20 kHz. The noise measurement shall be made using a tape previously recorded with bias but with no signal. The reference signal level shall be the 400 Hz NAB Standard Reference Level and the indicating meter shall have the dynamics of the Standard Volume Indicator (ASA Standard C16.5-1961). The measuring system shall have a full-wave rectified average measurement law.

Standard Test Tapes

4.01 The NAB Standard Test Tapes for reel-to-reel equipment shall be designated as follows:

Speed	*Test Tape*
15 ips	15 NAB 65
7-1/2 ips	7-1/2 NAB 65
3-3/4 ips	3-3/4 NAB 65
1-7/8 ips	1-7/8 NAB 65

4.02 All test tapes shall be recorded across the full width of the tape.

4.03 Each NAB Standard Test Tape shall contain five parts as defined in the following sections.

4.03.01 An azimuth adjustment tone of 60 seconds duration at the following frequencies:[29]

Speed	*Frequency*
15 ips	15 kHz
7-1/2 ips	15 kHz
3-3/4 ips	10 kHz
1-7/8 ips	5 kHz

4.03.02 A 400 Hz sine wave signal of 20 seconds duration at the following level referred to the NAB Standard Reference Level:

Speed	*Level*
15 ips	0 dB
7-1/2 ips	– 10 dB
3-3/4 ips	– 15 dB
1-7/8 ips	– 15 dB

4.03.03 A frequency response test containing the following frequencies at the indicated recorded levels. Each tone shall be approximately 12 seconds in duration and preceded by a voice announcement. The signal frequencies are recorded on these tapes in such a manner that they would supply a constant output level when reproduced on an Ideal Reproducing System.[30] The relative levels are measured during manufacture of the tape on a reproducing system of known, defined characteristics which are determined by the method described in Annex C.

15 ips 0 dB (in kHz)	*7-1/2 ips – 10 dB (in kHz)*	*3-3/4 ips – 15 dB (in kHz)*	*1-7/8 ips – 15 dB (in kHz)*
15	15		
12	12		
10	10	10	
7.5	7.5	7.5	
5	5	5	5
2.5	2.5	2.5	2.5
1	1	1	1
(in Hz)	*(in Hz)*	*(in Hz)*	*(in Hz)*
750	750	750	750
500	500	500	500
250	250	250	250
100	100	100	100
75	75	75	75
50	50	50	50
30	30	30	30

4.03.04 A 400 Hz sine wave signal of 20 seconds duration at the NAB Standard Reference Level.[31]

4.03.05 A 1000 Hz sine wave signal of 60 seconds duration at the NAB Standard Recorded Program Level. (See Section 2.04)

[29]The recorded level shall be the same as that of the corresponding frequency in the Frequency Response portion of the tape. The recorded azimuth shall be at 90° + 1 minute with respect to the edge of the tape.

[30]See Annex B of this Standard for a definition of the Ideal Reproducing System and the equalization to be used. Note that the curves of Fig. 6 are frequency response curves of the Ideal Reproducer with constant flux in the core of the Ideal Head instead of the basic amplifier curve which was used in the 1953 NAB Standard. The concept of expressing a curve in terms of time constants remains unchanged and it is still necessary to modify the amplifier response to compensate for practical reproduce head losses in a Standard Reproducing System.

[31]The level on the NAB Primary Reference Tape is that of a 400 Hz tone at a tape speed of 7-1/2 ips, and thus represents a wavelength of 18.75 mils. Test Tapes for speeds other than 7-1/2 ips are recorded such that they would supply the same ideal head flux at the same wavelength as the Primary Reference Tape, when measured on an Ideal Reproducing System.

Annex A

Methods of Tape Speed Measurement

It shall be standard that tape speed be measured by applying the 1/4 in. wide circumference of a precision pulley mounted on precision low friction bearings to the surface of the tape between the capstan and head assembly. The rotational speed of the pulley when driven by the tape may be measured by the use of an ac tachometer generator or by a stroboscope disc mounted on the pulley's flat surface. Tests of tape speed shall be made relative to the power line frequency.

It must be recognized that tape speed depends to some extent on tape thickness and tension, and on room temperature and humidity. Therefore, speed checks should be made under normal operating conditions with the machine adjusted according to manufacturer's recommendations.

Measurements shall be made with a tape the thickness of which is 0.0019 in. ± 0.0002 in. which corresponds to the thickness of nominal 1.5 mil base tape.

A suggested design for a practical stroboscope disc consists of a pulley with a diameter of 1.4305 + 0.0002 — 0.0000 in. upon which is attached a printed disc having 72 and 36 equally spaced dots or solid lines. A neon lamp operating from the 60 Hz motor supply flashes at a 120 Hz rate. The stroboscope disc, when illuminated by this lamp, will indicate 7-1/2 and 15 ips tape speeds, respectively. For 3-3/4 ips operation, a diode in series with a neon lamp is required so that the lamp will flash at a 60 Hz rate.

It shall be standard that when using a stroboscope disc as recommended above, no more than 14 dots per minute shall drift past a fixed reference point in either direction for 7-1/2 or 15 ips operation. For 3-3/4 ips operation the drift per minute shall not exceed 7 dots on the 36 dot disc. These limits of drift correspond to the speed tolerance limits of ± 0.2%.

Annex B

Ideal Reproducing System

It shall be standard that the NAB Ideal Reproducing System is a theoretical reproducer system. It consists of an "ideal reproducing head[a] and an amplifier the output voltable of which shall conform to the voltage-frequency curve of Fig. 6, with constant flux versus frequency in the core of the head.[b]

The curve of voltage versus frequency shall be uniform with frequency except where modified by the following equalizations:

a. The voltage attenuation of a single resistance-capacitance high-pass filter having an RC time constant t_1.

b. The inverse of the voltage attenuation of a single resistance-capacitance low-pass filter having an RC time constant t_2.

The curve expressed in decibels is represented by the following expressions:

$$\text{Where: } N_{dB} = 20 \log_{10} \omega t_1 \sqrt{\frac{1 + (\omega t_2)^2}{1 + (\omega t_1)^2}}$$

$\omega = 2\pi f$

f = frequency

And, t_1 and t_2 are as follows:

Tape Speed	t_1	t_2
15 ips	3180 μs	50 μs
7-1/2 ips	3180 μs	50 μs
3-3/4 ips	3180 μs	90 μs
1-7/8 ips	3180 μs	90 μs

[a]An "ideal" reproducing head is defined as a ferromagnetic ring head, the losses of which are negligible. This means that the gap is short and straight, the long wavelength flux paths are controlled so that no low-frequency contour effects are present and the losses in the head materials are negligibly small.

[b]It is recognized that the flux in the core of an "ideal" head is not necessarily the same as the surface flux on a tape in space for various reasons. Since most of these effects are not readily measured, it has been decided to base this standard on "ideal" head core flux rather than surface induction.

Annex C

Primary Calibrated Reproducing System[a]

A Primary Calibrated Reproducing System used for the purpose of calibrating Standard Test Tapes shall meet the following specifications:

1. The system response shall not deviate more than ± 3 dB from the ideal over the frequency range of interest.

2. Electrical—Apparent core loss at the highest frequency of interest shall not exceed 3 dB undamped head resonance shall not exceed 3 dB and amplifier deviation from the Ideal Response shall not exceed ± 3 dB.

3. Magnetic—Head gap losses shall not exceed 3 dB at the highest frequency of interest and the head contour effect curve shall not deviate more than ± 2 dB from the average.

Electrical losses shall be determined from measurements of the amplifier frequency response characteristic and the reproduce system

[a]An NAB Standard Reproducing System need not fulfill the requirements for a Primary Calibrated Reproducting System as described in this Annex.

output voltage characteristic with constant flux versus frequency in the head core.

Magnetic losses shall be determined from calculations of gap loss and measurements of head contour effects.

The following paragraphs specify the methods by which these characteristics shall be measured and the reproduce system calibrated. The procedure is to determine the various losses independently and consider them as deviations from the theoretical "Ideal Reproducing System."

Electrical Measurements

Three response frequency curves shall be made. First, the amplifier response alone with voltage directly proportional to frequency (voltage doubles for each octave frequency increase) measured by conventional methods; second, the head and amplifier response measured by applying a small voltage proportional to frequency across a low resistance connected in series with the head, and finally, the head and amplifier response measured with a constant flux versus frequency induced into the core of the reproduce head. The third measurement can be made by placing a fine wire over the head gap, securing it firmly in place, and feeding constant current through the wire. Although the resultant flux distribution is not identical to that from a tape, it is considered to be satisfactory for the purposes of this measurement. Ideally the third curve would follow the Standard Reproducing Characteristic as shown in Fig. 6. However, in practice the curve may vary from the ideal because of head resonance effects, and apparent core losses. Resonance effects are determined by comparing curves 1 and 2 while apparent core losses are identified by comparing curves 2 and 3.

Magnetic Measurements

A curve of approximate gas loss versus frequency shall be calculated from the following expression:

$$\text{Gap loss} = -20 \log_{10} \frac{\sin [(180^\circ)(d/\lambda)]}{\pi d/\lambda}$$

where d = null wavelength

λ = wavelength at which the gap loss is calculated.

The null wavelength is determined by finding the recorded wavelength at which the reproducing head output reaches a distinct minimum of at least 20 dB below maximum output. It is desirable to make this measurement at 1/2 or 1/4 normal speed and with a tuned voltmeter with no greater than a one-third octave band width. In order to reach the 20 dB null the head gap edges must be sharp, straight and parallel.

In order to determine that a gap meets these requirements visual examination of the gap at about 1000X magnification is necessary. This may be accomplished with a toolmaker's microscope or with suitable photomicrographs taken at several locations along the gap. It has been shown that the null wavelength will be 1.14 times the optical gap length for a perfectly constructed head.[b] In practice it is usually greater. However, it is recommended that the null wavelength not be greater than 1.25 times the optical gap length for this application.

A curve of the low frequency reproducing response shall be made using a constant current vs. frequency recording made with normal bias and the result compared to the curve of reproduce system response with constant flux vs. frequency induced into the head core (Curve 3 above), in order to determine contour effects. This reproducing response curve ideally should follow the Standard Reproducing Characteristic at frequencies below approximately 750 Hz at 7-1/2 in. per second. In practice it is known that all of the flux from a tape at long wavelengths does not enter the head core. The amount that does enter varies with wavelength depending upon the length of tape to head contact, the shields in and around the head and the shape of the pole pieces.

It is important to accurately measure frequency when making the recording so that slight frequency errors are not interpreted as response errors. It is recommended that the slope of the contour effects curve not exceed 10 dB per octave so that a frequency error of 1/2% will result in a response error of not more than 0.07 dB.

Calibrated System Response

Having determined the various losses or deviations from the Ideal System Response, a calibration of the actual system is obtained as follows: From the system response curve, Curve 3 under Electrical Measurements, subtract the gap loss curve at high frequencies and algebraically add the low frequency portion by the contour effect curve. The resulting curve is the reproducing system response for constant available flux from a tape. The difference between this curve and the Standard Reproducing System Characteristic represents the deviation from the ideal response.

Glossary of Magnetic Tape Recording and Reproducing Terms and Definitions

Azimuth Loss—The signal loss due to misalignment of the playback head gap and the recorded signal.

[b] W. K. Westmijze, "Studies on Magnetic Recording" Philips Research Reports, Vol. 8, No. 3, pp. 161-183, 1953.

Bias—See Magnetic Biasing.

Capstan—The spindle or shaft which drives the pressure roller and tape.

Contour Effect—The alteration of the voltage output from a magnetic reproducing head at long wavelengths due to the shape of the pole pieces and the presence of magnetic shielding close to the tape.

Distortion, Harmonic—Distortion charazterized by the appearance in the output of harmonics of the fundamental frequency when the input wave is sinusoidal.

Distortion, Per Cent Harmonic—A measure of the Harmonic Distortion in a system or component, numerically equal to 100 times the ratio of a root-mean-square voltages (or currents) of each of the individual harmonic frequencies, to the root-mean-square voltage (or current) of the fundamental.

Equalization—Equalization is the process of modifying the amplitude-frequency response characteristics in a recording and reproducing system, for one or both of the following purposes:

1. To produce a flat overall frequency response.
2. To match the signal handling capabilities of the recording system to the frequency distribution of the signal to be recorded and/or to minimize the audible noise of the reproducer, in order to produce the maximum audible signal-to-noise ratio.

Equalizer—A device designed to modify the amplitude-frequency response of a system or component.

Flutter—In recording and reproducing, flutter is the deviation of frequency which results in general from non-uniform motion during recording, or reproduction. (*Note:* The term "wow" usually refers to flutter occurring at a relatively low rate as, for example, a once-per-revolution speed variation of a phonograph turntable.)

Frequency Response—The relative output versus frequency of a recording or reproducing system. A more specific term than "frequency range," and usually presented in the form of a curve plotted with frequency as the ordinate and the output in dB as the abscissa.

Gap Length, Physical—The physical distance between adjacent surfaces of the pole tips of a magnetic head measured in the direction of tape travel.

Gap Length, Effective—The recorded wavelength at which the output of a magnetic head goes through the first null point. (*Note:* The effective gap length is greater than the physical length for both theoretical and practical reasons.)

Head Alignment—Positioning of the record and reproduce heads on a tape recorder so that their gaps are mutually parallel and perpendicular to the path of travel of the tape.

Level, Recorded—The recorded level on a magnetic tape is the level measured by a standard reproducing system with respect to the NAB Standard Reference Level, expressed in decibels.

Magnetic Biasing—Magnetic biasing is the simultaneous conditioning of the magnetic recording medium during recording by superposing an additional magnetic field upon the signal magnetic field. (*Note:* In general, magnetic biasing is used to obtain a substantially linear relationship between the amplitude of the signal and the remanent flux density in the recording medium.)

Magnetic Biasing, AC—The ac magnetic biasing is magnetic biasing accomplished by the use of an alternating current usually well above the signal frequency range, in the recording head.

Magnetic Head—A transducer for converting electrical signal currents into magnetic signals for storage on magnetic media, for converting stored magnetic signals into electrical signals, or for erasing stored magnetic signals. (*Note:* A ferromagnetic head is one in which the permeability of the material is much greater than one, being most often several thousands.)

Magnetic Head Core—The high permeability structure which forms the head gap and supports the head winding.

Magnetic Recording Head—A magnetic head for transforming electric signals into magnetic signals for storage on magnetic tape.

Magnetic Reproducing Head—A transducer for converting magnetic signals on magnetic tape into electric signals.

Noise (audio frequency)—Any electrical disturbance including both hum and hiss introduced from sources extraneous to the signal.

Noise, Unweighted—The noise measured within the audio frequency pass band using a measuring instrument which is uniform in response with respect to frequency over some specified pass band.

Noise, Weighted—The noise measured within the audio frequency pass band using a measuring instrument which has a frequency selective characteristic. The sensitivity is usually greatest in the frequency range where the car is most sensitive.

Post-emphasis—That portion of the equalization which is applied in the reproducer.

Pre-emphasis (preequalization)—That portion of the equalization which is applied in the recorder.

Print-through—The undesired transfer of a recorded signal from one layer of magnetic tape to adjacent layers.

Ring Head—A magnetic head in which the magnetic core material forms an enclosure with one or more gaps. The magnetic tape bridges one of these gaps and is contacted by the pole pieces.

Surface Induction—The flux density at right angles to the surface of the tape in a medium of unity permeability and not in contact with a reproducing device.

Test Tape—A test tape is a recording of various known frequencies at known amplitudes, usually for the purpose of testing and measuring reproducing equipment.

Weighting Characteristic—The shaped response-frequency characteristic of a measuring device used to produce more realistic indications of the subjective effects than are obtained with unweighted (flat) measurements.

NAB MAGNETIC TAPE CARTRIDGE SYSTEM RECORDING AND REPRODUCING STANDARDS[1]

Mechanical Specifications

Cartridge Sizes

1.05 It shall be standard that there shall be three cartridge sizes physically identified and designated as NAB-A, NAB-B, and NAB-C. Pertinent dimensions are shown in Chart A, Table 1.

CHART A
NAB CARTRIDGE STANDARD

THE SPRING ACTION DEVICE MUST NOT PROTRUDE MORE THAN 1/4" INTO CUT-OUT FROM REFERENCE B-B, NOR MORE THAN 3/16" ABOVE DECK SURFACE C-C.

FORCE REQUIRED TO DEFLECT SPRING FULLY SHALL BE 4 TO 8 OZ. MEASURED ALONG A-A, PARALLEL TO BASE.

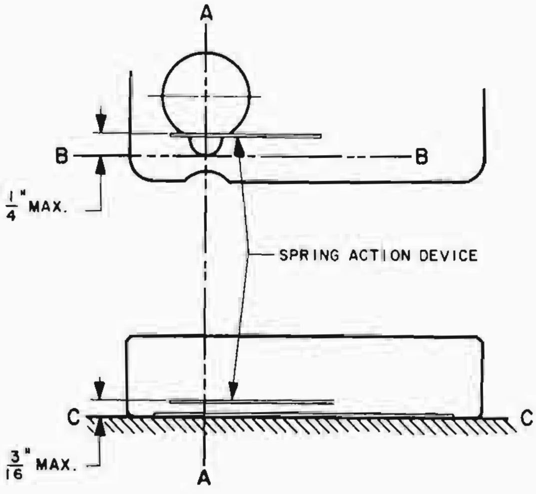

FIG. 1 REQUIRED SPRING ACTION DEVICE LIMITATIONS

TABLE 1

CARTRIDGE NAB TYPE	WIDTH "W" ± 1/64"	LENGTH "L" MAX.	HEIGHT "H" MAX.
A	4"	$5\frac{1}{4}$"	.9375
B	6"	7"	.9375
C	$7\frac{5}{8}$"	$8\frac{1}{2}$"	.9375

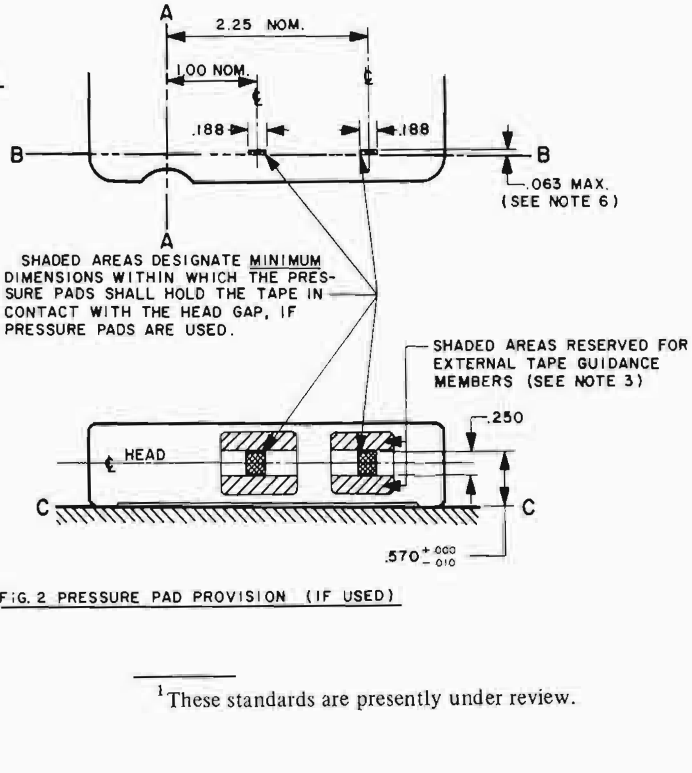

FIG. 2 PRESSURE PAD PROVISION (IF USED)

[1]These standards are presently under review.

CHART A NAB CARTRIDGE STANDARD (Continued)

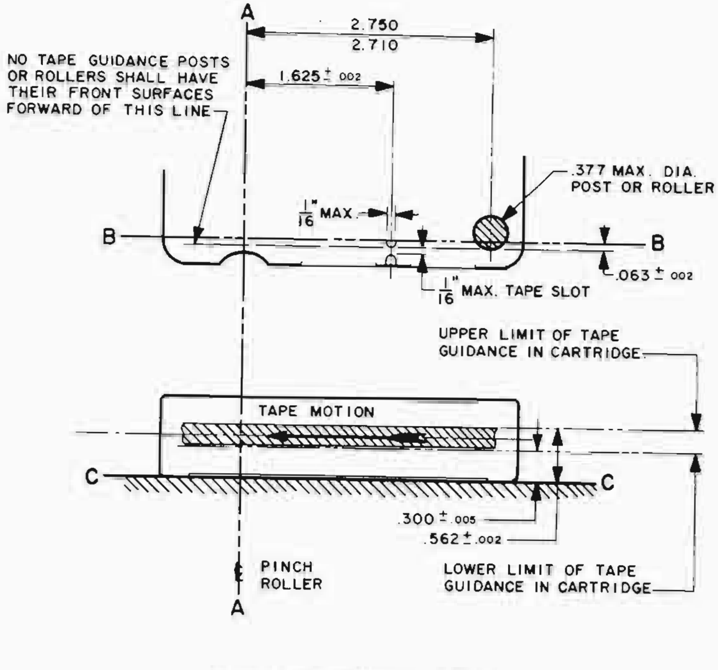

FIG. 4 TAPE GUIDANCE LIMITS

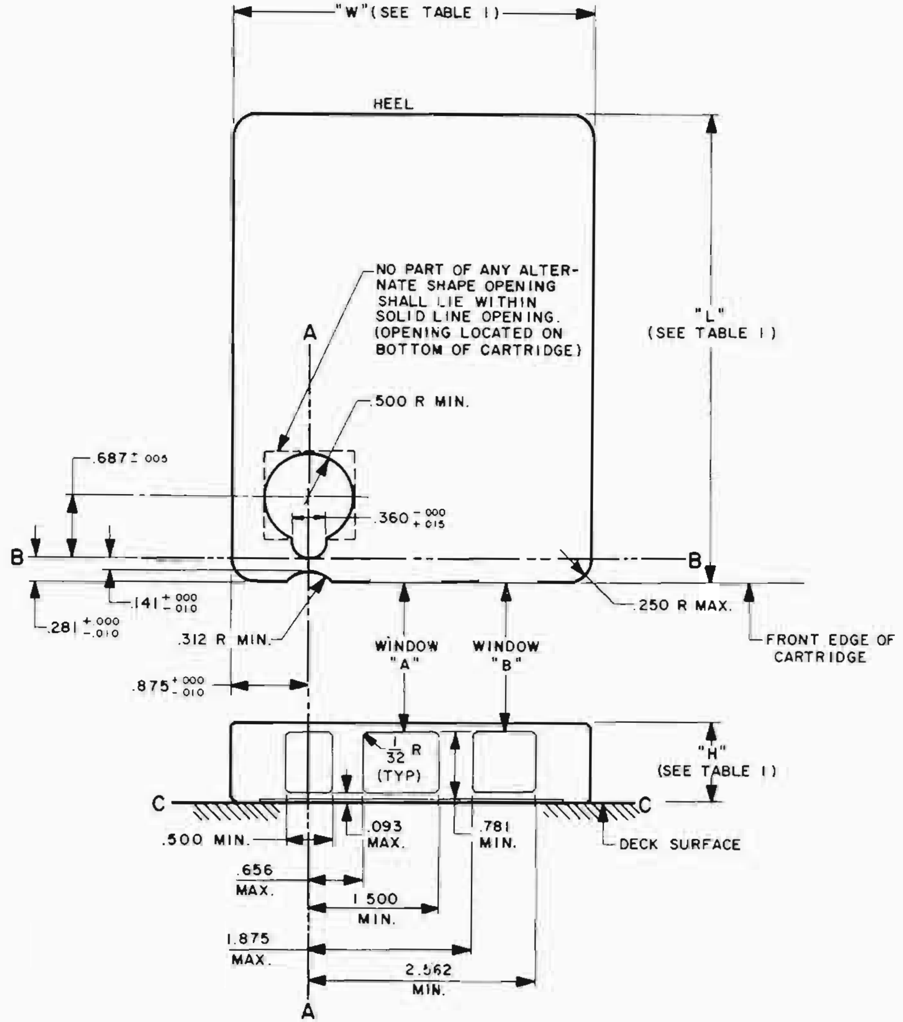

FIG. 3 CARTRIDGE DIMENSIONS

NOTES

1. DIMENSIONS
ALL IMPORTANT OPERATING DIMENSIONS ARE REFERENCED FROM TWO IMAGINARY MUTUALLY PERPENDICULAR, VERTICAL PLANES MARKED A-A & B-B, AND A THIRD HORIZONTAL PLANE C-C, REPRESENTING THE DECK SURFACE OF THE CARTRIDGE TAPE PLAYER.

WHERE APPLICABLE, DIMENSIONS INCLUDE DRAFT ALLOWANCES.

2. MATERIALS
ALL MATERIALS USED IN THE CARTRIDGE CONSTRUCTION SHALL BE NON-MAGNETIC.

3. TAPE GUIDANCE
PRECISE TAPE GUIDANCE SHALL BE PROVIDED BY TAPE GUIDE OR GUIDES EXTERNAL TO THE CARTRIDGE. INTERNAL GUIDANCE, AS SPECIFIED IS TOLERANCED AND DIMENSIONED SO AS NOT TO INTERFERE WITH EXTERNAL HEAD GUIDES PROPERLY SET AND USING STD 1/4" TAPE (.246"±.002)

ROLLERS, POSTS, OR OTHER TAPE GUIDING SURFACES MUST BE SMOOTH AND PROVIDE A VERTICAL TAPE PLANE IN THAT PORTION OF TAPE WHICH PASSES ACROSS THE FRONT OF THE CARTRIDGE.

THE MINIMUM WINDOW AREA, EXCEPT FOR THE AREA COVERED BY THE TAPE PATH, SHALL BE KEPT CLEAR FOR A DISTANCE OF .187 TO THE REAR OF B-B TO PROVIDE FOR EXTERNAL TAPE GUIDES.

4. TAPE TENSION
TAPE TENSION SHALL NOT EXCEED 6 OZ AT CAPSTAN.

5. TAPE LENGTH
TAPE LENGTH IN PLAYING TIME SHALL BE LEGIBLY MARKED ON THE HEEL OF CARTRIDGE BASE.

6. HEAD PENETRATION
HEAD PENETRATION SHALL CONFORM TO CROSS-HATCHED AREA SHOWN IN FIG. 2.

Tape Thickness

1.10 It shall be standard that the thickness of magnetic tape for use in tape cartridges shall not exceed 0.0016 in.

Tape Width

1.15 It shall be standard that the width of magnetic tape be 0.246 in. ± 0.002 in.

Tape Speed

1.20 It shall be standard that the cartridge tape speed shall be 7-1/2 in. per second with a speed accuracy of ± 0.4% as measured over a 150 foot ± 1.0 in. loop of 1 mil (base film thickness) lubricated tape loaded in an NAB Type A cartridge.

Flutter[32]

1.25 It shall be standard that the flutter shall not exceed 0.2% RMS.

Machine Tape Pulling Force[33]

1.30 It shall be standard that the machine shall be capable of a minimum tape pulling force of one-and-one-half pounds (1-1/2) using clear (no-oxide) unlubricated 1/4 in. 1 mil (base film thickness) polyester tape.

Cartridge Loading

1.35 It shall be standard that a loaded NAB cartridge shall have the tape length in playing time clearly marked on the heel of the cartridge (see Chart A).

1.35.01 It shall be standard that a loaded cartridge shall contain no less tape than that required to provide the indicated playing time marked on the cartridge and that excess tape footage shall be in accordance with the following:

Length	*Excess Tape*
Up to 63 ft.	3 seconds maximum (22-1/2 in.)
Over 63 ft.	6 seconds maximum (45 in.)

Head and Track Configuration—Monophonic[34]

1.40 It shall be standard that: (a) The system shall be a two track system consisting of one program track and one cue track. (b) The upper track recorded by Head B shall be the program channel; the lower track recorded by Head B shall be the cue channel; the upper section of Head A shall be the program reproducing channel; the lower section of Head A shall be the cue reproducing channel. (c) The standard tape track dimensions shall conform to Chart B.

Head and Track Configuration—Stereophonic[34]

1.45 It shall be standard that: (a) The system shall be a three track system consisting of two program tracks and one cue track. (b) The upper track shall be the left program channel; the center track shall be the right program channel; the lower track shall be the cue channel. (c) The standard track dimensions shall conform to Chart C.

Electrical Specifications

Standard Reference Level[35]

2.05 It shall be standard that the NAB Standard Reference Level shall be that 400 Hz level which is equal to the recorded level on the NAB Primary Reference Tape.

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[32]The measurement shall be made within the band from 0.5 to 200 Hz by playing an NAB standard flutter tape containing a 3 kHz recording. The flutter meter shall have no frequency weighting. The meter shall have the dynamics of the Standard Volume Indicator (ASA C16.5-1961). When making flutter measurements it is recommended that the meter be read for 10 seconds, recording peak readings but excluding peaks which do not occur more often than three times in a 10-second period.

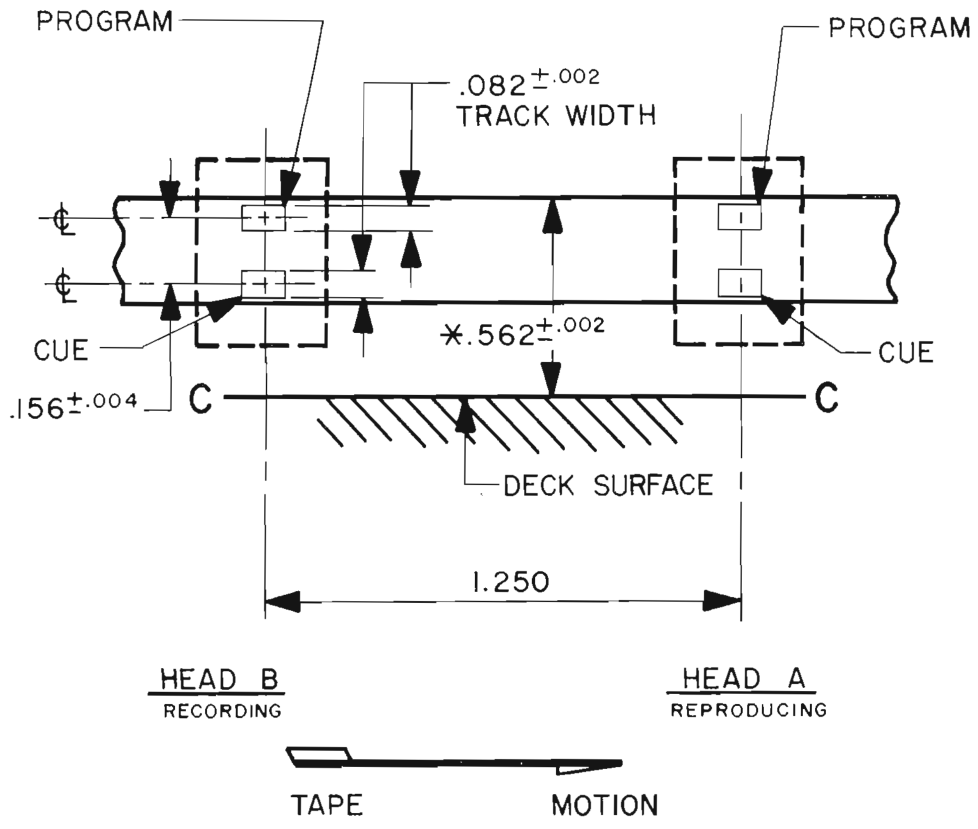
[33]This measurement shall be made by securing a length of 1/4 in. nonlubricated one mil polyester recording tape to a suitable tension scale. The tape is then threaded between the capstan and pressure roller and the machine set in motion. An indication of at least 1-1/2 lbs. on the scale should then be observed before tape slippage occurs.

[34]It is recognized that during the recording process there may be partial erasing of the cue tone and program material within the first 1/4 second of a recording. This possibility exists due to the arrangement of the recording and reproducing heads, the spacing between them and the fact that recording bias current may be present in the recording heads during the primary cue process after a recording has been completed. Some over-running of the tape is also to be expected at the stop (primary) cue. Audible degradation of the program material will usually not be noted in so short a period of time but to prevent this possibility it is recommended that the recording of program material be delayed by 1/4 second after the beginning of the primary cue tone.

[35]The NAB Primary Reference Tape is a tape of the normal general purpose type which has been selected for average characteristics of output, sensitivity, and distortion. The 400 Hz recording on it was made at 7-1/2 ips with bias adjusted for maximum output, at an output level 8 dB below that which produced 3% third harmonic distortion. This does not imply a failure to meet the 10 dB overload margin of Footnote 36. It is rather, an arbitrary but convenient method of specification and measurement which is consistent with this requirement for the magnetic recording process. Since neither the tape nor the measurement conditions can be duplicated exactly in the field, all NAB Standard Test Tapes contain a 400 Hz recording at the NAB Standard Reference Level within + 0.25 dB as a means for making this level available.

CHART B

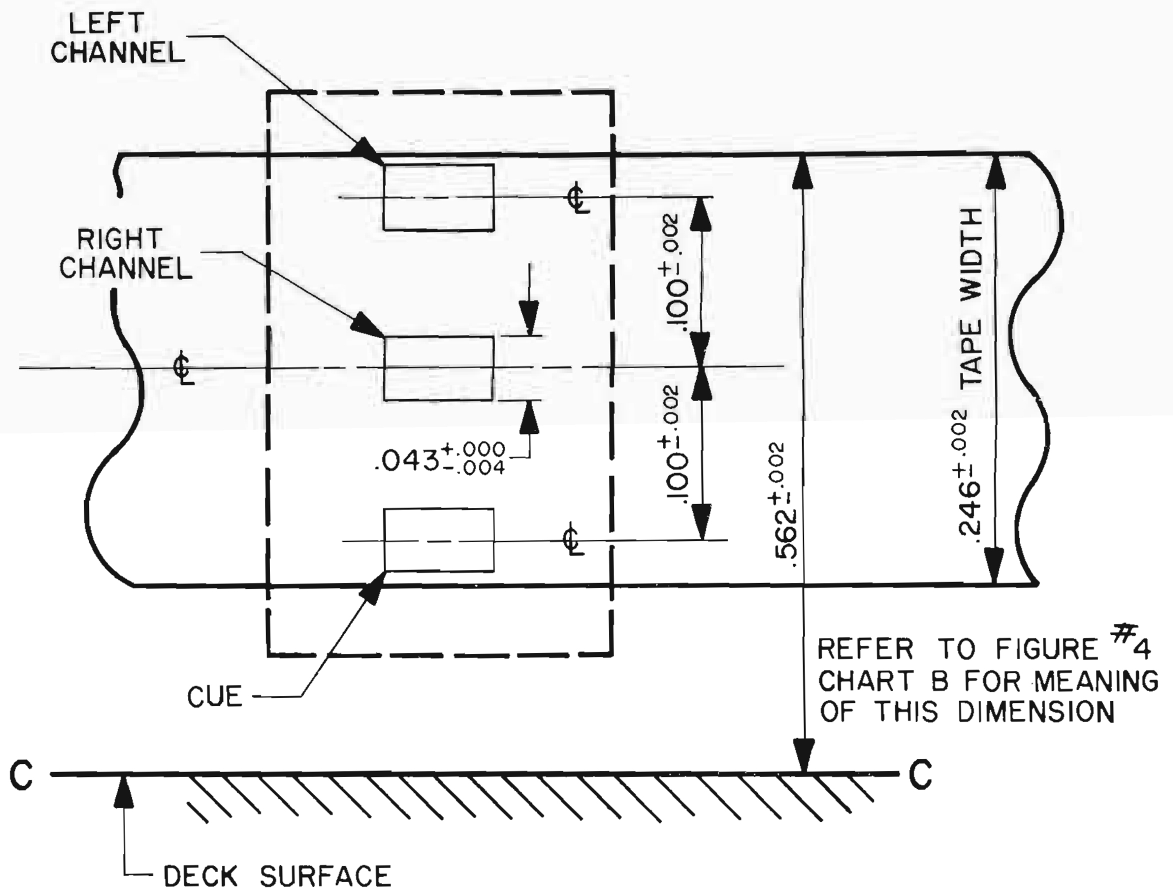
MONOPHONIC TWO-TRACK
RECORDED TRACK DIMENSIONS



* REFER TO FIG. 4, IN CHART A, FOR MEANING OF THIS DIMENSION

CHART C

STEREO 3-TRACK
RECORDED TPAE TRACK DIMENSIONS



NOTES:

1. IF SECOND STEREO HEAD IS USED IT SHOULD BE PLACED 1.250 FROM FIRST HEAD.
2. TRACK WIDTH: ALL TRACKS SHALL BE .043 $^{+.000}_{-.004}$

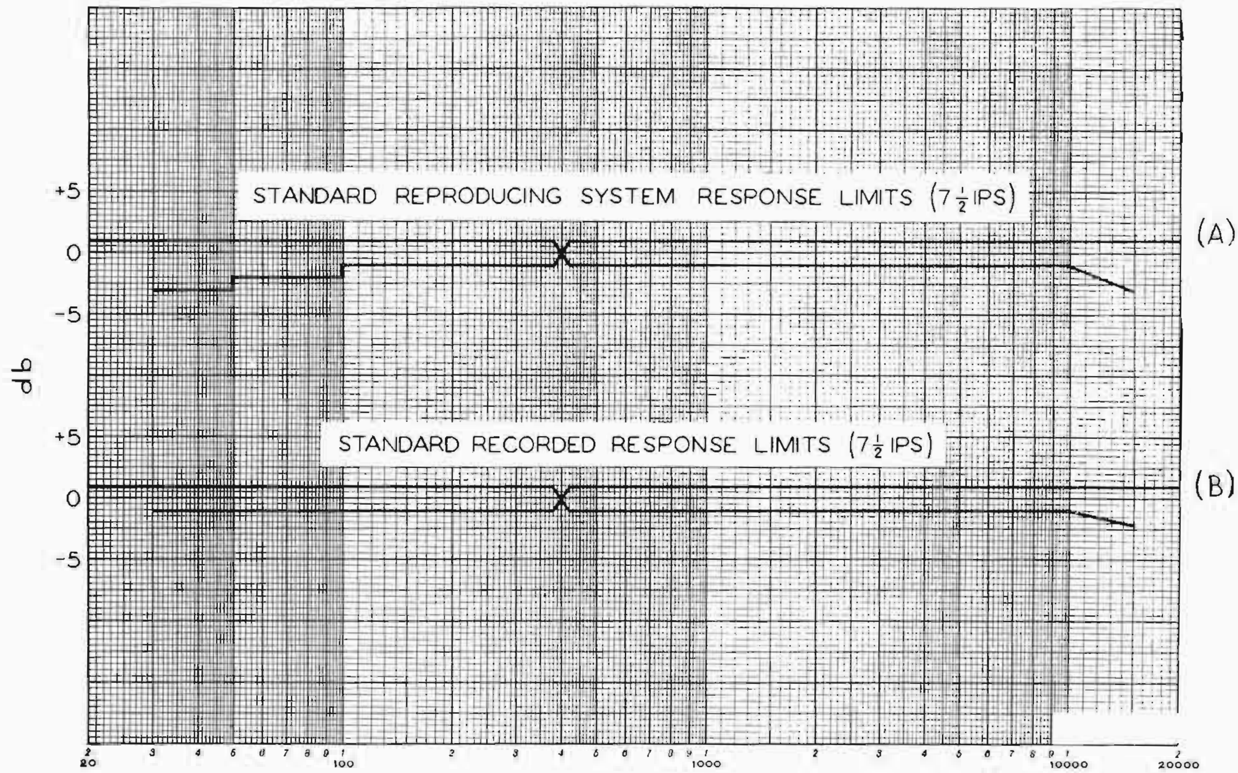


Fig. 10. Standard reproducing system response limits and standard recorded response limits.

Recorded Program Level[36]

2.10 It shall be standard that the recorded program level shall produce the same reference deflection on a Standard Volume Indicator (ASA Standard C16.5-1961) as that produced by a 400 Hz tone recorded at the Standard Reference Level.

Cue Tone Recorded Level

2.15 It shall be standard that primary and tertiary cue tones be recorded at a level that produces an output 8 dB, ± 3 dB, above that produced by the NAB Standard Reference Level at the open-circuit terminals of an ideal head. The secondary cue tone shall be recorded at a level that produces an output 2 dB, ± 3 dB, below that produced by the NAB Standard Reference Level at the open-circuit terminals of an ideal head. (See Annex C)

Frequency Response—Reproduce[37]

2.20 It shall be standard that the frequency response of a reproducing system, when reproducing an NAB cartridge frequency test tape, shall fall within the limits shown in Fig. 10, Part A, between the frequencies of 50 and 12,000 Hz.

Frequency Response—Record[38]

2.25 It shall be standard that the recorded response and level shall be the same as the NAB frequency test tape, within the limits shown in Fig. 10, Part B, when such recorded tape is reproduced through the same reproducing system.

[36]It is well established that at least a 10 dB margin is required between the sine wave load handling capacity of a system and the level of program material measured by a Standard Volume Indicator. This is believed to be approximately the maximum level which can be recorded on available tapes without excessive distortion. This specification of level is believed to represent the optimum compromise between distortion and signal-to-noise ratio for the magnetic recording process at audio bandwidths suitable for broadcasting.

[37]See Annex A, Part 2.

[38]The response measurement shall be made at the same recorded level as that of the NAB Test Tape.

System Distortion[39]

2.30 It shall be standard that the total record-reproduce system harmonic distortion shall be less than 3% for a 400 Hz tone recorded so as to produce a level 6 dB above the standard NAB Reference Level.

System Signal-to-Noise Ratio

2.35 It shall be standard that the unweighted signal-to-noise ratio shall be not less than the following:

Monophonic[40]	*Stereophonic*
45 dB	42 dB

2.35.01 Unweighted noise shall be measured over the frequency range of 20 Hz to 20 kHz. The noise measurement shall be made using a tape previously recorded with bias but with no signal. The reference signal level shall be the 400 Hz NAB Standard Reference Level and the indicating meter shall have the dynamics of the Standard Volume Indicator (ASA Standard C16.5-1961). The measuring system shall have the characteristics of a full-wave rectified average measurement law.

System Crosstalk—Monophonic

2.40 It shall be standard that the cue tone (normal level) to program channel system crosstalk at the NAB Standard Reference Level shall not be less than the following:

150 Hz	50 dB
1000 Hz	55 dB
8000 Hz	50 dB

System Crosstalk—Stereophonic

2.45 It shall be standard that the cue tone (normal level) to program channel system crosstalk shall not be less than 50 dB for stereophonic systems referenced to the NAB Standard Reference Level.

Channel Phasing—Stereophonic

2.50 It shall be standard that for stereophonic recordings the two program tracks shall be recorded with head gaps in line and phased for reproduction on equipment so connected that when a full track tape is reproduced it produces in phase signals in the two channel outputs.

Tape Erasure

2.55 It shall be standard that no erasing function shall be provided as a machine capability. Bulk erasing of tape cartridges is required.

Cue Tones

2.60 It shall be standard that the primary standard cue tone frequency shall be 1000 Hz ± 75 Hz.

2.60.01 The primary cue tone shall be the stop cue.

2.65 It shall be standard that the secondary cue tone shall be 150 Hz ± 30 Hz.

2.65.01 The secondary cue tone shall be the end of message cue.

2.70 It shall be standard that the tertiary cue tone shall be 8 kHz ± 1 kHz.

2.70.01 The tertiary cue tone shall be an auxiliary tone to be used as desired.

Cue Tone Burst Duration

2.75 It shall be standard that the cue tone burst duration shall be 500 milliseconds ± 250 milliseconds.

Test Tape Specifications

The NAB Test Tapes shall consist of four standard test tapes in NAB-A cartridges, each loaded with approximately 150 ft. of tape.

3.05 *Test Tape 1—Azimuth:* The azimuth adjustment tone shall be 15 kHz recorded full track 10 dB below the NAB Standard Reference Level and the recorded azimuth shall be 90°, ± 1 minute, with respect to the length of the tape. The tone shall be recorded over the full length of the tape.

3.10 *Test Tape 2—Flutter:* The flutter test tone shall be 3 kHz recorded full track at the NAB Standard Reference Level. The flutter content of the flutter test tape shall be no greater than 0.05%, measured in the same manner as described in Footnote 32. The test tone shall be recorded over the full length of the tape.

[39]The recording amplifier should not overload with high frequency input signals equal in level to the maximum expected 400 Hz level. In practice this means that the recording equalization places an additional demand on the undistorted amplifier output. Furthermore, bias leakage into the amplifier output may produce additional distortion. High frequency distortion products may not be detected by harmonic distortion measurements.

[40]This measurement is intended to give a measure of noise in terms of a fixed reference. In this way it becomes a measure of merit. It does not, however, take into account the program level which may be recorded on a particular tape nor the dynamic range of the program material. Heretofore, by common practice, the signal-to-noise ratio was determined by using peak recording level (3% THD) as a reference. When determined in this manner, the signal-to-noise ratio is improved by approximately 8 dB resulting in an effective signal-to-noise ratio of 53 dB. (Rev. 12/64)

3.15 *Test Tape 3—Frequency Response, Monophonic:* Test tones shall be recorded on the program track in accordance with the following table:

400 Hz	– 10 seconds	Standard Reference Level ± 0.25 dB
400 Hz	– 10 seconds	Calibration Level (10 dB below Standard Reference Level)
15 kHz	– 20 seconds	
12 kHz	– 5 seconds	
10 kHz	– 5 seconds	
8 kHz	– 5 seconds	
5 kHz	– 5 seconds	
2.5 kHz	– 5 seconds	
1 kHz	– 5 seconds	
600 Hz	– 5 seconds	
300 Hz	– 5 seconds	
150 Hz	– 5 seconds	
75 Hz	– 5 seconds	
50 Hz	– 5 seconds	
30 Hz	– 5 seconds	

Each test tone shall be identified by voice announcement preceding the tone. All test tones, with the exception of the Standard Reference Level Tone, shall be recorded so as to produce a uniform response ± 1/2 dB, when the test tape is reproduced through an ideal reproducing system (See Annexes A & B). The recording level shall be 10 dB below the NAB Standard Reference Level[41]

Test tones shall be recorded on the cue track in the following manner: 1000 Hz to coincide with the beginning of the program track test tones, 1000 Hz stop cue between the first and second 400 Hz tones, 150 Hz at the end of the program track test followed by 8000 Hz, with additional 150, 1000, and 8000 Hz tones of 4 seconds duration each added for calibration of cue circuitry. Unless otherwise specified, the cue test tones shall be recorded so as to comply with Sections 2.15 and 2.75 of these Standards.

3.20 *Test Tape 4—Frequency Response, Stereophonic:*[42] Test tones shall be recorded on the stereophonic program tracks in accordance with the following table:

[41]In lieu of the + 1/2 dB tolerance specification, a + 3 dB tolerance specification may be used provided that the deviation from uniform response when the test tape is reproduced on an ideal reproducing system is supplied for each test frequency.

[42]The test frequencies shall be recorded with a phase additive relationship. Channels shall be identified as "left" or "right" as applicable by voice announcement.

400 Hz	– 10 seconds	Standard Reference Level ± 0.25 dB
400 Hz	– 10 seconds	Calibration Level (10 dB below Standard Reference Level)
15 kHz	– 20 seconds	
12 kHz	– 5 seconds	
10 kHz	– 5 seconds	
8 kHz	– 5 seconds	
5 kHz	– 5 seconds	
2.5 kHz	– 5 seconds	
1 kHz	– 5 seconds	
600 Hz	– 5 seconds	
300 Hz	– 5 seconds	
150 Hz	– 5 seconds	
75 Hz	– 5 seconds	
50 Hz	– 5 seconds	
30 Hz	– 5 seconds	

Each test tone shall be identified by voice announcement preceding the tone. All test tones, with the exception of the Standard Reference Level tone, shall be recorded so as to produce a uniform response ± 1/2 dB when the test tape is reproduced through an ideal reproducing system (See Annexes A & B). The recording level shall be 10 dB below the NAB Standard Reference Level.[43]

Test tones shall be recorded on the cue track in the following manner: 1000 Hz to coincide with the beginning of the program track test tones, 1000 Hz stop cue between the first and second 400 Hz tones, 150 Hz at the end of the program track test tones followed by 8000 Hz, with additional 150, 1000, and 8000 Hz tones of 4 seconds duration each added for calibration of cue circuitry. Unless otherwise specified, the cue test tones shall be recorded so as to comply with Sections 2.15 and 2.75 of the Standards.

Annex A

Ideal Reproducing System

It shall be standard that the NAB Ideal Reproducing System is a theoretical reproducing system. It consists of an "ideal" reproducing head[a] and an amplifier the output voltage of which shall conform to the voltage-frequency

[43]In lieu of the + 1/2 dB tolerance specification, a + 3 dB tolerance specification may be used provided that the deviation from uniform response when the test tape is reproduced on an ideal reproducing system is supplied for each test frequency.

[a]An "ideal" reproducing head is defined as a ferromagnetic head, the losses of which are negligible. This means that the gap is short and straight, the long wavelength flux paths are controlled so that no low frequency contour effects are present, and the losses in the head materials are negligibly small.

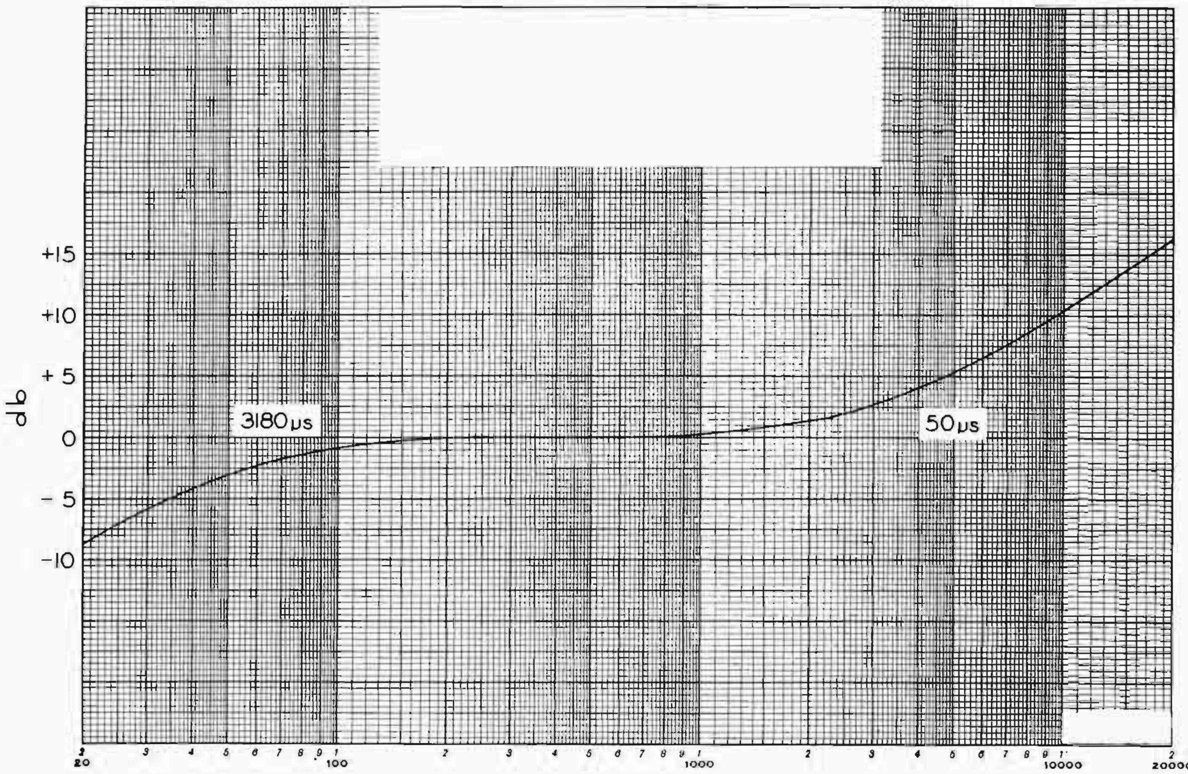


Fig. A. NAB standard reproducing charactertistic. Reproducing amplifier output for constant flux in the core of an ideal reproducing bead.

curve of Fig. A with constant flux versus frequency in the core of the head.[b]

The curve of voltage amplification versus frequency shall be uniform with frequency except where modified by the following equalizations:

a. The voltage attenuation of a single resistance—capacitance high pass filter having an RC time constant t_1.

b. The inverse of the voltage attenuation of a single resistance capacitance low pass filter having an RC time constant t_2. The curve expressed in decibels is represented by the following expression:

$$N_{\mathrm{dB}} = 20 \log_{10} \omega t_1 \sqrt{\frac{1 + (\omega t_2)^2}{1 + (\omega t_1)^2}}$$

$\omega = 2\pi$ times frequency

[b]It is recognized that the flux in the core of an "ideal" head is not necessarily the same as the surface flux on a tape in space for various reasons. Since most of these effects are not readily measured it has been decided to base this standard on "ideal" head core flux rather than surface induction.

For 7-1/2 in. per second tape speed $t_1 = 3180$ microscends, and $t_2 = 50$ microseconds.

Standard Reproducing System[c]

It shall be standard that an NAB Standard Reproducing System shall consist of a suitable tape transport, reproduce head and amplifier equalized to compensate for head losses insofar as possible and to produce a reproduce response from an NAB Standard Test Tape, within the limits specified in Fig. 10. It shall also meet the specifications for distortion, signal-to-noise ratio and other applicable parts of this Standard.

[c]The practical method of measuring a reproduce system response characteristic is with an NAB Test Tape. More precise methods of measuring and calibrating a reproduce system are discussed in Annex B of this Standard. A reproducer calibrated by these methods and meeting the recommendations set forth in Annex B is considered suitable for measuring and calibrating test tapes.

It is recommended that the Reproducing System response roll off at the rate of at least 6 dB per octave beyond the frequency limits shown in Fig. 10.

Annex B

Primary Calibrated Reproducing System[a]

It shall be standard that a Primary Calibrated Reproducing System shall meet the following specifications:

a. The total net system response shall not deviate more than ± 3 dB from the ideal over the frequency range of interest.

b. *Electrical*—Eddy current loss at the highest frequency of interest shall not exceed 3 dB, undamped head resonance shall not exceed 3 dB and amplifier deviation from the ideal shall not exceed ± 3 dB.

c. *Magnetic*—Head gap losses shall not exceed 3 dB at the highest frequency of interest and the head contour effect curve shall not deviate more than ± 2 dB from the average.

Electrical losses shall be determined from measurements of the amplifier response frequency characteristic and the reproduce system output voltage characteristic with constant flux versus frequency in the head core.

Magnetic losses shall be determined from calculations of gap loss and measurements of head contour effects.

The following paragraphs specify the methods by which these characteristics shall be measured and the reproduce system calibrated. The procedure is to determine the various losses independently and apply them as corrections to the theoretical "Ideal Reproducing System."

Electrical Measurements

Three response frequency curves shall be made. First, the amplifier response alone with voltage proportional (voltage doubles for each octave frequency increase) to frequency, measured by conventional methods, second, the head and amplifier response measured by applying a small voltage proportional to frequency across a low resistance connected in series with the head, and finally the head and amplifier response measured with a constant flux versus frequency induced into the core of the reproduce head. The third measurement can be made by placing a fine wire over the head gap, securing it firmly in place, and feeding constant current through the wire. Although the resultant flux distribution is not identical to that from a tape, it is considered to be satisfactory for the purposes of this measurement. Ideally the third curve would follow the Ideal Reproducing Characteristic as shown in Fig. A. However, in practice the curve may vary from the ideal because of head resonance effects, and apparent core losses. Resonance effects are determined by comparing Curves 1 and 2 while eddy current losses are identified by comparing Curves 2 and 3.

[a]It is recognized that commercial production recorders may deviate from the stated system losses and response, however, this does not invalidate the calibration procedure for such machines.

Magnetic Measurements

A curve of approximate gap loss versus frequency shall be calculated from the following expression:

$$\text{Gap loss} = -20\log_{10}\frac{\sin\frac{d}{\lambda}\,180\text{ degrees}}{\pi\frac{d}{\lambda}}$$

where d = null wavelength
λ = wavelength at which the gap loss is calculated.

The null wavelength is determined by finding the recorded wavelength at which the reproducing head output reaches a distinct minimum of at least 20 dB below maximum output. It is desirable to make this measurement at 1/2 or 1/4 normal speed and with a tuned voltmeter with no greater than one-third octave band width. In order to reach the 20 dB null the head gap edges must be sharp, straight, and parallel.

In order to determine that a gap meets these requirements visual examination of the gap at about 1000X magnification is necessary. This may be accomplished with a toolmaker's microscope or with suitable photomicrographs taken at several locations along the gap. It has been shown that the null wavelength will be 1.14 times the optical gap length for a perfectly constructed head.[b] In practice it is usually greater. However, it is recommended that the null wavelength not be greater than 1.25 times the optical gap length for this application.

A curve of the low frequency reproducing response shall be made using a constant current versus frequency recording made with normal bias and the result compared to the curve of reproduce system response with constant flux versus frequency induced into the head core (Curve 3 above), in order to determine contour effects. This reproducing response curve ideally should follow the Standard Reproducing Characteristic at frequencies below approximately 750 Hz at 7-1/2 in. per second. In practice it is known that all of the flux from a tape at long wavelengths does not enter the head core. The amount that does enter varies with wavelength depending upon the length of tape to head contact, the shields in and around the head and the shape of the pole pieces.

[b]W. K. Westmijze, "Studies on Magnetic Recording" Philips Research Reports, Vol. 8, No. 3, pp. 161-183, 1953.

TABLE A

Response of Ideal Reproducing System

Frequency (in Hz)	Response (in dB)	Frequency (in kHz)	Response (in dB)
20	− 8.6	1.5	+ 0.9
25	7.0	2	1.4
30	5.8	2.5	2.1
40	4.1	3	2.7
50	3.0	4	4.1
60	2.3	5	5.4
70	1.8	6	6.6
75	1.6	7	7.6
80	1.4	7.5	8.2
90	1.2	8	8.6
100	1.0	9	9.5
150	0.4	10	10.3
200	0.2	11	11.1
250	0.1	12	11.8
300	− 0.1	13	12.5
400	±0	14	13.1
500	+ 0.1	15	13.6
600	0.1	16	14.2
700	0.2	17	14.7
750	0.2	18	15.2
800	0.2	19	15.6
900	0.3	20	+ 16.1
1	+ 0.4		

It is important to accurately measure frequency when making the recording so that slight frequency errors are not interpreted as response errors. It is recommended that the slope of the contour effects curve not exceed 10 dB per octave so that a frequency error of 1/2% will result in a response error of not more than 0.07 dB.

Calibrated System Response

Having determined the various losses or deviations from the Ideal System Response a calibration of the actual system is obtained as follows: To the system response curve (Curve 3 under Electrical Measurements), subtract the gap loss curve at high frequencies and algebraically add the low frequency portion by the contour effect curve. The resulting curve is the reproducing system response for constant available flux from a tape. The difference between this curve and the Standard Reproducing System Characteristic represents the variation from the ideal response.

Annex C

Cue Tone Recorded Levels

1. The choice of the recorded level for the three cueing tones is based on two primary considerations. The first is the signal to noise ratio of the cue track. Maximum reliability of the cue system requires a high signal to noise ratio. Assuming that the cue system is well designed and is operating at a minimum noise level, it then remains that any improvement in the signal to noise ratio will be the result of recording the cueing tones at the highest practical level.

The second consideration is crosstalk of the cueing tones into the program channel. The crosstalk level can be kept to a minimum by recording the cueing tones at a low level. Since these two considerations aim in opposite directions, a compromise becomes necessary.

2. On the basis of experience, it was felt that the primary cueing tone (1000 Hz) could be recorded at the same level on the tape as the NAB Standard Reference Level, i.e., at normal program level. At 1000 Hz most systems exhibit good signal to noise and crosstalk ratios. Further, it was felt that the secondary cueing tone (150 Hz) should be recorded about 6 dB above program level in order to overcome possible interference from fundamental or harmonics of the power line frequency. The resulting slight increase in crosstalk should not be annoying because the ear is relatively insensitive to low level low frequency tones.

Finally, the tertiary cueing tone (8 kHz) posed a special problem because it may be recorded several times during a recording and the crosstalk could be annoying if at a high level. Accordingly, a level about 10 dB below program level was adopted. This level is still high enough for a good signal to noise ratio in the cue channel.

3. The recorded level of each of the three cueing tones is referenced to the NAB Standard Reference Level at 400 Hz. A direct comparison may then be made by means of an "ideal" head and a suitable voltmeter. Although the standard is written in terms of an "ideal" head, a practical head can be used if its losses are known.

The procedure for converting the original estimated tone levels from a "program level" reference to a voltage output of a head is as follows: the original tone levels are converted to relative flux by means of a correction factor. The correction factor is the inverse of the NAB equalization given in Table A, Annex B. These relative fluxes are converted into "ideal" head voltages by applying the response of an "ideal" head. Such a head has an output which rises 6 dB per octave with increasing frequency.

This procedure is shown in Table A, which converts to relative fluxes, and Table B, which converts to the output of the "ideal" head. The last column lists the adopted values, which are rounded off to whole numbers. The 8 kHz tone was rounded off to equal the 1000 Hz tone.

4. A practical method for measuring the recorded cue tone levels is to reproduce the recorded tape cue track through an NAB equalized playback channel. The output levels observed may then be compared with the Standard NAB

TABLE A

Converting from Program Level to Flux

Frequency (in Hz)	Recording level (ref. pgm level) (in dB)	Conversion factor (– NAB equalization) (in dB)	Relative flux (in dB)
400	0	0	0
1000	0	– 0.4	+ 0.4
150	+ 6	+ 0.4	+ 6.4
8 kHz	– 10	– 8.6	– 18.6

TABLE B

Converting from Flux to Ideal Head Output

Frequency (in Hz)	Relative flux (in dB)	Response of ideal head (in dB)	Output of ideal head (in dB)	Adopted level (in dB)
400	0	0	0	0
1000	– 0.4	+ 8.0	+ 7.6	+ 8
150	+ 6.4	– 8.5	– 2.1	– 2
8 kHz	– 18.6	+26.0	+ 7.4	+ 8

Reference Level. Table C shows the correct relationship of the various cueing tones to the standard levels when measured in this manner.

TABLE C

NAB Cue Tone Output Levels as Reproduced through an NAB Equalized Playback Channel

Frequency (in Hz)	Output (in dB)
400	0 (NAB Standard Reference Level)
1000	+ 0.4
150	+ 6.1
8 kHz	– 9.4

Glossary of Magnetic Cartridge Tape Recording and Reproducing Terms and Definitions

Azimuth Loss—The signal loss due to misalignment of the playback head with respect to the recorded signal.

Background Noise—Background noise is the total system noise independent of the signal. The signal is not included as part of the noise.

Bias—See Magnetic Biasing.

Capstan—The spindle or shaft—often the motor shaft itself—which drives the pressure roller and tape.

Cartridge—A plastic or metal enclosure containing an endless loop of lubricated magnetic tape, wound on a rotatable hub in such a fashion as to allow continuous tape motion.

Contour Effect—The alteration of the voltage output from a magnetic reproducing head at long wavelengths.

Crosstalk—The presence of an undesirable signal in a system channel from external sources.

Cue Tone—A recorded audio frequency of specified duration arranged in a physical fashion on the recorded tape so as to provide a signalling system available for positioning the tape at the start of message, end of same, and such auxiliary functions as may be necessary and desirable.

Cue Track—That portion of recorded tape which is used to actuate tape motion or auxiliary functions within or external to the recorder/playback device.

DBM—1 MW of power (usually 600 ohms). The standard reference level used in broadcast work.

Distortion—An undesired change in waveform.

Distortion, Harmonic—Nonlinear Distortion characterized by the appearance, in the output, of harmonics of the fundamental input frequency.

Distortion, Intermodulation—Nonlinear Distortion characterized by the appearance of frequencies in the output, equal to the sums and differences of the component frequencies present in the input wave.

Distortion, Nonlinear (Amplitude)—Distortion caused by a deviation from a linear relationship between the input and output of a system or component.

Distortion, Percent Harmonic—A measure of the Harmonic Distortion in a system or component, numerically equal to 100 times the ratio of the root-mean-square voltages (or currents) of each of the individual harmonic frequencies, to the root-mean-square voltage (or current) of the fundamental.

Equalization—The process of modifying the frequency response characteristics in a recording and reproducing system.

Equalizer—A device designed to modify the frequency response of a system or component.

Erasing Head—A device which is used to produce the magnetic field necessary for erasing a magnetic recording. (*Note:* AC erasing is achieved by subjecting the medium to a frequency modulated magnetic field of decreasing magnitude. The medium is then essentially left in a demagnetized condition.)

Erasure—Neutralizing the magnetic pattern on tape by placing it in a strong magnetic field, thereby removing any recorded signal from the tape. An "erase" head on a tape recorder does this automatically to any signal previously recorded on the tape just before the tape reaches the "record" head. A permanent magnet can also be used to erase magnetic tape, but with a resultant increase in background noise compared to ac erasure.

Flutter (*wow*) (*drift*)—The deviation of frequency which results in general from irregular motion during recording, or reproduction. (*Note:* The term "flutter" usually refers to cyclic deviations occurring at a relatively high rate, as for example, 10 Hz. The term "wow" usually refers to cyclic deviations occurring at a relatively low rate, as for example, a once-per-revolution speed variation of a phonograph turntable. The term "drift" usually refers to a gradual average variation over an extended period of time.)

Flutter Rate—The number of cyclical variations per second of the flutter.

Frequency Response—The relative output versus frequency of a recording or reproducing system usually presented in the form of a curve plotted with frequency as the ordinate and dB as the abscissa.

Frequency Tape—A recording of various test frequencies at known amplitudes, usually for the purposes of testing and measuring reproducing equipment.

Gap Length—The physical distance between adjacent surfaces of the pole tips or a magnetic head measured in the direction of tape travel. (*Note:* The effective gap length is usually greater than the physical length.

Gap Length, Effective—The recorded wavelength at which the output of a magnetic head goes through the first null point. (*Note:* The effective gap length is usually about 1.14 times the physical length.)

Head Alignment—Positioning of the record and reproduce head on a tape recorder so that their gaps are mutually parallel and perpendicular to the path of travel of the tape.

Level, Recorded—The level measured by a reproducing system with respect to the NAB Standard Level, expressed in decibels.

Magnetic Biasing—The simultaneous conditioning of the magnetic recording medium during recording by superposing an additional magnetic field upon the signal magnetic field. (*Note:* In general, magnetic biasing is used to obtain a substantially linear relationship between the amplitude of the signal and the remanent flux density in the recording medium.)

Magnetic Biasing, AC—Magnetic biasing accomplished by the use of an alternating current which is usually well above the highest signal frequency.

Magnetic Head—A transducer for converting electrical signal currents into magnetic signals for storage on magnetic media, for converting stored magnetic signals into electrical signals, or for erasing stored magnetic signals. (*Note:* A ferromagnetic head is one in which the permeability of the material is much greater than one (1) being most often several thousand.)

Magnetic Head Core—The high permeability (usually laminated) structure which forms the head gap and supports the head windings.

Magnetic Printing—The permanent transfer of a recorded signal from a section of a magnetic recording medium to another section of the same or a different medium when these sections are brought in proximity.

Magnetic Recorder—Equipment incorporating an electromagnetic transducer and means for moving a ferromagnetic recording medium relative to the transducer for recording electric signals as magnetic variations in the medium. (*Note:* The generic term "magnetic recorder" can also be applied to an instrument which has not only facilities for recording electric signals as magnetic variations, but also for converting such magnetic variations back into electric variations.)

Magnetic Recording Head—A magnetic head for transforming electric signals into magnetic signals for storage on magnetic media.

Magnetic Recording Medium—A magnetizable material used with a magnetic recorder for retaining the magnetic signals imparted during the recording process.

Magnetic Recording Reproducer—Equipment for converting magnetic signals on magnetic recording media into electric signals.

Magnetic Reproducing Head—A transducer for converting magnetic signals on magnetic media into electric signals.

Magnetic-coated Tape—A tape consisting of a coating of uniformly dispersed, ferromagnetic material on a nonmagnetic base.

Modulation Noise—The noise caused by the signal. The signal is not included as part of the noise.

Multitrack Magnetic Recording System—A recording system which provides, on a medium such as magnetic tape, two or more recording paths which are parallel to each other, and which may carry either related or unrelated program material in common time relationship.

Noise (audio frequency)—Any electrical disturbance introduced from a source extraneous to the signal.

Noise, Unweighted—The noise measured within the audio frequency pass band using a measuring instrument which is uniform in output with respect to frequency.

Noise, Weighted—The noise measured within the audio frequency pass band using a measuring instrument which has a frequency selective characteristic. The sensitivity is usually greatest in the frequency range where noise is most objectionable subjectively.

Playback—An expression used to denote reproduction of a recording.

Postemphasis—That portion of the equalization which is applied in the reproducer.

Preemphasis (preequalization)—That portion of the equalization which is applied in the recorder.

Pressure Roller—Also called "capstan idler" or "puck." A rubber-tired roller which holds the magnetic tape tightly against the capstan.

Recording Channel—The term "recording channel" refers to one of a number of independent recorders in a recording system or to independent recording tracks on a recording medium. (*Note:* Two or more channels are used at the same time for stereophonic recording or for multichannel monophonic recording.)

Recording Loss—The loss in recorded level whereby the amplitude of the wave in the recorded medium differs from the amplitude of the recording current.

Ring Head—A magnetic head in which the magnetic core material forms an enclosure with one or more gaps. The magnetic recording medium bridges one of these gaps and is contacted by the pole pieces on one side only.

Sound Recording System—A combination of transducing devices and associated equipment suitable for storing sound in a form capable of subsequent reproduction.

Sound Reproducing System—A combination of transducing devices and associated equipment for reproducing recorded sound.

Strobotron—A gas filled electron tube with a cold cathode used especially as a source of stroboscopic light.

Surface Induction—The flux density at right angles to the surface of the tape in a medium of unity permeability and not in contact with a reproducing device.

Tachometer—A device for measuring or indicating the rotational speed of a shaft or associated moving part.

Track Configuration—The relative position of the active recording area referenced to the entire cross-sectioned surface of the magnetic recording medium.

Weighting Characteristic—The response-frequency characteristic of a measuring device used to measure Weighted Noise.

NAB Audio Cassette Recording and Reproducing Standards

Mechanical Specifications

Cassette Size

1.05 It shall be standard that there be a co-planar magnetic tape cassette physically identified and designed as shown in Fig. 11, 12, 13, with a window area as specified in Fig. 13.

Tape Thickness

1.10 It shall be standard that the thickness of the magnetic tape for use in an NAB Audio Cassette be 800 micro in. (20.3 μ) maximum and 600 micro in. (15.2 μ) minimum.

Tape Width

1.15 It shall be standard that the magnetic tape and leaders for use in an NAB Audio Cassette be 0.150 + 0.000, — 0.002 in. (3.81 mm. + 0, — 50.8 μ) wide.

Standard Tape for Measurements

1.20 The standard measurement tape shall be equivalent to 3M Magnetic Tape Type 277. This is a 500 micro in. (12.7 μ) tensilized polyester backed tape with a 200 micro in. (5.1 μ) low noise oxide coating. The tape has a minimum yield strength of 1.5 pounds (.650 Kg.) at 5% elongation under environmental test conditions. (See Section 1.80.)

Tape Wind

1.25 It shall be standard that the magnetic tape be wound on both hubs within the cassette with the magnetic coating facing out from the hub and out of the cassette head openings and with the tape travel direction as specified in Fig. 14.

Tape Length within Cassette

1.30 It shall be standard that an NAB Audio Cassette labeled as "NAB-300" contain 295 ± 5 ft. (89.9 ± 1.52 meters) of splice free magnetic tape. The "NAB-150" cassette shall contain 150 ± 5 ft. (45.7 ± 1.52 meters) of splice free magnetic tape.

Cassette Head Shield

1.35 It shall be standard that an NAB Audio Cassette contain a hum reducing magnetic shield behind the pressure pad as located in Fig. 14.

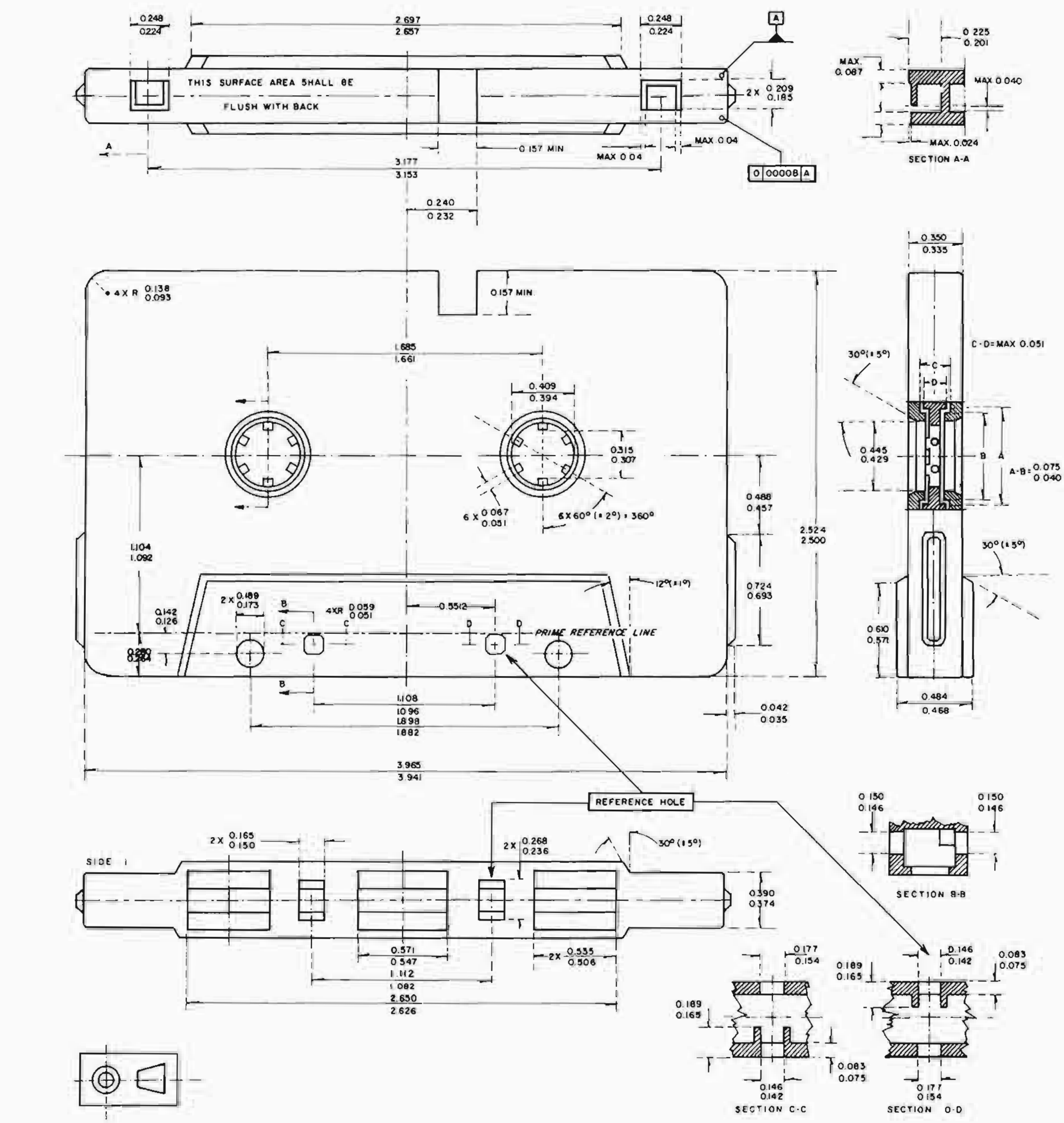
Pressure Pad[44]

1.40 It shall be standard that an NAB Audio Cassette have a pressure pad which is located and sized as described in Fig. 14. The pressure the pad exerts on the record/play head, when placed in the cassette in accordance with Fig. 15 shall be 11.4 to 34.1 oz./in.^{2} (0.5 to 1.5 gm./mm.^{2}).

Cassette Torque

1.45 It shall be standard that the maximum friction torque of the full hub in the cassette be 0.28 oz. in (20 gm. cm.). The maximum friction

[44]Record/play as used in these standards may be either a record head, a play head, or a combination record/play head.



DIMENSIONS IN INCHES

WHERE TWO NUMBER ARE MENTIONED, THE UPPER ONE GIVES THE MAXIMUM, THE LOWER ONE THE MINIMUM DIMENSION

Fig. 11. External dimensions.

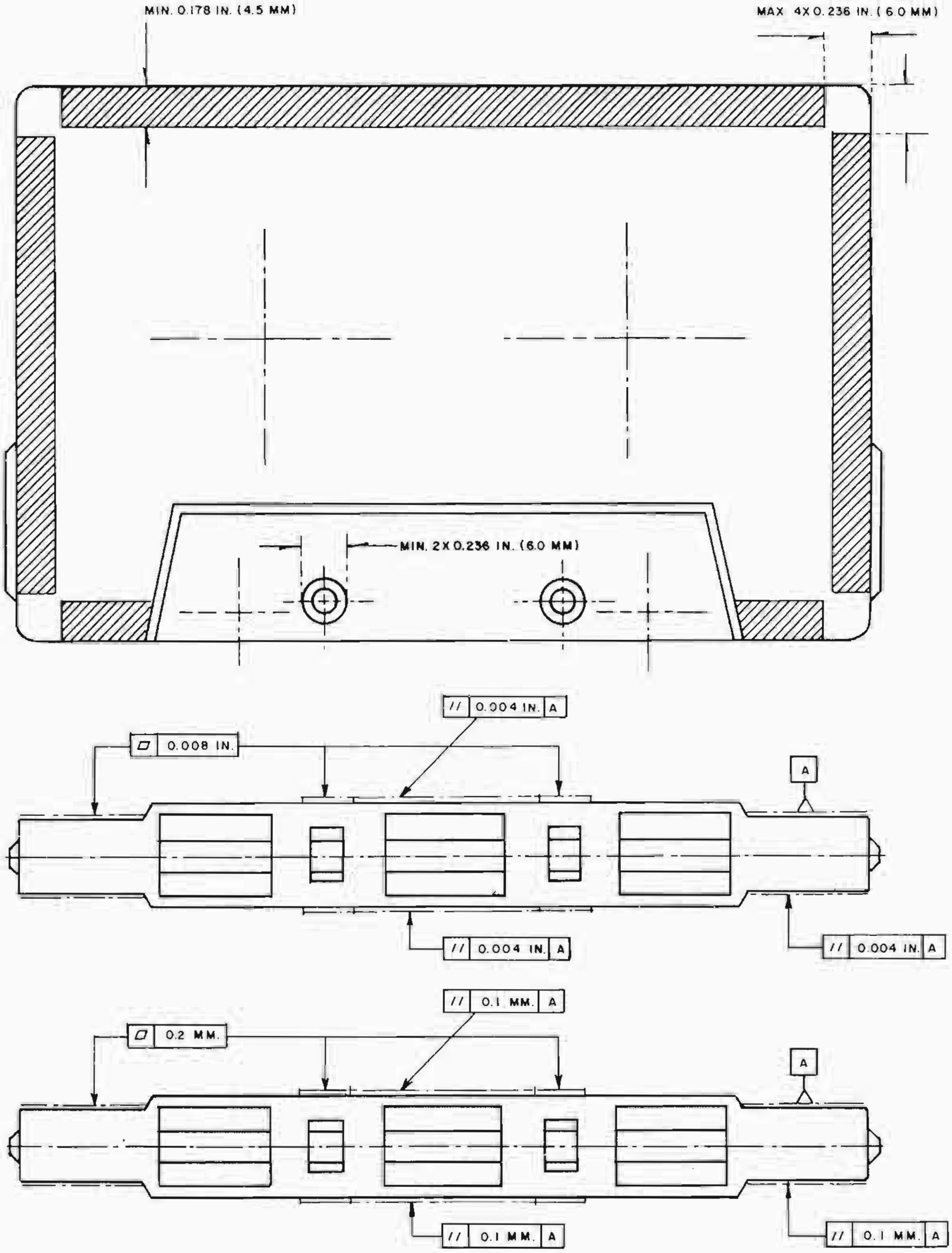


Fig. 12. Support planes.

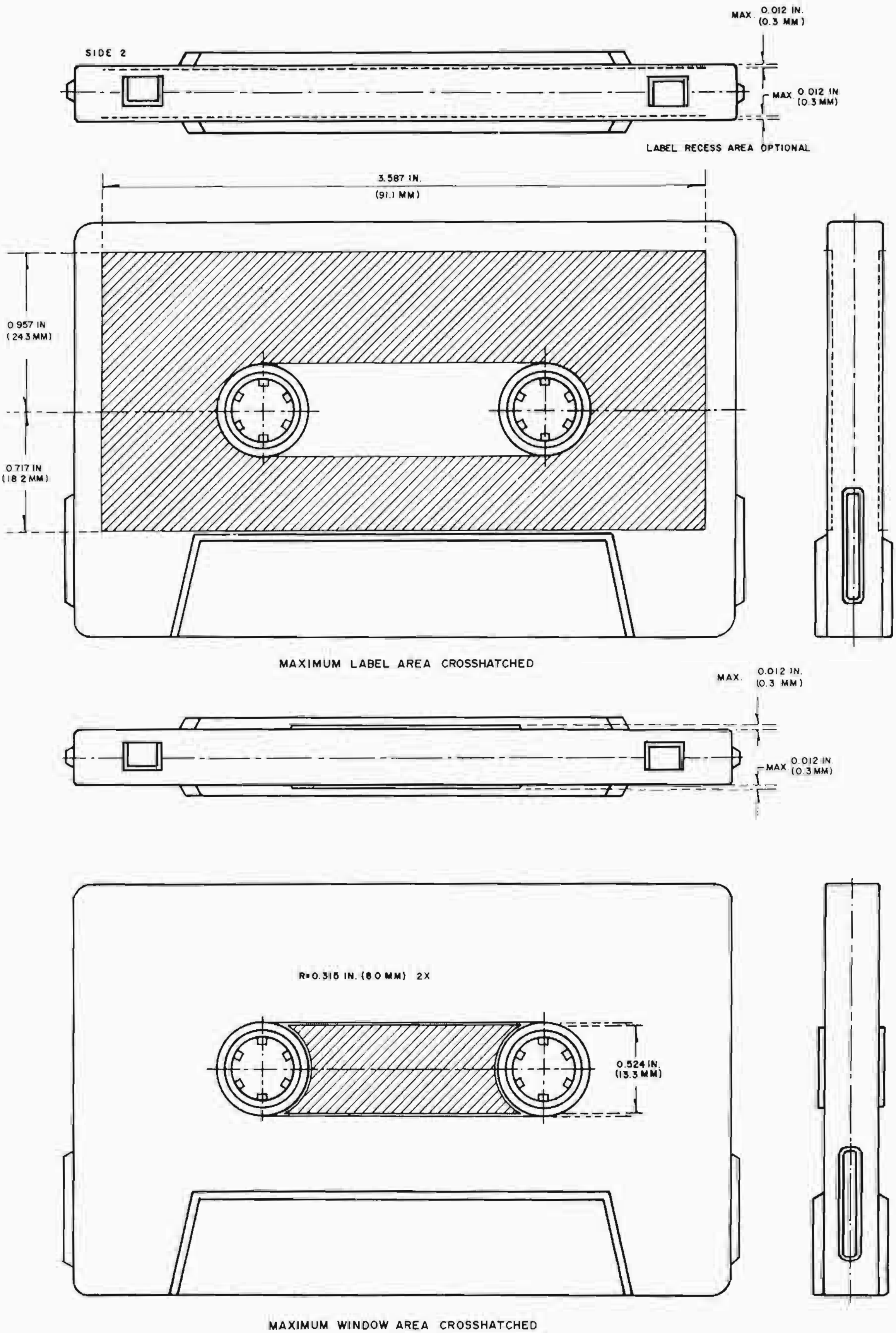

MAX. 0.012 IN. (0.3 MM)
SIDE 2
MAX. 0.012 IN (0.3 MM)
LABEL RECESS AREA OPTIONAL
3.587 IN. (91.1 MM)
0.957 IN (24.3 MM)
0.717 IN (18.2 MM)
MAXIMUM LABEL AREA CROSSHATCHED
MAX. 0.012 IN. (0.3 MM)
MAX 0.012 IN. (0.3 MM)
R=0.318 IN. (8.0 MM) 2X
0.524 IN. (13.3 MM)
MAXIMUM WINDOW AREA CROSSHATCHED

Fig. 13.

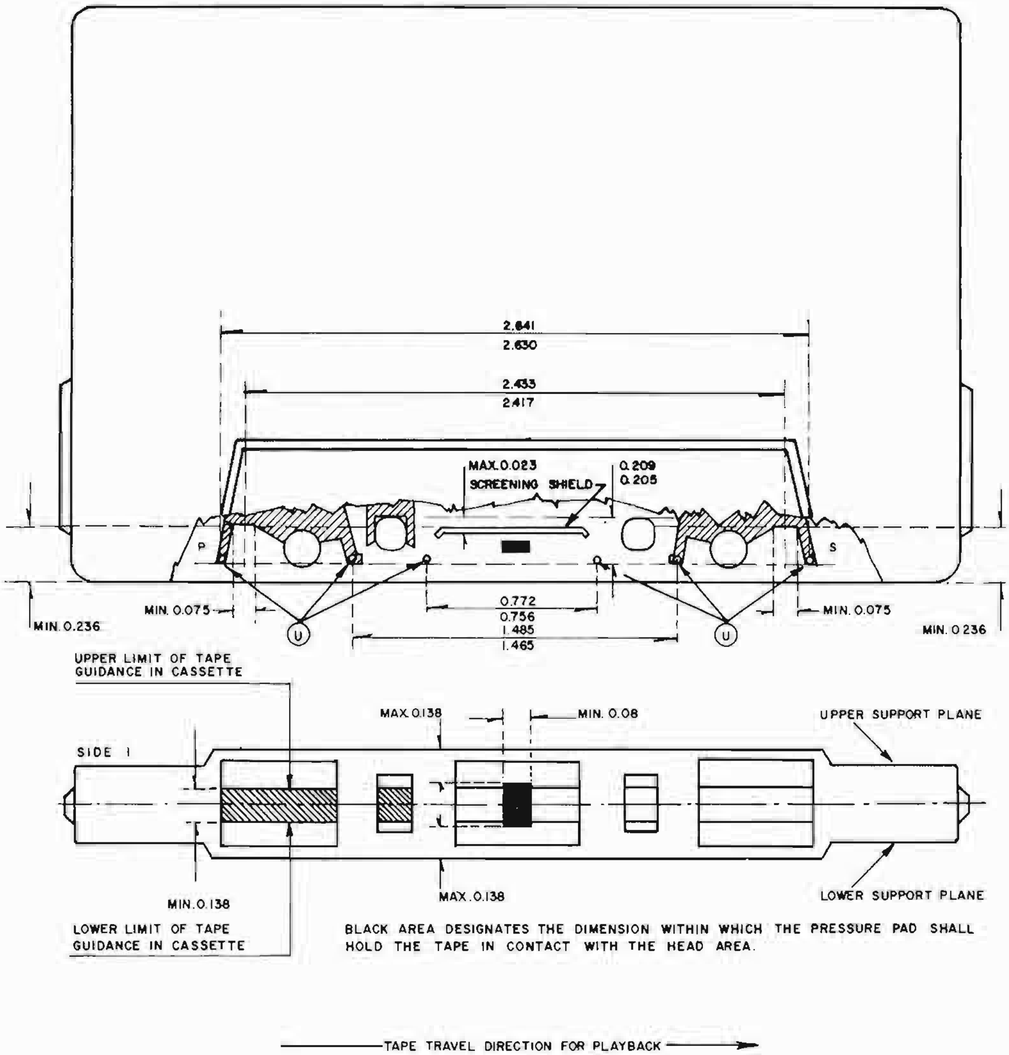


Fig. 14. Tape path dimensions and travel direction.

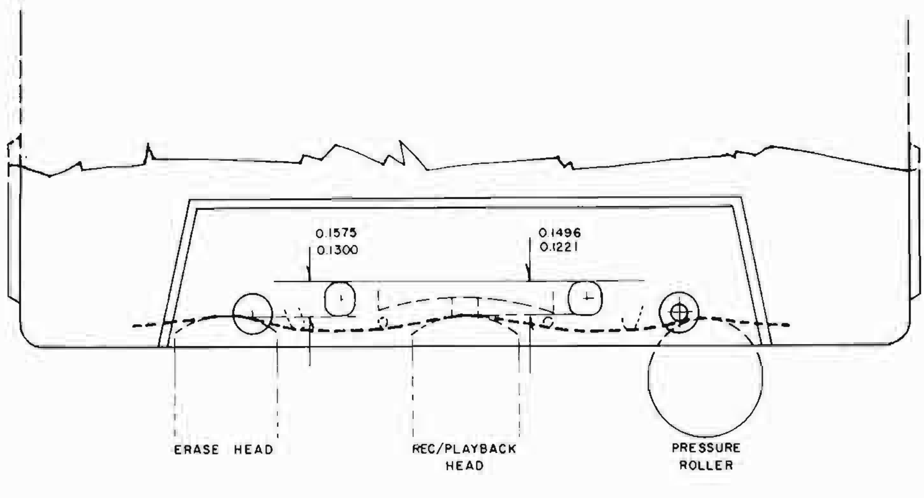


Fig. 15. Head penetration dimensions in record/play mode.

torque of both hubs measured in the cassette itself at the nearly full hub shall be 0.38 oz. in (27 gm. cm.). With the holdback torque of 0.11 oz. in (8 gm. cm.) applied to the nearly empty hub, the required maximum torque to be applied to the nearly full hub shall not exceed 0.78 oz. in (55 gm. cm.).

Cassette Leaders

1.50.

1.50.01 It shall be standard that an NAB Audio Cassette have a leader on each end of the tape having a minimum light transmittance of 75% and that the tape have a maximum light transmittance of 5% when using a light source having a color temperature of 2000 ± 200 ° K and using a silicon phototransistor for detection.

1.50.02 It shall be standard that the leader be 12 to 15 in. (30.48 to 38.10 cm.) long with a typical thickness of 0.0015 in. (38.1 μ).

1.50.03 It shall be standard that the leaders not part from the hub with a force of 2.20 lbs. (1000 gm.) under operating environment.

1.50.04 It shall be standard that the leader-to-tape splice not separate with a force of 1.54 lbs. (700 gm.) under operating environment.

Tape Position and Travel Direction

1.55 It shall be standard that the magnetic tape position and travel direction in the cassette head openings correspond to Fig. 14.

Cassette Breakage

1.60 It shall be standard that an NAB Audio Cassette withstand 10 random drops of 12 in. (30.48 cm.) onto concrete without causing functional damage.

Track Designation

1.65 It shall be standard that the track numbering be as shown in Fig. 16.

Cassette Support Planes

1.70 It shall be standard that the cassette be supported by the record/play instrument on only the cross hatched areas in Fig. 12 designated as support planes.

Label

1.75 It shall be standard that the label be located on side one only and shall fit within the area defined in Fig. 13.

The label shall include the following:

Side 1 designation, manufacturer, NAB designation (NAB-150 or NAB-300 per paragraph 1.30) and a blank area for content identification.

Cassette Environmental Conditions

1.80 Test environmental conditions are 70 ± 5° F. (21 ± 3° C.) and 50 ± 10% relative humidity. Operating environmental conditions shall be 20 to 125° F. (— 7 to + 52° C.) and 5 to 85% relative humidity noncondensing. Storage environmental conditions shall be a maximum of 125° F. minimum — 40° F. (+ 52°, — 40° C.) and maximum 85% relative humidity. After a period of 24 hours storage at these extremes and then normalized at the test environment, the NAB cassette shall meet the NAB specification.

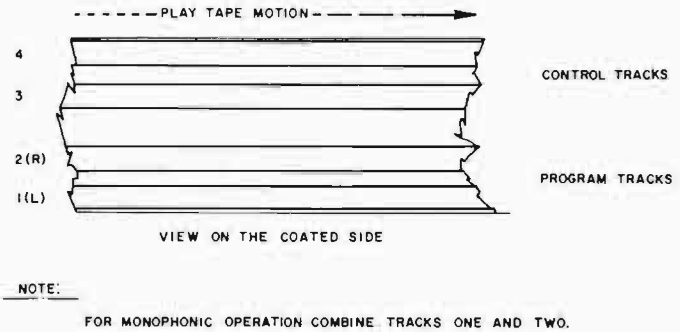


Fig. 16. Tape track designation.

Mechanical Specifications for Cassette Transport

Transport Cassette Acceptance

2.05 It shall be standard that the transport accept the standard NAB Audio Cassette.

Tape Speeds

2.10 It shall be standard that the tape speeds be 1-7/8 and 3-3/4 ips ± 0.3% (4.76 cm./s & 9.53 cm./s ± 0.3%).

Flutter and Wow

2.15 It shall be standard that the flutter and wow not exceed 0.2% NAB weighted rms in the play mode at either speed.

Tape Guides

2.20 It shall be standard that the tape guides have a width of 0.151 ± 0.001 in. (3.84 mm. ± 25.4 μ) and be centered on the nominal centerline of the cassette within 0.010 in. (254 μ). Two guides shall be provided, one located each side of (but not necessarily adjacent to) the record/play head.

Head Configuration

2.25 It shall be standard that the magnetic record/play head be 1/4 track 4 track in-line. The erase head shall be 1/2 track 1/4 track with 1/2 track covering tracks 1 and 2 and with 1/4 track covering track 3.

Head Track Dimensions

2.30 It shall be standard that the track dimensions of the magnetic record/play head be in conformity with the track dimensions shown in Fig. 17. (Track width is the effective track defined as the region of the common interface on the abutting pole pieces).

Head Penetration

2.35 It shall be standard that the head penetration be in accordance with Fig. 15.

Head Phasing and Azimuth

2.40 It shall be standard that the phasing between tracks 1 and 2 result in no more than 90° difference at 10 kHz when the head is adjusted within 1 dB of peak azimuth at 1-7/8 ips (4.76 cm./s). The head may be adjusted for optimum within the phase and azimuth loss limits.

Head Zenith

2.45 It shall be standard that the head face be no more than 2° out of perpendicularity with respect to the cassette support planes.

Tape Wrap

2.50 It shall be standard that the tape wrap extend a minimum of 0.030 in. (762 μ) on each side of the head gap.

Spindle Take Up Torque

2.55 It shall be standard that the spindle take up torque during play or record mode be within 0.41 to 0.83 oz. in (30 to 60 gm. cm.).

Fast Wind Torque

2.60 It shall be standard that the fast wind torque be within the range of 1.39 to 3.47 oz. in (100 to 250 gm. cm.).

Fast Wind Times

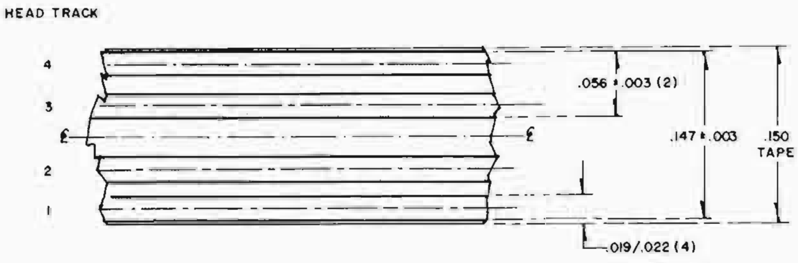
2.65 It shall be standard that the minimum fast forward or rewind time of a machine be 30 seconds for an NAB 300 cassette.

Maximum Tape Tension

2.70 It shall be standard that the maximum tension exerted on the tape not exceed 1.32 lbs. (600 gm.) for any mode of operation.

Start-Stop Time

2.75 It shall be standard that the tape motion start and meet all applicable standards within 500 milliseconds. The tape motion shall stop within 50 milliseconds from play speed.



NOTE:

THE OUTSIDE EDGES OF EFFECTIVE HEAD TRACK NUMBERS ONE AND FOUR SHALL NOT OVERLAP THE TAPE GUIDE AREA BY MORE THAN 0.002 INCHES.

Fig. 17. Head track dimensions.

Cueing Accuracy

2.80 It shall be standard that the machine cue and stop within 75 milliseconds of the leading edge of the primary cue tone in the play mode.

System Electrical Specifications [45]

Standard Operating Reference Levels

3.05 It shall be standard that the operating reference level be a recorded 400 Hz signal that produces an rms short circuit tape flux per unit track width of 200 nWb/m at 1-7/8 and 3-3/4 ips (4.76 and 9.53 cm./s) speeds. (This is approximately 3 to 4 dB below 3% third harmonic tape distortion.)

Cue and Function Tone Recorded Level

3.10 It shall be standard that the cue and function tones be recorded at a level which produces an output 15 dB below the standard operating reference level.

Playback Equalization Time Constants

3.15 It shall be standard that the higher frequency equalization time constant at 3-3/4 ips (9.53 cm/s) be 90 microseconds. The lower frequency equalization time constant shall be 3180 microseconds.

At 1-7/8 ips (4.76 cm/s) the higher frequency equalization time constant shall be 120 microseconds and the lower frequency equalization time constant shall be 1590 microseconds.

Signal-to-Noise Ratio (either audio channel)[46]

3.20 It shall be standard that at 3-3/4 ips (9.53 cm./s) the signal-to-noise ratio be not less than 48 cm./s) the signal-to-noise ratio be not less than 48 dB weighted (NAB) below standard operating level (Reference Fig. 18).

At 1-7/8 ips (4.76 cm./s) it shall not be less than 45 dB.

The foregoing figures shall include residual noise contributed by machine erasing and biasing functions.

[45]All recordings to be made on bulk erased tape.

[46]Weighted noise shall be measured using the weighting curve of Fig. 18 in the measuring circuit. This curve is based on the ASA "A" curve (ASA Standard S1.4-1961). The noise measurement shall be made using a tape previously recorded with bias but with no signal. The reference level is to be established, with the weighting network inserted, at 1000 Hz using the 1000 Hz noise reference level signal included for this purpose on the NAB Test Tape. The indicator meter shall have the dynamics of the Standard Volume Indicator (ASA Standard C16.5-1961) and the measuring system shall conform with a full-wave rectified average measurement law.

Frequency Response[47]

3.25 It shall be standard that the system response be within the limits shown in Fig. 19.

Control Tones

3.30 Seven control tones shall be standard for use in NAB Cassette Machine control: 261 Hz, 408 Hz, 639 Hz, 1000 Hz, 1565 Hz, 2449 Hz, and 3833 Hz, each within a tolerance of ± 4%.

Primary Cue Tone[48]

3.35 It shall be standard that 639 Hz be used as the Primary Cue Tone on tracks 3 or 4 for both "address" and "non-address" services. A tone burst of 0.75 ± 0.25 seconds shall be employed for the Primary Cue Tone, with the machine cueing at the beginning of the tone at play speed. An inhibit circuit shall be employed to prevent the operation of the primary cue tone sensor for a period of 2 seconds ± 0.5 seconds after machine start.

Secondary Cue Tone

3.40 It shall be standard that 1 kHz be used as the Secondary Cue Tone on track 3 as the "End of Message" and "Overlap" tone. There shall be no constraint on the length of the tone. The "End of Message" function shall operate by sensing the leading edge of the tone. (The "Overlap" function may be used to start the next programed event on the leading edge and drop the current even on the trailing edge.)

Tertiary Cue Tone

3.45 It shall be standard that 3833 Hz be used as the Tertiary Cue Tone on track 3 for special requirements, e.g., digital logging (coded numeric) or alphaneumeric (plain English). For logging systems using FSK, 3833 Hz may be replaced with tones in the 2.5 to 5 kHz region.

Address Code

3.50 It shall be standard that an 8-bit binary code for two digit addresses (0-99) be recorded on tracks 3 and 4.

A 261 Hz tone shall be employed for encoding the address in pulse groups of 8 cycles per group (making each group 30.64 milliseconds long).

[47]Frequency response measurements shall be made at a level of at least 20 dB below the standard operating reference level.

[48]The Primary Cue Tone may be used on track 4 when it is desired to retain a semi-permanent cue (which must be bulk-erased); or on track 3 when it is desired that it be erased as a normal machine function. The sensor shall react to a Primary Cue Tone on either track 3 or 4 at play speed.

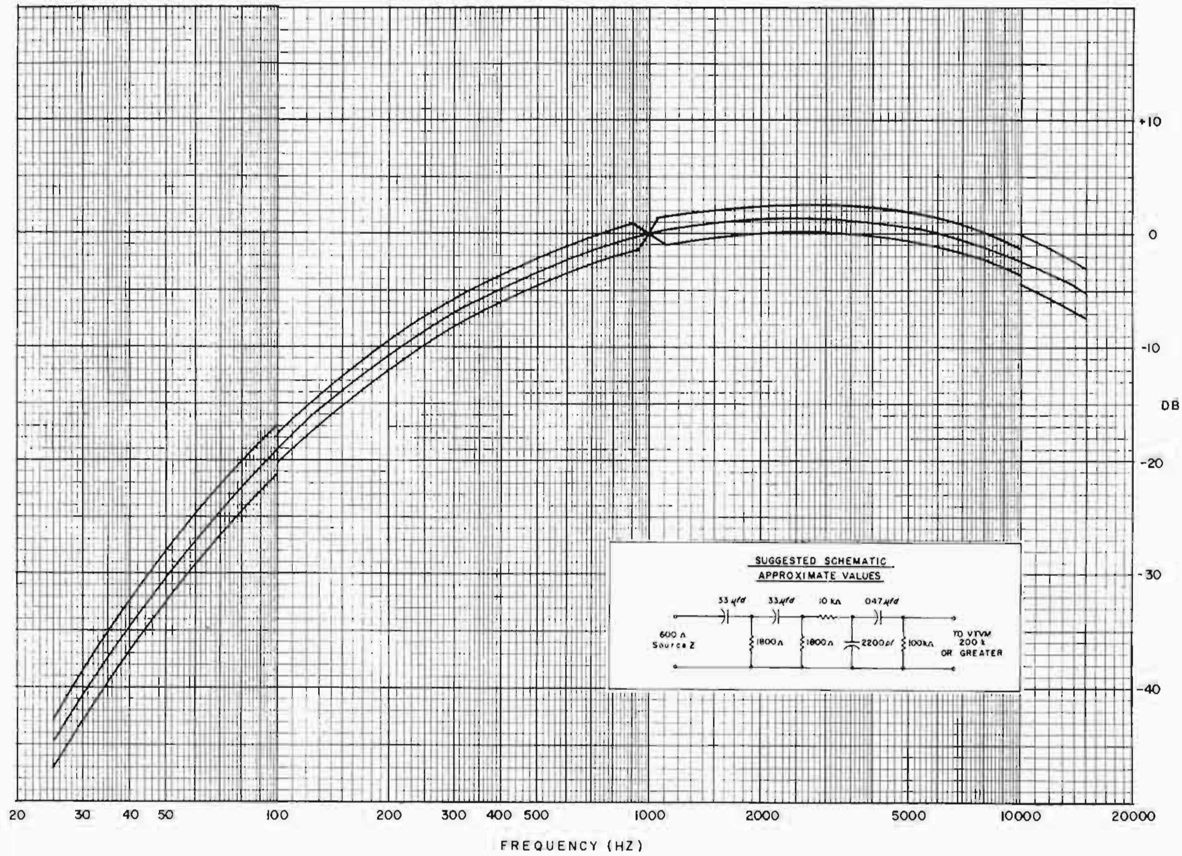


Fig. 18. Weighting curve for weighted noise measurements.

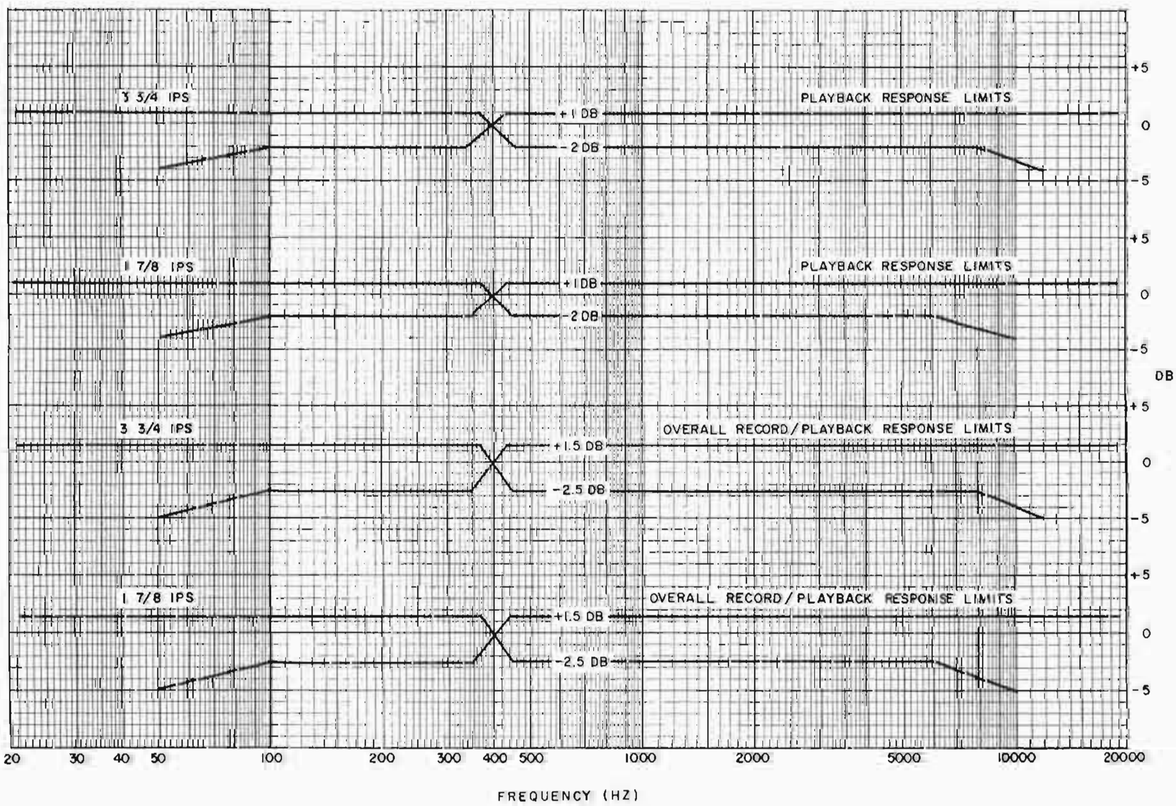


Fig. 19. Frequency responses limits.

A zero bit shall be defined as a tone burst on track 3 immediately followed by a tone burst on track 4. A one bit shall be defined as a tone burst on track 4 immediately followed by a tone burst on track 3. A single set of simultaneous tone bursts at the leading edge of the code group on tracks 3 and 4 shall be recorded to denote the forward direction of the tape. A double set of simultaneous tone bursts shall be recorded at the trailing edge of the address code group. (The reading of a double set of simultaneous tone bursts prior to the address code indicates a reverse motion of the tape.[49]

In address type service, the primary cue tone shall follow the address code.

Auxiliary Tones

3.55 It shall be standard that 408, 1565, and 2449 Hz be designated as Auxiliary Tones for use as required. (2449 Hz shall be eliminated if FSK tones in the 2.5 kHz region are used.)

Track Code

3.60 It shall be standard that the following track configuration be utilized:

Stop Tone (non-address)—Tracks 3 and/or 4.
Address/Stop Tone —Tracks 3 and 4.
Secondary, Tertiary, and
Auxiliary Tones —Track 3.

Crosstalk

3.65 It shall be standard that the playback crosstalk be not less than 26 dB between tracks 3 and 4, and tracks 1 and 2 within the frequency range of 50 to 10,000 Hz.

The crosstalk shall be not less than 40 dB between tracks 2 and 3, 2 and 4, 1 and 4, or 1 and 3 within the frequency range of 50 to 10,000 Hz.[47]

Transient Noise

3.70 It shall be standard that any transients generated within the machine result in an oscilloscope measurement at least 40 dB below the standard operating reference level.

[49]An example is shown in Fig. 20 of a recorded code group, address 48, with directions sensing marker. A leading and YZ trailing in the forward direction. Immediately following direction sensing marker A is the most significant bit of the least significant digit. After the first four bits (which comprise the least significant digit) there follows the most significant bit of the most significant digit.

[50]Since control tones are recorded at a level 15 dB below standard operating reference level, this results in an effective crosstalk level from the control tracks to the program tracks of 55 dB below standard operating reference level.

Test Tape Specifications

There shall be two NAB Audio Cassette Test Tapes, one for use at 1-7/8 ips (4.76 cm./s) and one for use at 3-3/4 ips (9.53 em./s) which shall conform to the following specifications.

Cassette and Tape

4.05 The cassette and tape shall conform with the requirements of Section I of this Standard except for tape length.

Track Width

4.10 All recorded tones shall be full track.

Tone Spacing

4.15 There shall be a 2-second interval between tones which may be used for voice announcements.

Tape Erasure

4.20 All tape shall be bulk erased prior to recording the test tones.

Recorded Level

4.25 All levels shall be as specified within ±0.5 dB.

All test tones specified in 4.35 having a level of — 20 dB shall be recorded so as to produce a uniform response when the test tape is reproduced through an ideal reproducing system. (See Annex A)

In lieu of the ± 0.5 dB tolerance specification, a ± 3 dB tolerance specification may be used provided that the deviation from uniform response when the test tape is reproduced on an ideal reproducing system is supplied for each test frequency.

Frequency Accuracy

4.30 All frequencies recorded on the test tape shall be within 1% of the specified frequency when the tapes are reproduced.

Test Tape Format

4.35

Time (seconds)	*Frequency (Hz)*	*Level (dB)*	*Function*
0.5-1	639	−15	Stop tone to cue tape
10	400	0	Operating reference level
10	400	−20	Calibration level

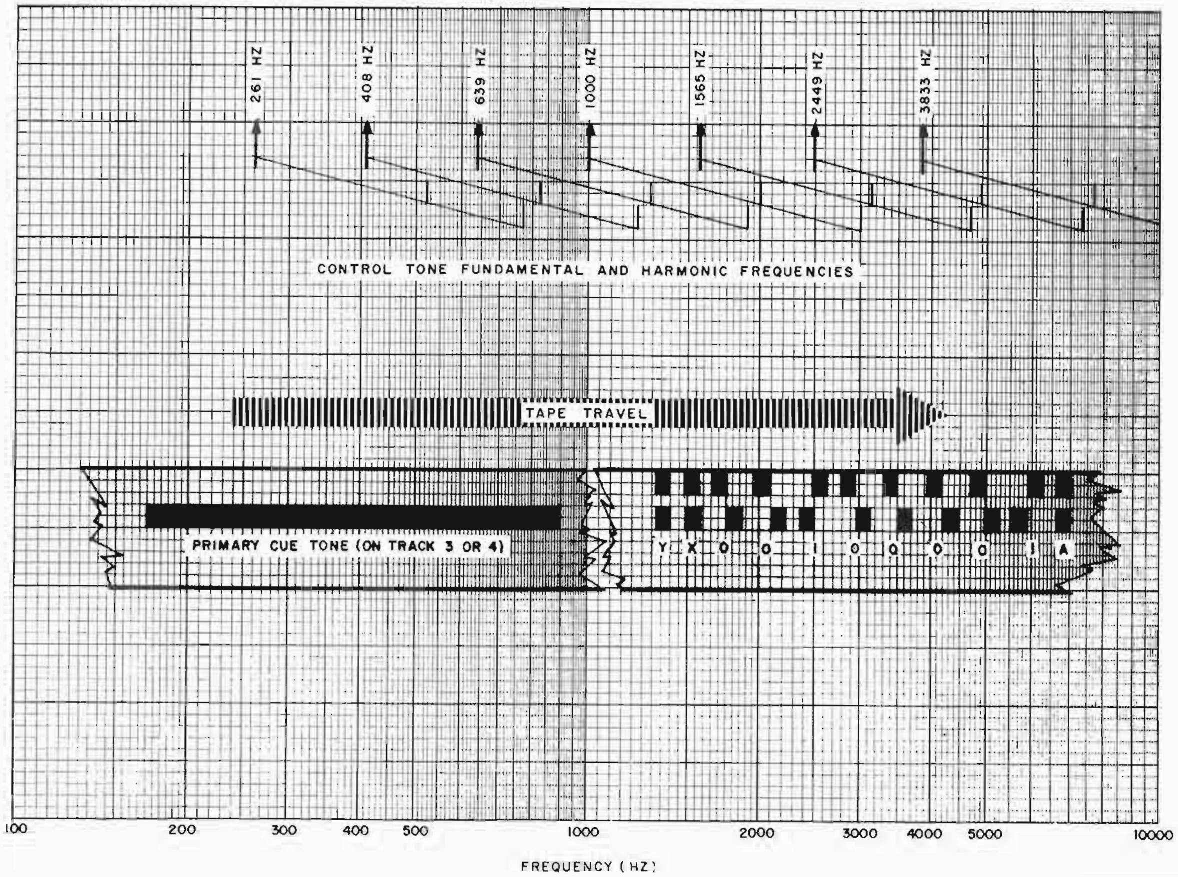


Fig. 20. Control tones and address codes.

(seconds)	*Frequency (Hz)*	*Level (dB)*	*Function*
30	10,000	−20	Azimuth
3	6,000	−20	Frequency Response
3	3,000	−20	Frequency Response
3	1,000	−20	Frequency Response
3	500	−20	Frequency Response
3	100	−20	Frequency Response
3	50	−20	Frequency Response
15	Blank		To allow meter scale adjustment
10	1,000	0	Signal reference for signal/noise measurement
20	Blank		Noise measurement segment
0.030	1,000	−15	Tone bursts for cue tests
0.030	1,000	−15	Tone bursts for cue tests
0.030	3,833	−15	Tone bursts for cue tests
0.030	3,833	−15	Tone bursts for cue tests
0.030	3,833	−15	Tone bursts for cue tests
0.5-1	639	−15	Stop tones
0.5-1	639	−15	Stop tones
0.5-1	639	−15	Stop tones

Annex A

Ideal Reproducing System

The standard NAB Ideal Reproducing System is a theoretical reproducing system. It consists of an "ideal" reproducing head[a] and an amplifier the output voltage of which shall conform to the voltage-frequency curve of Fig. A with constant flux versus frequency in the core of the head.[b]

The curve of voltage amplification versus frequency shall be uniform with frequency except where modified by the following equalizations.

[a] An "ideal" reproducing head is defined as a ferromagnetic head, the losses of which are negligible. This means that the gap is short and straight, the long wavelength flux paths are controlled so that no low frequency contour effects are present, and the losses in the head materials are negligibly small.

[b] It is recognized that the flux in the core of an "ideal" head is not necessarily the same as the surface flux on a tape in space for various reasons. Since most of these effects are not readily measured it has been decided to base this standard on "ideal" head core flux rather than surface induction.

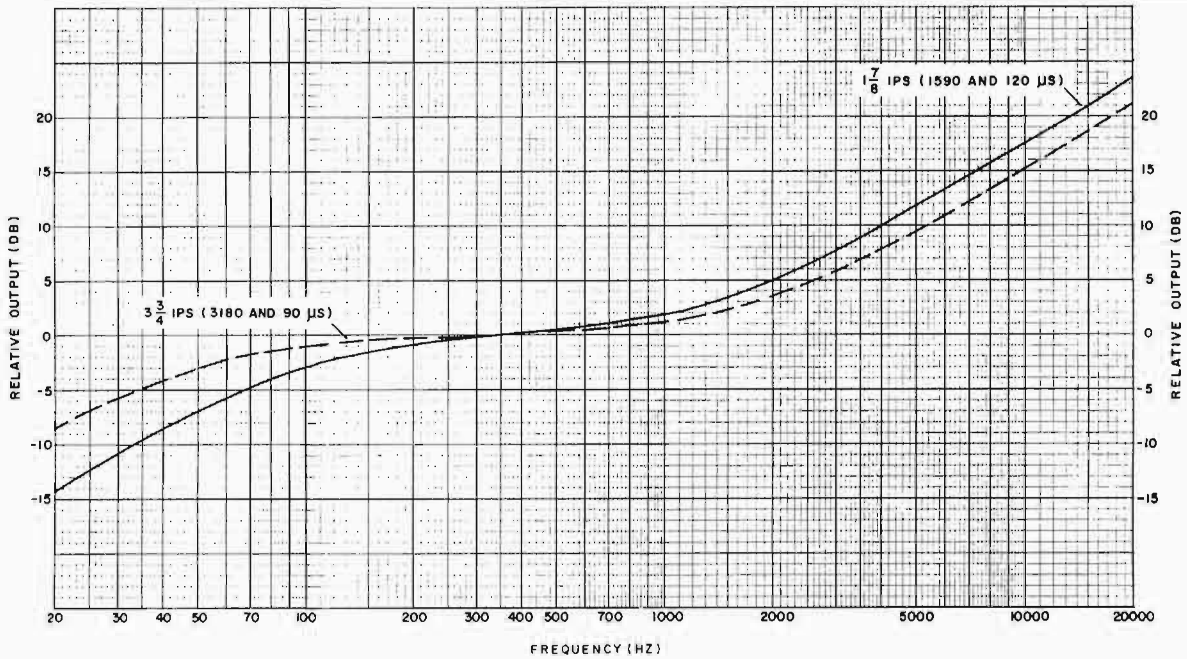


Fig. A. Reproducing characteristic reproducing amplifier output for constant flux in the core of an ideal reproducing head.

a. The voltage attenuation of a single resistance—capacitance high pass filter having an RC time constant t^1.

b. The inverse of the voltage attenuation of a single resistance capacitance low pass filter having an RC time constant t^2. The curve expressed in decibels is represented by the following expression:

$$N_{dB} = 20 \log_{10} \omega t_1 \sqrt{\frac{1 + (\omega t_2)^2}{1 + (\omega t_1)^2}}$$

$\omega = 2\pi$ times frequency

Standard Reproducing System[c]

It shall be standard that an NAB Standard Reproducing System shall consist of a suitable tape transport, reproduce head and amplifier equalized to compensate for head losses insofar as possible and to produce a reproduce response from an NAB Standard Test Tape, within the limits specified in Fig. 19. It shall also meet the specifications for distortion, signal-to-noise ratio and other applicable parts of this Standard.

[c]It is recommended that the Reproducing System response roll off at the rate of at least 6 dB per octave beyond the frequency limits shown in Fig. 19.

NAB STANDARD REPRODUCING CHARACTERISTIC
3-3/4 ips (3180 and 90 μs)

Reproducing amplifier output for constant flux in the core of an ideal reproducing head

Frequency (in Hz)	Response (in dB)	Frequency (in kHz)	Response (in dB)
20	− 8.6	1.5	+ 2.4
25	− 7.0	2	+ 3.6
30	− 5.8	2.5	+ 4.8
40	− 4.1	3	+ 5.8
50	− 3.0	4	+ 7.9
60	− 2.3	5	+ 9.5
70	− 1.8	6	+ 10.9
75	− 1.6	7	+ 12.2
80	− 1.4	7.5	+ 12.8
90	− 1.2	8	+ 13.3
100	− 1.0	9	+ 14.3
150	− 0.4	10	+ 15.2
200	− 0.2	11	+ 16.0
250	− 0.1	12	+ 16.7
300	±0	13	+ 17.4
400	+ 0.1	14	+ 18.0
500	+ 0.3	15	+ 18.6
600	+ 0.4	16	+ 19.2
700	+ 0.6	17	+ 19.7
750	+ 0.7	18	+ 20.2
800	+ 0.8	19	+ 20.6
900	+ 1.0	20	+ 21.1
1 kHz	+ 1.2		

NAB STANDARD REPRODUCING CHARACTERISTIC
1-7/8 ips (1590 and 120 μs)

Reproducing amplifier output for constant flux in the core of an ideal reproducing head

Frequency (in Hz)	Response (in dB)	Frequency (in kHz)	Response (in dB)
20	−14.2	1.5	+3.5
25	−12.3	2	+5.1
30	−10.9	2.5	+6.6
40	−8.6	3	+7.9
50	−7.0	4	+10.0
60	−5.8	5	+11.8
70	−4.8	6	+13.3
75	−4.4	7	+14.6
80	−4.1	7.5	+15.2
90	−3.5	8	+15.7
100	−3.0	9	+16.7
150	−1.5	10	+17.6
200	−1.0	11	+18.4
250	−0.5	12	+19.2
300	−0.2	13	+19.8
400	+0.1	14	+20.4
500	+0.4	15	+21.1
600	+0.6	16	+21.7
700	+1.0	17	+22.1
750	+1.1	18	+22.7
800	+1.3	19	+23.1
900	+1.6	20	+23.6
1 kHz	+1.9		

Bibliography Of Organizations Promulgating Standards of Interest to the Broadcasting Industry

Arbeitsgemeinschaft der Rundfunkanstalten der Brundesrepublik Deutschland (Association of Radio Stations of the German Federal Republic, *ARD*).

British Standards Institution (BSI), British Standards House, 2 Park Street, London W.1, England.

Deutscher Normenausschus (German Standards Committee, DNA).

This organization formulates the Deutsche Industrie Normen (German Industrial Standards, DIN). Although the titles are given here in English, the original standards are, of course, all in German. Some of the Standards are also available in English translations, sometimes very literal, indicated by "E/DIN." These standards are sold by Beuth-Vertrieb GmbH, 1 Berlin 30, Burggrafenstrasse 4-7, West Germany. Standards in German, and the "E/DIN" translations, are available in the U.S.A. only from USASI.

Electronic Industries Association (EIA) Engineering Department, 2001 Eye Street, N.W., Washington, D.C. 20006.

Institute of Electrical and Electronics Engineers, Inc. (IEEE formerly AIEEE and IRE), 345 East 47th St., New York, N.Y. 10017.

These Standards are available from the IEEE, Order Department, and also from USASI.

International Broadcasting and Television Organization (IBTO or *OIRT)*, Liebknechtova 15, Prague, 5 Czechoslovakia.

International Electrotechnical Commission (IEC), 1, rue de Varembe, Geneva, Switzerland.

International Radio Consultative Committee (CCIR), International Telecommunication Union, Place des Nations, Geneva, Switzerland.

Japanese Standards Association (JSA), 1-24 Akasaka 4, Minato-ku, Tokyo, Japan.

Magnetic Recording Industries Association (MRIA), Merged with EIA in 1965; no Standards issued.

National Association of Broadcasters (NAB) Engineering Department, 1771 N Street, N.W., Washington, D.C. 20036.

Philips Phonographic Industries, Baarn, The Netherlands.

Record Industry Association of America, Inc. (RIAA), One East 57th St., New York, N.Y. 10022.

Society of Motion Picture and Television Engineers (SMPTE), 9 East 41st St., New York, N.Y. 10017.

These Standards are published in the journal of the SMPTE in their draft and finally approved forms. The approved Standards are available from USASI.

Union Technique de l'Electricite, 20, rue Hamelin, Paris (16^{e}), France.

Available in the U.S.A. through USASI, in French only.

United States of America, Federal Specifications,
a) Bureau of Ships. Department of the Navy.

Standards can be ordered from Naval Ship Engineering Center, Code 6665.2M, Washington, D.C. 20360.

USA Standards Institute (USASI, formerly American Standards Association Inc.), 10 East 40th St., New York, N.Y. 10016.

USASI does not originate standards itself, but rather provides procedures for establishing national standards called "USA Standards" based on a consensus of those substantially concerned with the scope of the corresponding standards.

Standards sponsored by IEEE and approved by USASI are listed.

Standards sponsored by SMPTE and approved by USASI are listed.

Most foreign and international standards are distributed in the USA by the USASI.

Audio Cartridge Tape Recording and Reproducing Systems

1. General

1.1 *Scope*

The purpose of this standard is to describe and define the NAB Audio Cartridge Tape Recording and Reproducing System. This standard does not apply to special purpose tape cartridge systems which vary significantly from those described in this standard (tape speed, track configuration, noise reduction, etc.). This standard does not include any applicable safety requirements and supersedes the NAB Cartridge Standard dated October 1964.

1.2 *General Description of System and Applications*

This standard applies to an endless loop cartridge system for the recording and reproduction of audio broadcast programs on lubricated magnetic tape.

The NAB cartridge is an enclosure containing an endless loop of lubricated magnetic tape wound in such a fashion as to allow continuous tape motion.

The cartridge case has an opening in its lower side in order to accommodate a pressure roller, a corresponding cutout in the front side for a capstan, and two or more cutouts for insertion of magnetic head(s).

In the working position, the pressure roller pushes the tape against the capstan. At the same time, the pressure roller shaft may position the cartridge via a spring action device or other cartridge member.

The Standard requires either one program track and one cue track for monophonic programs; or two program tracks and one cue track for stereophonic programs.

A standard machine shall have the capability of accepting a single or multiplicity of NAB Size AA, Size AA and BB, or Size AA, BB, and CC cartridges.

A standard machine shall transport the tape, record and/or reproduce the signals recorded thereon in accordance with the requirements herein stated.

A standard cartridge shall maintain the tape in the position and condition shown in Fig. 1B. The cartridge shall permit the tape to be transported so as to meet the requirements herein stated.

1.3 *Description of Cue System*

This standard employs one track on the tape on which may be recorded four different signals, one each for (a) cueing the tape to a starting point, (b) providing an end of message signal, (c) a third signal, and (d) a fourth signal. Signals (b), (c), and (d) are used externally to the system. Refer to Section 3.4.

1.4 *Fast Wind (High Speed Cueing)*

High speed cueing is an optional feature and is intended for use in advancing the tape at a rate in excess of the normal (7.5 in/s, 190.5 mm/s) playing speed and stopping upon sensing the primary cue signal recorded on the cue track.

1.5 *Environment*

This standard applies when machines and NAB Type AA cartridges are operated in free air circulation under the following conditions:

1.5.1 *Relative Humidity*

Relative humidity not less than 25 percent or more than 80 percent.

1.5.2 *Ambient Temperature*

The ambient temperature shall not be less than 40°F (4°C) or more than 90°F (32°C).

1.5.3 *Power Source*

The line voltage is to be 117 v, ± 10 percent, 1ø, 60 Hz. Alternate voltages and frequencies may be used as specified on the equipment.

1.5.4 *Radio Frequency Interference (RFI)*

Cartridge tape equipment commonly operates in RF fields. The problem of determining a suitable test condition is under study.

2. Mechanical Requirements for Cartridges, Tape, Recording and Reproducing Equipment

2.1 *Mechanical Dimensions*

2.1.1 *Cartridges*

2.1.1.1 *Sizes and Dimensions*

Three cartridge sizes are standard; NAB Type AA, NAB Type BB, and NAB Type CC.[1]

The standard dimensions for NAB Type AA cartridge are shown in Fig. 1A and 1B.

Dimensions for NAB Type BB and Type CC are shown in Table 1. The dimensions for Type AA apply to Type BB and Type CC except for width and length.

TABLE 1

All Dimensions in Inches

Cartridge NAB type	Width	Length	Height
BB	6.010 5.990	7.025 6.975	.895 .865
CC	7.635 7.615	8.525 8.475	.895 .865

All Dimensions in Millimeters

Cartridge NAB type	Width	Length	Height
BB	152.65 152.15	178.44 177.17	22.73 21.97
CC	193.93 193.42	216.54 215.27	22.73 21.97

2.1.1.2 *Spring Action Device*

The cartridge spring action device when used, shall meet the requirements shown in Fig. 2.

2.1.1.3 *Form of the Cartridge Heel*

The cartridge heel shape is not standardized, but must fall within the outline shown in Fig. 1.

2.1.1.4 *Tape Path*[2]

The running path of the uppermost edge of the tape shall be parallel to the C plane (deck plane) at a distance perpendicular to said plane of 0.562 in. (14.275 mm). Tolerance is ± 0.002 in. (0.051 mm).

No member of the cartridge or playing mechanism shall prevent the tape from running within the prescribed limits. See Fig. 3.

2.1.1.5 *Tape Tension*

The tape tension measured with tape moving in the direction of normal travel, with heads and external guides eliminated, and any braking system defeated, shall not exceed 3 oz. (0.834 N).

2.1.1.6 *Tape Orientation*

The magnetic coating shall face the windows at the front of the cartridge, and shall move across the windows from right to left as the cartridge is held with the bottom down and the windows facing the observer. See Fig. 1B.

2.1.1.7 *Playing Time*

The playing time shall be clearly marked on the cartridge. Loaded cartridges shall contain no less tape than that required to provide the indicated playing time (at 7.5 in/s 190.5 mm/s). Excess tape shall not exceed 3 sec. playing time for playing times up to 100 sec., and not more than 6 sec. for playing times greater than 100 sec.

2.1.1.8 *Identification*

Cartridges conforming to this standard shall be

[1] The cartridges meeting this standard are similar to the former Type A, Type B and Type C, respectively. Certain differences in the Type AA, BB, and CC may prevent full compatibility with those described in the 1964 NAB Standard.

[2] Fig. 1B gives a dimension for the lower edge of the tape when it is in a relaxed static condition.

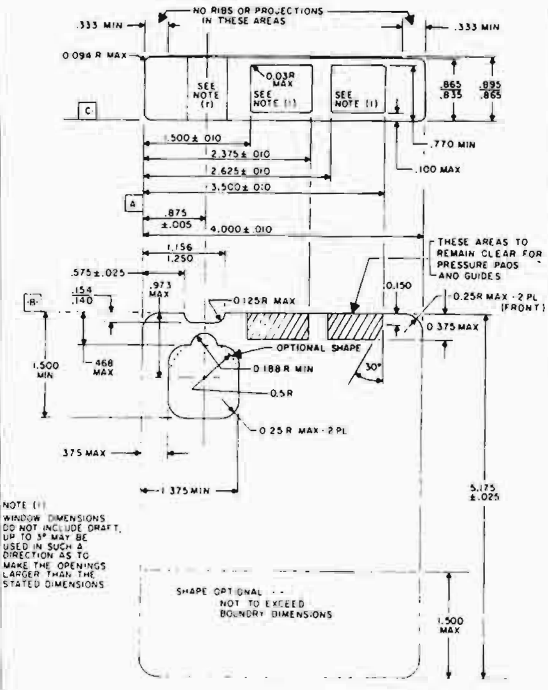


Fig. 1A. NAB "AA" cartridge.

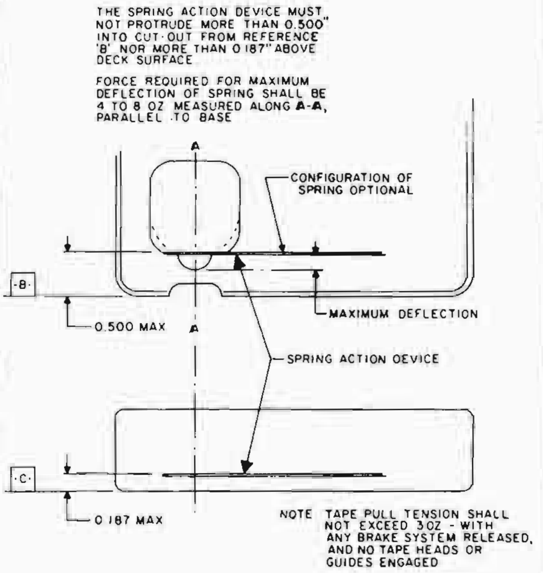


Fig. 2. NAB "AA" cartridge spring action device limitations.

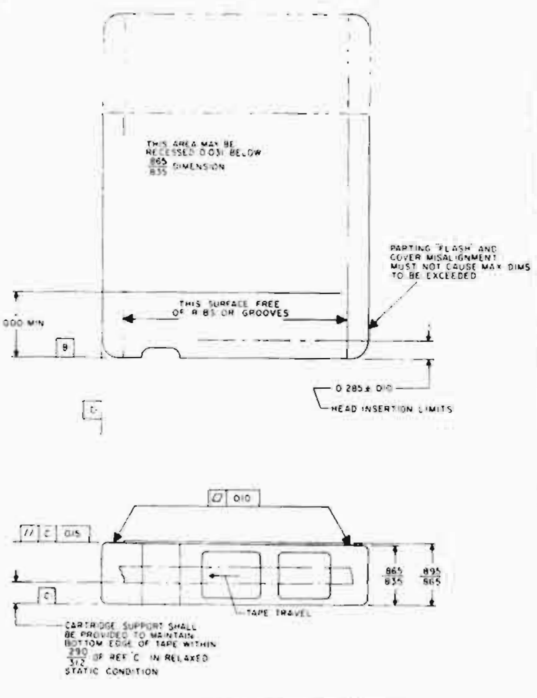


Fig. 1B. NAB "AA" cartridge.

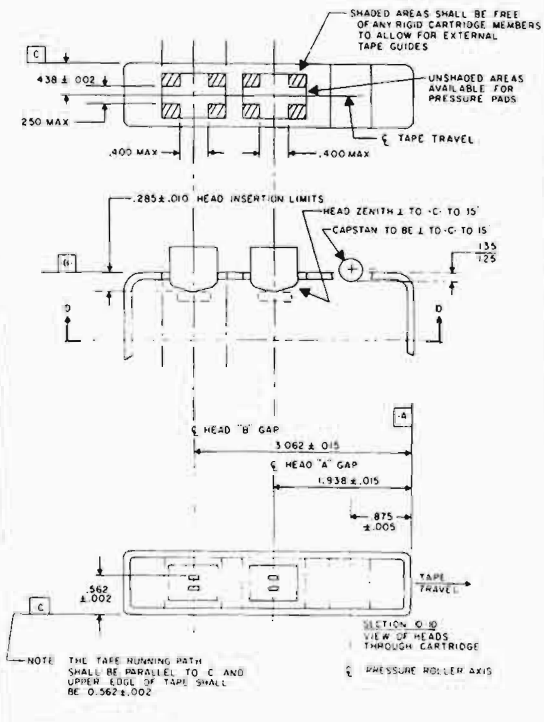


Fig. 3. Machine/cartridge interface dimensions.

clearly identified with the appropriate NAB Type (AA, BB, CC).

2.1.1.9 *Tape Stop Time*

The tape shall stop within 40 msec (maximum) of the transport release at 7.5 in/s (190.5 mm/s), or 80 msec (maximum) equivalent playing time from fastest speed.

2.1.2 *Tape*

2.1.2.1 *Tape Thickness*

Total thickness of tape (base film plus coatings) shall not exceed 1.6 mils (0.04 mm).

2.1.2.2 *Tape Width*

The tape width shall be 0.248 in. +0.000, -0.002. (6.30 mm +0.000, -0.05 mm.)

2.1.2.3 *Tape Lubrication*

Tape used, in cartridges shall be lubricated on the side opposite the magnetic coating.

2.1.3 *Transport*

2.1.3.1 *Head Location*

The location of the center line of the gap of each head referenced to Plane A shall be as shown in Fig. 3.

2.1.3.2 *Head Insertion*

The tape contact surface of the head(s) relative to the B plane shall be as shown in Fig. 3.

2.1.3.3 *Head Zenith*

The tape contact surface of the head(s) shall be perpendicular to C plane within 15 min. of arc as shown in Fig. 3.

2.1.3.4 *Head/Tape Contact Area*

The tape-to-head contact area shall be within limits as shown in Fig. 3.

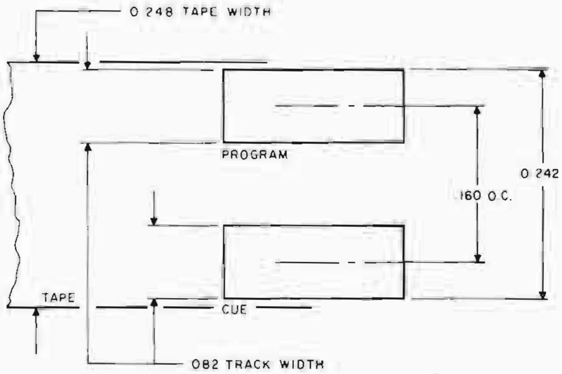


Fig. 4A. Mono track system reference dimensions.

2.1.3.5 *Track Reference Dimensions and Formats*

The monophonic track system reference dimensions are given in Fig. 4A. The stereophonic track system reference dimensions are given in Fig. 4B.

2.1.3.6 *Capstan Perpendicularity*

The capstan shall be perpendicular to Plane C (deck plane) within 15 min. of arc.

2.2 *Transport Performance*

2.2.1 *Tape Speed*

The standard tape speed shall be 7.5 in/s (190.5 mm/s) tolerance shall be ± 0.2 percent.

2.2.2 *Fast Wind (Optional)*

2.2.2.1 *Maximum Tape Speed*

The maximum tape speed shall be 30 in/s (762 mm/s) in fast wind mode (Me-

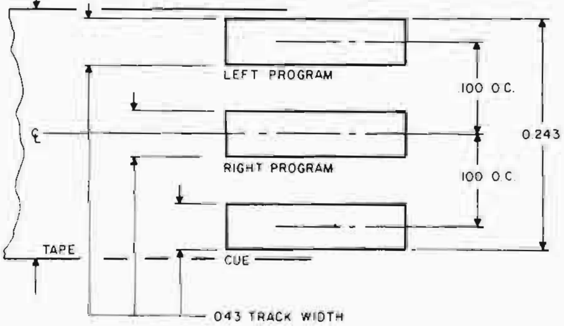


Fig. 4B. Stereo track system reference dimensions.

chanical considerations for tape and cartridge).

2.2.2.2 *Initiate Fast Wind Mode*

The fast wind mode shall be initiated by the trailing edge of the secondary cue tone (EOM) for automatic, or by actuation of a contact closure or equivalent for manual operation.

2.2.2.3 *Inhibit Start Command*

When stopping from the fast wind mode, the start command is to be inhibited for the maximum motor speed transition time (from fast to normal speed).

2.2.2.4 *Defeat Fast Wind Mode*

Machines with fast wind shall have a switch to allow the defeat of automatic fast wind mode. When in a recording mode, fast wind operation shall be defeated.

2.2.3 *Transport Stop Time*

The transport stop time shall be 80 msec. maximum at 7.5 in/s (190.5 mm/s); 120 msec. divided by the ratio of fast wind speed to 7.5 in/s (190.5 mm/s) when set in the recommended minimum time release adjustment or mode.

2.2.4 *Transport Start Time*

The transport start time from initiation of start command shall be 120 msec. maximum to first reach 7.5 in/s (190.5 mm/s).

2.2.5 *Maximum Temperature Rise*

The maximum temperature rise above ambient for any machine part in long-term contact with the tape or cartridge shall be 50°F (28°C).

2.2.6 *Flutter*

The weighted peak flutter of the reproducer shall be less than ± 0.15 percent measured according to ANSI S4.3, using a flutter test tape as described in Section 4.4 of this standard.

2.2.7 *Phase Difference (Stereo)*

The peak stereophonic phase difference shall not exceed 90° at 12.5 Hz.

3. Electrical Requirements for Recording and Reproducing Equipment

3.1 *Equalization*

3.1.1 *Recorded Tape Flux Characteristic*

The standard characteristic of the short circuit magnetic tape flux (and also the fluxivity) versus frequency shall fall with increasing frequency in conformity with the impedance of a parallel combination of a capacitance and a resistance having a time constant of 50 microseconds. Refer to Table 2 and Fig. 5.

3.2 *Standard Tape Reference and Operating Level*

3.2.1 *Reference Fluxivity*

For all measurements in this standard, the reference fluxivity shall be 160 nWb/m at 1 kHz as measured according to ANSI S4.6.

3.2.2 *Standard Operating Level*

The standard operating level is not specified.

160 nWb/m at 1 kHz is recommended if a VU Meter, or instrument of similar characteristics is used in the recording process with currently available magnetic tape.

3.3 *Program System Performance Requirements*

3.3.1 *Minimum Input Level*

3.3.1.1 *Reproducer Limit*

The maximum gain of the reproducer shall be such that a recorded fluxivity of

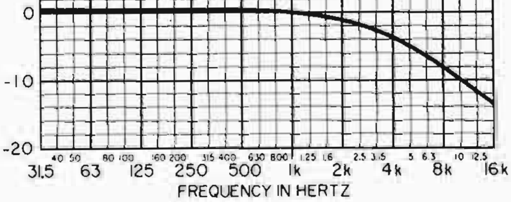


Fig. 5. Standard recorded tape short circuit flux characteristic.

50 nWb/m at 1 kHz (10 dB below reference fluxivity) will produce at least 0 dBm output level.

3.3.1.2 *Recorder Limit*

The recorder shall be capable of recording a 1 kHz signal at reference fluxivity from the following minimum input levels: -22 dBm (60 mv/600 ohms, or 30 mv/150 ohms) 600/150 ohm connection; -8 dBm (300 mv/600 ohms), -2 dBm (300 mv/150 ohms) bridging connection.

3.3.2 *Maximum Input Level*

3.3.2.1 *Reproducer Limit*

The reproducer shall be capable of reproducing no less than 1250 nWb/m equivalent input fluxivity at 1 kHz (18 dB above reference fluxivity).

3.3.2.2 *Recorder Limit*

The record amplifier shall be capable of accepting the following maximum levels: 0 dBm (780 mv/600 ohms or 390 mv/150 ohms) 600/150 ohm connection; +14 dBm (4.0 mv/600 ohms), +20 dBm (4.0 mv/150 ohms) bridging connection.

3.3.3 *Amplitude/Frequency Response*

3.3.3.1 *Reproducer Limit*

When reproducing a calibration tape meeting the requirements of paragraph 4, the output level of the reproducer shall be within a 2 dB window from 315 Hz to 10 kHz, 3 dB window from 150 to 314 Hz, 5 dB window from 50 to 149 Hz, and opening from 2 to 3 dB between 10 and 16 kHz, as shown in Fig. 6A, with the upper limit of the window to be flat from 20 Hz to 20 kHz.

3.3.3.2 *Recorder Limit*

When recording a tape and comparing its reproduced output with that of an NAB Standard test tape, the difference shall be within a 2 dB window from 50 Hz to 10 kHz, and opening from 2 to 3 dB between 10 kHz and 16 kHz, as shown in Fig. 6B.

3.3.3.3 *Level Difference (Stereo)*

The maximum level difference between stereo program channels shall be 1.5 dB for a reproducer, and 3.0 dB for a recorder/reproducer over the frequency range from 50 Hz to 16 kHz.

3.3.4 *Total Harmonic Distortion*

3.3.4.1 *Reproducer Limit*

The total harmonic distortion of the reproducer at +18 dBm output (from 50 Hz to 16 kHz) shall be less than 0.5 percent.

3.3.4.2 *Recorder Limit*

The total harmonic distortion of the record amplifier at 1 kHz, with a level 18 dB above that required to record 160 nWb/m on currently available magnetic tape, shall be less than 0.5 percent.

3.3.4.3 *System Limit*

The total harmonic distortion when recording and reproducing 160 nWb/m at 1 kHz, on currently available tape, shall be less than 2.0 percent.

With a 1 kHz tone recorded with peak bias on any lubricated tape at a level which produces 3.0 percent rms 3rd harmonic distortion, the distortion should result mainly from the tape nonlinearity and not from the recording or reproducing amplifiers.

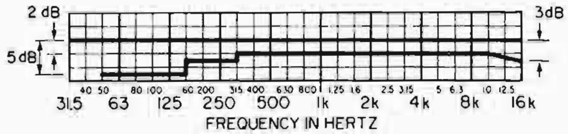


Fig. 6A. Reproduce characteristic tolerance.

3.3.5 *Signal/Noise Ratio*

3.3.5.1 *Reproducer Limit*

The reproducer signal-to-noise ratio shall be measured unweighted with a bandpass of 20 Hz to 20 kHz *without tape running,* but with an otherwise fully operating reproducer, from 160 nWb/m at 1 kHz reference level. The minimum signal-to-noise ratio shall be 50 dB for mono and 47 dB for stereo.

3.3.5.2 *System Limit*

The system signal-to-noise ratio shall be measured unweighted with a band-pass of 20 Hz to 20 kHz, using a tape recorded with bias but with no signal, from 160 nWb/m at 1 kHz reference level. The minimum system signal-to-noise ratio shall be 47 dB for mono and 44 dB for stereo.

3.3.6 *System Crosstalk*

3.3.6.1 *Stereo Program Crosstalk*

Stereo program crosstalk shall be measured at 50 Hz, 1 kHz, 10 kHz with 160 nWb/m and 50 nWb/m respective fluxivities, correct source and load impedances, and with normal gain control settings. The maximum stereo program crosstalk shall be -45 dB.

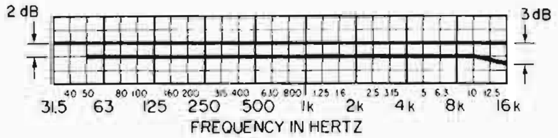


Fig. 6B. Record characteristic tolerance.

3.3.6.2 *Cue to Program Crosstalk*

Cue to program crosstalk shall be measured at 150 Hz, 1 kHz, 3.5 kHz and 8 kHz, with nominal levels, correct source and load impedances, and with normal gain control settings. The maximum cue to program crosstalk shall be -50 dB.

3.3.7 *Channel Phasing (Stereo)*

3.3.7.1 *Record Polarity*

In-phase stereo inputs to record amplifier input terminals shall produce in-phase magnetic signals on the tape (as from a full-track record head).

3.3.7.2 *Reproduce Polarity*

In-phase magnetic signals on the tape (as from full-track recording) shall be reproduced as in-phase stereo signals at the reproduce amplifier output terminals.

3.3.7.3 *Phase Difference*

The peak phase difference between stereo channels (record and subsequently reproduce) shall be less than 90° for all frequencies between 50 Hz and 12.5 kHz.

3.3.8 *Interface Impedances*

The recorder and/or reproducer shall be required to meet all of the specifications of this standard only when properly terminated in the rated source and load impedances.

3.3.8.1 *Reproducer Load Impedance*

The reproducer rated load impedances shall be 600 ohms on output connection *and* 150 ohms available on external connection or by internal wiring.

3.3.8.2 *Reproducer Output Impedance*

The reproducer output impedances shall not exceed 0.125 times the rated load impedance (75 ohms maximum for 600 ohms rated load, 18.8 ohms maximum for 150 ohms rated load), over the frequency range from 50 Hz to 16 kHz.

3.3.8.3 *Recorder Source Impedance*

The recorder source impedance shall be 150 ohms or less; on the 150 ohm connection, or 600 ohms or less on the 600 ohm connection.

3.3.8.4 *Recorder Input Impedance*

The recorder input impedances shall be 8 (minimum) times the rated source impedance (4,800 ohms minimum for 600 ohms rated source, 1,200 ohms minimum for 150 ohms rated source), and 10,000 ohm minimum bridging over the frequency range from 50 Hz to 16 kHz.

3.3.8.5 *Input/Output Connections*

The program record input and reproduce output connections shall be floating (ungrounded), capable of being connected to sources/loads with either side or centerpoint grounded while meeting all other specifications.

3.4 *Cue System Performance Requirements*

3.4.1 *Required and Optional Cue Facilities*[3]

There shall be a Primary cue system in NAB Standard Cartridge Tape Recorders and Reproducers. All other cue/logging facilities are optional. When used, the optional Secondary, Tertiary and Logging cue tones shall be as assigned in paragraph 3.4.2, the cue sensor limits shall be as specified in paragraph 3.4.6; and all other requirements listed in paragraph 3.4 for cue system performance must be met.

[3]Recording of the Secondary cue, Tertiary cue and Logging signals shall be possible during the record and reproduce modes of the cartridge machines without causing any of the parameters to exceed the specified limits.

3.4.2 *Cue/Logging Generator Frequencies and Tolerances*

Primary cue: 1 kHz, ± 50 Hz.
Secondary cue: 150 Hz, ± 8 Hz.
Tertiary cue: 8 kHz, ± 400 Hz.
Logging signal: 3.5 kHz, ± 150 Hz for single-tone On/Off system.
3.3 kHz to 3.7 kHz maximum window for FSK logging system.

3.4.3 *Cue/Logging Tone Levels*

3.4.3.1 *Recorded Fluxivity*

Primary cue: 160 nWb/m, +20 nWb/m, -40 nWb/m.

Secondary cue: 360 nWb/m, +40 nWb/m, -110 nWb/m.

Tertiary cue: 20 nWb/m, +2 nWb/m, -6 nWb/m.

Logging signal: 35 nWb/m, +5 nWb/m, -10 nWb/m.

3.4.3.2 *Relative Output Levels*

When a tape with standard recorded cue tones is reproduced through an amplifier having the ideal NAB reproducing characteristic and compared to the NAB Standard Tape Reference Fluxivity (paragraph 4.2.1.2), the corresponding relative output levels are:

Primary cue: 0 dB standard, +1 dB maximum, -3 dB minimum (+1 -3 dB).

Secondary cue: +6 dB standard, +7 dB maximum, +3 dB minimum (+1 -3 dB).

Tertiary cue: -10 dB standard, -9 dB maximum, -13 dB minimum (+1 -3 dB).

Logging signal: -10 dB standard, -9 dB maximum, -13 dB minimum (+1 -3 dB).

3.4.4 *Cue/Logging Tone Distortion*

The total harmonic distortion as recorded on the tape at the frequencies and levels listed above shall not exceed 5.0 percent.

3.4.5 *Cue/Logging Tone Duration*

Primary cue: 500 msec. minimum, 750 msec. maximum.
Secondary cue: 100 msec. minimum (15 cycles at 150 Hz), no maximum specified.
Tertiary cue: 2 msec. minimum (16 cycles at 8 kHz), no maximum specified.
Logging signal: No minimum or maximum specified. External logging encoding and decoding systems may have differing requirements.

3.4.6 *Cue Sensor Requirements*

3.4.6.1 *Cue Sensor Operation*[4]

The individual cue sensors shall operate satisfactorily with the levels listed in Section 3.4.3 for tones within the frequency tolerances listed below:

Primary cue: 1 kHz ± 100 Hz.
Secondary cue: 150 Hz ± 15 Hz.
Tertiary cue: 8 kHz ± 800 Hz.
Logging signal: No tolerance specified.

3.4.6.2 *Primary Cue Sensor Inhibitor*

A Primary cue sensor inhibit timer shall be incorporated to prevent the operation of the Primary cue sensor until after the Primary cue tone has initially passed the cue reproduce head. The duration of the inhibit or protect timer shall be 1.75 sec., ± 0.25 sec.

3.4.6.3 *Protection against False Cueing*

The Primary, Secondary and Tertiary cue sensors shall not respond to other standard cue or logging tones within the frequency tolerances listed in Section 3.4.2 (and with up to 6 dB above standard levels in 3.4.3 with no more than 5 percent distortion) when either in the normal speed or fast speed mode of operation.

3.4.7 *Cue Sensor External Switching Requirements*

The Secondary and Tertiary cue sensors shall have a ground switching output when the optional sensors are provided. The switching circuit shall be one-side grounded with a current sinking capability of at least 50 mA., voltage rating of at least +25 v when open and, with 50 mA. current, shall have 0.4 v maximum voltage drop across the switch when closed.

Protection shall be included to prevent damage of the switching circuit components with a reverse voltage of up to -25 v, and a reverse current of up to 100 ma. in the event the load switching supply is reversed in polarity.

3.4.8 *Logging Input/Output Requirements*

3.4.8.1 *Input Level*

The required input logging signal shall be 0.5 v., ± 0.25 v RMS level for a tape fluxivity of 35 nWb/m.

[4]The external logging system sensor must reject the Primary, Secondary and Tertiary cue signals at the maximum specified levels for error-free operation.

3.4.8.2 *Input Impedance*

The logging input impedance shall be 10,000 ohms minimum. The input may be one-side grounded.

3.4.8.3 *Output Level*

The required logging output level shall be 0.5 v, ± 0.25 v RMS from a logging signal of 35 nWb/m tape fluxivity.

3.4.8.4 *Load Impedance*

The logging load impedance shall be 10,000 ohms minimum. The output may be unbalanced.

3.4.8.5 *Protection From External Cue Tones*

The output circuit shall provide 40 dB minimum isolation for internal cue sensors from external cue signals appearing on the output connector from other machines connected in parallel with the output.

3.4.8.6 *Logging Output Distortion*

The total harmonic distortion for Primary, Secondary and Tertiary cue tones, and for Logging tones appearing at the logging output, recorded at maximum levels with up to 5.0 percent distortion on the tape shall be 7.0 percent maximum.

3.5 *Remote Input Switching Requirements*

3.5.1 *Reproducer Requirements*

Connections and circuitry for start and stop remote switching functions shall be provided in reproducers.

3.5.2 *Recorder Requirements*

Record set remote switching functions shall be provided in recorders. Connections and circuitry for Secondary and Tertiary cue remote record switching functions shall be provided when these optional facilities are provided in the recorder.

3.5.3 *Voltage and Current Requirements*

All circuits for remote switching shall be one-side grounded and capable of operation by the closure of an external normally open set of contacts, or equivalent. They shall operate from a positive supply voltage, with + 25 v maximum appearing on the switching terminals.

They shall require no more than 50 mA. current for operation, and shall operate when the switching voltage is pulled down to +0.4 v with respect to ground by the external switch.

Proteciton shall be included to prevent damage of the switching circuit components with a sustained reverse current of up to 100 mA. in the event an external supply is connected to the switching terminals.

3.5.4 *Response Time*

The switching circuits of 3.5.1 and 3.5.2 shall operate with a switch closure of 40 msec. or more.

4. Calibration/Test Tapes

4.1 *Label Information*

The cartridge shall be labeled. It shall state the test tape category, tape speed, NAB Standard and edition, the manufacturer and catalog number, and the track format.

4.2 *Spot Frequency Calibration Tape*

There is nothing at the present time for Section 4.2.

4.2.1 *General*

4.2.1.1 *Reference Frequency*

The reference frequency for calibration tapes shall be 1000 Hz.

4.2.1.2 *Reference Fluxivity*

The reference fluxivity for calibration tapes shall be an RMS short-circuit flux per unit track width of 160 nWb/m of track width at 1000 Hz, as measured according to ANSI S4.6-1973.

4.2.1.3 *Flux versus Frequency*

The recorded tape flux versus frequency shall be as given by the following equation:

$$(f) = 1/^2\ [1+(f/3180)^2]$$

where f is the frequency in Hz.

4.2.2 *Tolerances*

4.2.2.1 *Recorded Frequencies*

The recorded frequencies, when reproduced at the standard speed, shall be the specified values ± 1 percent.

4.2.2.2 *Reference Fluxivity*

The reference fluxivity shall be the specified value ± 3 percent.

4.2.2.3 *Flux versus Frequency*

The fluxivity versus frequency shall be the specified value in Table 2 ± 0.5 dB up to the frequency of 10 kHz, and ± 1.0 dB for frequencies above 10 kHz.

4.2.2.4 *Azimuth Angle*

The tape flux shall be parallel to the longitudinal axis of the tape with an azimuth alignment error across the entire track width not to exceed ± 0.2 milliradians (40 sec.).

4.2.3 *Recorded Tracks*

4.2.3.1 *Monophonic*

The recorded test signals may be recorded on the program track shown in Fig. 4A, or they may be recorded across the entire upper 0.16 in. (4 mm) of the tape.

4.2.3.2 *Stereophonic*

The recorded test signals may be recorded on the two program tracks shown in Fig. 4B, or they may be recorded (with fringing compensation) across the entire upper 0.16 in. (4 mm) of the tape.

4.2.4 *Test Tape Format*

4.2.4.1 *Announcements*

Each test tone shall be preceded by a voice announcement.

4.2.4.2 *Format*

The calibration tape shall contain at least the following frequencies, durations, and levels, preferably in the following sequence:

Frequency (Hz)	Duration (sec.)	Level (dB)	Function
1,000	5	- 0	Cue (Recorded on Cue Track)
1,000	20	0	Reference Fluxivity
1,000	10	-10	Response reference level
12,500	30	-10	Azimuth & phase calib.
50	5	-10	
63	5	-10	
125	5	-10	
250	5	-10	
500	5	-10	
1,000	5	-10	
2,000	5	-10	
4,000	5	-10	
8,000	5	-10	
10,000	5	-10	
12,500	5	-10	
16,000	5	-10	
1,000	20	0	Reference fluxivity

4.3 *Standard Speed/Timing Tape*

4.3.1 *Accuracy Requirement*

The speed timing error, when used within manufacturer's specified environmental conditions, traceable to a recognized timing standard such as the National Bureau of Standards, shall be less than 0.2 percent.

4.3.2 *Minimum Load Requirement*

The speed/timing cartridge shall contain no less than 2 min. of 1 mil base film lubricated tape, at standard operating speed of 7.5 in/s (190.5 mm/s), and shall be recorded on the top 0.082 in. track.

4.3.3 *Instructions for Use*

Instructions for use shall be stated in a concise and unambiguous way, since several differing types of test tapes are available. Instrumentation requirements and practical alternates shall be described, along with possible areas of error in their use.

4.4 *Flutter Test Tape*

4.4.1 *Frequency and Level*

The Flutter Test Tape shall be recorded at 3150 Hz ± 1.0 percent at 120 nWb/m ± 2 dB and to the requirements of ANSI S4.3.[5]

4.4.2 *Peak Flutter Content*

The weighted peak flutter content, when loaded in a cartridge shall not exceed ± 0.05 percent.

4.4.3 *Minimum Load Requirement.*

The Flutter Test Cartridge shall contain no less than 3½ min. of 1 mil base film lubricated tape at a standard operating speed of 7.5 in/s.

4.5 *Swept-Frequency Test Tape*

4.5.1 *General*

Two sweep modes are required: a rapid sweep followed by a slow sweep.

4.5.1.1 *Monophonic Test Tape*

The Monophonic Swept-Frequency Test Tape shall be recorded on the top 0.082 in. (2.08 mm) track.

4.5.1.2 *Stereophonic Test Tape*

The Stereophonic Swept-Frequency Test Tape shall be recorded in-phase ± 10° maximum. It shall be recorded either on the top and center 0.043 in. (1.09 mm) tracks or full track (cue track erased) provided fringing factor corrections are noted.

4.5.2 *Fast Sweep Test Tape*

4.5.2.1 *Voice Announcement*

No voice announcement is required.

4.5.2.2 *Cue Tones*

The tape shall be recorded without Primary cue tones and shall have 2 sec. of silence between sweeps.

4.5.2.3 *Format*

The fast sweep section shall start with 20 sec. of 1 kHz signal recorded at a −10 dB level ± 0.5 dB referenced to the 160 nWb/m Standard Reference Fluxivity. The 1 kHz Standard Reference Fluxivity shall be followed by 1 min. of the repetitive sweep frequency from 500 Hz to 16 kHz at the same level and at a 100 msec. sweep rate. The frequency shall change logarithmically in respect to time.

4.5.3 *Slow Sweep Section*

4.5.3.1 *Voice Announcements*

The frequencies shall be announced at a level low enough not to interfere with measurement accuracy.

4.5.3.2 *Cue Tones*

The Slow Frequency Sweep Calibration Tape shall include the Primary cue tone recorded one sec. before the beginning of each sweep.

4.5.3.3 *Format*

The slow sweep section shall follow the fast sweep section of the Sweep-Fre-

[5]American National Standard Institute.

quency Test Tape with three cycles of a repetitive sweep frequency recorded at a -10 dB level ± 0.5 dB referenced to the 160 nWb/m Standard Reference Fluxivity. The sweep frequency shall be 50 Hz to 16 kHz at a 25 sec. sweep rate. The frequency shall change logarithmically in respect to time.

4.6 *Cue/Logging Test Tape*

4.6.1 *Mono Test Tape*

The Mono Cue/Logging Test Tape shall be recorded on the bottom 0.082 in. (2.08 mm) cue track.

4.6.2 *Stereo Test Tape*

The Stereo Cue/Logging Test Tape shall be recorded on the bottom 0.043 in. (1.09 mm) cue track.

4.6.3 *Test Tape Format*

Using 160 nWb/m, ± 0.25 percent as 0 dB reference, the following tones shall be recorded within ± 0.5 percent of the nominal frequencies and within ± 0.5 dB of the specified levels, with a maximum total harmonic distortion of 5.0 percent. Each test tone is to be preceded by a voice announcement on the top track.

Freq.	Time	Level	Function
THRESHOLD SENSITIVITY			
1 kHz	10 sec	— 7 dB	Primary threshold
150 Hz	10 sec	— 1 dB	Secondary threshold
8 kHz	10 sec	—17 dB	Tertiary threshold
LOGGING TONE			
3.5 kHz	10 sec	—10 dB	Logging, nominal level
3.35 kHz[a]	10 ms[b]	—10 dB	
3.65 kHz[a]	10 ms	—10 dB	
STANDARD LEVEL AND DURATION			
1 kHz[a]	500 ms	0 dB	Primary minimum time
150 Hz[a]	100 ms	+ 6 dB	Secondary minimum time
8 kHz	2 ms	—10 dB	Tertiary minimum time
BANDWIDTH SELECTIVITY			
900 Hz	500 ms	— 3 dB	Primary limits
1100 Hz	500 ms	— 3 dB	
135 Hz	100 ms	+ 3 dB	Secondary limits
165 Hz	100 ms	+ 3 dB	
7200 Hz	2 ms	—13 dB	Tertiary limits
8800 Hz	2 ms	—13 dB	

[a]Repeat four times.
[b]ms = millisecond.

TABLE 2

Standard Recorded Tape Short Circuit Flux Characteristic (50 μsec)

Frequency (in Hz)	Flux Level (in dB)	Frequency (kHz)	Flux Level (in dB)
16	+.41	1	0
25	+.41	1.25	— .21
31.5	+.41	1.6	— .57
40	+.41	2	— 1.04
50	+.41	2.5	— 1.68
63	+.41	3.15	— 2.56
80	+.41	4	— 3.70
100	+.41	5	— 4.99
125	+.40	6.3	— 6.51
160	+.40	8	— 8.23
200	+.39	10	— 9.95
250	+.38	12.5	—11.74
315	+.37	16	—13.78
400	+.34	20	—15.66
500	+.30		
630	+.24		
800	+.14		

Relative flux level calculated by:

$$-10 \text{ Log} \left[1 + \left(\frac{f}{F}\right)^2\right]$$

where f is the frequency of interest and F is the transition frequency (3,183 Hz for 50 μsec.). The expression gives attenuation, with no attenuation for Zero Hz. The table is normalized for reference level at 1 kHz.

APPENDIX A

Glossary of Magnetic Cartridge Tape Recording and Reproducing Terms and Definitions

Azimuth Error, Mean (average)—The signal loss in each of two or more heads due to gap misalignment when adjusted for phase coincidence.

Cue Tones—Recorded audio frequencies of specified duration arranged in a physical fashion on the recorded tape so as to provide a signaling system available for positioning the tape at the start of message and/or such auxiliary functions as may be necessary and desirable.

Cue Track—That portion of the tape upon which the cue tones are recorded.

Flux (recorded)—A measure of the amplitude of the signal recorded on the magnetic tape.

Fluxivity—The name of short-circuit flux per unit track width. The usual multiple of the unit is nanoWebers per meter (nWb/m).

Gap Scatter—An expression for the horizontal displacement of two or more head gaps.

Logging Input—An external recording input connection to the cue track for the purpose of recording logging information.

Logging Output—An output connection from the cue channel for the purpose of reproducing logging information.

Logging Signal (tone)—Tones within an assigned frequency band used for the recording of logging information.

Motor Transition Time—The time in seconds for the tape drive motor to change from high to standard operating speed.

Primary Cue System—The tone and sensor used to cue the tape to the beginning of the recorded program.

5

NAB Operating and Maintenance Log Recommendations

NAB OPERATING AND MAINTENANCE LOG RECOMMENDATIONS

The Rules and Regulations of the Federal Communications Commission require that operating and maintenance logs be maintained by all broadcasting stations. These requirements are set forth in Part 73 of the FCC Rules and Regulations and in some instances in the instrument of authorization: i.e., license, construction permit, temporary authorization, etc. The following article consolidates the FCC Rules and Regulations pertaining to AM, FM, and TV broadcast station maintenance and operating logs, and, in addition, presents an up-to-date version of the NAB Sample Logs.

Unless otherwise specified, all section numbers in this chapter refer to FCC Rules and Regulations.

GENERAL RULES PERTAINING TO LOGS

73.111 General Requirements Relating to Logs

(a) The licensee or permittee of each standard broadcast station shall maintain program, operating, and maintenance logs as set forth in 73.112, 73.113, and 73.114. Each log shall be kept by the station employee or employees (or contract operator) who is competent to do so and who has actual knowledge of the facts required. In the case of program and operating logs this person shall sign the appropriate log when starting duty, and again when going off duty.

(b) The logs shall be kept in an orderly and legible manner, in a suitable form, and in such detail that the required data for the particular class of station concerned is readily available. Key letters or abbreviations may be used if proper meaning or explanation is contained elsewhere in the log. Each sheet shall be numbered and dated. Time entries shall be made in local time. For the period from the last Sunday in April until the last Sunday in October of each year, the program and operating log entries showing times of sign-on, sign-off, and change of the station's mode of operation shall specifically indicate advanced or nonadvanced time.

(c) No log or preprinted log or schedule which becomes a log, or portion thereof, shall be erased, obliterated, or willfully destroyed within the period of retention provided by the provisions of Part 73. Any necessary correction shall be made only pursuant to 73.112, 73.113, and 73.114, and only by striking out the erroneous portion, or by making a corrective explanation on the log or attachment to it as provided in these sections.

(d) Entries shall be made in the logs as required by 73.112, 73.113, and 73.114. Additional information such as that needed for billing purposes or for the cueing of automatic equipment may be entered on the logs. Such additional information, so entered, shall not be subject to the restrictions and limitations of the Commission's rules on the making of corrections and changes in logs.

(e) The operating log and the maintenance log may be kept individually or on the same sheet in one common log at the option of the permittee or licensee.

73.115 Retention of Logs

Logs of standard broadcast stations shall be retained by the licensee or permittee for a period of 2 years; however, logs involving communications incident to a disaster or which include communications incident to or involved in an investigation by the Commission and of which the licensee or permittee has been notified, shall be retained by the licensee or permittee until he is specifically authorized in writing by the Commission to destroy them. Furthermore, those logs incident to or involved in any claim or complaint of which the licensee or permittee has notice shall be retained by the licensee or permittee until such claim or complaint has been fully satisfied, or until the same has been barred by statute of limitations for the filing of suits on such claims.

73.116 Availability of Logs and Records

The following shall be made available upon request by an authorized representative of the Commission:

1. Program, operating, and maintenance logs;
2. Equipment performance measurements required by 73.47;
3. A copy of most recent antenna resistance or common-point impedance measurements submitted to the Commission; and
4. A copy of most recent field intensity measurements to establish performance of directional antennas required by 73.151.

AM BROADCASTING

73.113 Operating Log

(a) Entries shall be made in the operating log either manually by a properly licensed operator in actual charge of the transmitting apparatus, or by automatic devices meeting the requirements of paragraph (b) of this section. Indications of operating parameters shall be logged prior to any adjustment of the equipment. Where adjustments are made to restore parameters to their proper operating values, the corrected indications shall be logged, accompanied, if any parameter deviation was beyond a prescribed tolerance, by a notation describing the nature of the corrective action. Indications of all parameters whose values are affected by modulation of the carrier shall be read without modulation. The actual time of observation shall be included in each log entry. The operating log shall include the following information:

1. For all stations

(i) Entries of the time the station begins to supply power to the antenna and the time it ceases to do so;

(ii) Entries required by S.17.49(a), (b), and (c) of this chapter concerning daily observations of tower lights;

(iii) Any entries not specifically required in this section, but required by the instrument of authorization or elsewhere in this part. See, particularly, the additional entries required by S.73.51 (e)(2), when power is being determined by the indirect method;

(iv) The following indications shall be entered in the operating log at the time of commencement of operation and, thereafter, at successive intervals not exceeding three hours in duration.

(a) Total plate voltage and total plate current of the last radio stage and

(b) Antenna current or remote antenna current (for nondirectional operation), common-point current or remote common-point current (for directional operation).

2. For stations with directional antennas not operated by remote control the following indications, in addition to those specified in (1) above, shall be read and entered in the operating log at the time of commencement of operation and, thereafter, at successive intervals not exceeding three hours in duration. (This schedule shall apply regardless of any provision in the station instrument of authorization requiring more frequent log entries.)

(i) Phase indications.

(ii) Remote antenna base current or antenna monitor sample current or current radio indications.

3. For stations with directional antennas operated by remote control, the following indications in addition to those specified in subparagraph (1) of this paragraph shall be read and entered in the operating log at the time of commencement of operation and, thereafter, at successive intervals not exceeding 3 hours in duration. (This schedule shall apply regardless of any provision in the station instrument of authorization requiring more frequent log entries.)

(i) Either remote indications of base currents, or currents extracted from antenna monitor sampling lines, or current indications or their ratios provided by a type-approved antenna monitor.

(ii) Phase indications, if provided by a type-approved antenna monitor.

(b) Automatic devices accurately calibrated and with appropriate time, date, and circuit functions may be utilized to record the entries in the operating log provided that:

1. They do not affect the operation of circuits of accuracy of indicating instruments of the equipment being recorded;
2. The recording devices have an accuracy equivalent to the accuracy of the indicating instruments;
3. The calibration is checked against the original indicators at least once a week and the results noted in the maintenance log;
4. Provision is made to actuate automatically an aural alarm circuit located near the operator on duty if any of the automatic log readings are not within the tolerances or other requirements specified in the rules or instrument of authorization;
5. Unless the alarm circuit operates continuously, devices which record each parameter in sequence must read each parameter at least once during each 10-minute period and clearly indicate the parameter being recorded;
6. The automatic logging equipment is located at the remote control point if the transmitter is remotely controlled, or at the transmitter location if the transmitter is manually controlled;

7. The automatic logging equipment is located in the near vicinity of the operator on duty and is inspected by him periodically during the broadcast day; and

8. The indicating equipment conforms with the requirements of S.73.39 except that the scales need not exceed 2 in. in length and arbitrary scales may not be used.

(c) In preparing the operating log, original data may be recorded in rough form and later transcribed into the log, but in such a case all portions of the original memoranda shall be preserved as a part of the complete log.

(d) Operating logs shall be changed or corrected only in the manner prescribed in S.73.111 (c) and only in accordance with the following:

1. *Manually kept log.* Any necessary corrections in a manually kept operating log shall be made only by the person making the original entry who shall make and initial each correction prior to signing the log when going off duty in accordance with S.73.111(a). If corrections or additions are made on the log after it has been so signed, explanation must be made on the log or on an attachment to it, dated and signed by either the operator who kept the log, the station technical supervisor or an officer of the licensee.

2. *Automatic logging.* No automatically kept operating log shall be altered in any way after entries have been recorded. Any errors or omissions found in an automatically kept operating log shall be noted and explained in a memorandum signed by the operator on duty (who, under the provisions of paragraph (b)(7) of this section, is required to inspect the equipment periodically. Such memorandum shall be affixed to the original log in question.

(e) If required by 73.93(h)(4)(iv) each completed operating log shall bear a signed and dated notation by the station's chief operator of the results of the review of that log.

73.114 Maintenance Log

(a) All entries in the maintenance log specified hereunder shall be made by the holder of a first class radiotelephone license, and shall reflect the results of maintenance procedures or of observations performed by him.

1. An entry each week of the following shall be made where applicable.

(i) A notation indicating the readings of the tower base current ammeter(s) and the associated remote antenna ammeter(s) actual readings observed prior to remote antenna ammeter recalibration and indicating calibration of the remote ammeter(s) against the tower base ammeter(s).

(ii) Time and result of any auxiliary transmitter test.

(iii) A notation of the results of all frequency measurements including date performed and description of method used.

(iv) A notation of the calibration check of automatic recording devices as required by S.73.113(b)(3).

(v) A notation of the calibration check of the antenna monitor.

(vi) A notation of the calibration check of indicating instruments at each remote control point against the instruments at the transmitter.

2. An entry shall be made of the date and time of removal from and restoration of services of any of the following equipment in the event it becomes defective:

(i) Modulation monitor.

(ii) Final stage plate voltmeter.

(iii) Final stage plate ammeter.

(iv) Base current ammeter(s).

(v) Common point ammeter.

(vi) Antenna monitor.

3. The entries that are required by S.17.49(d) of this chapter concerning quarterly inspections of the condition of tower lights and associated control equipment and an entry when towers are cleaned or repaired as required by S.17.50 of this chapter shall be made.

4. Entries made so as to describe fully any experimental operation pursuant to S.73.10.

5. Any other entries that are required by the current instrument of authorization of the station and the provisions of this subpart shall be made.

6. If required by the station authorization or S.73.93(e)(5), the results of field strength measurements at the monitoring points specified in the station authorization shall be noted.

7. If a remote antenna ammeter normally employed to provide indications of antenna or common-point current for entry in the operating log (see S.73.113) becomes defective entries once each day, for each mode of operation of such antenna or common-point current, until such time as the defective remote antenna ammeter is repaired or replaced.

8. For stations with directional antennas, in addition to those entries of operating parameters required in the operating log (see S.73.113) specific entries shall be made in the maintenance log based on observations made without modulation, if instrument readings are affected by modulation. The date and time of each observation shall be shown. The schedule for making such observations and entries is set forth in subparagraph (9) of this section. The entries are as follows:

(i) Common-point current.

(ii) Base currents, their ratios, and the deviation of those ratios, in percentages, from the licensed values.

(iii) Remote base current or sample current indications, the computed or indicated ratios of those currents, and the deviation of such ratios, in percent, from values specified in the license.

(iv) Phase indications.

9. The entries in subparagraph (8) shall be made pursuant to the following schedule:

(i) For stations not operating by remote control, entries shall be made once each day, five days of each week, for each directional radiation pattern, regardless of any provision in the station authorization for more frequent entries *provided that* a first-class radiotelephone operator is on duty at the transmitter for all periods of operation with a directional radiation pattern, and the station authorization permits antenna base current readings at less frequent intervals than specified in this subparagraph, entries may be made pursuant to the schedule specified in that authorization.

(ii) For stations operation by remote control, where phase indications are not observed and entered in the operating log at the remote control point, the entries specified in subparagraph (8) shall be based on observations made at the transmitter not more than 2 hours after the time of commencement of operation with each directional radiation pattern, *provided that* any separate period of operation with a specific pattern does not exceed one hour in duration. Observations and entries for such period need not be made. If a station utilizes a single directional radiation pattern during all hours of operation, observations and entries shall be made once each day, with no fewer than 12 hours elapsing between successive observations.

(iii) For stations operated by remote control, where phase indications, provided by a type approved antenna monitor, are observed and entered in the operating log at the remote control point, the entries specified in subparagraph (8) shall be based on observations made at the transmitter every second day for each directional radiation pattern, with no longer than 54 hours elapsing between successive observations for the same pattern. (This schedule shall apply, regardless of any provision, in the station authorization requiring more frequent observations.)

(b) Upon completion of the inspection required by S.73.93(e), the inspecting operator shall enter a signed statement that the required inspection has been made, noting in detail the tests, adjustments and repairs which were accomplished in order to insure operation in accordance with the provisions of this subpart and the current instrument of authorization of the station. The statement shall also specify the amount of time, exclusive of travel to and from the transmitter, which was devoted to such inspection duties. If complete repair could not be effected, the statement shall set forth in detail the items of equipment concerned, the manner and degree in which they are defective, and the reason for failure to make satisfactory repairs.

(c) The inspecting operator shall sign and date the maintenance log at the conclusion of each inspection. In preparing the maintenance log, original data may be recorded in rough form and later transcribed into the log, but in such cases all portions of the original memorandum shall be preserved as a part of the complete log.

(d) Any necessary corrections in the maintenance log shall be made by the inspecting operator who shall initial and date all changes prior to signing the log. If corrections or additions are made on the log after it has been so signed, explanation must be made the subject of a separate memorandum, dated and signed by the operator who made the entry in question, or the station's technical supervisor or by any officer of the licensee. Such memorandum shall explain fully the circumstances surrounding the errors or ambiguities, and shall be affixed to the original log in question. If written and signed by other than the inspecting operator who made the entry, the memorandum shall contain a satisfactory explanation of why such signature is lacking.

FM BROADCASTING

73.283 Operating Log

(a) The following entries shall be made in the operating log only by a properly licensed operator in actual charge of the transmitting apparatus:

1. An entry of the time the station begins to supply power to the antenna and the time it stops.

2. An entry shall be made at the beginning of operation and at intervals not exceeding three hours of the following (actual readings observed prior to making any adjustments to the equipment, and, when appropriate, an indication of corrections to restore parameters to normal operating values):

(i) Operating constants of last radio stage (total plate voltage and plate current);

(ii) RF transmission line meter reading, except when power is being determined by indirect method;

3. Any other entries required by the instrument of authorization or the provisions of this part;

4. The entries required by S.17.49(a), (b), and (c) of this chapter concerning daily observations of tower lights.

(b) Automatic devices accurately calibrated and with appropriate time, date, and circuit functions may be utilized to record the entries in the operating log provided that:

1. They do not affect the operation of circuits or accuracy of indicating instruments of the equipment being recorded;

2. The recording devices have an accuracy equivalent to the accuracy of the indicating instruments;

3. The calibration is checked against the original indicators at least once a week and the results noted in the maintenance log;

4. Provision is made to actuate automatically an aural alarm circuit located near the operator on duty if any of the automatic log readings are not within the tolerances or other requirements specified in the rules or instrument of authorization;

5. Unless the alarm circuit operates continuously, devices which record each parameter in sequence must read each parameter at least once during each 10-minute period and clearly indicate the parameter being recorded;

6. The automatic logging equipment is located at the remote control point if the transmitter is remotely controlled or at the transmitter location if the transmitter is manually controlled;

7. The automatic logging equipment is located in the near vicinity of the operator on duty and inspected by him periodically during the broadcast day; and

8. The indicating equipment conforms to the requirements of S.73.320 except that the scales need not exceed 2 in. in length. Arbitrary scales may not be used.

(c) In preparing the operating log, original data may be recorded in rough form and later transcribed into the log, but in such a case all portions of the original memoranda shall be preserved as a part of the complete log.

(d) Operating logs shall be changed or corrected only in the manner prescribed in S.73.281 (c) and only in accordance with the following:

1. *Manually kept log.* Any necessary corrections in a manually kept operating log shall be made only by the person making the original entry. He shall make and initial each correction prior to signing the log when going off duty in accordance with S.73.281(a). If corrections or additions are made on the log after it has been so signed, an explanation must be made on the log or on an attachment to it, dated and signed by either the operator who kept the log, the station technical supervisor, or an officer of the licensee.

2. *Automatic logging.* No automatically kept operating log shall be altered in any way after entries have been recorded. Any errors or omissions found in an automatically kept operating log shall be noted and explained in a memorandum signed by operator on duty (who, under the provisions of paragraph (b)(7) of this section, is required to inspect the automatic equipment) or by the station technical supervisor or an officer of the licensee. Such memorandum shall be affixed to the original log in question.

(e) As required by 73.265(d)(5)(iv), each completed operating log shall bear a signed and dated notation by the station's chief operator of the results of the review of that log.

S.73.284 Maintenance Log

(a) The following entries shall be made in the maintenance log:

1. Time and result of any auxiliary transmitter tests;

2. A notation of the results of all frequency measurements, including date performed and description of method used;

3. A notation each week of the calibration check of automatic recording devices as required by S.73.283(b)(3);

4. An entry of the date and time of removal from and restoration to service of any of the following equipment in the event it becomes defective:

(i) Modulation monitor,

(ii) Final stage plate voltmeter,

(iii) Final stage plate ammeter, and

(iv) Transmission line radio frequency voltage, current, or power meter.

5. The entries that are required by S.17.49(d) of this chapter concerning quarterly inspections of the conditions of tower lights and associated control equipment, and an entry when towers are cleaned or repainted as required by S.17.50 of this chapter.

6. Entries shall be made so as to describe fully any experimental operation pursuant to S.73.262;

7. Any other entries that are required by the current instrument of authorization of the station and the provisions of this subpart.

(b) Upon completion of the inspection required by S.73.265(e), the inspecting operator shall enter a signed statement that the required inspection has been made, noting in detail the tests, adjustments, and repairs that were made in order to insure operation in accordance with the provisions of this subpart and the current instrument of authorization of the station. The statement shall also specify the amount of time, exclusive of travel time to and from the transmitter, which was devoted to such inspection duties. If complete repair could not be effected, the statement shall set forth in detail the items of equipment concerned, the manner and degree in which they are defective, and the reasons for failure to make satisfactory repairs.

(c) The inspecting operator shall sign and date the maintenance log at the conclusion of each inspection. In preparing the maintenance log, original data may be recorded in rough form and later transcribed into the log, but in such cases all portions of the memorandum shall be preserved as a part of the complete log.

(d) Any necessary corrections in the maintenance log shall be made only by the inspecting operator who shall initial and date all changes prior to signing the log. If corrections or additions are made on the log after the log has been so signed, an explanation must be made the subject of a separate memorandum, dated, and signed by the operator who made the entry in question or the station technical supervisor or by an officer of the licensee. Such memorandum should explain fully the circumstances surrounding the errors or ambiguities, and shall be affixed to the original log in question. If written and signed by other than the inspecting operator who made the entry, the memorandum shall contain a satisfactory explanation of why such signature is lacking.

TELEVISION BROADCASTING

S.73.671 Operating Log

(a) The following entries shall be made in the operating log only by a properly licensed operator in actual charge of the transmitting apparatus:

1. An entry of the time the station begins to supply power to the antenna and the time it stops.
2. Reserved.
3. An entry shall be made at the beginning of operation and at intervals not exceeding three hours of the following (actual readings observed prior to making any adjustments to the equipment, and, when appropriate, an indication of corrections to restore parameters to normal operation values):

(i) Operating constants of last radio stage of aural transmitter (total plate voltage and plate current);

(ii) Transmission line meter readings for both transmitters. If power of the aural transmitter is being determined by the indirect method, enter the transmission line meter reading for the visual transmitter only.

For remote control operation, the results of observations of vertical test signal transmissions (see S.73.676(f) shall be noted.

4. Any other entries that are required by the instrument of authorization or provisions of this part.
5. The entries that are required by S.17.49 (a)(b)(c) of this chapter concerning daily observations of tower lights.

(b) Automatic devices accurately calibrated and with appropriate time, date, and circuit functions may be utilized to record the entries in the operating log provided that:

1. They do not affect the operation of circuits or accuracy of indicating instruments of the equipment being recorded;
2. The recording devices have an accuracy equivalent to the accuracy of the indicating instruments;
3. The calibration is checked against the original indicators at least once a week and the results noted in the maintenance log;
4. Provision is made to actuate automatically an aural alarm circuit located near the operator on duty if any of the automatic log readings are not within the tolerances or other requirements specified in the rules or instrument of authorization;
5. Devices which record each parameter in sequence must read each parameter at least once during each 10-minute period and clearly indicate the parameter being recorded, unless the alarm circuit operates continuously;
6. The automatic logging equipment is located in the near vicinity of the operator on duty and is inspected by him periodically during the broadcast day; and
7. The indicating equipment conforms to the requirements of S.73.688 except that the scales need not exceed 2 in. in length. Arbitrary scales may not be used.

(c) In preparing the operating log, original data may be recorded in rough form and later transcribed into the log, but in such a case all portions of the original memoranda shall be preserved as a part of the complete log.

(d) Operating logs shall be changed or corrected only in the manner prescribed in S.73.669 and only in accordance with the following:

1. *Manually kept log.* Any necessary corrections in a manually kept operating log shall be made only by the person making the original entry. He shall make and initial each correction prior to signing the log when going off duty in accordance with S.73.669(a). If corrections or additions are made in the operating log after it has been so signed, explanation must be made on the log or on an attachment to it, dated, and signed by either the person who kept the log or the station technical supervisor or an officer of the licensee.
2. *Automatic logging.* No automatically kept operating log shall be altered in any way after entries have been recorded. Any errors or omissions found in an automatically kept operating log shall be noted and explained in a memorandum signed by the operator on duty (who, under the provisions of paragraph (b)(7) of this section, is required to inspect the automatic equipment or, by the station technical supervisor or an officer of the licensee. Such memorandum shall be affixed to the original log in question.

S.73.672 Maintenance Log

(a) The following entries shall be made in the maintenance log:

1. Time and result of any auxiliary transmitters tests.

2. A notation each week of the calibration check of automatic recording devices as required by S.73.671(b)(3).

3. An entry whenever frequency measurements are made, including the date performed and description of method used.

4. An entry of the date and time of removal from and restoration of service of any of the following equipment in the event it becomes defective:

(i) Visual modulation monitoring equipment or aural modulation monitor;

(ii) Final stage plate voltmeters of aural and visual transmitters;

(iii) Final stage plate ammeters of aural and visual transmitters;

(iv) Visual and aural transmitter transmission line radio frequency voltage, current, or power meter.

5. The entries that are required by S.17.49(d) of this chapter concerning quarterly inspections of the condition of tower lights and associated control equipment and an entry when towers are cleaned or repainted that are required by S.17.50 of this chapter.

6. Entries shall be made so as to describe fully any operation for testing and maintenance purposes.

7. Whenever the calibration of the output power meter is made as required by S.73.689(b)(1) and (2) with a brief description of the method and results.

8. Any other entries required by the instrument of authorization or in the provisions of this part.

(b) The inspecting operation shall sign and date the maintenance log at the conclusion of each inspection. In preparing the maintenance log, original data may be recorded in rough form and later transcribed into the log, but in such cases all portions of the original memorandum shall be preserved as a part of the complete log.

(c) Any necessary corrections in the maintenance log shall be made only by the inspecting operator who shall initial and date all changes prior to signing the log. If corrections or additions are made on the maintenance log after the log has been so signed, explanation must be made the subject of a separate memorandum, dated, and signed by the operator who made the entry in question or the station technical supervisor or by an officer of the licensee. Such memorandum shall explain fully the circumstances surrounding the errors or ambiguities, and shall be affixed to the original log in question. If written and signed by other than the inspecting operator who made the entry the memorandum shall contain a satisfactory explanation of why such signature is lacking.

SAMPLE AM MAINTENANCE LOG

I. General

Fig. 1 is a sample maintenance log which fulfills the Commission's overall maintenance logging requirements. This form was developed as an example of how the logging requirements may be fulfilled. There are, undoubtedly, numerous other ways that the maintenance log could be prepared and still comply with the rules. The Commission does not prescribe, authorize, or approve the form in which logs must be kept. It is the responsibility of each licensee to develop a form which will comply with all the logging requirements for a particular type of facility as set forth in the Rules. *All entries must be made by the holder of a valid first-class radiotelephone license.*

Although the attached sample log contains all the entries necessary for compliance with the Commission's maintenance log requirement, it does not provide for additional information which may be required by the Station's instrument of authorization. Such requirements should, of course, be added to those specified. Although this sample log was prepared for a remotely controlled directional AM station, it may be easily modified by following the directions indicated below.

II. Log Composition

A. The first section of the sample log pertains to the equipment inspection statement. A transmitting system and monitoring equipment inspection must be made for all AM stations at least once each calendar week at intervals of at least five days apart upon completion of which a statement must be inserted in this section attesting to the fact that the inspection has been made, noting in detail any tests, adjustments, repairs and any other maintenance work which was performed to assure compliance with the rules. If complete repairs were not effected, the statement must set forth in detail the items of equipment concerned, the manner and degree in which they are defective, and the reasons for failing to make satisfactory repairs. The log entry should include the time of arrival at the transmitter and the time the inspection was concluded.

1. *Directional (not remote-controlled).* At least once each day, five days per week, entries must be made of the following observations: (a) common-point current; (b) base currents, their ratios, and the deviation of such ratios, in percent, from values specified in the license; (c) remote base current or sample current indications, the computed or indicated ratios of those currents, and the deviation of such ratios, in percentages, from values specified in the license; and (d) phase

SAMPLE AM MAINTENANCE LOG

EQUIPMENT INSPECTION

Date:	Time On:	Time Off:
Maintenance Performed (Note repairs and meter readings.):		
		Signature:

EQUIPMENT STATUS

Defective Equipment	Removed from Service		Restored to Service		Signature
	Date	Time	Date	Time	
Antenna Monitor					
Modulation Monitor					
Final Plate Ammeter					
Final Plate Voltmeter					
Base Current Ammeter					
Common Point Ammeter					

WEEKLY CALIBRATION ADJUSTMENTS

Date	Time	Meter Function	Main Meter Before Cal.	Remote Meter Before Cal.	Calibrated	Signature
		Ant. Mon.				
		Auto. Log				
		R/C Meters				
		Tower #1				
		Tower #2				
		Other ( )				

MONTHLY FREQUENCY MEASUREMENT

Date	Time	Measurement Procedure and Result	Signature

MONITORING-POINT MEASUREMENTS

Date	Time	Field Intensity	Remarks	Signature

EXPERIMENTAL OPERATION

Date	Time	Description and Results	
			Signature:

QUARTERLY TOWER-LIGHT AND LIGHTING-CONTROL INSPECTION

Date	Time	Description and Results	Signature

Fig. 1. Sample AM Maintenance Log.

indications (except when the station license specifies less frequent readings).

2. *Directional Stations (remote-controlled).* Those stations which do not employ an FCC-Type Approved Remote Antenna Monitor must, within 2-hours after the activation of each directional pattern, enter the observations as noted in (1) above (if operation is less than one-hour no entries are required). Stations utilizing FCC-Type Approved Remote Antenna Monitors must enter every second day, for each directional pattern, with no more than 54 hours elapsing between successive readings for each pattern, the meter observations as noted in (1) above.

B. The second section deals with inoperative monitoring equipment and meters and is self-explanatory.

C. The third section pertains to the weekly remote meter calibration requirements. It should be noted that in reading the remote and main meters, the log entries should be made prior to recalibration. Make the changes noted below for the different types of operation:

1. *Nondirectional (not remote-controlled).* Delete entries in sample log dealing with remote control (R/C) meter calibration, antenna monitor, Towers #1 and 2; and insert in lieu thereof ANTENNA CURRENT.

2. *Nondirectional (remote-controlled).* Follow above but retain entries dealing with calibration of remote control (R/C) meters.

3. *Directional (not remote-controlled).* Delete entries dealing with calibration of remote control (R/C) metering system.

4. *Directional (remote-controlled).* Follow sample log.

Stations using automatic logging equipment to record the operating parameters of the transmitter and antenna system should insert calibration entries in this section.

D. The fourth section pertains to the external frequency measurement of the main and auxiliary transmitters. Effective November 21, 1973, the frequency monitor requirement has been deleted, and the frequency of the above transmitter must be measured at least once every 40 days. Entries pertaining to these measurements should be recorded in this section.

E. The fifth section (directional stations only) deals with field intensity entries. Directional stations operating with third-class license holders with broadcast endorsement are required to make field intensity measurements at the designated monitoring points at least once each 30 days and the results entered in the maintenance log. Any other field intensity measurements as required by the instrument of authorization should be recorded in this section. Nondirectional stations should delete this section.

F. The sixth section deals with entries during the experimental period, i.e., testing the main and auxiliary transmitter, routine maintenance and repairs, including all other entries which are required during the nonprogramming portion of the day or by the instrument of authorization.

G. The final section of the sample log deals with entries made of the quarterly tower-light and lighting control inspection.

SAMPLE FM MAINTENANCE LOG

I. Log Composition

All entries in the FM maintenance log (Fig. 2) must be made by the holder of a valid first-class radiotelephone license.

A. The first section of the sample log pertains to the equipment inspection statement. An inspection must be made of the transmitter and monitoring equipment at least once during each calendar week, the interval between successive inspections must be at least five days. Upon completion of the inspection, a statement must be inserted in this section attesting to the fact that the inspection has been made and noting in detail any repairs and maintenance work which was performed to assure compliance with the rules. If complete repairs were not effected, the statement must set forth in detail items and equipment concerned and the manner and degree in which they are defective, and the reasons for failure to make satisfactory repairs. The log entry should include the time the first-class license holder arrived at the transmitter and the time the inspection was concluded.

B. The second section deals with inoperative monitoring equipment and meters and is self-explanatory.

C. The third section pertains to remote meter calibration. It should be noted that in reading the remote meters, the long entries should be made prior to calibration. Calibration compliance should be noted in this section. Those stations employing remote control (R/C) should list individual meters in lieu of the single entry. Automatic logger calibration should also be entered here.

D. The fourth section pertains to the external frequency measurement of the main and auxiliary transmitters. Effective November 21, 1973, all frequency monitor requirements for the FM service have been deleted and all licensees must make an external frequency measurement of the main, auxiliary, SCA, and pilot subcarriers at least once each 40 days.

E. The fifth section deals with entries required during the experimental period, i.e., testing the main and auxiliary transmitters, routine maintenance and repairs, including all other entries

SAMPLE FM MAINTENANCE LOG

DAILY EQUIPMENT INSPECTION

Date:	Time On:	Time Off:
Maintenance Performed (Note any repairs pending.):		
		Signature:

EQUIPMENT STATUS

Defective Equipment	Removed from Service		Restored to Service		Signature
	Date	Time	Date	Time	
Modulation Monitor					
Final Plate Voltmeter					
Final Plate Ammeter					
Transmission Line Meter					

WEEKLY CALIBRATION ADJUSTMENTS

Date	Time	Meter Function	Main Meter Before Cal.	Remote Meter Before Cal.	Calibrated	Signature
		R/C Meters				
		Auto. Log				
		Other ( )				

FREQUENCY MEASUREMENT

Date	Time	Measurement Procedure and Result	Signature

EXPERIMENTAL OPERATION

Date	Time	Description and Results
		Signature:

QUARTERLY TOWER-LIGHT AND LIGHTING-CONTROL INSPECTION

Date	Time	Description and Results	Signature

Fig. 2. Sample FM Maintenance Log.

SAMPLE TV MAINTENANCE LOG

EQUIPMENT INSPECTION

Date:	Time On:	Time Off:
Maintenance Performed (Note any repairs pending.):		
		Signature:

INOPERATIVE EQUIPMENT

Item	Removed from Service		Restored to Service		Signature
	Date	Time	Date	Time	
Visual Modulation Monitor					
Aural Modulation Monitor					
Final Aural Plate Voltmeter					
Final Aural Plate Ammeter					
Final Visual Plate Voltmeter					
Final Visual Plate Ammeter					
Visual Transmission Line Meter					
Aural Transmission Line Meter					

WEEKLY CALIBRATION ADJUSTMENTS

Date	Time	Meter Function	Main Meter Before Cal.	Remote Meter Before Cal.	Main Meter After Cal.	Remote Meter After Cal.	Signature

FREQUENCY MEASUREMENT

Date	Time	Measurement Procedure and Result	Signature

EXPERIMENTAL OPERATION

Date	Time	Description and Results
		Signature:

QUARTERLY TOWER-LIGHT AND LIGHTING-CONTROL INSPECTION

Date	Time	Description and Results	Signature

Fig. 3. Sample TV Maintenance Log.

which are required during the nonprogramming portion of the day or the instrument of authorization.

F. The sixth and final section of the sample log deals with entries made of the quarterly tower-light and lighting control inspection.

SAMPLE TV MAINTENANCE LOG

I. Log Composition

All entries in the TV maintenance log (Fig. 3) must be made by the holder of a valid first-class radiotelephone license holder.

A. The first section deals with inspection of transmitting facilities for remotely controlled television stations. The remote control and monitoring equipment must be calibrated and tested and the television broadcast transmitter inspected as often as is necessary to insure compliance with the rules at least once each seven days. Upon completion of the calibration, testing and inspection requirement enter a signed statement log that the required tests and inspection have been made, noting in detail the tests, adjustments and repairs which were made to insure proper operation. Specify the amount of time, exclusive of travel time to and from the transmitter which was devoted to this task. If complete repair could not be effected, the statement shall set forth in detail the items of equipment concerned, the nature of the defect, and the reasons for failure to make the needed repairs.

B. The second section deals with defective monitoring equipment and is self-explanatory.

C. The third section deals with the calibration of meters and the remote control system as outlined above.

D. The fourth section pertains to the external frequency measurement of the main and auxiliary transmitters. Effective November 21, 1973, the frequency monitor requirement has been deleted, and all licensees must make an external frequency measurement at least once every 30 days. Entries pertaining to this should be recorded in this section.

E. The fifth section deals with operation during nonprogramming or the experimental period. Entries such as testing the main and auxiliary transmitters, routine maintenance and repairs, including all other entries which may be required during the nonprogramming portion of the day or the instrument of authorization should be made in this section.

F. The sixth and final section of the sample log deals with entries made of the quarterly tower light and lighting control inspection.

EXPLANATIONS AND ILLUSTRATIONS OF SAMPLE OPERATING LOGS

Important Points of Consideration in Designing an Operating Log Format

1. The log should be properly identified as to station location, frequency and power.

2. Put the date and day in a convenient place in the event reference must be made to a specific day.

3. If abbreviations of any nature are used, be certain that each abbreviation is fully explained on each log and is a permanent part of the log. This is generally done at the bottom of each page when the logs are printed.

4. When directional antennas are used, identify each tower in a manner consistent with the instrument of authorization.

5. Keep the log neat, precise, simple, and free of extraneous remarks.

6. Provide sufficient room for a "Remarks" column, which may be used for the following:

(a) Operator's signature (not initials) when going on and off duty.

(b) Notation "Carrier On" and "Carrier Off" with appropriate time.

(c) Observation of tower lights and remarks as to steps taken if tower lights fail.

(d) Any unusual occurrences affecting transmissions.

(e) Notations and initialing in the case of corrections in log entries.

(f) Time of power change or change in radiating system if required.

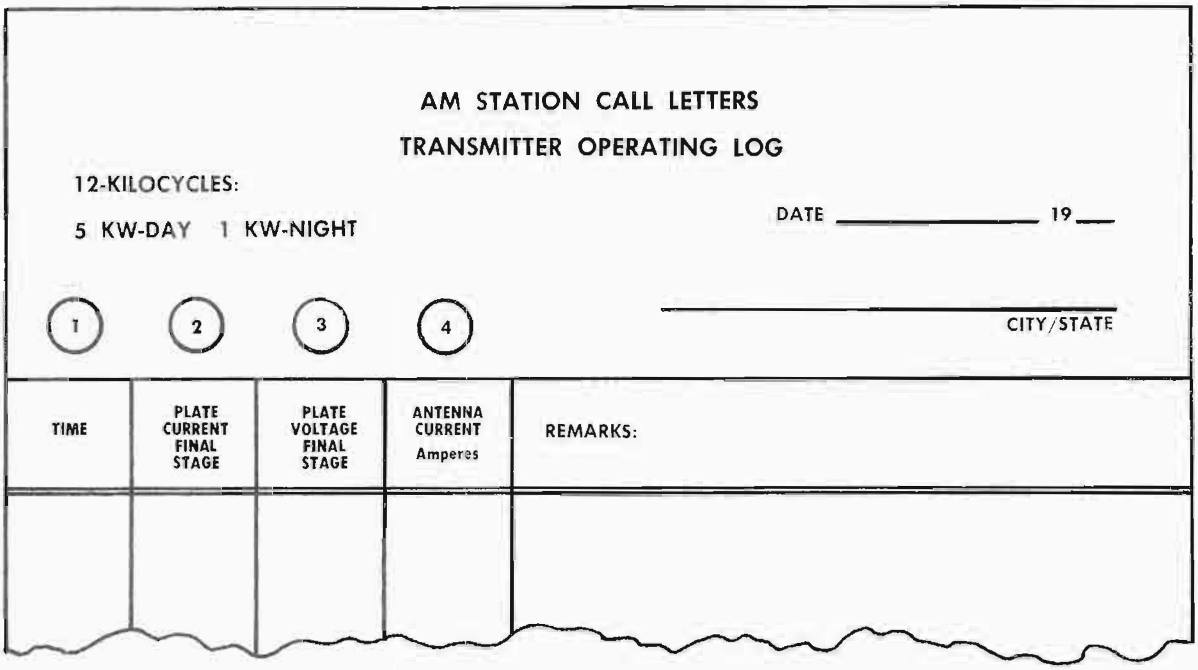
(g) Entries pertaining to Emergency Broadcasting System (EBS).

(h) Time and results of observation of vertical interval test signal (VITS) for remotely controlled TV transmitters.

(i) Efficiency factor when power is determined by indirect method.

(j) Any corrective action taken to restore out-of-tolerance operating parameters to their normal values.

(k) Signature, date, and time log was reviewed by Chief Operator at directional stations utilizing third class license holders.



AM STATION CALL LETTERS
TRANSMITTER OPERATING LOG

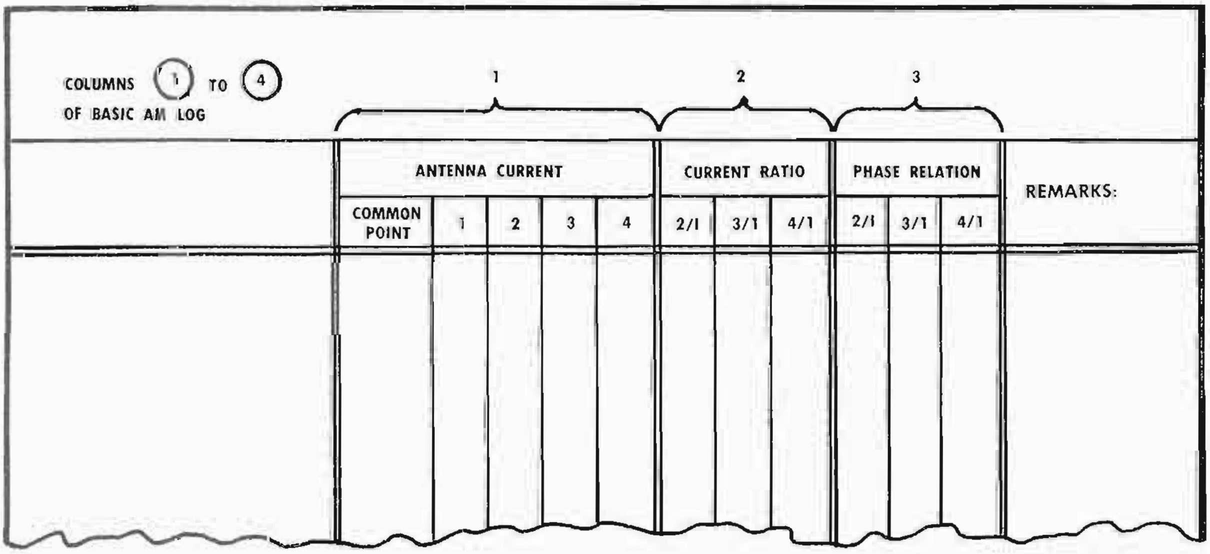
12-KILOCYCLES:
5 KW-DAY 1 KW-NIGHT

DATE ______________ 19___

____
CITY/STATE

1	2	3	4	
TIME	PLATE CURRENT FINAL STAGE	PLATE VOLTAGE FINAL STAGE	ANTENNA CURRENT Amperes	REMARKS:

Fig. 4. Basic AM Log. The columns set forth in this form cover the basic AM requirements, the form being suitable for stations having no special log requirements occasioned by the use of directional antennas.



COLUMNS 1 TO 4 OF BASIC AM LOG	1					2			3			
	ANTENNA CURRENT					CURRENT RATIO			PHASE RELATION			REMARKS:
	COMMON POINT	1	2	3	4	2/1	3/1	4/1	2/1	3/1	4/1	

Fig. 5. This figure consists of three sections to be added to the Basic AM Log if directional antennas are employed. The number of columns to be employed would be equal to the number of antennas used in the directional array.

1. *Antenna Current.* This is as may be read on remote reading meters. If this method is elected by the station, calibration checks must be made at least once weekly. Most stations, however, provide this calibration check daily.

2. *Current Ratios.* Ratios are not required to be logged. It is the usual practice to log only currents in the sampling loops (remote base currents may be logged) from which ratios may be determined when needed. However, if it appears desirable that operators compute ratios, this column may be used. The common point current must also be checked in the normal manner.

3. *Phase Relation.* This group of columns must be used if an Antenna Monitor is employed. The readings should follow those values set forth in the instrument of authorization and should show degrees of head or lag with respect to the reference tower.

TRANSMITTER OPERATING LOG

CALL LETTERS

LOCATION

DATE ______________ 19 __

FREQUENCY _____ POWER ______ TIME OF OPERATION ___________

TIME	PLATE CURRENT FINAL STAGE Amperes	PLATE VOLTAGE FINAL STAGE Kilovolts	ANTENNA CURRENTS				PHASE RELATION		REMARKS:
			CP	A_1	A_2	A_3	T_1/T_2	T_1/T_3	

ABBREVIATIONS:

CP —COMMON POINT ANTENNA CURRENT—AMPS—REMOTE

$A_1 A_2 A_3$ —ANTENNA MONITOR SAMPLING LOOP CURRENTS. A_1 CURRENT USED IN LIEU OF ANTENNA CURRENT ON NON-DA OPERATION.

T_1/T_2 —PHASE DIFFERENCE BETWEEN TOWER # 1 AND TOWER # 2.

T_1/T_3 —PHASE DIFFERENCE BETWEEN TOWER #1 AND TOWER #3.

Fig. 6. This is a sample log for a station using a three-element directional array at night and nondirectional operation daytime.

FM STATION CALL LETTERS

TRANSMITTER OPERATING LOG

CHANNEL ________

POWER ________

DATE ______________ 19 ___

____

CITY/STATE

TIME	PLATE CURRENT FINAL STAGE	PLATE VOLTAGE FINAL STAGE	TRANSMISSION LINE (*) CURRENT	REMARKS:

(*) OR VOLTAGE

Fig. 7. Basic FM Log. The Columns set forth in this sample log cover the basic FM requirements.

TV STATION CALL LETTERS

TRANSMITTER OPERATING LOG

CHANNEL ________

AUDIO FREQUENCY ________

VIDEO FREQUENCY ________

DATE ____________ 19 ___

____

CITY/STATE

TIME	(I) AUDIO TRANSMITTER				(II) VIDEO TRANSMITTER		REMARKS:
	PLATE CURRENT FINAL STAGE	PLATE VOLTAGE FINAL STAGE	REFLECTOMETER		REFLECTOMETER		
			INCI.	REFL.	INCI.	REFL.	

(I) —AUDIO: ______ MICROAMPERES INCIDENT IS EQUAL TO ______ WATTS.

(II) —VIDEO: ______ MICROAMPERES INCIDENT IS EQUAL TO ______ WATTS.

(I) AND (II) —CALIBRATED, USING DUMMY LOAD BEYOND SIDE BAND FILTER.

Fig. 8. Basic TV Log. The columns set forth in this sample log cover the basic television requirements.

6

Standard Frequency Transmissions

NATIONAL BUREAU OF STANDARDS

There are seven technical services provided by the National Bureau of Standards radio station WWV, WWVH, WWVB, and WWVL. These services are: (1) standard radio frequency; (2) standard audio frequencies; (3) standard musical pitch; (4) standard time intervals; (5) time signals; (6) UT1 corrections; and (7) official announcements.

TABLE 1

Services and coordinates of the NBS broadcast stations

Station	Date in Service	Radio Frequencies	Audio Frequencies	Musical Pitch	Time Intervals	Time Signals	UT1 Corrections	Official Announcements
WWV	1923	√	√	√	√	√	√	√
WWVH	1948	√	√	√	√	√	√	√
WWVB	1956	√			√	√	√	
WWVL	1960	√						

The coordinates of these NBS radio stations are as follows:

WWV	40° 40′ 49.0″ N	105° 02′ 27.0″ W
WWVB	40° 40′ 28.3″ N	105° 02′ 39.5″ W
WWVL	40° 40′ 51.3″ N	105° 03′ 00.0″ W
WWVH	21° 59′ 26.0″ N	159° 46′ 00.0″ W

John Stanley, Engineer-in-Charge
NBS Radio Stations WWV/WWVB/WWVL
Route 2, Box 83-E
Fort Collins, Colorado 80521
Telephone (303) 484-2372

Charles Trembath, Engineer-in-Charge
NBS Radio Station WWVH
P.O. Box 417
Kekaha, Kauai, Hawaii 96752
Telephone (808) 337-5217

1.1. STANDARD RADIO FREQUENCIES

Program

WWV and WWVH broadcast nominal frequencies and time consistent with the internationally agreed upon time scale, Universal Coordinated Time[1] (UTC). Changes in UTC effective January 1, 1972, are discussed in section 1.5(b).

WWV broadcasts on radio carrier frequencies of 2.5, 5, 10, 15, 20, and 25 MHz. WWVH broadcasts on radio carrier frequencies of 2.5, 5, 10, 15, and 20 MHz. The broadcasts on both stations are continuous, night and day.

The broadcasts of WWV may also be heard via telephone by dialing (303) 499-7111, Boulder, Colorado. The telephone user will hear the live broadcasts as transmitted from the station. Considering the instabilities and variable delays of propagation by telephone, the listener should not expect accuracy of the telephone time signals to be better than 30 milliseconds. This service is automatically limited to 3 minutes per call.

Accuracy and Stability

Since December 1, 1957, the standard radio transmissions from WWV and WWVH have been held as nearly constant as possible with respect to the atomic frequency standards maintained and operated by the National Bureau of Standards. Atomic frequency standards have been shown to realize the ideal cesium resonance frequency, f_{Cs}, to within a few parts in 10^{11}. The present NBS frequency standard and time scale system realizes this resonance frequency to an uncertainty of ± 9 parts in 10^{13} [1].

The definitions for time and frequency are based on the same physical process: "The second is the duration of 9,192,631,770 periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of the cesium-133 atom" as was decided in October 1967 by the XIIIth General Conference of

[1] As noted in a resolution of Commission 31 of the International Astronomical Union, August 1970: "The terms 'GMT' and 'Z' are accepted as the general equivalents of UTC in navigation and communication."

Weights and Measures. For frequency, the hertz is one cycle per second.

On January 1, 1960, the NBS standard was brought into agreement with this definition as quoted above by increasing its assigned value by 74.5 parts in 10^{10}. Frequencies measured in terms of the NBS standard between December 1, 1957 and January 1, 1960 need to take the above correction into account [2].

The frequencies transmitted by WWV and WWVH are held stable to better than ± 2 parts in 10^{11} at all times. Deviations at WWV are normally less than 1 part in 10^{12} from day to day. Incremental frequency adjustments not exceeding 1 part in 10^{11} are made at WWV as necessary. Frequency adjustments made at WWVH do not exceed 2 parts in 10^{11}.

Changes in the propagation medium (causing Doppler effect, diurnal shifts, etc.) result in fluctuations in the carrier frequencies as received which may be very much greater than the uncertainties quoted above.

Corrections

All carrier and modulation frequencies at WWV and WWVH are derived from cesium-controlled oscillators. These frequencies, in conformity with the UTC scale, are broadcast with no intentional offset from the nominal frequency. Previously, the fractional frequency offset for 1960 and 1961 was —150 parts in 10^{10}; in 1962 and 1963, —130 parts in 10^{10}; in 1964 and 1965, —150 parts in 10^{10}; and in 1966 through 1971, —300 parts in 10^{10}.

At the recommendation of the International Radio Consultative Committee (CCIR), the frequency offset of UTC was made permanently zero effective 0000 hours UTC January 1, 1972.

Corrections to the transmitted frequency or phase are regularly determined with respect to the NBS time standard and are published monthly (since March 1966) in the *NBS Time and Frequency Services Bulletin.*

1.2. STANDARD AUDIO FREQUENCIES

Program

The hourly broadcast format of WWV and WWVH is presented in Fig. 1. Standard audio frequencies of 440 Hz, 500 Hz, and 600 Hz are broadcast on each radio carrier frequency by the two stations. The duration of each transmitted standard tone is approximately 45 seconds. A 600-Hz tone is broadcast during odd minutes by WWV and during even minutes by WWVH. A 500-Hz tone is broadcast during alternate minutes unless voice announcements or silent periods are scheduled. The 440-Hz tone is broadcast beginning one minute after the hour at WWVH and two minutes after the hour at WWV. The 440-Hz tone period is omitted during the first hour of the UTC day.

No audio tones or special announcements are broadcast during a semi-silent period from either station. The periods are from 45 minutes to 50 minutes after the hour at WWV, and from 15 minutes to 20 minues after the hour at WWVH.

Accuracy

The audio frequencies are derived from the carrier and have the same basic accuracy as transmitted. Changes in the propagation medium sometimes result in fluctuations in the audio frequencies as received.

While the 100-Hz subcarrier (Sec. 1.7) is not considered one of the standard audio frequencies, the modified IRIG-H time code which is transmitted continuously from WWV and WWVH does contain this frequency and may be used as a standard with the same accuracy as the audio frequencies.

1.3. STANDARD MUSICAL PITCH

The frequency 440 Hz, for the note A above middle C, is the standard in the music industry in many countries and has been in the United States since 1925. The radio broadcast of this standard was commenced by the National Bureau of Standards in 1937. The 440-Hz tone is broadcast for approximately 45 seconds beginning 1 minute after the hour at WWVH and 2 minutes after the hour at WWV. The tone is omitted during the zero hour of each UTC day. In addition to its application as a musical standard, the 440-Hz tone may be used to provide an hourly marker for chart recorders or other automated devices.

1.4. STANDARD TIME INTERVALS

UTC seconds pulses at precise intervals are derived from the same frequency standard that controls the radio carrier frequencies; i.e., they commence at intervals of 5,000,000 cycles of the 5-MHz carrier. They are given by means of double-sideband amplitude-modulation on each radio carrier frequency. Each minute, except the first of the hour, begins with an 800-millisecond tone of 1000 Hz at WWV and 1200 Hz at WWVH. The first minute of every hour begins with an 800-millisecond tone of 1500 Hz at both stations.

The 1-second markers are transmitted throughout all programs of WWV and WWVH except that the 29th and 59th markers of each minute are omitted. As noted above, the seconds marker which begins the minute is lengthened to 800 milliseconds. All other markers consist of a

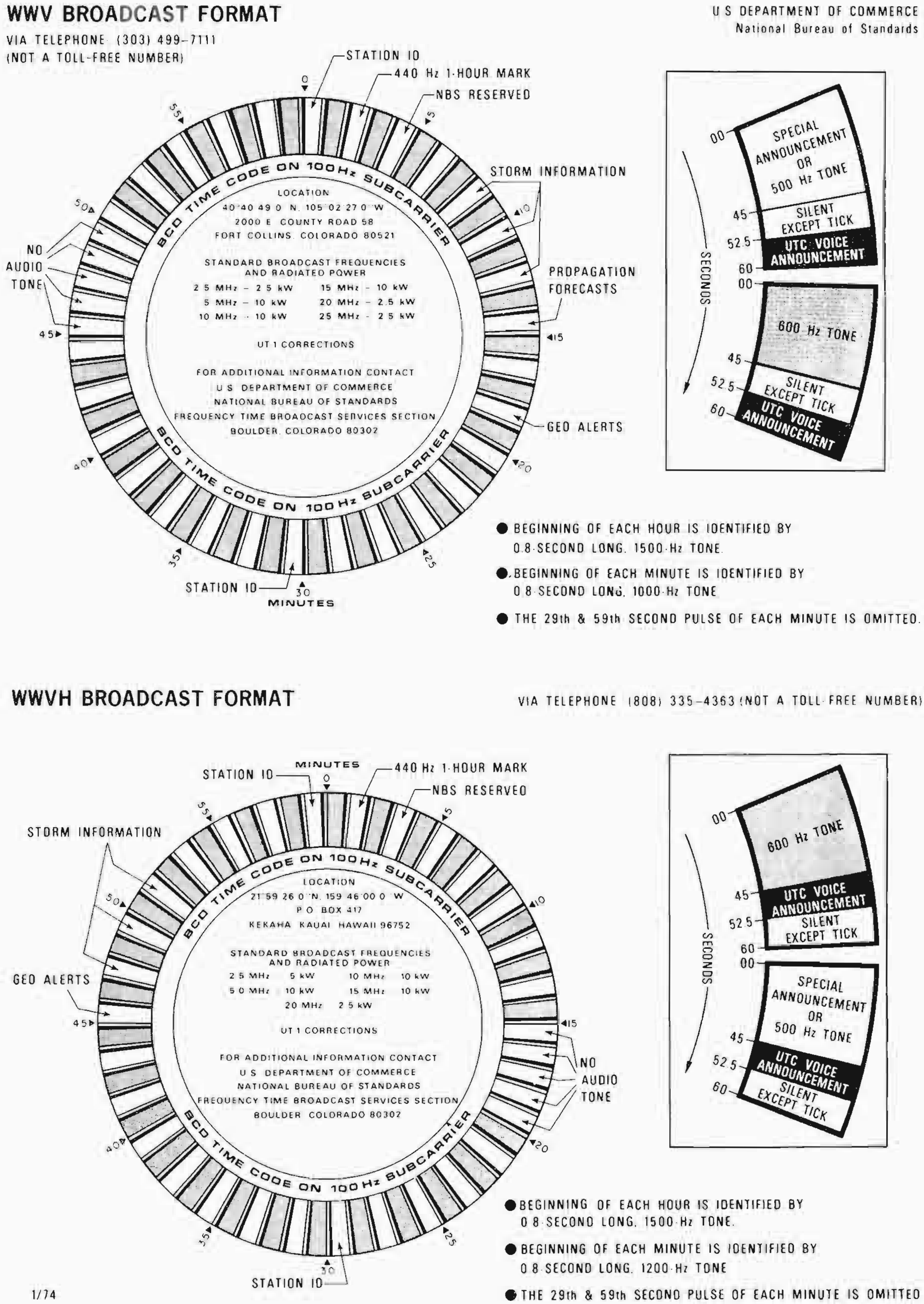


Fig. 1. The hourly broadcast schedules of WWV and WWVH.

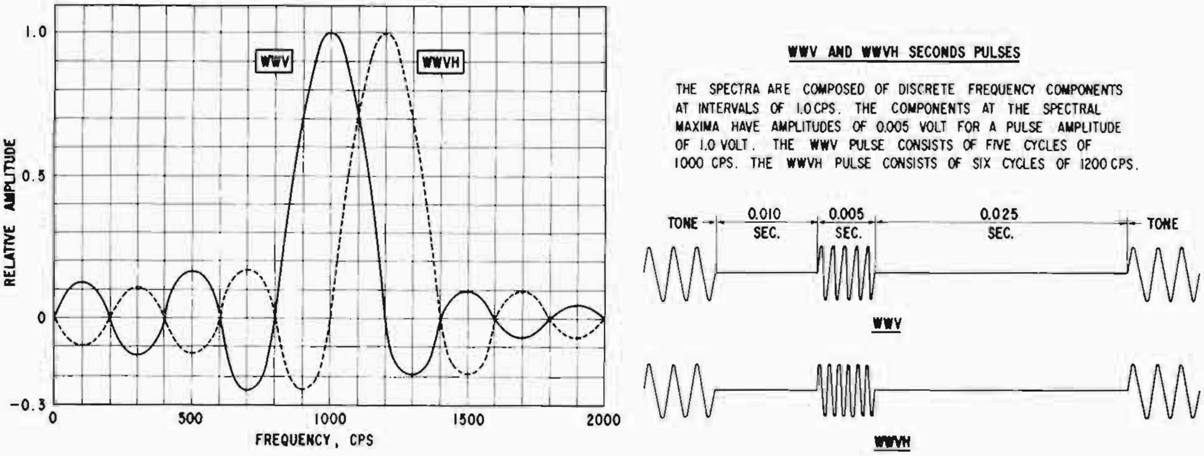


Fig. 2. Sample characteristics of time pulse broadcast from NBS radio stations WWV and WWVH.

5-millisecond pulse of 1000 Hz at WWV and 1200 Hz at WWVH, commencing at the beginning of the second (Fig. 2).

The seconds pulse spectrum is composed of Fourier frequency components as shown in Fig. 2. Each pulse is preceded by 10 milliseconds of silence and followed by 25 milliseconds of silence. These 40-millisecond interruptions do not appreciably degrade the intelligibility of voice announcements.

1.5. TIME SIGNALS

Program

Because of the common usage of the name Greenwich Mean Time, the time announcements on WWV and WWVH are referred to by this name. More precisely, the actual reference time scale is the Coordinated Universal Time Scale as maintained by the National Bureau of Standards, UTC (NBS).

The 0 to 24 hour system is used starting with 0000 for midnight at longtitude zero. The first two figures give the hour and the last two figures give the number of minutes past the hour when the tone returns. The time announcement refers to the end of an announcement interval, i.e., to the time when the 0.8 second long audio tone begins.

At WWV a voice announcement of Greenwich Mean Time is given during the last 7.5 seconds of every minute. At 1035 GMT, for instance, the voice announcement (given in English) is: "At the tone—ten hours, thirty-five minutes Greenwich Mean Time."

At WWVH a voice announcement of Greenwich Mean Time occurs during the period 45 seconds to 52.5 seconds after the minute. It should be noted that the voice announcement for WWVH precedes that of WWV by 7.5 seconds. However, the tone markers referred to in both announcements occur simultaneously, though they may not be so received due to propagation effects.

Corrections

Prior to January 1, 1972, time signals broadcast from WWV and WWVH were kept in close agreement with UT2 (astronomical time) by making step adjustments of 100 milliseconds as necessary.

On December 1, 1971 at 23h 59 min 60.107600 sec. UTC (i.e., GMT), UTC (NBS) "was retarded 0.107600 second" to give the new UTC scale an initial difference of 10 seconds late with respect to International Atomic Time (IAT) as maintained by the Bureau of International de L'Heure (BIH) in Paris, France.

Corrections to UTC will be made in step adjustments of exactly 1 second when the BIH determines they are needed to keep the broadcast time signals within ± 0.7s of astronomical time, UT1. (Note: the corrections no longer relate to UT2.)

UT1 Corrections

Since the new UTC rate (effective January 1, 1972) is no longer adjusted periodically to agree with the earth's rotation rate, the new UTC departs more rapidly than before from earth rotation time (known as UT1), gaining about 1 second per year. In order to prevent this difference from exceeding 0.7 second, step adjustments of exactly one second, to be called a leap second, will be made as necessary at the end of the UTC month, preferably on 31 December or 30 June.

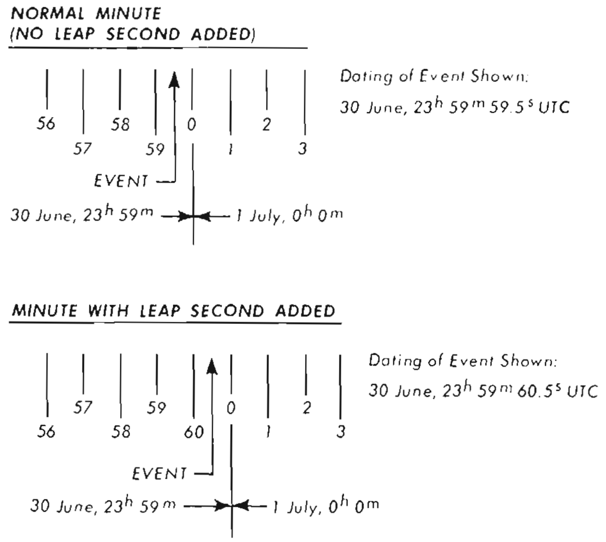


Fig. 3. Illustration of how events are dated in the vicinity of a leap second.

Thus, when required, a leap second will be inserted between the end of the 60th second of the last minute of the last day of a month, and the beginning of the next minute. This is analogous to adding an extra day (which might be called a leap day) during a leap year. Fig. 3 illustrates how events will be dated in the vicinity of a leap second. The BIH will announce the occurrence of leap seconds two months in advance.

The method of coding the UT1 corrections uses a system of double seconds pulses. The first through the seventh seconds pulse, when marked by a double pulse, will indicate a "plus" correction, and from the ninth through the fifteenth a "minus" correction. The eighth seconds pulse is not used. The amount of correction in units of 0.1 second is determined by counting the number of seconds pulses that are doubled. For example, if the first, second, and third second pulses are doubled, the UT1 correction is "plus" 0.3 second. Or in the ninth, tenth, eleventh, twelfth, thirteenth, and fourteenth seconds pulses are doubled, the UT1 ccorrection is "minus" 0.6 second. To obtain UT1, use the relationship

$$\text{UT1—Broadcast} = \text{Correction.}$$

That is, add the correction to the time broadcast if "plus" is transmitted, subtract if "minus" is is transmitted. Thus, a clock keeping step with the time signals broadcast will be early with respect to UT1 if a "minus" is broadcast. These corrections will be revised as needed, the new value appearing for the first time during the hour after 0000 UTC.

The UT1 corrections are also encoded in the time code transmitted continuously on a 100-Hz subcarrier from WWV and WWVH. The value of the correction is indicated by the weight of the control bits that occur at the end of the code frame. The "plus" or "minus" indication is encoded in the first control bit; i.e., if the bit is a binary one the correction is "plus," if it is a binary zero it is "minus." The correction is to the nearest 0.1 second.

1.6. OFFICIAL ANNOUNCEMENTS

The 45-second announcement segments available every other minute from WWV and WWVH are offered on a subscription basis to other agencies of the federal government to disseminate official and public service information. The accuracy and content of these announcements is the responsibility of the originating agency—not necessarily the National Bureau of Standards.

All segments except those reserved for NBS use and the semisilent periods are available. Arrangements for use of segments at the two stations may be made through the Frequency-Time Broadcast Services Section, 273.02, National Bureau of Standards, Boulder, Colorado 80302.

Propagation Forecasts

A forecast of radio propagation conditions is broadcast in voice during part of every 15th minute of each hour from WWV. The announcements are short-term forecasts and refer to propagation along paths in the North Atlantic area, such as Washington, D.C. to London or New York to Berlin. These forecasts are also applicable to high latitudes provided the appropriate time correction is made for other latitudes. The forecasts are prepared by the Office of Telecommunications Services Center, OT, Boulder, Colorado.

The broadcast consists of the statement, "The radio propagation quality forecast at . . . (one of the following times: 0100, 0700, 1300, or 1900 UTC) is . . . (one of the following adjectives: excellent, very good, good, fair-to-good, fair, poor-to-fair, poor, very poor, or useless). Current geomagnetic activity is . . . (one of the following characteristics: quiet, unsettled, or disturbed)."

Geophysical Alerts

Current geophysical alerts (Geoalerts) as declared by the World Warning Agency of the International Ursigram and World Days Service (IUWDS) are broadcast in voice during the 19th minute of each hour from WWV and during the 46th minute of each hour from WWVH. The messages are changed daily at 0400 UTC with provisions to provide real-time data alerts of outstanding occurring events. These are followed by a summary of selected solar and geophysical events in the past 24 hours. Information concerning these forecasts are prepared by the Space Environment Laboratory, NOAA, Boulder, Colorado.

Weather Information

Weather information about major storms in the Atlantic and Pacific areas is broadcast from WWV and WWVH, respectively. The brief messages are designed to tell mariners of storm threats in their areas. If there are no warnings in the designated areas, the broadcasts will so indicate. The ocean areas involved are those for which the U.S. has warning responsibility under international agreement. The regular times of issue by the National Weather Service are 0500, 1100, 1600, and 2300 UTC by WWV and 0000, 0600, 1200, and 1800 UTC by WWVH. These broadcasts are updated effective with the next scheduled announcement following the time of issue.

WWV broadcasts information about storms in the western North Atlantic, and WWVH lists storms in the eastern and central part of the North Pacific. These broadcasts are given in voice during the 11th and 13th minute from WWV and during the 50th and 52nd minute from WWVH.

Sample broadcasts that exemplify the type of information mariners might expect to receive from WWV, for instance, are as follows:

"North Atlantic weather, west of 35 degrees West at 1700 GMT: Hurricane Donna, intensifying, 24 North, 60 West, moving northwest, 20 knots, winds 75 knots; storm 65 North, 35 West, moving east, 10 knots, seas 15 feet."

1.7. WWV/WWVH TIME CODE

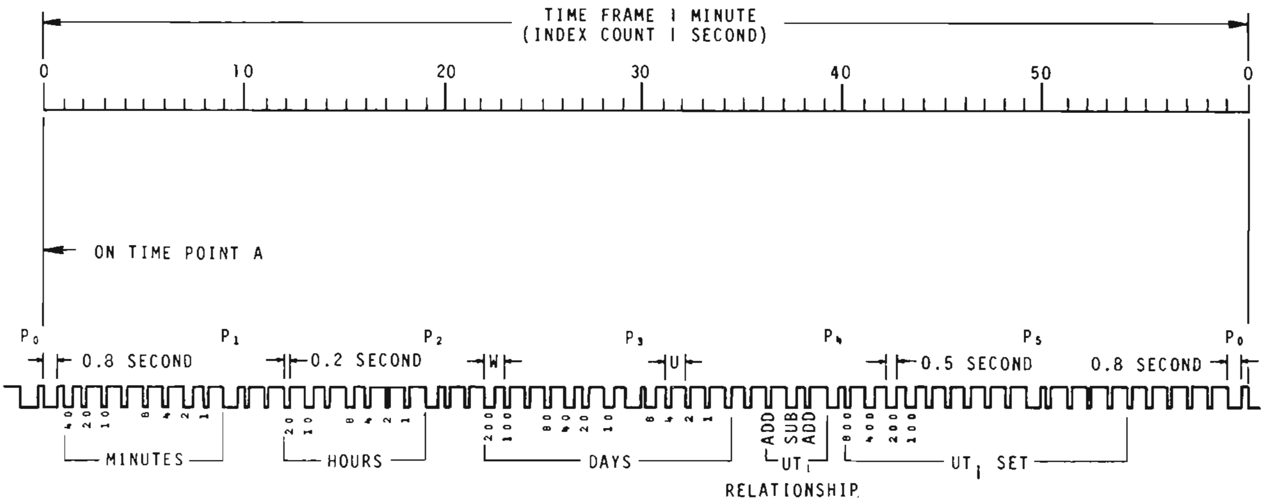
On July 1, 1971, WWV commenced broadcasting the time code shown in Fig. 4. The time code is now transmitted continuously by both WWV and WWVH on a 100-Hz subcarrier. This time code provides a standardized timing base for use when scientific observations are made simultaneously at widely separated locations. It may be used, for instance, where signals telemetered from a satellite are recorded along with the time code; subsequent analysis of the data is then aided by having unambiguous time markers accurate to about 10 milliseconds.

The code format being broadcast is a modified IRIG-H time code. The code is produced at a 1-pps rate and is carried on 100-Hz modulation.

The code contains UTC time-of-year information in minutes, hours, and day of year. Seconds information may be obtained by counting pulses. The code is synchronous with the frequency and time signals.

The binary coded decimal (BCD) system is used. Each minute contains seven BCD groups in this order: two groups for minutes, two groups for hours, and three groups for day of year. The code digit weighting is 1-2-4-8 for each BCD group multiplied by 1, 10, or 100 as the case may be.

A complete time frame is 1 minute. The binary groups follow the 1 minute reference marker. "On-time" occurs at the positive-going leading edge of all pulses.



1 PPM FRAME REFERENCE MARKERS
BINARY CODED DECIMAL TIME-OF-YEAR CODE WORD (23 DIGITS)
CONTROL FUNCTIONS (15 DIGITS) USED FOR UT_1 CORRECTIONS
6 PPM POSITION IDENTIFIER MARKERS AND PULSES (P_0 THRU P_5)
(REDUCED CARRIER 0.8 SECOND DURATION PLUS 0.2 SECOND DURATION PULSE)
W - WEIGHTED CODE DIGIT (CARRIER RESTORED IN 0.5 SECOND - BINARY ONE)
U - UNWEIGHTED CODE DIGIT (CARRIER RESTORED IN 0.2 SECOND - BINARY ZERO)

UTC AT POINT A
258 DAYS
18 HOURS
42 MINUTES

UT1 AT POINT A
258 DAYS
18 HOURS
41 MINUTES
59.3 SECONDS

Fig. 4. Chart of time code transmissions from NBS radio stations WWVB.

The code contains 60 markers per minute clocking rate, 6 per minute position identification markers, and a 1 per minute reference marker. The 100-Hz subcarrier is synchronous with the code pulses so that 10-millisecond resolution is readily obtained.

The 6 per minute position identification markers consist of 0.8 second pulses preceding each code group. The 1 per minute reference marker consists of one 0.8 second pulse followed by a 1.03 second "hole" in the code followed by eight binary zero pulses. The minute begins with the 1.03 second "hole" at the beginning of the code.

A binary zero pulse consists of 20 cycles of 100-Hz amplitude modulation, and the binary one pulse consists of 50 cycles of 100-Hz amplitude modulation. The leading edges of the time code pulses coincide with positive-going zero-axis-crossings of the 100-Hz modulating frequency.

1.8. STATION IDENTIFICATION

WWV and WWVH identify by voice every 30 minutes. The station identification voice announcements are automatically synchronized recordings, not live broadcasts. The regular announcer for WWV is Mr. Don Elliott of Atlanta, Georgia; the regular announcer for WWVH is Mrs. Jane Barbe, also of Atlanta.

1.9. RADIATED POWER, ANTENNAS AND MODULATION

Radiated Power

Frequency, MHz	Radiated Power, kW	
	WWV	WWVH
2.5	2.5	5
5	10	10
10	10	10
15	10	10
20	2.5	2.5
25	2.5	–

Transmitting Antennas

The broadcasts on 5, 10, 15, and 20 MHz from WWVH are from phased vertical half-wave dipole arrays. They are designed and oriented to radiate a cardioid pattern directing maximum gain in a westerly direction. The 2.5-MHz antenna at WWVH and all antennas at WWV are half-wave vertical dipoles which radiate omnidirectional patterns.

Modulation

At WWV and WWVH, double sideband amplitude modulation is employed with 50% modulation on the steady tones, 25% for the IRIG-H code, 100% for seconds pulses, and 75% for voice.

2. WWVB BROADCAST SERVICES

WWVB transmits a standard radio frequency, standard time signals, time intervals, and UT1 corrections. The station is located near WWV on the same site. The coordinates of WWVB are

40°40′28.3″ N   105°02′39.5″ W.

Alternating its scheduled maintenance periods with those of experimental and intermittently operated station WWVL, it suspends operation for several hours between 1300 UTC and 2400 UTC every other Tuesday. Otherwise the service is continuous.

Program

WWVB broadcasts a standard radio carrier frequency of 60 kHz with no offset. It also broadcasts a time code consistent with the internationally coordinated time scale UTC(NBS).

Accuracy and Stability

The frequency of WWVB is normally within its prescribed value to better than 2 parts in 10^{11}. Deviations from day to day are less than 1 part in 10^{12}. Effects of the propagation medium on received signals are relatively minor at low frequencies (LF); therefore, the accuracy of the transmitted signals may be fully utilized by employing appropriate receiving and averaging techniques [3, 4].

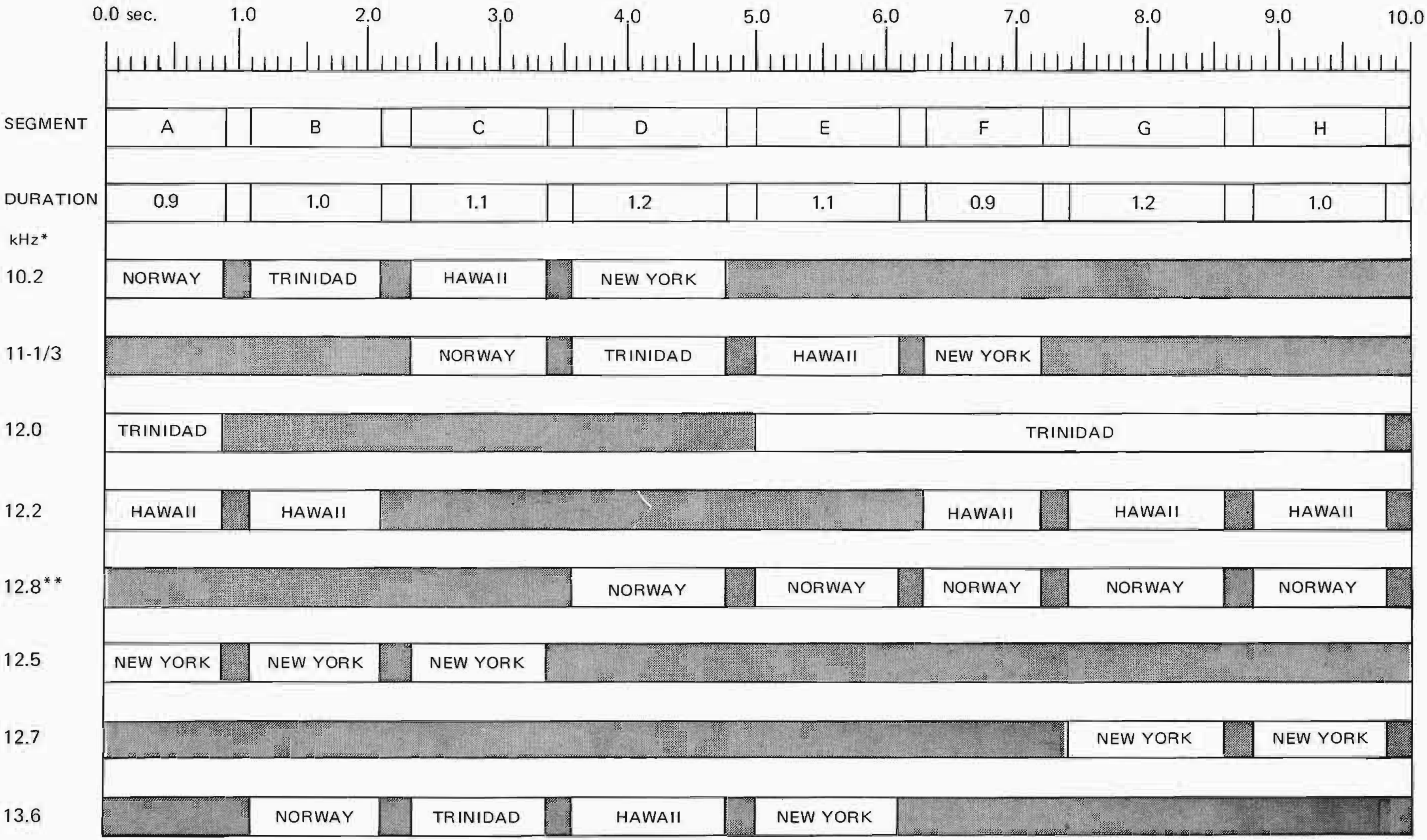
Station Identification

WWVB identifies itself by advancing its carrier phase 45° at 10 minutes after every hour and returning to normal phase at 15 minutes after the hour. WWVB can also be identified by its unique time code.

Radiated Power, Antenna, and Modulation

The effective radiated power from WWVB is 13 kW. The antenna is a 122-meter, top-loaded vertical installed over a radial ground screen. The station uses 10-dB carrier-level reduction in transmitting its time code.

CHART A
OMEGA SIGNAL FORMAT



*Frequency is offset according to the current rate for UTC.
**Transmissions on unique frequency from Norway have started for testing purposes.

FORMAT H, SIGNAL H001, IS COMPOSED OF THE FOLLOWING:

1) 1 ppm FRAME REFERENCE MARKERS R = (P_0 AND 1.03 SECOND "HOLE")
2) BINARY CODED DECIMAL TIME-OF-YEAR CODE WORD (23 DIGITS)
3) CONTROL FUNCTIONS (9 DIGITS) USED FOR UT_1 CORRECTIONS, ETC.
4) 6 ppm POSITION IDENTIFIERS (P_0 THROUGH P_5)
5) 1 pps INDEX MARKERS

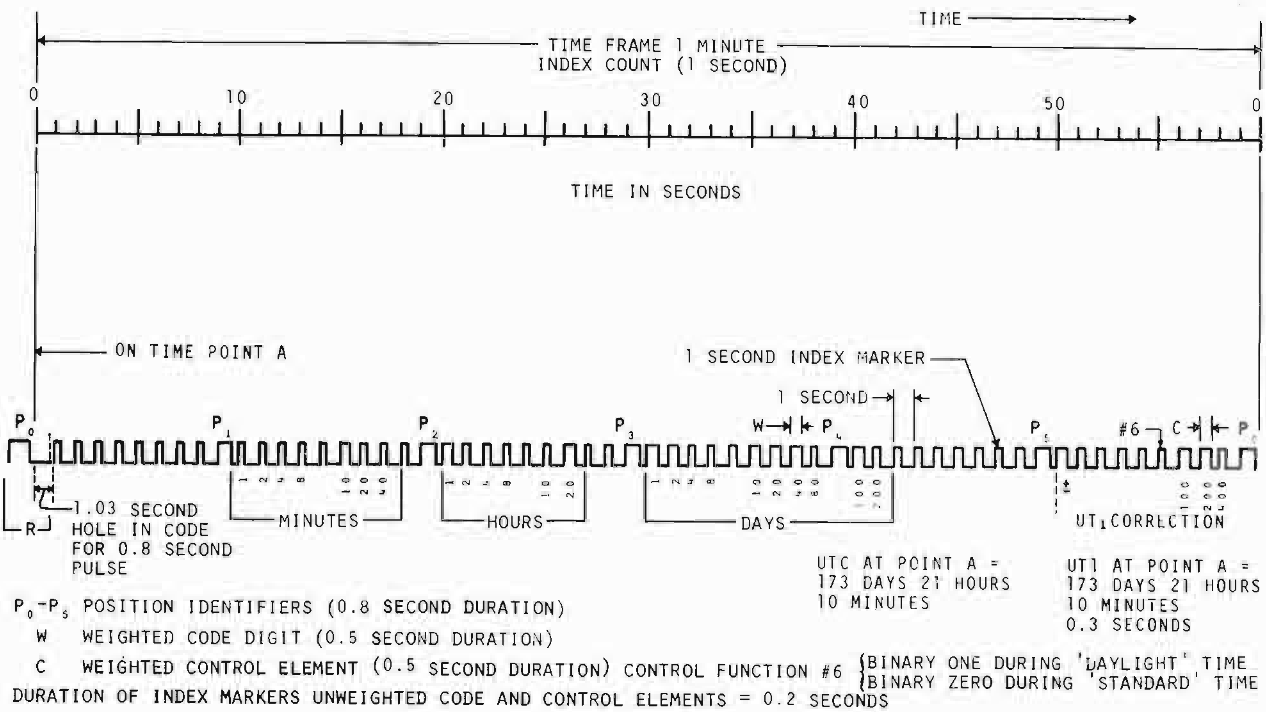


Fig. 5. Chart of time code transmissions from NBS radio stations WWV and WWVH.

2.1. WWVB TIME CODE

Code and Carrier

On July 1, 1965, WWVB began broadcasting time information using a level-shift carrier time code. The code, which is binary coded decimal (BCD), is broadcast continuously and is synchronized with the 60-kHz carrier signal.

Marker Generation

As shown in Fig. 5, the signal consists of 60 markers each minute, with one marker occurring during each second. (Time progresses from left to right.) Each marker is generated by reducing the power of the carrier by 10 dB at the beginning of the corresponding second and restoring it 0.2 second later for an uncoded marker or binary zero, 0.5 second later for a binary one, and 0.8 second later for a 10-second position marker or for a minute reference marker. Several examples of binary ones are indicated by I in Fig. 5. The leading edge of every negative-going pulse is on time.

Marker Order and Groups

The 10-second position markers, labeled P0 to P5 on the diagram, occur respectively in the 60th, 10th, 20th, 30th, 40th, and 50th seconds of each minute.[2] The minute reference marker occurs in the 1st second of the minute. Uncoded markers occur periodically in the 5th, 15th, 25th, 35th, 45th, and 55th seconds of each minute, and also in the 11th, 12th, 21st, 22nd, 36th, 56th, 57th, 58th, and 59th seconds. Thus, every minute contains 12 groups of 5 markers, each group ending either with a position marker or an uncoded marker. The signal pulses lasting for 0.2 seconds after a position marker are shown blackened in Fig. 4; the signal pulses lasting for 0.8 seconds after a periodically uncoded marker are shaded; other signal pulses following uncoded markers are labeled with a U.

With the exception of the uncoded and reference markers specifically mentioned above, the remaining markers in each of the groups are utilized to convey additional information.

[2] Effective January 1, 1972, during the minute in which a one-second step correction occurs, that minute will contain either 59 or 61 seconds.

Information Sets

Each minute the code presents time-of-year information in seconds, minutes, hours, and day of the year and the actual milliseconds difference between the time as broadcast and the best known estimate of UT1. The first two BCD groups in the frame specify the minute of the hour; the third and fourth BCD groups make up a set which specifies the hour of the day; the fifth, sixth, and seventh groups form a set which specifies the day of the year; a set, made up of the ninth, tenth, and eleventh BCD groups, specifies the number of milliseconds to be added or subtracted from the code time as broadcast in order to obtain UT1. The twelfth group is not used.

The relationship of the UT1 scale to the time as coded is indicated in the eighth group. If UT1 is late with respect to the code time, a binary one, labeled SUB in Fig. 5, will be broadcast in the eighth group during the 38th second of the minute. If UT1 is early with respect to the code time, binary ones, labeled ADD, will be broadcast in the eighth group during the 37th and 39th seconds of the minute.

Digital Information

When used to convey numerical information, the four coded markers used as digits in a BCD group are indexed 8-4-2-1 in that order. Sometimes only the last two or three of the coded markers in a group are needed, as in the first groups of the minutes, hours, and days sets. In these cases, the markers are indexed 2-1, or 4-2-1, accordingly. The indexes of the first group in each set which contains two groups are multiplied by 10, those of the second group of such a set are multiplied by 1. The indexes of the first group in each set which contains three groups are multiplied by 100, those of the second group by 10, and those of the third group by 1.

Example

A specific example is indicated in Fig. 5. The occurrence of two binary ones in the "minutes set" indicates that the minute contemplated is the $40 + 2 = 42$nd minute. Similarly, the two binary ones in the "hours set" indicate the $10 + 8 = 18$th hour of the day, while the four binary ones in the "days set" indicate the $200 + 40 + 10 + 8 = 258$th day of the year. It is seen from the "UT1 Relationship" group and the "UT1 Set" that one should subtract, from any second in this minute, $40 + 1 = 41$ milliseconds to get the best estimate of UT1. For example, the 35th UT1 interval would end 41 milliseconds *later* than the end of the 35th second; or, in other words, the UT1 scale reading for the end of the 35th second would be 18h 42 min. 34.959 sec. since $35.000 - 0.041 = 34.959$.

3. WWVL EXPERIMENTAL BROADCASTS

WWVL broadcasts experimental programs, usually involving multiple frequencies. The station is located in the same building with WWVB and on the same site with WWV. The coordinates of WWVL are

40°40′51.3″ N 105°03′00.0″ W.

Alternating its scheduled maintenance periods with those of WWVB, it suspends operation for several hours between 1300 UTC and 2400 UTC every other Tuesday. Otherwise the programs are continuous.

Effective 0000 hours UTC, January 1, 1972, all transmissions from WWVL will be on an intermittent and experimental basis only. These broadcasts are planned to be curtailed within a few months thereafter. Users of this service are urged to explore alternative solutions to their needs.

Program Format

WWVL transmits only carrier frequencies with no modulation. In accordance with the new UTC system, the frequency offset used prior to January 1, 1972, was reduced to zero on that date. The transmissions presently alternate between 20.0 kHz and 19.9 kHz on a 50% duty cycle with each frequency being broadcast for 10 seconds. The 20.0 kHz transmissions commence on the minute. The format and frequencies used by WWVL are subject to change to meet the requirements of the particular experiment being conducted.

Accuracy and Stability

The transmitted frequencies from WWVL are normally within their prescribed values to better than 2 parts in 10^{11}. Deviations from day to day are less than 1 part in 10^{12}. Because of the excellent coverage and phase stability in the very low frequency (VLF) region, this mode of transmission permits the frequencies to be received with an accuracy approaching that of signals at the transmitter itself.

Station Identification

WWVL is identified only by its unique program format.

Radiated Power, Antenna

The effective radiated power from WWVL is 2 kw. The antenna is a 122-meter, top-loaded vertical installed over a radial ground screen.

CHART B

U.S. NAVAL OBSERVATORY
SCHEDULE OF TIME AND FREQUENCY TRANSMISSIONS
ON VLF FROM U.S. NAVAL RADIO STATIONS

Station	Location	Frequency (kHz)*	Nominal Radiated Power (kw)	Maintenance	Special Transmissions
NAA	Cutler, Maine 44°38!9N, 67°16! 9W	17.80	1,000 (1)	1400 to 1800 UT each Friday	FSK for two hours followed by CW for one hour. Phase stable on 17.80 but not on 17.85 kHz.*
NBA	Balboa, Canal Zone 09°03!3N, 79°38!9W	24.00	150 (2)	1200 to 1800 UT each Monday	Time signals on CW Morse from 55 to 60th minute every even hour except 2355 to 2400 UT. FSK continuous at other times. Phase stable on 24.00 but not on 24.05 kHz.*
NLK	Jim Creek, Wash. 48°12!2N, 121°55!0W	18.60	250	1700 to 2200 UT 1st & 3rd Thursday of each month	FSK continuous except five minutes before each even hour on locked key. Phase stable on 18.60 but not on 18.65 kHz.*
NPM	Lualualei, Hawaii 21°25!5N, 158°09!3W	23.40	140	1700 UT Monday to 0200 UT Tuesday 1st & 3rd Monday of each month	FSK continuous. Phase stable on 23.40 but not on 23.45 kHz.
NSS	Annapolis, Md. 38°59!1N, 76°27!2W	21.40	85	1300 to 1900 UT each Wednesday	Time signals from 55 to 60th minute each hour. CW Morse continuous. Phase stable.
NWC	North West Cape, Australia 21°49!0S, 114°09!8E	22.30	1,000	0000 to 0300 UT each Monday (3)	FSK and CW. Phase stable on 22.30 but not on 22.35 kHz.* (4)

*Frequency is offset according to the current rate for UTC.

Notes: (1) Each Wednesday and Thursday 1200 to 2000 UT, transmitter will operate at half power for limited maintenance.

(2) Each Tuesday 1200 to 2000 UT, radiated power will be reduced from 150 kw to 90 kw for limited maintenance.

(3) Maintenance schedule may be extended to 0600 UT when required.

(4) Transmissions will be CW first half hour of each even hour followed by FSK for 1½ hours. CW may be replaced by FSK transmissions as required.

(5) *Omega Segment Assignments.* The Omega navigational transmitters operate on the UTC system. The transmissions have 8 scheduled segments each, repeating with a period of 10 seconds. Segment A starts at the zero second and repeats each 10 seconds thereafter. Segment E starts at five seconds and repeats each 10 seconds thereafter. A schematic of the segment duration is attached.

The Omega Project Management Office controls the phase of the Omega transmissions. The system maintains internal synchronization using very long integration times. All Omega emissions will normally be within 10 μs of the U.S. Naval Observatory Master Clock.

(6) All stations transmit from cesium beam oscillators.

(7) The coordinates of the receiving antenna of the U.S. Naval Observatory monitoring and control station in Washington, D.C. are: 38°55!2N, 77°04!0W.

(8) The use of Navy VLF controlled transmissions for precise timing applications is explained in some detail in the U.S. Naval Observatory's Time Service Letter of 30 September 1968. This publication, as well as others, is available free of charge upon request.

(9) For information concerning precise time and frequency services, address your requests to: Superintendent, Attn: Time Service Division, U.S. Naval Observatory, Washington, D.C. 20390.

CHART A (Continued)

Station	Location	Frequency (kHz)*	Estimated Radiated Power (kw)	Maintenance
Omega Norway	Aldra, Norway 66°25'15"N, 13°09'10"E	10.2 Seg A 11 1/3 Seg C 12.3 Seg D,E,F,G,H 13.6 Seg B	4	When routine maintenance is required, advance notice will be given. This maintenance will be accomplished during the 24-hour day (UT) Tuesday.
Omega Trinidad	Trinidad, West Indies, 10°42'06"N, 61°38'20"W	10.2 Seg B 11 1/3 Seg D 12.0 Seg A,E,F,G,H 13.6 Seg C	1	When routine maintenance is required, advance notice will be given. This maintenance will be accomplished during the 24-hour day (UT) Wednesday.
Omega Hawaii	Haiku, Hawaii 21°24'21"N, 157°49'48"W	10.2 Seg C 11 1/3 Seg E 12.2 Seg A,B,F,G,H 13.6 Seg D	2	When routine maintenance is required, advance notice will be given. This maintenance will be accomplished during the 24-hour day (UT) Thursday.
Omega New York	Forestport, New York, 43°26'41"N, 75°05'10"W	10.2 Seg D 11 1/3 Seg F 12.5 Seg A,B,C 12.7 Seg G,H 13.6 Seg E	0.25	When routine maintenance is required, advance notice will be given. This maintenance will be accomplished during the 24-hour day (UT) Friday.

FEDERAL COMMUNICATIONS COMMISSIONS RULES PERTAINING TO REBROADCAST OF TIME SIGNALS

73.1207 Rebroadcast

(a) The term "rebroadcast" means reception by radio of the programs of a radio station, and the simultaneous or subsequent retransmission of such programs by a broadcast station.

Note: As used in § 73.1207 "program" includes any complete program or part thereof.

The transmission of a program from its point of origin to a broadcast station entirely by common carrier facilities, whether by wire line or radio, is not considered a rebroadcast.

(b) No broadcasting station shall rebroadcast the program, or any part thereof of another U.S. broadcasting station without the express authority of the originating station. A copy of the written consent of the licensee originating the program shall be kept by the licensee of the station rebroadcasting such program and shall be made available to the Commission upon request. Stations originating emergency communications under a Detailed State EBS Operational Plan, shall be deemed to have conferred rebroadcast authority on other participating stations. The broadcasting of a program relayed by a remote pickup broadcast station (§ 74.401 of this chapter) is not considered a rebroadcast.

(c) The rebroadcast of time signals originated by the Naval Observatory and the National Bureau of Standards is permitted without further Commission authorization under the conditions set forth in Note 1 to this paragraph. The rebroadcast of National Weather Service (NWS) transmissions is permitted without further Commission authorization under the conditions set forth in Note 2 to this paragraph. Programs originated by the Voice of America (VOA) and the American Forces Radio and Television Service (AFRTS) cannot, in general, be cleared for domestic rebroadcast, and may therefore be rebroadcast only by special arrangement among the parties concerned. Except as otherwise provided by international agreement, programs originated by foreign broadcasting stations may be rebroadcast without the consent of the originating station. In the case of retransmissions of subcarrier background music and other FM multiplex subscription services, permission must first be obtained from the originating station. The retransmission of point-to-point messages originated by government and privately owned nonbroadcast stations must be authorized by the Commission prior to retransmission; such authority may be requested informally by telephone, to be followed within one week with a written confirmation accompanied by the written consent of the originating station.

Note 1: (a) *Naval Observatory Time Signals.* (1) The time signal rebroadcast must be obtained by direct radio reception from a naval radio station.

(2) Announcement of the time signal must be made without reference to any commercial activity.

(3) Identification of the Naval Observatory as the source of the time signal must be made by an announcement, substantially as follows: "With the signal, the time will be__________, courtesy of the U.S. Naval Observatory."

Schedules of time signal broadcasts may be obtained upon request from the Superintendent, U.S. Naval Observatory, Washington, D.C. 20390.

(b) *National Bureau of Standards Time Signals.* (1) Time signals for rebroadcast must be obtained by direct radio reception from an NBS station.

(2) Use of receiving and rebroadcasting equipment must not delay the signals by more than 0.05 seconds.

(3) Signals must be rebroadcast live, not from tape or other recording.

(4) Voice or code announcements of the call letters of NBS stations are not to be rebroadcast.

(5) Identification of the origin of the service and the source of the signals must be made by an announcement substantially as follows: "At the tone, 11 hours 25 minutes Greenwich mean time. This is a rebroadcast of a continuous service furnished by the National Bureau of Standards, Time and Frequency Division, Boulder, Colo." No commercial sponsorship of this announcement is permitted and none may be implied.

(6) Notice of use of NBS time signals for rebroadcast should be forwarded semiannually to Frequency-Time Broadcast Services, Time and Frequency Division, National Bureau of Standards, Boulder, Colo. 80302.

(7) In the rebroadcasting of NBS time signals, announcements will not state that they are standard frequency transmissions. Voice announcements of G.m.t. are given in voice every minute. Each minute, except the first of the hour, begins with a 0.8-second long tone of 1000 Hz at WWV and 1200 Hz tone at WWVH. The first minute of every hour begins with an 0.8-second long tone of 1500 Hz at both stations. This tone is followed by a 3-second pause, then the announcement, "National Bureau of Standards Time." This is followed by another 3-second pause before station identification. This arrangement allows broadcast stations sufficient time to retransmit the hour time tone and the words "National Bureau of Standards Time" either by manual or automatic switching.

(8) Time signals or scales made up from integration of standard frequency signals broadcast from NBS stations may not be designated as national standard scales of time or attributed to the NBS as originator. For example, if a broadcasting station transmits time signals obtained from a studio clock which periodically calibrated against the NBS time signals from WWV or WWVH, such signals may not be announced as NBS standard time or as having been originated by the NBS.

Schedules of time signal broadcasts may be obtained upon request from Frequency-Time Broadcast Services Section, Time and Frequency Division, National Bureau of Standards, Boulder, Colo. 80302.

Note 2: (a) Messages must be rebroadcast within 1 hour of receipt from the National Weather Service (Weather Bureau).

(b) If advertisements are given in connection with a weather rebroadcast, these advertisements shall not directly or indirectly convey an endorsement by the Government of the products or services so advertised.

(c) Credit must be given to indicate that the rebroadcast messages originate with the National Weather Service (Weather Bureau). [37 FR 23726, Nov. 8, 1972, as amended at 38 FR 18378, July 10, 1973.]

7

Wave Propagation, Radiation, and Absorption

Edward W. Allen, Jr.
Sun City, Arizona
(Former Chief Engineer FCC)

THE NATURE OF RADIO-WAVE PROPAGATION

Radio waves are a part of a larger spectrum of electromagnetic radiation or wave motion extending from the very low frequencies which are now employed in servo-mechanisms, up through the extremely high frequencies and short wavelengths found in cosmic rays. Between these two extremes lie several ranges of frequencies which are related by reason of their being portions of a common spectrum but which exhibit such different characteristics under normal experience that their kinship may not be readily recognized. However, under certain conditions, analogies are useful for describing the characteristics of one range in terms of another. These other ranges include the frequencies used for electric-power systems; the audio frequencies used in systems for the transmission, amplification, or recording of audible sounds; the radio frequencies; radiant heat; light; and the X-rays.

The portions of the spectrum occupied by these frequency ranges are shown in Fig. 1a. The limits of each frequency range are not defined sharply, but each range overlaps slightly into the ranges above and below. The frequency ranges are marked in terms of the frequency f in Hertz (cycles per second) and are also marked in terms of the wavelength λ in space in centimeters. The wavelength λ is related to the frequency f by the formula $C = f\lambda$, where C is the velocity of light and other electromagnetic radiation in space and is approximately equal to 3×10^{10} cm/sec ($2.99795 \pm 0.00003 \times 10^{10}$).

The range comprising the presently recognized limits of the radio spectrum has been expanded in Fig. 1b with the horizontal scale in terms of megaHertz (MHz), or millions of cycles per second. The portions of the radio spectrum to which television broadcasting and television relay stations are allocated have been further expanded in Fig. 1c. The following discussion and methods apply particularly to these portions of the spectrum. (The Administrative Radio Conference [ITU, Geneva, 1959] extended their consideration of the radio spectrum to 40 GHz).

The television broadcast allocations in the United States are: channels 2 to 4, 54 to 72 MHz; channels 5 and 6, 76 to 88 MHz; channels 7 to 13, 174 to 216 MHz; channels 14 to 83, 470 to 890 MHz. Allocations for television auxiliaries–remote pickup, studio-transmitter links, and intercity relay–are provided in eight bands between 1990 MHz and 40 GHz. Allocations for common carrier relay purposes, which carry intercity television programs, and for space communications are also interspersed throughout this frequency range. The specific frequency bands and their detailed usages and sharing arrangements are too complex for inclusion here. In addition, these allocations may change from time to time as the relative needs of various services for radio frequencies change, so that the allocations included herein should be considered to be merely illustrative. Current information should be obtained, when necessary, by consulting the Rules of the FCC.

PROPAGATION IN FREE SPACE

For simplicity and ease of explanation, propagation in space and under certain conditions involving simple geometry, in which the wavefronts remain coherent, may be treated as ray propagation. It should be kept in mind that this assumption may not hold in the presence of obstructions, surface roughness, and other conditions which may be encountered in practice.

For the simplest case of propagation in space, namely that of uniform radiation in all directions from a point source, or isotropic radiator, it is

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Reprinted in part from "Television Engineering Handbook," edited by Donald G. Fink, McGraw-Hill Book Company, Inc., 1957.

Superscript numbers refer to references at the end of this chapter.

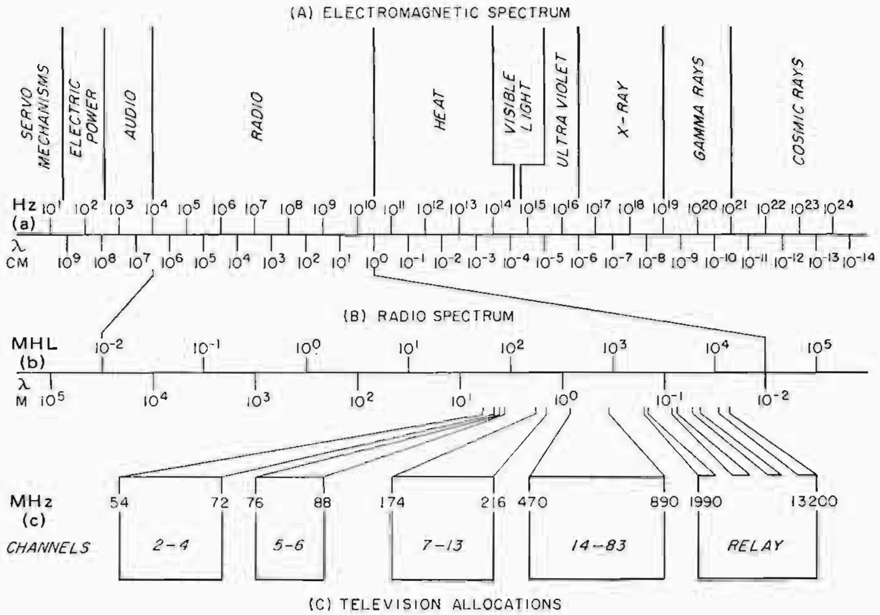


Fig. 1. (a) Electromagnetic spectrum, (b) radio spectrum, (c) television allocations.

useful to consider the analogy to a point source of light. The radiant energy passes with uniform intensity through all portions of an imaginary spherical surface located at a radius r from the source. The area of such a surface is $4\pi r^2$, and the power flow per unit area $W = P_t/4\pi r^2$, where P_t is the total power radiated by the source. In the engineering of broadcasting and of some other radio services, it is conventional to measure the intensity of radiation in terms of the strength of the electric field E_O rather than in terms of power flux density W. The power flux density is equal to the square of the field strength divided by the impedance of the medium, so for free space $W = E_O{}^2/120\pi$, and $P_t = 4\pi r^2 E_O{}^2/120\pi$, or

$$P_t = \frac{r^2 E_O{}^2}{30} \qquad [1]$$

where P_t is in watts radiated, W is in watts per square meter, E_O is the free-space field in volts per meter, and r is the radius in meters. A more conventional and useful form of this equation, which applies also to antennas other than isotropic radiators, is

$$E_O = \frac{\sqrt{30 g_t P_t}}{r} \qquad [2]$$

where g_t is the power gain of the antenna in the pertinent direction compared with an isotropic radiator.

An isotropic antenna is useful as a reference for specifying the radiation patterns for more complex antennas but does not in fact exist. The simplest forms of practical antennas are the electric doublet and the magnetic doublet, the former a straight conductor which is short compared with the wavelength and the latter a conducting loop of short radius compared with the wavelength. For the doublet radiator the gain is 1.5 and the field strength in the equatorial plane is

$$E_O = \frac{\sqrt{45 P_t}}{r} \qquad [2a]$$

For a half-wave dipole, namely, a straight conductor one-half wave in length, the power gain is 1.64 and

$$E_O = \frac{7\sqrt{P_t}}{r} \qquad [2b]$$

From the above formulas it can be seen that for free space (1) the radiation intensity in watts per square meter is proportional to the radiated power and inversely proportional to the square of the radius or distance from the radiator, (2) the electric field strength is proportional to the square root of the radiated power and inversely proportional to the distance from the radiator.

Typical Antennas in Free Space

The formulas for the free-space patterns, power gains, and effective areas of the fundamental doublet antennas and of a few typical antennas which are used frequently in television broadcast and relay systems are shown in Fig. 2. For purposes of pattern calculation, the element spacings S are

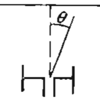
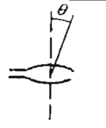
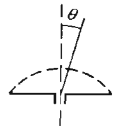
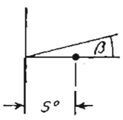
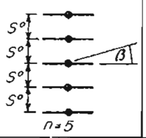
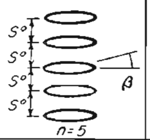
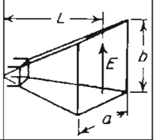
TYPE	CONFIGURATION	PATTERN	POWER GAIN OVER ISOTROPIC	EFFECTIVE AREA
ELECTRIC DOUBLET		$\cos\theta$	1.5	$1.5\,\frac{\lambda^2}{4\pi}$
MAGNETIC DOUBLET OR LOOP		$\sin\theta$	1.5	$1.5\,\frac{\lambda^2}{4\pi}$
HALF WAVE DIPOLE		$\frac{\cos(\frac{\pi}{2}\sin\theta)}{\cos\theta}$	1.64	$1.64\,\frac{\lambda^2}{4\pi}$
HALF WAVE DIPOLE AND SCREEN		$2\sin(S^o \cdot \cos\beta)$	6.5	$1.64\,\lambda^2/\pi$
TURNSTILE ARRAY		$\frac{\sin(n\frac{S^o}{2}\sin\beta)}{n\sin(\frac{S^o}{2}\sin\beta)}$	n OR $2L/\lambda$	$n\lambda^2/4\pi$ OR $L\lambda/2\pi$
LOOP ARRAY		$\frac{\cos\beta\sin(n\frac{S^o}{2}\sin\beta)}{n\sin(\frac{S^o}{2}\sin\beta)}$	n OR $2L/\lambda$	$n\lambda^2/4\pi$ OR $L\lambda/2\pi$
OPTIMUM HORN $L \geq a^2/\lambda$		HALF POWER WIDTH $70\,\lambda/a$ DEGREES (H PLANE) $51\,\lambda/b$ DEGREES (E PLANE)	$10\,ab/\lambda^2$	0.81 ab
PARABOLA		HALF POWER WIDTH $70\,\lambda/d$ DEGREES	$2\pi d^2/\lambda^2$	$d^2/2$

Fig. 2. Patterns, gains, and areas of typical antennas.

measured in electrical angles $S^0 = 2\pi S/\lambda$. For the turnstile and loop arrays the length $L = nS$, and for $S = \lambda/2$, $n = 2L/\lambda$.

The effective area B is related to the power gain g by the formula $B = g\lambda^2/4\pi$. The physical dimensions of the antennas, their effective areas, the wavelength, etc., should be expressed in the same units. The values given for power gain and effective area are for optimum conditions, and departures will result in lesser values of power gain and effective area.[1,2]

Transmission Loss between Antennas in Free Space[9]

The maximum useful power P_r that can be delivered to a matched receiver is given by

$$P_r = \left(\frac{E\lambda}{2\pi}\right)^2 \frac{g_r}{120} \text{ watts} \qquad [3]$$

where E = received field strength in volts per meter
λ = wavelength in meters, $300/f$

f = frequency in MHz
g_r = receiving antenna power gain over an isotropic radiator

This relation between received power and the received field strength is shown by scales 2, 3, and 4 in Fig. 3 for a half-wave dipole. For example, the maximum useful power at 100 MHz that can be delivered by a half-wave dipole in a field of 50 dB above 1 μv per meter is 95 dB below 1 watt. A general relation for the ratio of the received power to the radiated power obtained from Equations 2 and 3 is

$$\frac{P_r}{P_t} = \left(\frac{\lambda}{4\pi r}\right)^2 g_t g_r \left(\frac{E}{E_o}\right)^2 \qquad [4]$$

When both antennas are half-wave dipoles, the power-transfer ratio is

$$\frac{P_r}{P_t} = \left(\frac{1.64\lambda}{4\pi r}\right)^2 \left(\frac{E}{E_o}\right)^2 = \left(\frac{0.13\lambda}{r}\right)^2 \left(\frac{E}{E_o}\right)^2 \qquad [4a]$$

and is shown on scales 1 to 4 of Fig. 3. For free-space transmission $E/E_o = 1$.

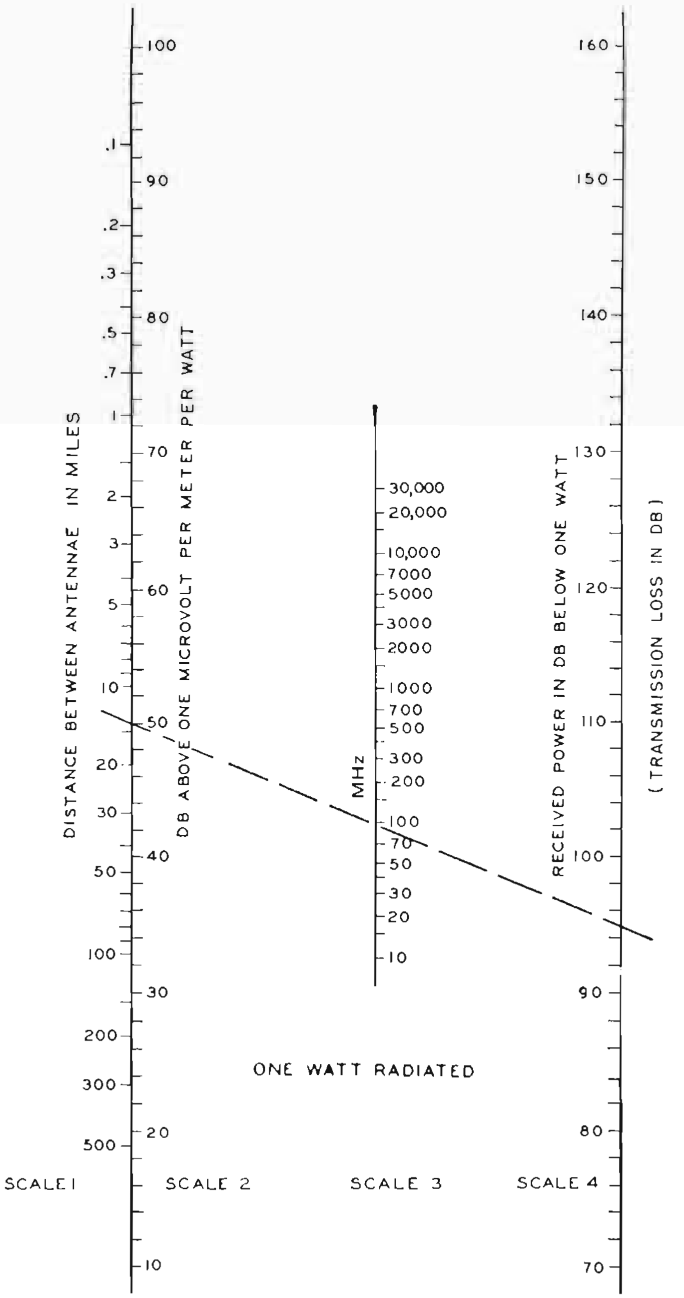


Fig. 3. Free-space field intensity and received power between half-wave dipoles.

When the antennas are horns, paraboloids, or multielement arrays, a more convenient expression for the ratio of the received power to the radiated power is given by

$$\frac{P_r}{P_t} = \frac{B_t B_r}{(\lambda r)^2}\left(\frac{E}{E_o}\right)^2 \qquad [4b]$$

where B_t and B_r are the effective areas of the transmitting and receiving antennas, respectively. This relation is obtained from Eq. 4 by substituting $g = 4\pi B/\lambda^2$, and is shown in Fig. 4 for free-space transmission when $B_t = B_r$. For example, the free-space loss at 4,000 MHz between two antennas of 10 sq. ft. effective area is about 72 dB for a distance of 30 miles.

The following formulae for the attenuation of field strengths and the loss between isotropic antennas in free space have been found useful in the engineering of space and terrestrial communication systems:

$$F_o = 102.8 + P_t - 20 \log r$$
$$L_b = 36.6 + 20 \log f + 20 \log r$$
$$L_b = 139.4 + 20 \log f - F$$
$$L_b = L + G_t + G_r$$
$$A_{iso} = 38.55 - 20 \log f$$
$$A = A_{iso} + G$$

where

F_o = free space field in dB above 1 μv/m in equatorial plane of dipole antenna

r = radius in miles from antenna to point of interest

P_t = power into antenna in dB relative to one kilowatt (dBk)

L_b = basic transmission loss in dB between the terminals of two lossless isotropic antennas

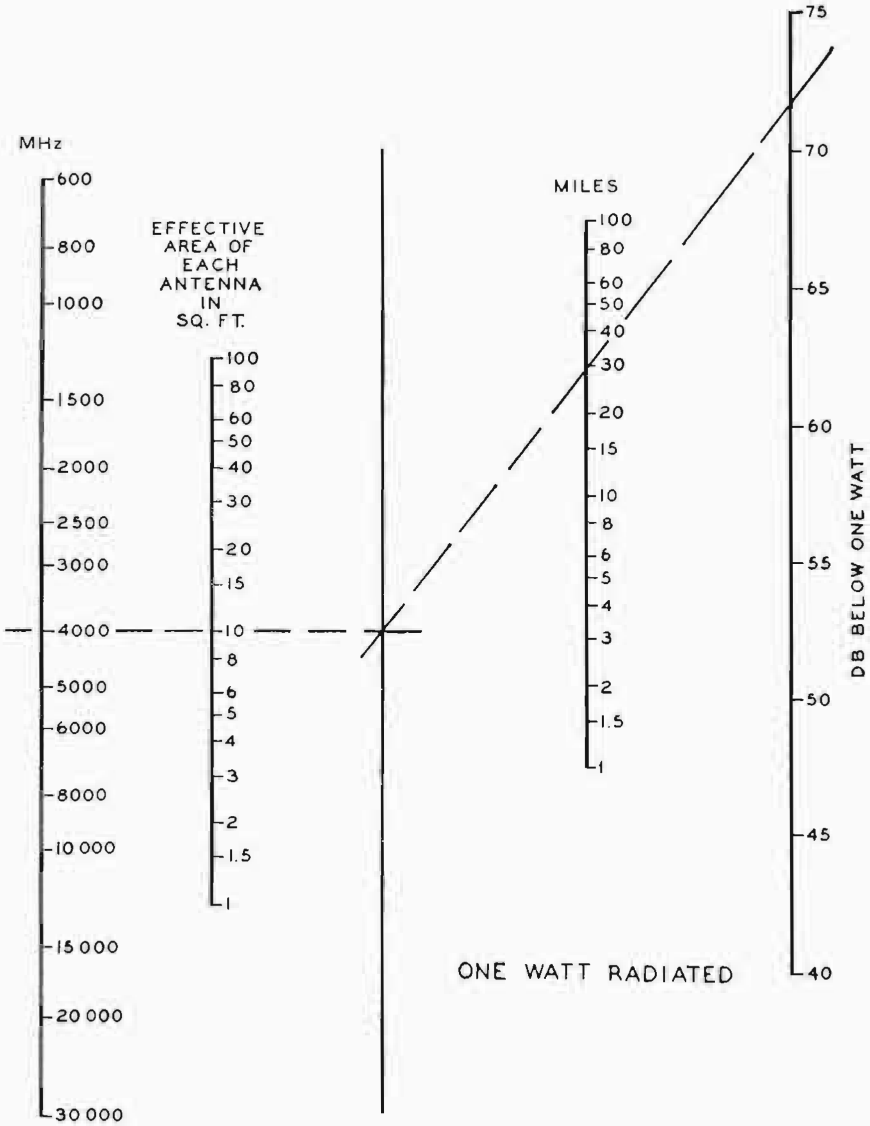


Fig. 4. Received power in free space between two antennas of equal effective areas.

G_t = gain in dB of transmitting antenna relative to isotropic
G_r = gain in dB of receiving antenna relative to isotropic
A_{iso} = area of isotropic antenna
A = effective area of antenna with gain G

PROPAGATION OVER PLANE EARTH[3,7]

The presence of the ground modifies the generation and the propagation of the radio waves so that the received field strength is ordinarily different than would be expected in free space. The ground acts as a partial reflector and as a partial absorber, and changes the phase of the refluted wave, and these properties affect the distribution of energy in the region above the earth.

Field Strengths Over Plane Earth

The geometry of the simple case of propagation between two antennas each placed several wavelengths above a plane earth is shown in Fig. 5. For isotropic antennas, for simple magnetic-doublet antennas with vertical polarization, or for simple electric-doublet antennas with horizontal polarization the resultant received field is[5,7]

$$E = \frac{E_o d}{r_1} + \frac{E_o d R e^{i\Delta}}{r_2} = E_o (\cos\theta_1 + R\cos\theta_2 e^{i\Delta}) \qquad [5]$$

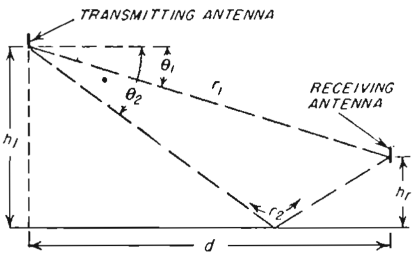


Fig. 5. Ray paths for antennas above plane earth.

For simple magnetic-doublet antennas with horizontal polarization or electric-doublet antennas with vertical polarization at both transmitter and receiver, it is necessary to correct for the cosine radiation and absorption patterns in the plane of propagation. The received field is

$$E = E_o (\cos^3\theta_1 + R\cos^3\theta_2 e^{i\Delta}) \qquad [5a]$$

where E_o is the free-space field at distance d in the equatorial plane of the doublet, R is the complex reflection coefficient of the earth, $j = \sqrt{-1}$; $e^{i\Delta} = \cos\Delta + j\sin\Delta$, and Δ is the phase difference between the direct wave received over path r_1 and the ground-reflected wave received over path r_2, which is due to the difference in path lengths.

For distances such that θ is small and the differences between d and r_1 and r_2 can be neglected, Eqs. 5 and 5a become

$$E = E_o (1 + Re^{i\Delta}) \qquad [6]$$

When the angle θ is very small, R is approximately equal to -1. For the case of two antennas, one or both of which may be relatively close to the earth, a surface-wave term must be added[3,4] and Eq. 6 becomes

$$E = E_o [1 + Re^{i\Delta} + (1 - R)Ae^{i\Delta}] \qquad [7]$$

The quantity A is the surface-wave attenuation factor which depends upon the frequency, ground constants, and type of polarization. It is never greater than unity and decreases with increasing distance and frequency, as indicated by the following approximate equation:[9]

$$A \simeq \frac{-1}{1 + j(2\pi d/\lambda)(\sin\theta + z)^2} \qquad [7a]$$

This approximate expression is sufficiently accurate as long as $A < 0.1$, and it gives the magnitude of A within about 2 dB for all values of A. However, as A approaches unity, the error in phase approaches 180°. More accurate values are given by Norton[7] where, in his nomenclature, $A = f(P,B)e^{i\phi}$.

The Eq. 7 for the absolute value of field strength has been developed from the successive consideration of the various components which make up the ground wave, but the following equivalent expressions may be found more convenient for rapid calculation:

$$E = E_o \left\{2\sin\frac{\Delta}{2} + j[(1 + R) + (1 - R)A]e^{i\Delta/2}\right\} \qquad [8]$$

When the distance d between antennas is greater than about five times the sum of the two antenna heights h_t and h_r, the phase difference angle Δ is equal to $4\pi h_t h_r/\lambda d$ radians. Also when the angle Δ is greater than about 0.5 radian the terms inside the brackets, which include the surface wave, are usually negligible, and a sufficiently accurate expression is given by

$$E = E_o \left(2\sin\frac{2\pi h_t h_r}{\lambda d}\right) \qquad [8a]$$

In this case the principal effect of the ground is to produce interference fringes or lobes, so that the field strength oscillates about the free-space field as the distance between antennas or the height of either antenna is varied.

When the angle Δ is less than about 0.5 radian, there is a region in which the surface wave may be important but not controlling. In this region $\sin \Delta/2$ is approximately equal to $\Delta/2$ and

$$E = E_O \frac{4\pi h_t' h_r'}{\lambda d} \qquad [8b]$$

In this equation $h' = h + jh_O$, where h is the actual antenna height and $h_O = \lambda/2\pi z$ has been designated as the minimum effective antenna height. The magnitude of the minimum effective height h_O is shown in Fig. 6 for sea water and for "good" and "poor" soil. "Good" soil corresponds roughly to clay, loam, marsh, or swamp, while "poor" soil means rocky or sandy ground.[9]

The surface wave is controlling for antenna heights less than the minimum effective height, and in this region the received field or power is not affected appreciably by changes in the antenna height. For antenna heights that are greater than the minimum effective height, the received field or power is increased approximately 6 dB every time the antenna height is doubled, until free-space transmission is reached. Ordinarily it is sufficiently accurate to assume that h' is equal to the actual antenna height or the minimum effective antenna height, whichever is the larger.

When translated into terms of antenna heights in feet, distance in miles, effective power in kilowatts radiated from a half-wave dipole, and frequency f in MHz per second, Eq. 8b becomes the following very useful formula for the rapid calculation of approximate values of field strength for purposes of prediction or for comparison with measured values:

$$E \simeq F \frac{h_t' h_r' \sqrt{P_t}}{3d^2} \qquad [8c]$$

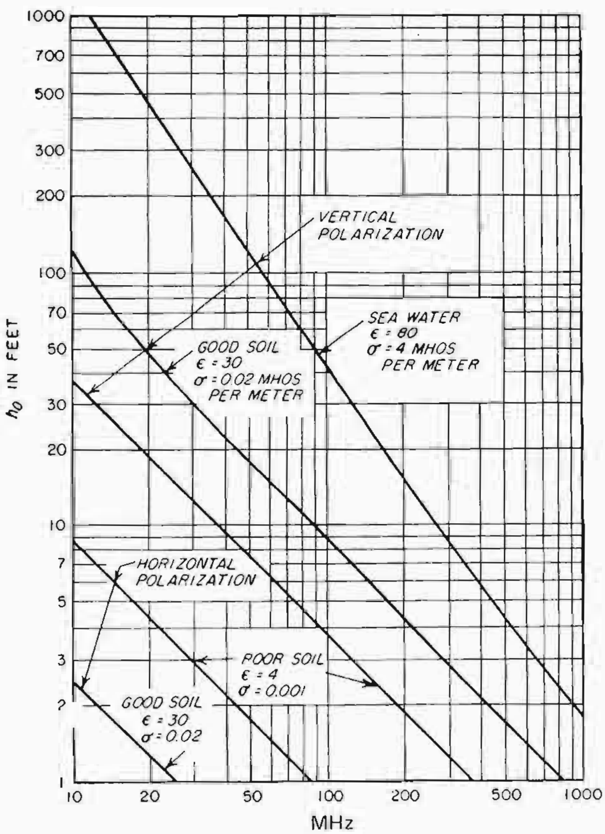


Fig. 6. Minimum effective antenna height.

Transmission Loss between Antennas Over Plane Earth

The ratio of the received power to the radiated power for transmission over plane earth is obtained by substituting Eq. 8b into 4, resulting in

$$\frac{P_r}{P_t} = \left(\frac{\lambda}{4\pi d}\right)^2 g_t g_r \left(\frac{4\pi h_t' h_r'}{\lambda d}\right)^2 = \left(\frac{h_t' h_r'}{d^2}\right)^2 g_t g_r \qquad [9]$$

This relation is independent of frequency, and is shown on Fig. 7 for half-wave dipoles ($g_t = g_r = 1.64$). A line through the two scales of antenna height determines a point on the unlabeled scale between them, and a second line through this point and the distance scale determines the received power for 1 watt radiated. When the received field strength is desired, the power indicated on Fig. 7 can be transferred to scale 4 of Fig. 3, and a line through the frequency on scale 3 indicates the received field strength on scale 2. The results shown on Fig. 7 are valid as long as the value of received power indicated is lower than that shown on Fig. 3 for free-space transmission. When this condition is not met, it means that the angle Δ is too large for Eq. 8b to be accurate and that the received field strength or power oscillates around the free-space value as indicated by Eq. 8a.[9]

PROPAGATION OVER SMOOTH SPHERICAL EARTH

Propagation within the Line of Sight

The curvature of the earth has three effects on the propagation of radio waves at points within the line of sight. First, the reflection coefficient of the ground-reflected wave differs for the curved surface

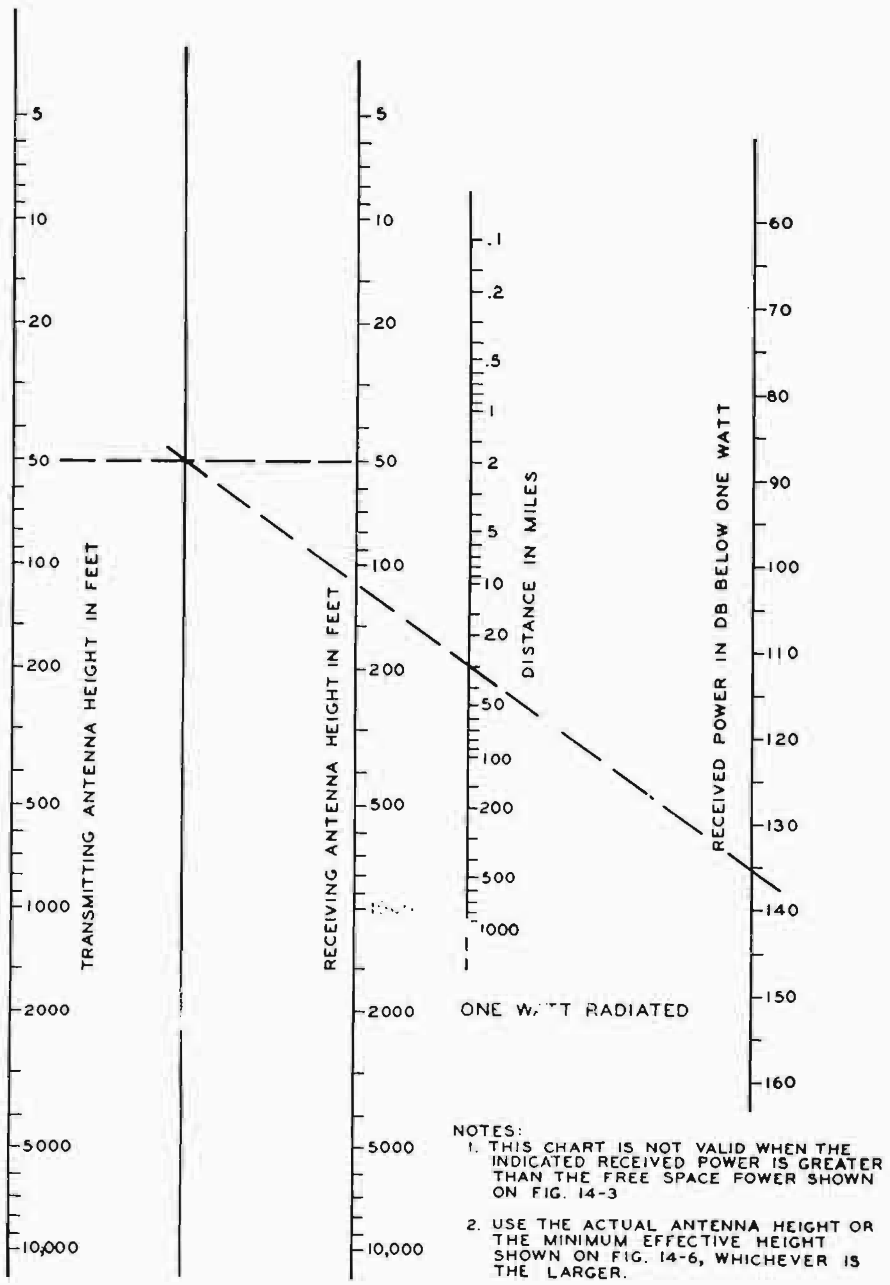


Fig. 7. Received power over plane earth between half-wave dipoles.

of the earth from that for a plane surface. This effect is of little importance, however, under the circumstances normally encountered in practice. Second, since the ground-reflected wave is reflected against the curved surface of the earth, its energy diverges more than would be indicated by the inverse distance-squared law and the ground-reflected wave must be multiplied by a divergence factor D. Finally, the heights of the transmitting and receiving antennas h_t' and h_r', above the plane which is tangent to the surface of the earth at the point of reflection of the ground-reflected wave, are less than the antenna heights h_t and h_r, above the surface of the earth, as shown in Fig. 8.

Under these conditions Eq. 6, which applies to larger distances within the line of sight and to antennas of sufficient height that the surface component can be neglected, becomes

$$E = E_0 (1 + DR' e^{i\Delta}) \qquad [10]$$

Similar substitutions of the values which correspond in Figs. 5 and 8 may be made in Eqs. 7 through 9. However, under practical conditions, it is generally satisfactory to use the plane-earth formulas for the purpose of calculating smooth-earth values. An exception to this is usually made in the preparation of standard reference curves, which are

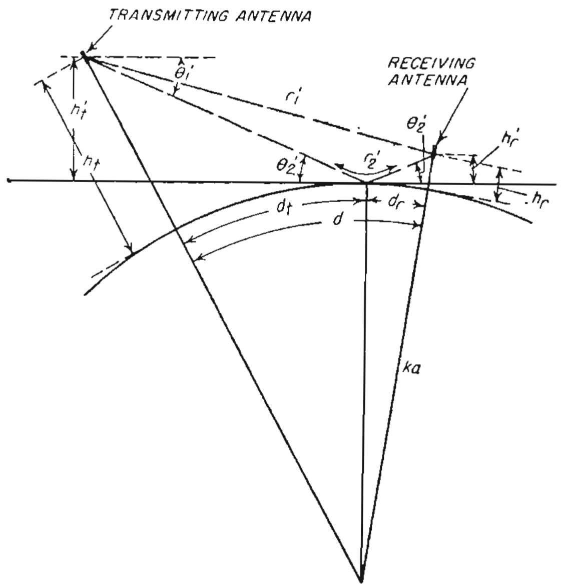


Fig. 8. Ray paths for antennas above spherical earth.

generally calculated by the use of the more exact formulas.[4-10]

Propagation beyond the Line of Sight

Radio waves are bent around the earth by the phenomenon of diffraction, with the ease of bending decreasing as the frequency increases. Diffraction is a fundamental property of wave motion, and in optics it is the correction to apply to geometrical optics (ray theory) to obtain the more accurate wave optics. In wave optics, each point on the wavefront is considered to act as a radiating source. When the wavefront is coherent or undisturbed, the resultant is a progression of the front in a direction perpendicular thereto, along a path which constitutes the ray. When the front is disturbed, the resultant front may be changed in both magnitude and direction with resulting attenuation and bending of the ray. Thus all shadows are somewhat "fuzzy" on the edges and the transition from "light" to "dark" areas is gradual, rather than infinitely sharp.

The effect of diffraction around the earth's curvature is to make possible transmission beyond the line of sight, with somewhat greater loss than is incurred in free space or over plane earth. The magnitude of this loss increases as either the distance or the frequency is increased, and it depends to some extent on the antenna height.

The calculation of the field strength to be expected at any particular point in space beyond the line of sight around a spherical earth is rather complex, so that individual calculations are seldom made. Rather, nomograms or families of curves are usually prepared for general application to large numbers of cases. The original wave equations of van der Pol and Bremmer[4] have been modified by Burrows[6] and by Norton[5,7] so as to make them more readily usable and particularly adaptable to the production of families of curves. Such curves have been prepared, but have not been included herein, in view of the large number of curves which are required to satisfy the possible variations in frequency, electrical characteristics of the earth, polarization, and antenna height. Also, the values of field strength indicated by smooth-earth curves are subject to considerable modification under actual conditions found in practice. For VHF and UHF broadcast purposes, the smooth-earth curves have been to a great extent superseded by curves modified to reflect average conditions of terrain.

Fig. 9 is a nomogram to determine the additional loss caused by the curvature of the earth.[9] This loss must be added to the free-space loss found from Fig. 3. A scale is included to provide for the effect of changes in the effective radius of the earth, caused by atmospheric refraction. Fig. 9 gives the loss relative to free space as a function of three distances: d_1 is the distance to the horizon from the lower antenna, d_2 is the distance to the horizon from the higher antenna, and d_3 is the distance between the horizons. The total distance between antennas is $d = d_1 + d_2 + d_3$.

The horizon distances d_1 and d_2 for the respective antenna heights h_1 and h_2 and for any assumed value of the earth's radius factor k can be determined from Fig. 10.

EFFECTS OF HILLS, BUILDINGS, VEGETATION, AND THE ATMOSPHERE

The preceding discussion assumes that the earth is a perfectly smooth sphere with a uniform or a simple atmosphere, for which condition calculations of expected field strengths or transmission losses can be computed for the regions within the line of sight and regions well beyond the line of sight, and interpolations can be made for intermediate distances. The presence of hills, buildings, and trees has such complex effects on propagation that it is impossible to compute in detail the field strengths to be expected at discrete points in the immediate vicinity of such obstructions or even the median values over very small areas. However, by the examination of the earth profile over the path of propagation and by the use of certain simplifying assumptions, predictions which are more accurate than smooth-earth calculations can be made of the median values to be expected over areas representative of the gross features of terrain.

Effects of Hills

The profile of the earth between the transmitting and receiving points is taken from available topogra-

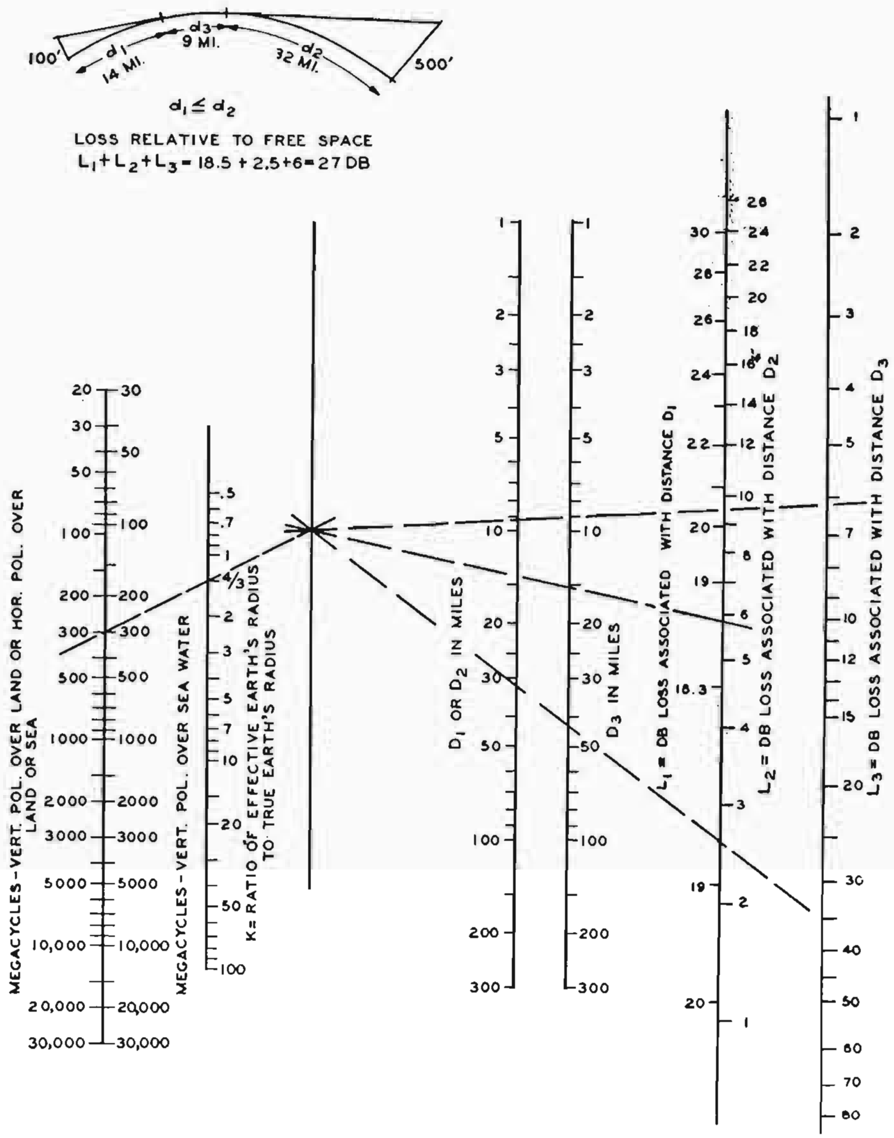


Fig. 9. Decibel loss beyond line of sight.

phic maps (available from the U.S. Geological Survey, Department of the Interior, Washington, D.C.) and is plotted on a special chart which provides for average air refraction by the use of a four-thirds earth radius, as shown in Fig. 11. The vertical scale is greatly exaggerated for convenience in displaying significant angles and path differences. Under these conditions vertical dimensions are measured along vertical parallel lines rather than along radii normal to the curved surface, and the propagation paths appear as straight lines. The field to be expected at a low receiving antenna at A from a high transmitting antenna at B can be predicted by plane-earth methods, by drawing a tangent to the profile at the point at which reflection appears to occur with equal incident and reflection angles. The heights of the transmitting and receiving antennas above the tangent are used in conjunction with Fig. 7 to compute the transmission loss or with Eq. 8c to compute the field strength. A similar procedure can be used for more distantly spaced high antennas when the line of sight does not clear the profile by at least the first Fresnel zone.[11]

Propagation over a sharp ridge or over a hill when both the transmitting and receiving antenna locations are distant from the hill may be treated as diffraction over a knife edge, shown schematically in Fig. 12a.[9-15] The height of the obstruction H is measured from the line joining the centers of the two antennas to the top of the ridge. As shown in Fig. 13, the shadow loss approaches 6 dB as H approaches 0, grazing incidence, and it increases with increasing positive values of H. When the direct ray clears the obstruction, H is negative, and the shadow loss approaches 0 dB in an oscillatory manner as the clearance is increased. Thus, a

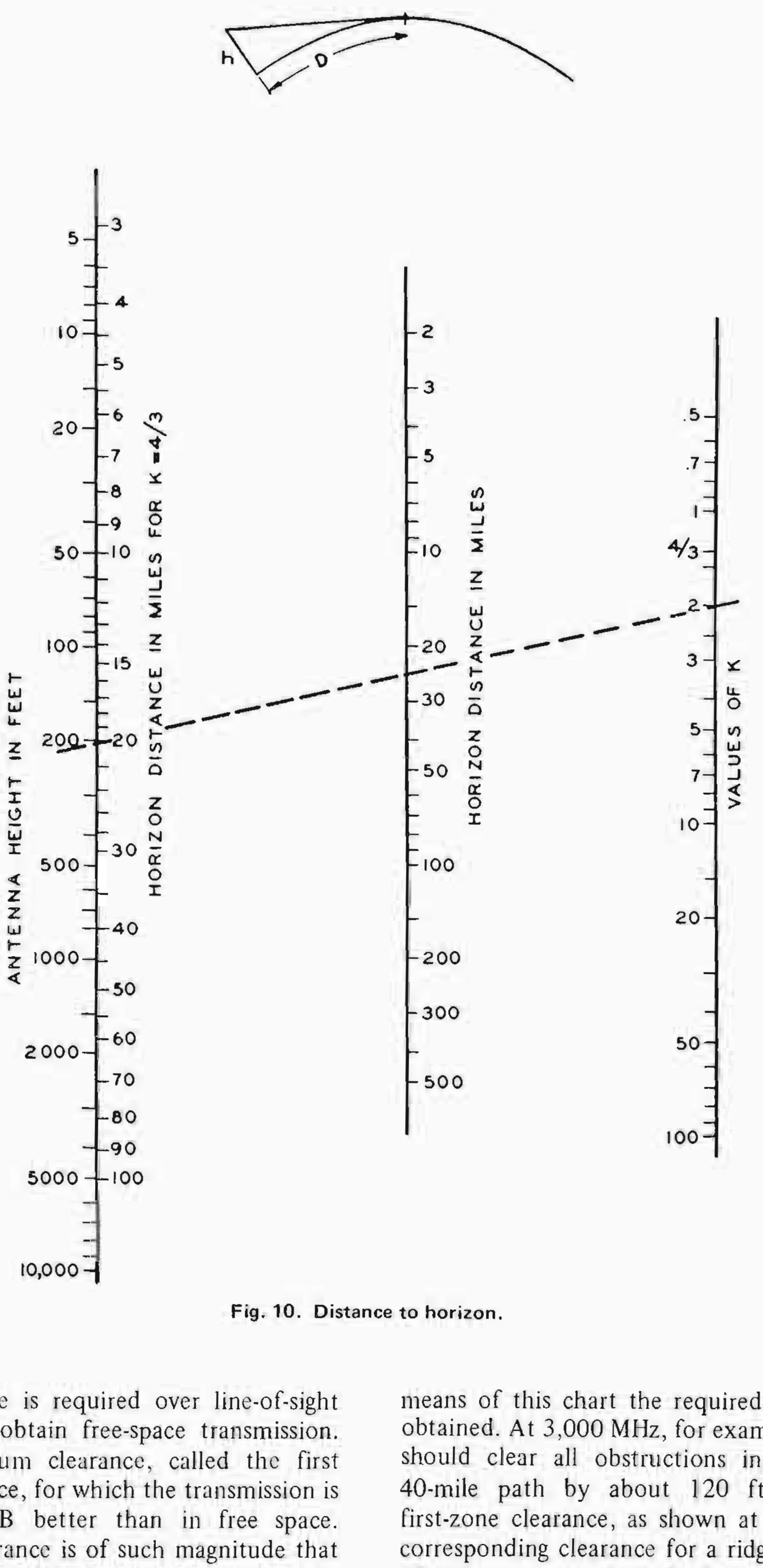


Fig. 10. Distance to horizon.

substantial clearance is required over line-of-sight paths in order to obtain free-space transmission. There is an optimum clearance, called the first Fresnel-zone clearance, for which the transmission is theoretically 1.2 dB better than in free space. Physically, this clearance is of such magnitude that the phase shift along a line from the antenna to the top of the obstruction and from there to the second antenna is about one-half wavelength greater than the phase shift of the direct path between antennas.

The locations of the first three Fresnel zones are indicated on the right-hand scale on Fig. 13, and by means of this chart the required clearances can be obtained. At 3,000 MHz, for example, the direct ray should clear all obstructions in the center of a 40-mile path by about 120 ft., to obtain full first-zone clearance, as shown at *C* in Fig. 11. The corresponding clearance for a ridge 100 ft. in front of either antenna is 4 ft. The locus of all points which satisfy this condition for all distances is an ellipsoid of revolution with foci at the two antennas.

When there are two or more knife-edge obstructions or hills between the transmitting and receiving antennas, an equivalent knife edge may be repre-

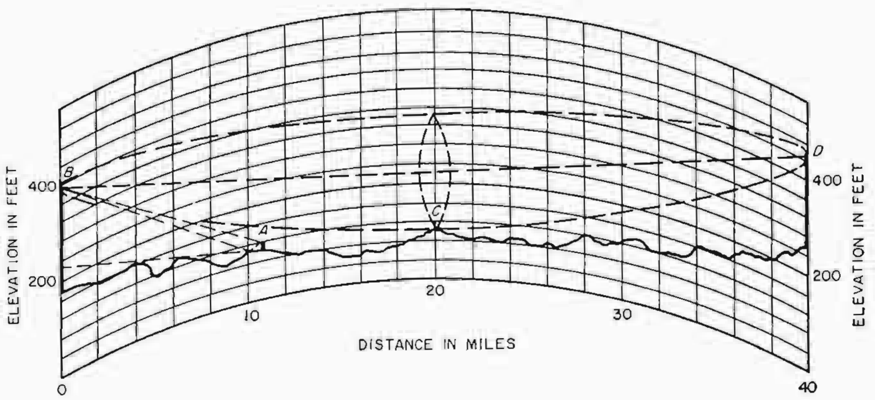


Fig. 11. Ray paths for antennas over rough terrain.

sented by drawing a line from each antenna through the top of the peak that blocks the line of sight, as in Fig. 12b.

Alternatively, the transmission loss may be computed by adding the losses incurred when passing over each of the successive hills, as in Fig. 12c. The height H_1 is measured from the top of hill 1 to the line connecting antenna 1 and the top of hill 2. Similarly, H_2 is measured from the top of hill 2 to the line connecting antenna 2 and the top of hill

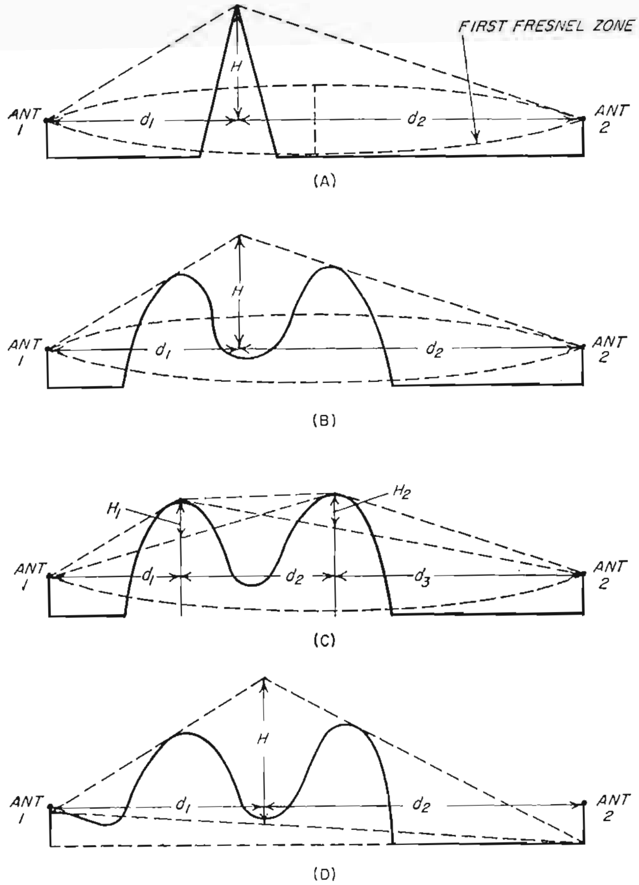


Fig. 12. Ray path for antennas behind hills.

1. The nomogram in Fig. 13 is used for calculating the losses for terrain conditions represented by Fig. 12a, b, and c.

The above procedure applies to conditions for which the earth-reflected wave can be neglected, such as the presence of rough earth, trees, or structures at locations along the profile at points where earth reflection would otherwise take place at the frequency under consideration or where first Fresnel-zone clearance is obtained in the foreground of each antenna and the geometry is such that reflected components do not contribute to the field within the first Fresnel zone above the obstruction. If conditions are favorable to earth reflection, the base line of the diffraction triangle should not be drawn through the antennas, but through the points of earth reflection, as in Fig. 12d. H is measured vertically from this base line to the top of the hill, while d_1 and d_2 are measured to the antennas as before. In this case Fig. 14 is used to estimate the shadow loss to be added to the plane-earth attenuation.[9]

Under conditions where the earth-reflected components reinforce the direct components at the transmitting and receiving antenna locations, paths may be found for which the transmission loss over an obstacle is less than the loss over spherical earth. This effect may be useful in establishing VHF relay circuits where line-of-sight operation is not practical. Little utility may be expected for mobile or broadcast services.[15]

An alternate method for predicting the median value for all measurements in a completely shadowed area is as follows:[16] (1) The roughness of the terrain is assumed to be represented by height H, shown on the profile at the top of Fig. 15. (2) This height is the difference in elevation between the bottom of the valley and the elevation necessary to

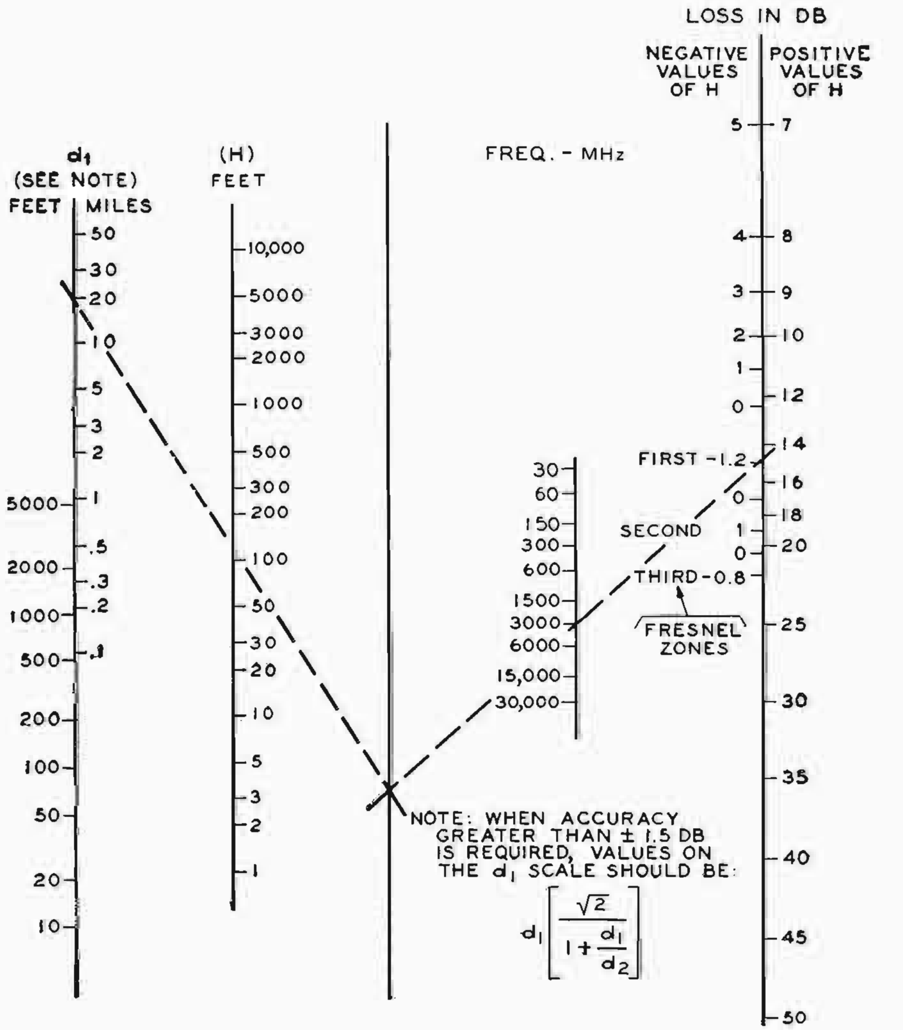


Fig. 13. Shadow loss relative to free space.

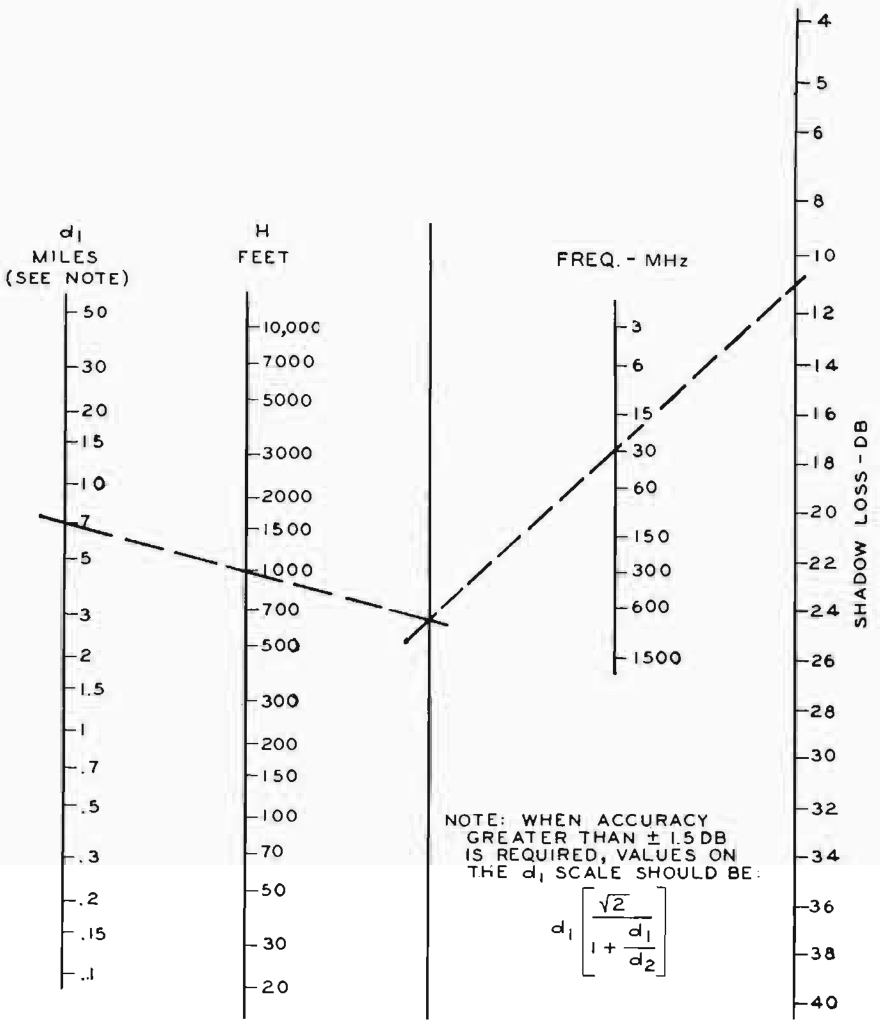


Fig. 14. Shadow loss relative to plane earth.

obtain line of sight with the transmitting antenna. (3) The difference between the measured value of field intensity and the value to be expected over plane earth is computed for each point of measurement within the shadowed area. (4) The median value for each of several such locations is plotted as a function of $\sqrt{H/\lambda}$.

These empirical relationships are summarized in the nomogram shown in Fig. 15. The scales on the right-hand line indicate the median value of shadow loss, compared with plane-earth values, and the difference in shadow loss to be expected between the median and the 90 percent values. For example, with variations in terrain of 500 ft. the estimated median shadow loss at 4,500 MHz is about 20 dB and the shadow loss exceeded in 90 percent of the possible locations is about 20 + 15 = 35 dB. This analysis is based on large-scale variations in field intensity and does not include the standing-wave effects which sometimes cause the field intensity to vary considerably in a matter of a few feet.

Effects of Buildings

Built-up areas have little effect on radio transmission at frequencies below a few megacycles, since the size of any obstruction is usually small compared with the wavelength and the shadows caused by steel buildings and bridges are not noticeable except immediately behind these obstructions. However, at 30 MHz and above, the absorption of a radio wave in going through an obstruction and the shadow loss in going over it are not negligible, and both types of losses tend to increase as the frequency increases. The attenuation through a brick wall, for example, may vary from 2 to 5 dB at 30 MHz and from 10 to 40 dB at 3,000 MHz, depending on whether the wall is dry or wet. Consequently, most buildings are rather opaque at

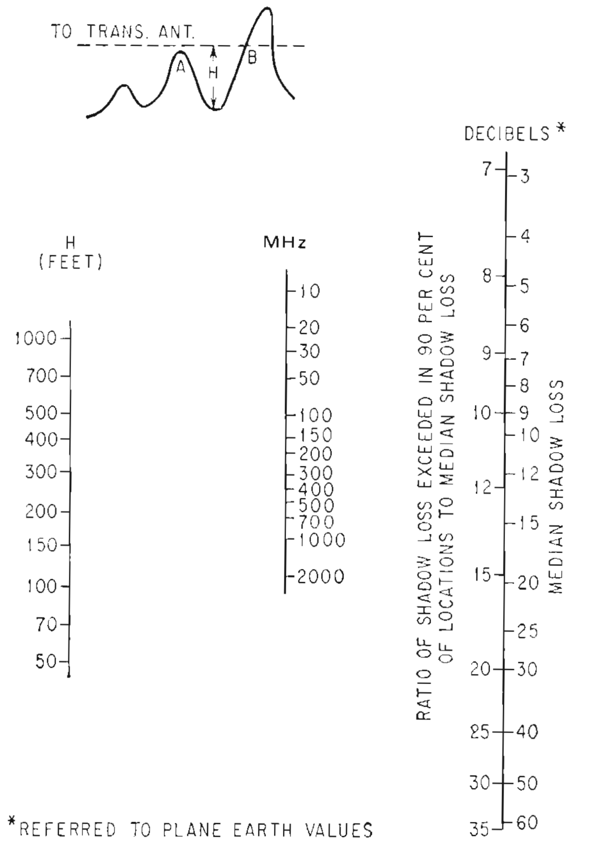


Fig. 15. Estimated distribution of shadow loss for random locations.

frequencies of the order of thousands of megacycles.

For radio-relay purposes, it is the usual practice to select clear sites, but where this is not feasible the expected fields behind large buildings may be predicted by the preceding diffraction methods. In the engineering of mobile- and broadcast-radio systems it has not been found practical in general to relate measurements made in built-up areas to the particular geometry of buildings, so that it is conventional to treat them statistically. However, measurements have been divided according to general categories into which buildings can readily be classified, namely, the tall buildings typical of the centers of cities on the one hand, and typical two-story residential areas on the other.

Buildings are more transparent to radio waves than the solid earth, and there is ordinarily much more back scatter in the city than in the open country. Both of these factors tend to reduce the shadow losses caused by the buildings. On the other hand, the angles of diffraction over or around the buildings are usually greater than for natural terrain, and this factor tends to increase the loss resulting from the presence of buildings. The quantitative data on the effects of buildings indicate that in the range of 40 to 450 MHz there is no significant change with frequency, or at least the variation with frequency is somewhat less than the square-root relationship noted in the case of hills. The median field strength at street level for random locations in Manhattan (New York City) is about 25 dB below the corresponding plane-earth value. The corresponding values for the 10 and 90 percent points are about −15 and −35 dB, respectively.[9,16,37,38]

Measurements in congested residential areas indicate somewhat less attenuation than among large buildings. In the Report of the Ad Hoc Committee[19] measurements between 4 and 10 miles from the transmitter, which include some large building areas and some open areas but are made up principally of residential areas, shown median values of 4 to 6 dB below plane earth for frequencies below 100 MHz and about 10 dB for frequencies near 200 MHz. More recent measurements at 850 MHz[20] show values of 15 to 26 dB below free space, which appear to be about 10 to 15 dB below plane earth. These measurements were not random, however, but were the maximum values of field between 10 and 30 ft. above the earth. The Television Allocations Study Organization has recently made similar measurements and has recommended appropriate values for the application of average curves to urban conditions.[37] The average effects for measurements taken in built-up areas have been accounted for in the preparation of the modified propagation curves of Figs. 19 and 20, and in new curves proposed for adoption by the FCC.[39]

Effects of Trees and Other Vegetation

When an antenna is surrounded by moderately thick trees and below treetop level, the average loss at 30 MHz resulting from the trees is usually 2 or 3 dB for vertical polarization and negligible with horizontal polarization. However, large and rapid variations in the received field strength may exist within a small area, resulting from the standing-wave pattern set up by reflections from trees located at a distance of as much as 100 ft. or more from the antenna. Consequently, several nearby locations should be investigated for best results. At 100 MHz the average loss from surrounding trees may be 5 to 10 dB for vertical polarization and 2 or 3 dB for horizontal polarization. The tree losses continue to increase as the frequency increases, and above 300 to 500 MHz they tend to be independent of the type of polarization. Above 1,000 MHz trees that are thick enough to block vision present an almost solid obstruction, and the diffraction loss over or around these obstructions can be obtained from Fig. 13 or 14.[9,10]

There is a pronounced seasonal effect in the case of deciduous trees, with less shadowing and absorption in the winter months when the leaves have fallen. However, when the path of travel through the trees is sufficiently long that it is obscured, losses of the above magnitudes may be incurred, and the principal mode of propagation may be by diffraction over the trees.

When the antenna is raised above trees and other forms of vegetation, the prediction of field strengths again depends upon the proper estimation of the height of the antenna above the areas of reflection and of the applicable reflection coefficients. For growth of fairly uniform height and for angles near grazing incidence, reflection coefficients will approach -1 at frequencies near 30 MHz. As indicated by Rayleigh's criterion of roughness, the apparent roughness for given conditions of geometry increases with frequency so that near 1,000 MHz even such low and relatively uniform growth as farm crops or tall grass may have reflection coefficients of about -0.3 for small angles of reflection.[20]

The distribution of losses in the immediate vicinity of trees does not follow normal probability law but is more accurately represented by Rayleigh's law, which is the distribution of the sum of a large number of equal vectors having random phases. This distribution is shown by the graph R of Fig. 23.

Effects of the Lower Atmosphere, or Troposphere

The dielectric constant of the air is slightly greater than 1 and is variable. It depends on the pressure and temperature of the air and on the amount of water vapor present, so that it varies with weather conditions and with the height above the earth. Whenever the dielectric constant varies with height, a horizontally traveling wave will be refracted and the path deviated from a straight line. A general solution of the problem for any possible distribution of dielectric constant with the height at any point along the radio path is virtually impossible because of a large number of variables involved, so some simplifying assumptions are needed in order to obtain an engineering solution which will permit the calculation of radio field strengths under known meteorological conditions. The complexity of this problem, together with the facts that detailed meteorological data which would permit calculation are no more readily available than radio data and that meteorological conditions are not readily predictable over long periods of time, has led to the statistical treatment of radio data, for the purpose of predicting long-distance effects and for the calculation of television service and inference, as in Statistical Evaluation of Propagation.

Stratification and Ducts

In the earlier work in this field the assumption was made that the air was horizontally stratified.[22,23] A simple engineering solution for average conditions can be obtained by making the additional assumption that the dielectric constant is a linear function of the height. On this basis, the effect of atmospheric refraction can be included in the expression of diffraction around the smooth earth, without discarding the useful concept of straight-line propagation, by multiplying the actual earth's radius by k, to obtain an effective earth's radius, where

$$k = \frac{1}{1 + a/2\,(\Delta\epsilon/\Delta h)} \qquad [11]$$

where a is the radius of the earth and $\Delta\epsilon$ is the change in dielectric constant in going from height h to $h + \Delta h$.[9]

Meteorological measurements indicate that the actual curve of dielectric constant vs. the height above the ground is frequently complex with one or more sharp bends, rather than a straight line as required in using the concept of an effective earth's radius. Theoretical considerations indicate that this curve can be approximated with reasonable accuracy by a series of straight lines as long as each individual line corresponds to a change in height of not more than 20 to 50 wavelengths. At 30 MHz height intervals of 600 to 1,500 ft. can be assumed. Since most of the radio energy transmitted between two ground stations travels in the first of these height intervals, the concept of effective earth radius is a useful one and is sufficiently accurate at 30 MHz. However, as the frequency increases, the straight-line approximation is valid over smaller and smaller height intervals. At 3,000 MHz, for example, this interval is only 6 to 15 ft. and the concept of effective earth radius becomes inadequate for analytical use. The rate of decrease of time-median measurements with distance is relatively consistent with theoretical propagation over an equivalent knife edge rather than with values calculated from assumed earth-radius factors.[16]

The dielectric constant normally decreases with increasing height, k is greater than unity, and the radio waves are bent toward the earth. Since the earth's radius is about 2.1×10^7 ft., a decrease in dielectric constant of only 2.4×10^{-8} per foot of height results in a value of $k = 4/3$, which is commonly assumed to be a good average value. When the dielectric constant decreases about four times as rapidly (or by about 10^{-7} per foot of height), the value of k becomes infinite. This means that, as far as radio propagation is concerned, the earth can be considered flat, since any ray that starts parallel to the earth will remain parallel.

When the dielectric constant decreases more rapidly than 10^{-7} per foot of height, radio waves that are radiated parallel to or at an angle above the earth's surface may be bent downward sufficiently to be reflected from the earth, after which the ray is again bent toward the earth, and so on.[8,9,24] The radio energy is thus trapped in a duct or waveguide between the earth and the maximum height of the radio path. For low-layer heights, this phenomenon is variously known as trapping, duct transmission, anomalous propagation, or guided propagation. Elevated layers of this type at heights up to several thousand feet are believed to be responsible for the occurrence of high field strengths at distances somewhat beyond the horizon from the transmitter. Theoretical studies indicate that attainable values of dielectric variation could produce the field strengths which are usually observed at such distances for small percentages of the time.[23] Confirmation has also been obtained through simultaneous observations of radio field strengths and of meteorological conditions.[22] In addition to the simple form of a duct where the earth is the lower boundary, trapping may also occur in an elevated duct. For example, in the lower segment of the duct the dielectric constant may decrease very slowly or may even increase, so that the waves travel upward into an upper segment in which the dielectric constant decreases more rapidly than 10^{-7} per foot and in which the waves are again refracted in a downward direction to encounter the lower segment again, after which the process is repeated. In the case of either of the two foregoing forms of ducts, if there were no losses of energy involved, the field strengths at any given distance would exceed the free-space fields, since the spread of energy is restrained in the vertical dimension. However, experience indicates that over land paths the losses are such that the received field strengths are seldom greater than the plane-earth values.[9]

Tropospheric Scatter

More recently a theory has been developed by Booker and Gordon[25,26] attributing the distant tropospheric fields to the scattering of the radio waves by atmospheric turbulence rather than by reflection from horizontal stratification. There is considerable activity, both theoretical and experimental, to determine whether elevated stratified layers, turbulence, residual effects from the normal gradients of dielectric constant, or contributions from all three, are responsible for the high field strengths beyond the line of sight, which are of concern in estimating the interference between television broadcast stations. In addition to these higher field strengths, which occur for small percentages of the time, there are rather consistent fields of about 80 dB below free space, which are largely independent of frequency. The rate of decrease for the median values of these fields is consistent with the theory of scatter from random turbulence.[22,28]

Atmospheric Fading

Variations in the received field strengths around the median value are caused by changes in atmospheric conditions. Field strengths tend to be higher in summer than in winter and higher at night than during the day for paths over land beyond the line of sight. As a first approximation, the distribution of long-term variations in field strength in decibels follows a normal probability law, as shown by graph N of Fig. 20.

Measurements indicate that the fading range reaches a maximum somewhat beyond the horizon and then decreases slowly with distance out to several hundred miles. Also the fading range at the distance of maximum fading increases with frequency, while at the greater distances where the fading range decreases, the range is also less dependent on frequency. Thus the slope of the graph N must be adjusted for both distance and frequency. This behavior does not lend itself to treatment as a function of the earth's radius factor k, since calculations based on the same range of k produce families of curves in which the fading range increases systematically with increasing distance and with increasing frequency. Methods for the statistical treatment of fading are described in Statistical Evaluation of Propagation.

Effects of the Upper Atmosphere, or Ionosphere

At the present time four principal layers or regions in the ionosphere are recognized. These are the E layer, the $F1$ layer, and the $F2$ layer, centered at heights of about 100, 200, and 300 km, respectively, and the D region, which is less clearly defined but lies below the E layer. These "regular" layers are produced by radiation from the sun, so that the ion density, and hence the frequency of the radio waves which can be reflected thereby, is higher in the day than at night. The characteristics of the layers are different for different geographic locations, and the geographic effects are not the same for all layers. The characteristics also differ with the seasons and with the intensity of the sun's radiation, as evidenced by the sunspot numbers, and the differences are generally more pronounced upon the $F2$ than upon the $F1$ and E layers. There are also certain random effects which are not fully explained. Some of these are associated with solar and magnetic disturbances. Other effects which occur at or just below the E layer have been established as being caused by meteors.

Briefly the presently recognized ionospheric effects can be grouped into seven major categories as follows: (1) D region, (2) regular E layer, (3) regular $F1$ layer, (4) regular $F2$ layer, (5) sporadic E layer, (6) meteoric, and (7) anomalous and irregular ionization. While categories (4), (5), and (6) may be expected to have some impact upon television service below 88 MHz, it is not expected to be serious. Moreover, the Rules of the FCC do not provide protection from this type of interference. For these reasons these effects will not be described in detail. A more extensive discussion, with references, appears in the Fifth Edition.

STATISTICAL EVALUATION OF PROPAGATION

In previous sections a partial statistical description has been given of the separate effects of terrain and of the variation of field strengths with time. Methods have been given for the prediction of the median field strengths to be expected for areas of size comparable to the gross features of the terrain, to which correction factors may be applied for the presence of buildings and vegetation and within which the fields may be described in terms of the strengths which are expected to be exceeded at a given percentage of locations. Alternatively, the distribution of field strengths as a function of the percentage of locations may be regarded as the probability, in percent, that a given field strength will be exceeded at a particular location within the area in question.

For the purpose of formulating a national plan for the assignment of television channels, it was felt to be impractical to consider in detail even the gross features of terrain, so that a statistical approach has been adopted to prepare families of propagation curves reflecting the median values found from all available data. Figs. 19 and 20 show the field strengths in decibels relative to 1 μv/m for 1 kw of effective radiated power to be expected at the best 50 percent of receiving locations for at least 50 percent of the time, for antenna heights from 100 to 10,000 ft. These field strengths are referred to as $F(50,50)$. The field strengths are based on an effective power of 1 kw radiated from a half-wave dipole in free space, which produces an unattenuated field strength at 1 mile of 102.8 dB above 1 μv/m (102.8 dBμ). The antenna height to be used with these charts in any particular case is the height of the center of the radiating element above the average height of the profile between 2 and 10 miles from the transmitter along the desired radial. Figs. 21 and 22 show the corresponding field strengths for 50 percent of the locations and 10 percent of the time $F(50,10)$. These families of curves, in conjunction with curve N of Fig. 20, may be used to estimate the service provided by television stations, in accordance with the following procedures. More recent propagation curves are available in FCC Report R 6602, but these have not yet been adopted into the FCC Rules.[39]

Prediction of Field Strengths for Television Service[19]

The field strengths required to provide television service are derived in the following manner: Test receivers of known characteristics as to sensitivity, selectivity, etc., are set up under typical home lighting and viewing conditions. Viewers then rate the relative acceptability of pictures at varying levels of input signals as obtained from a calibrated source, such as a television signal generator. The ratings are then analyzed statistically in terms of the percentages of viewers who rate the pictures as of a given quality, such as satisfactory, at each level of signal input. These results follow the normal probability law of curve N. It is impractical to satisfy 100 percent of viewers and values satisfying 50 to 70 percent are usually adopted for broadcast purposes. From the signal level thus selected and the known bandwidth and noise characteristics of the receiver, a required signal-to-noise ratio is determined. The required instantaneous fields F' to provide service of this quality are then derived by applying the proper values for the receiver-noise figure and the antenna and transmission line characteristics of the typical receiver installation. Similar procedures are used for deriving the desired to undesired ratio for various types of interfering signals. For this purpose the undesired signal is also fed into the receiver input in various ratios and at various frequencies in relation to the desired signal.[39]

The service at a particular location is said to be satisfactory if the minimum required field F', as above determined, is exceeded for some agreed percentage of the time T, such as 90 percent. This may be expressed as a T percent field strength $F'(T)$. The required time median field $F'(T = 50)$ to provide the minimum field for the desired percentage of time $F'(T)$ is given by the equation

$$F'(T) = F'(T = 50) + N'(T) \qquad [12]$$

$N'(T)$ is the time distribution factor in decibels for T percent of the time. This factor is assumed to be independent of location so that Eq. 12 can also be written

$$F'(L,T) = F(L,50) + N'(T) \qquad [12a]$$

and

$$F'(50,10) = F(50,50) + N'(T = 10) \qquad [12b]$$

Thus $N'(T = 10)$ can be determined for various frequencies, distances, and antenna heights, using the appropriate values of $F(50,10)$ shown in Fig. 18 and 19 and of $F(50,50)$ shown in Figs. 16 and 17. The distributions of field strengths for waves propagated via the troposphere are highly variable. For short periods of time during which the characteristics of the troposphere do not vary materially and the variation is due mainly to wave interference, the distribution may approach the Rayleigh distribution shown in curve R of Fig. 20. For longer periods of time the distributions of instantaneous values and of hourly median values assume complex forms of which the curve T of Fig. 20 is characteristic. Since the field strengths from which the curve was constructed have contributions from various modes of propagation and since the shape of the curve varies with such parameters as frequency, distance, transmitting antenna height, receiver location, etc., an exact expression is not

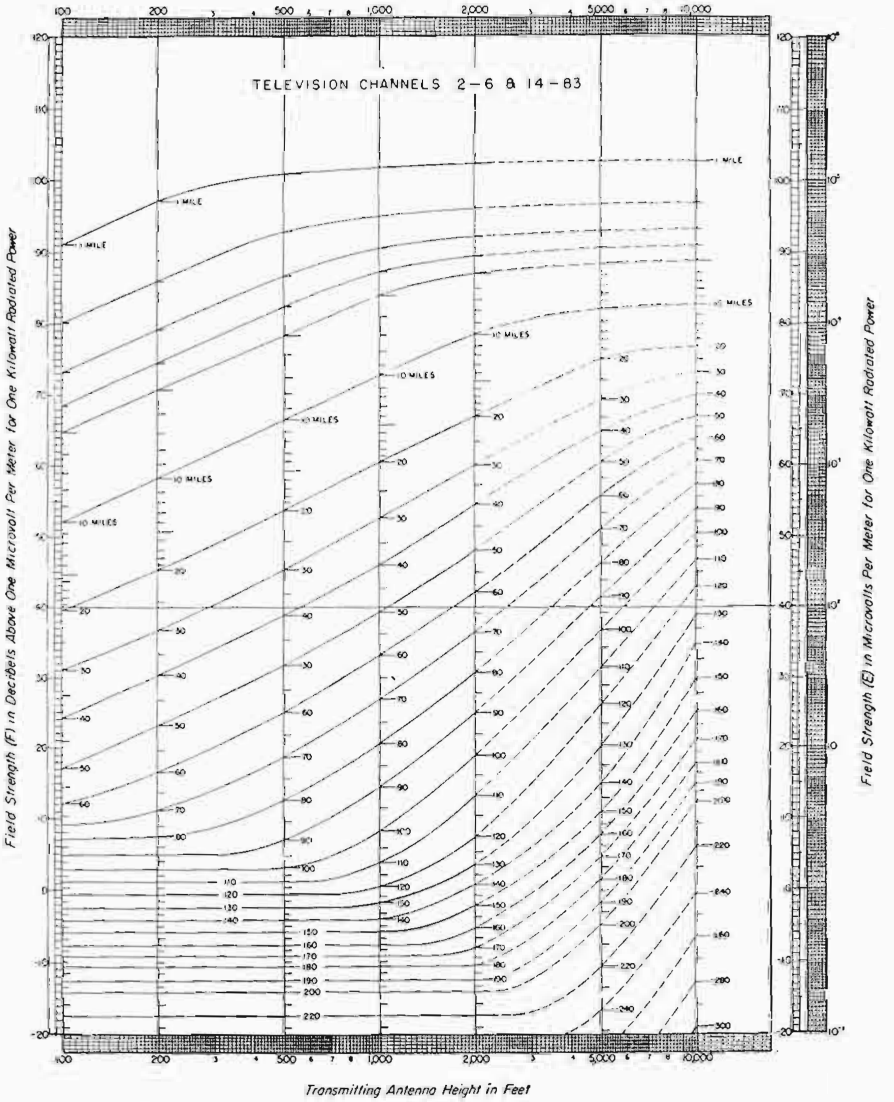


Fig. 16. $F(50,50)$ for television Channels 2 to 6, 14 to 83.

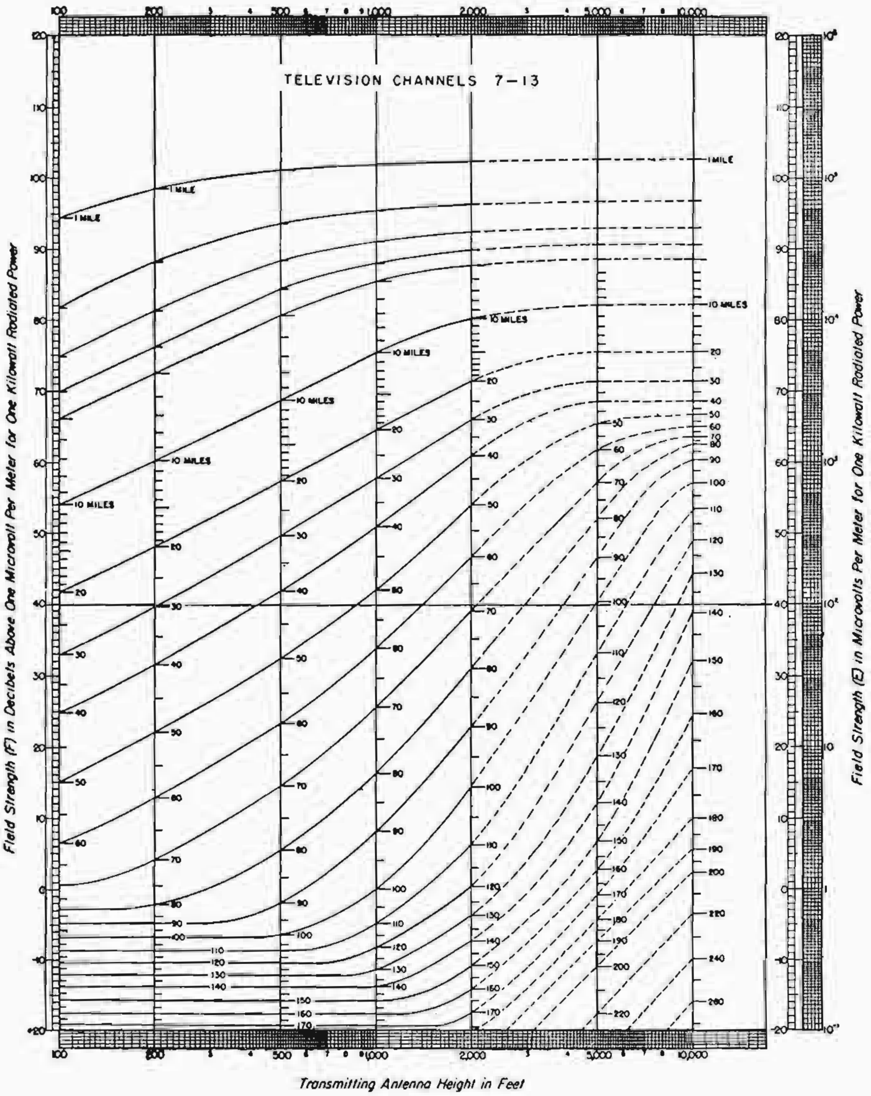


Fig. 17. $F(50,50)$ for television Channels 7 to 13.

possible. However, the curve is sufficiently close to the log normal curve N, so that with attention to the proper slope as determined by the appropriate value of $N'(T = 10)$, a log normal distribution can be used for the purposes of estimating service and interference. Thus $N'(T)$ for values of T other than 10 percent can be approximated by the formula

$$N'(T) = N'(T = 10)\,\frac{N(T)}{N(T = 10)} \qquad [13]$$

The percentage of locations L or the percentage probability L that the received fields $F'(L,T)$ will exceed the required T percent fields $F'(T)$ at a particular location within the area may be determined by the formula

$$N'(L) = F'(L,T) - P' - F(50,50) - N'(T) \qquad [14]$$

where $N'(L)$ is the location distribution factor in dB for L percent of locations or L percent probability at a particular location. For VHF television Channels 2 to 13, $N'(L)$ is equal to 0.53 times the values given by the normal probability curve N of Fig. 20, or $N'(L) = 0.53\ N(L)$. For UHF Channels 14 to 83

$$N'(L) = 0.75\ N(L)$$

$F'(L,T)$ is the minimum field strength, in dBμ, to be expected at the best L percent of locations for at least T percent of the time. P' is the effective radiated power in dB relative to 1 kw (dBk) radiated from a half-wave dipole. $F(50,50)$ is the median value of field strength in dBμ for an effective radiated power of 0 dBk for the area in question, as taken from Fig. 16 or 17, for the appropriate frequency, distance, and transmitting antenna height.

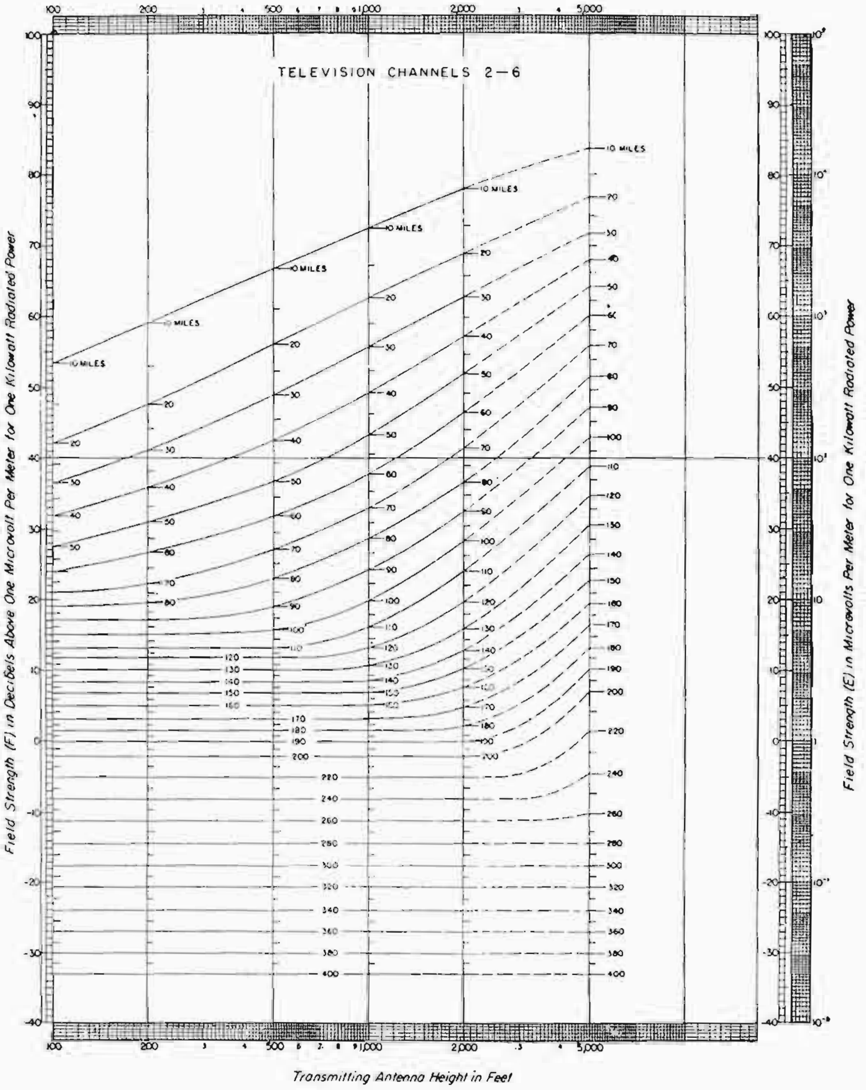


Fig. 18. *F* (50,10) for television Channels 2 to 6.

Example: For a television station operating on Channel 2, with an effective radiated power of 100 kw (20 dBk) and an average transmitting antenna height of 500 ft. for 2 to 10 miles along the radial, what percentage of locations in area 20 miles from the transmitter may be expected to have field strengths exceeding 74 dBμ for at least 90 percent of the time?

$$F'(L,90) = 74 \text{ dB}\mu$$
$$P' = 20 \text{ dBk}$$
$$F(50,50) = 54 \text{ dB}\mu \text{ (from Fig. 16)}$$
$$F(50,10) = 56 \text{ dB}\mu \text{ (from Fig. 18)}$$
$$N'(T=10) = 56 - 54 = 2 \text{ dB (from Eq. 12b)}$$
$$N'(T=90) = \frac{2(-20)}{20} = -2 \text{ dB (from Fig. 20 and Eq. 13)}$$

Substituting in Eq. 14

$$N'(L) = 74 - 20 - 54 - (-2) = +2$$
$$N(L) = \frac{N'(L)}{0.53} = 3.8$$
$$L = 41 \text{ percent (from Fig. 20)}$$

Several points at various distances along each radial can be calculated in the above manner and the distance at which desired percentages of locations, or desired probabilities, such as 50, 70, 90 percent, etc., occur may be determined by interpolation. Isoservice contours may be drawn by connecting the points having the same probability on each of the several radials.

Some analyses have been made of this problem using different characteristic slopes for values of T above and below 50 percent. Since values of T between 10 and 90 percent are usually of principal interest for broadcast purposes, a closer fit to the curve T can be made by this method within the range of interest.

Prediction of Service in the Presence of Interference from One Undesired Station[19]

The percentage of receiving locations, or the probability in percentage of L, at any given distance

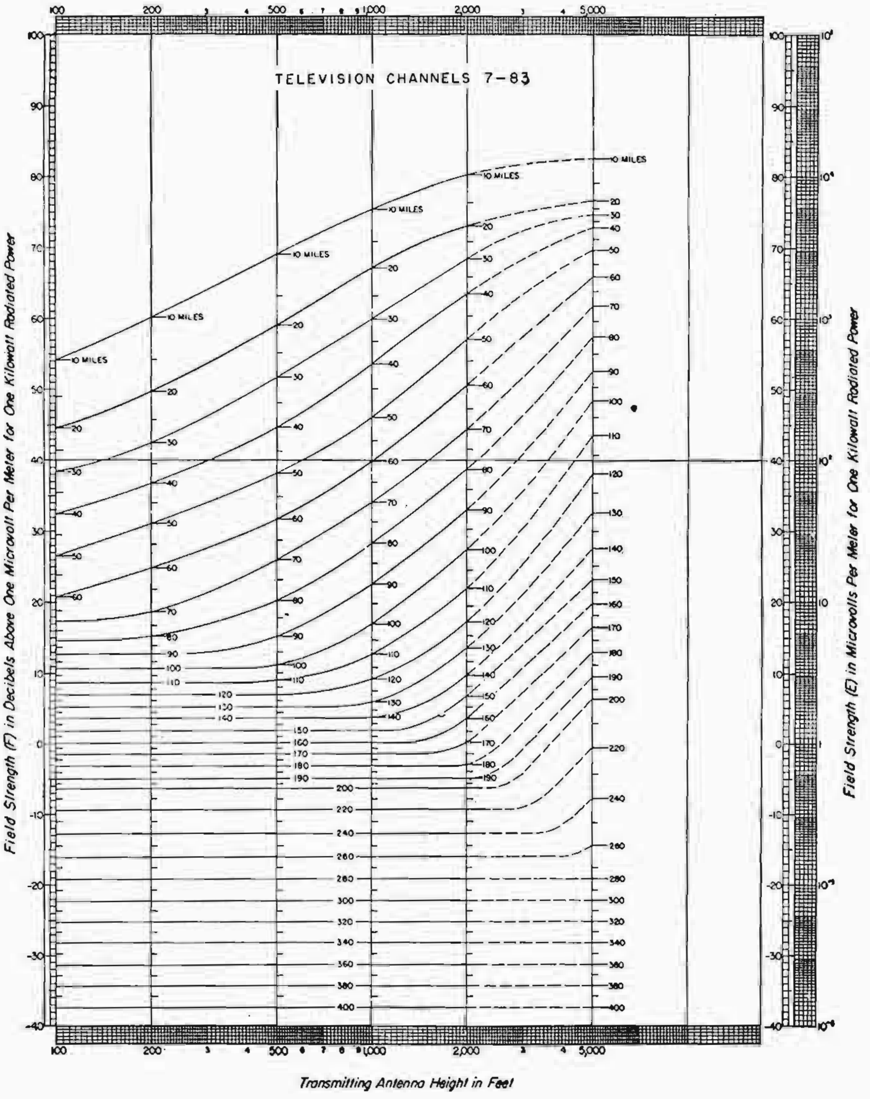


Fig. 19. *F* (50,10) for television Channels 7 to 83.

from a desired station and one undesired station (for which an acceptable ratio A in dB, of desired-to-undesired signals is exceeded for at least T percent of the time at the receiver input) can be determined from the following equation

$$n'(L) = A + P_u' - P_d' + g_{ru} - g_{rd} + F_u(50,50) - F_d(50,50) + \sqrt{N_d'(T)^2 + N_u'(T)^2} \qquad [15]$$

The subscript d denotes values applicable to the desired signal, and the subscript u denotes values applicable to the undesired signal. As above, the effective radiated powers of the desired and undesired station in P_d' and P_u' are expressed in dB above 1 kw radiated from a half-wave dipole. g_{ru} and g_{rd} are, respectively, the gains of the receiving antenna in the directions of the undesired and the desired transmitters. $F_u(50,50)$ and $F_d(50,50)$ are the indicated field strengths from the undesired and desired transmitters taken from the appropriate curves of Fig. 16 or 17. $N_d'(T)$ and $N_u'(T)$ are the time-distribution factors for the desired and the undesired field strengths, respectively. The factors for 90 percent of the time can be determined by subtracting the (50,10) field strength from the (50,50) field strength for each station at the proper distances on the appropriate curves of Figs. 16 to 19, in accordance with Eq. 12b. The factors for any other desired percentage of time may be found by the use of Eq. 13 and curve N of Fig. 20.

The answer for the factor $n'(L)$ is obtained in dB. For Channels 2 through 13, $n'(L) = 0.75\ N(L)$ and the percentage of locations at which the ratio A is exceeded may be read from the probability distribution, $N(L)$, as a function of L in Fig. 20. For Channels 14 through 83, $n'(L) = 1.05N(L)$.

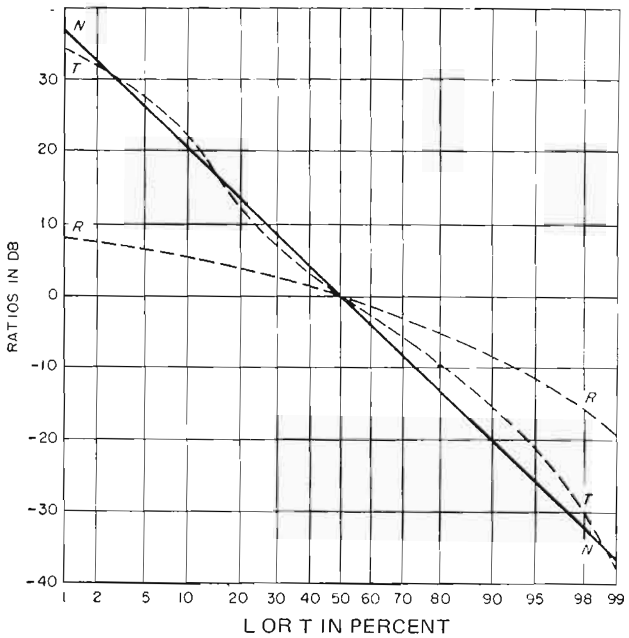


Fig. 20. Time and location distributions.

It will be seen from Eq. 15 that the time-distribution factor applicable to two fading signals combines as the root sum square of the individual factors. When the fading of the undesired signal is three or more times the fading of the desired, the latter fading may be neglected with negligible error. Thus, the charts for the desired signal $F(50,50)$ and the tropospheric charts $F(50,10)$ for the undesired, with appropriate corrections for the effective radiated powers of the two stations and the directional patterns of the receiving antennas, can be used to determine directly the isoservice contours for 90 percent of the time and 50 percent of the locations.

The approximate method, in which the fading of the desired signal is neglected, can be expressed in the following formula:

$$n'(L) = A + P_u' - P_d' + g_{ru} - g_{rd} + F_u(50,10) - F_d(50,50) \qquad [16]$$

This formula permits the approximate method to be applied to the case where it is desired to locate the contour at which an acceptable ratio is exceeded for a percentage of the locations other than 50 percent.

Prediction of Service in the Presence of Interference from Several Sources

This problem was studied by the Ad Hoc Committee and four methods of calculating the combined effects of several interfering signals were reported in vol. 2 of the report of the Committee.[11] The methods involve somewhat different assumptions as to the subjective effects of interference and as to the time and space correlations of the various signals. Reference should be made to that report for details as to the assumptions made and the limitations involved in each method. The application of three of these methods is somewhat tedious, and since the results obtained by all four methods are reasonably consistent, just one relatively simple method will be described in detail.

This method involves the conclusion that the probability of a receiving location receiving satisfactory service for a particular percentage of time in the presence of a plurality of interfering signals is equal to the product of the probabilities that satisfactory service will be received for the same percentage of time in the presence of each of the interfering signals alone. Thus the values of $n'(L)$ for the desired signal and each of the interfering signals are computed individually from Eq. 15 or 16, and the resulting probability found by multiplying the individual values together. Take as an example the case of two interfering signals, the first of which yields a location probability of 0.90 (90 percent of the locations), and the second of which yields a location probability of 0.70, at a given point. The probability of receiving satisfactory service of the same time availability at the same point is 0.90 X 0.70 = 0.63, or 63 percent.

Distribution and Summation of Service

The method of describing service areas by isoservice contours, while relatively simple and useful for some purposes, is in fact a rather incomplete method which may lead to erroneous conclusions unless applied with understanding. Contours are frequently used to describe the outer limits of recognized grades of service for administrative purposes. The treatment of an isoservice contour as a limit of service, rather than as a contour of equal service availability, leads to errors in estimating service availability as well as the number of people who are expected to receive service. The foregoing analysis shows that in any small area only a percentage of the residents is expected to have service of a given quality available and assuming that a typical receiving set and antenna will be used, only a percentage of the population, rather than the total population of the area, should be included in a population count. Also, the percentage varies from area to area within the contour, increasing generally with decreasing distance from the desired transmitter, so that to obtain a fairly reliable count, variable percentages should be used for different areas.

As the distance from the desired transmitter increases, the quality of available service does not change abruptly as might be inferred from the drawing of service contours but shades gradually from service of generally high quality to service of low quality. Thus it is proper to represent the expected quality of service as a continuous function of distance. Fig. 21 shows the percentages of locations at various radii from a television station, at 63 MHz, with 100 kw ($P' = 20$ dBk) radiated from a 500-ft. antenna, which would be expected to receive service for at least 90 percent of the time in the presence of receiver and cosmic noise only. In Fig. 22 the percentages of locations in each annular ring at the radius r from the transmitter have been multiplied by the area of the ring, to produce service distributions in terms of integrated service area Y, as a function of distance from the transmitter. The thickness of each ring has been taken as $1/2\pi$ so that the ring area is equal to the radius in each case. The curve labeled $P' = 20$ dBk corresponds to the conditions of Fig. 21. Curves for powers of $P' = 0$ dBk, $P' = 10$ dBk, and $P' = 30$ dBk are also shown to illustrate how the service varies with changes in the effective radiated power. In order to estimate the equivalent service area provided by the station, the area under the curve is integrated by the use of a planimeter or in accordance with the formula

$$\text{Service area} = 2\pi \int_0^\infty Yr\,dr$$

As an additional step, the integrated service area may be represented graphically by a circle of equivalent radius. These radii are indicated for each power on Fig. 22 by the dashed lines labeled d_{SO}.

A similar approach can be used for cases in which it is desired to estimate the resulting service areas in the presence of interference from other television stations and other sources. Needless to say, the procedure becomes exceedingly complex in particular cases where there is a lack of symmetry between the sources of interference and the various radials along which service is to be estimated. In addition, as stated above, the available propagation data are subject to large probable errors when used to estimate service for any particular station. For these reasons, application of the procedures has so far been limited to broad studies of channel utilization, which are useful in developing station assignment plans and rules.

As illustrative of the methods of estimating service in the presence of several sources of interference, assume a case in which co-channel and adjacent-channel stations are assigned in a saturated triangular lattice, as shown in the inset of Fig. 23. The probability of receiving service of a given quality for a specified percentage of time from the desired station in the presence of the several sources of interference can be calculated for particular receiving locations along a radial in accordance with

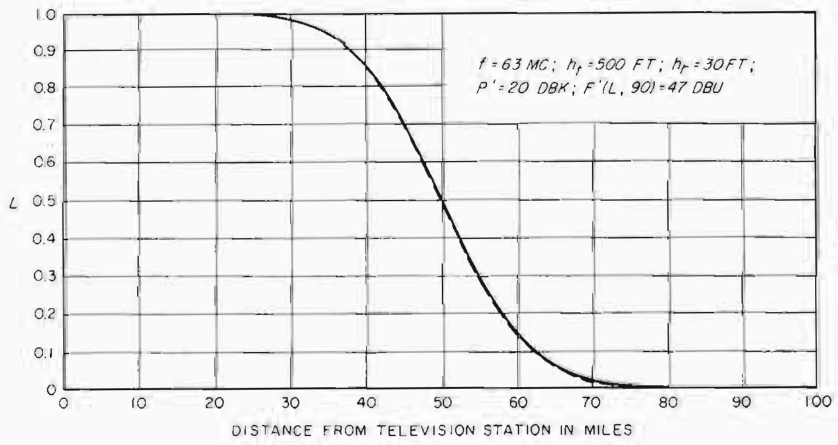


Fig. 21. Distribution of noise-limited service probability.

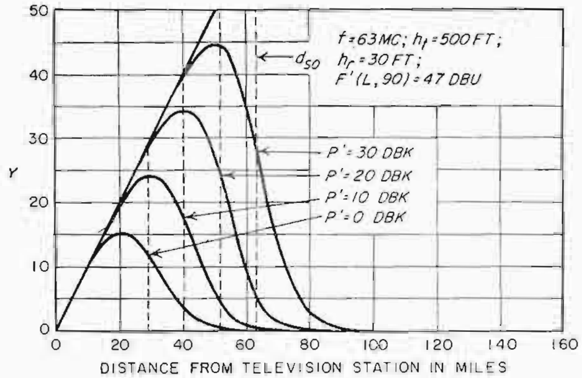


Fig. 22. Distribution of noise-limited service.

the four methods. The resulting distributions are shown in Fig. 23. Fig. 24 shows the corresponding area probability and total areas for the four methods. It can be seen that the simple method described in Appendix C of vol. 2 of the Ad Hoc Report, and described previously herein, yields smaller estimates of service than do the other three methods.

Using this concept of total area it is possible to estimate the probable efficiency of utilization of the available television channels for various combinations of station power, antenna heights, and station spacings. While it is known that as a practical matter the station assignment pattern will follow the pattern of cities rather than the idealized and somewhat more efficient lattice, from the standpoint of area coverage, useful conclusions as to station-spacing requirements have been drawn from such studies.[19] Subsequent studies, however, by the Television Allocations Study Organization (TASO)[37] have indicated that some modification of the concept of using a standard receiving installation is appropriate for studies such as the foregoing. That within reasonable limits the quality of the receiving installation will be upgraded to the point where the observer is receiving a picture which he considers to be satisfactory. This tends to flatten out the lower end of the location distribution curve as well as the rate of decay in picture quality with increasing distance from the transmitter, with a more rapid decay as the locations of very poor signal are reached, at which it is no longer economically feasible to upgrade the installation to the extent required. This effect tends to increase the validity of the use of field strength contours to specify service limits.

SELECTION OF STATION SITES

The sites for the antennas of permanent relay stations and for television broadcast stations should be selected carefully, as the success of the operation depends to a great extent upon the care and foresight used in selecting the sites. In previous sections, quantitative information has been given which will assist in estimating the transmission loss incurred over television relay links under specified conditions and in estimating the probable service obtained from a television broadcast station. The purpose of this section is to give a few guides which engineers have found to be of assistance in selecting sites which will yield optimum results for the area in question.

Selection of Sites for Radio Relay Stations

A large amount of preliminary work is necessary in laying out a radio relay system. For microwave

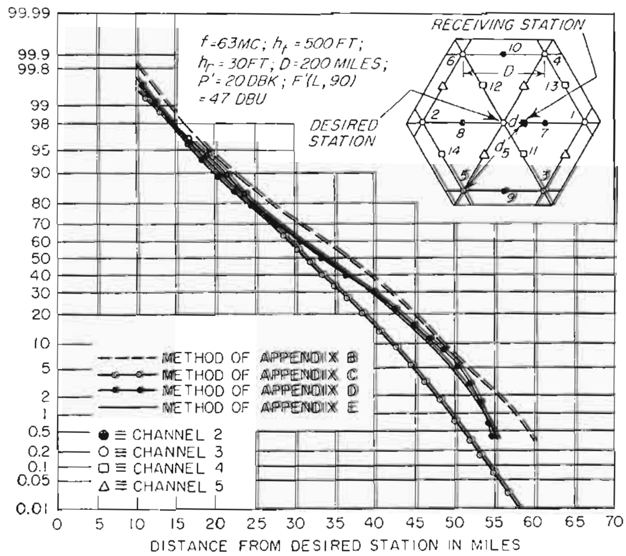


Fig. 23 Distribution of service probability limited by interference.

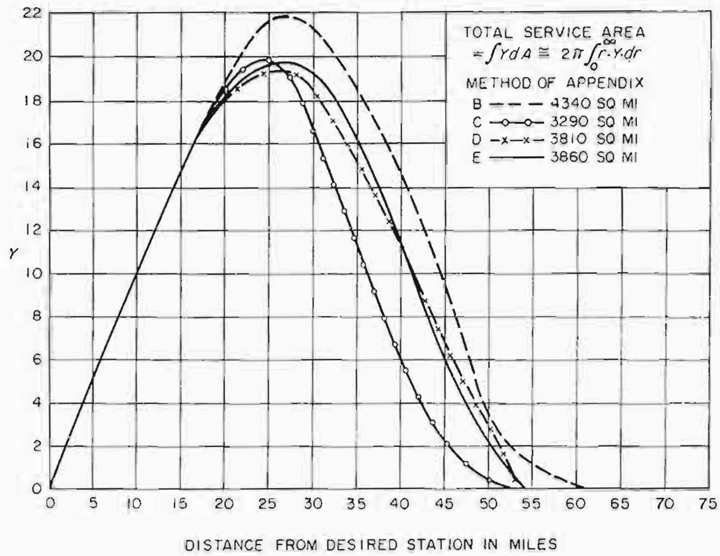


Fig. 24. Distribution of service limited by interference.

systems it is usual that adjacent sites have a clear line-of-sight path between their antennas. To determine station locations, the best available topographical maps should be used. These, however, usually will not be adequate for final station location, particularly since for some areas no maps are available and for others existing maps may be found to be inaccurate. In some cases, aerial surveys have been used. Before finally selecting a site, radio transmission tests should be made with the adjacent sites. For these tests, portable towers with parabolic antennas and transmitters mounted on carriages which can be moved up and down the towers are used.

If the intervening terrain is rough and the intermediate clearances satisfactory, no large change in received signal will be found as the antennas are raised and lowered on the towers, until the antennas are lowered so far that clearance of the first Fresnel zone no longer exists.

In some cases, however, substantial earth reflection may be encountered, and this will be evidenced by substantial variations in received signal strength as the antennas travel up and down. It is desirable that transmission be largely confined to a single ray arriving from the distant station. If one or more additional rays are present, owing to reflection from the earth at some intervening point or points, the resultant signal will be that due to the combination of rays and will depend on their relative phase relations. Sites showing such earth reflection are not desirable, as substantial amounts of fading may be expected at times when changes in the atmosphere cause the amount of bending of the waves to change with consequent changes in phase relation of the arriving rays. If such variations are observed in these path tests, the intervening terrain should be inspected with a view to determining whether by moving one or both sites a short distance the reflecting earth surface can be avoided.

It is usually difficult to recognize the areas which are responsible for earth reflection, but a few guides can be given to assist in inspection at the site. If the suspected area is fairly flat, areas of a size equivalent to an ellipse capable of reflecting the wavefront over the first Fresnel zone should be inspected. Smaller areas are capable of supporting a reflection, but in general the strength of the reflected component will be decreased. When the intervening area is rolling or irregular, the determination of the location and size of the responsible area is still more difficult. It will also be necessary to decide whether the surface roughness is too great to support reflection at the frequency of interest. For this purpose, Rayleigh's criterion of roughness is used. The surface is considered to be smooth if $h \sin \theta < \lambda/8$, where h is the average height of the features of roughness, θ is the angle of incidence of the wave to the reflecting surface, and λ is the wavelength expressed in the same units as h.

In one case where transmission was to take place over extensive salt flats which are smooth and of high conductivity, it was not possible to avoid earth reflection by any reasonable change in the station locations. The fading due to such reflection was minimized in this case by employing very low antennas at one end of the section and high mountain-top antennas at the adjacent station. With this arrangement, the earth-reflection point was close to one of the stations thereby minimizing the change in phase relations between the direct and reflected rays during periods of varying transmission conditions.[17]

Selection of Sites for Television Broadcast Stations

Sites for the antennas of television broadcast stations should be so chosen that at least first Fresnel-zone clearance is obtained over all near obstructions in the directions of the areas to be served. Thus hills with gentle slopes or with foothills which prevent such clearance should be avoided. Not only will the field strengths be reduced in the shadows of foothills and along the slope of the hill, owing to the low height of the antenna above the effective plane of reflection, but also nonuniform fields and ghosts may occur in distant areas which are within the line of sight of the transmitting antenna. Similarly, sites in the midst of tall buildings should be avoided unless the antenna can be placed well above them.

If relief maps of the proposed site are available or can be made, small grain-of-wheat lamps placed at the antenna location will assist in locating shadowed areas. Both theory and experience indicate that the radio shadows are of lesser length than the optical shadows.[37]

Profiles, taken from topographic maps, should be drawn for at least eight radials from the antenna site, and for any additional radials which from inspection appear to present particular problems, in the manner shown in Fig. 11. Estimates of the areas of service should be made, both by the above methods and the methods provided by the Rules of the FCC.[40]

In doubtful areas, actual measurements should be made over these radials, either from existing transmitters at or near the chosen site which have frequencies near the chosen frequency or from test transmitters installed for the purpose. If test transmitters are pulsed and mobile measurements are to be made, the pulse repetition rate should be sufficiently rapid so that the peak detector of the field-strength meter can distinguish between the pulse peaks and the peaks caused by standing-wave patterns through which the meter will pass. Otherwise the meter will indicate the peaks of such standing-wave patterns rather than the desired average value which is indicative of the strength of the incident fields.

There is as yet no unanimity among engineers as to the preferred method of making field-strength surveys for television broadcast stations. Because of the relative ease and dispatch with which the area may be covered, some prefer the taking of mobile measurements with a simple nondirectional antenna mounted on the vehicle at about 10 ft. above ground. Because of the difficulty of estimating height gain and antenna gain of the typical receiving antenna in a typical location as compared with the simple mobile measuring antenna under the nonideal conditions to be found in all service areas, many engineers prefer to obtain relatively fewer measurements under conditions which they consider to be more nearly typical for broadcast receiving installations. For this purpose a collapsible mast carrying a typical antenna is mounted on a vehicle and measurements are made at various accessible locations along each of the radials. Several techniques have been employed with this type of measuring equipment: (1) maintaining the antenna at a fixed height during a short run,[33] (2) clusters of spot-sampling measurements with the antenna at a fixed height,[34] or (3) moving the antenna vertically at a fixed location.[20] All three techniques have specific advantages and disadvantages. Spot sampling, which is most nearly analogous to the typical receiver situation, also presents the most difficulty in obtaining a significant sampling of the existing fields. All measurements should be made in accordance with the standards of the Institute of Radio Engineers.[41]

REFERENCES

1. Kraus, J. D.: "Antennas," 1st ed., McGraw-Hill Book Company, Inc., 1950.
2. Reference Data for Radio Engineers, 4th ed., Federal Telephone and Radio Corporation, 1956.
3. Eckersley, T. L.: Ultra-short-wave Refraction and Diffraction, *J. Inst. Elec. Engrs.*, p. 286, March, 1937.
4. van der Pol, Balth, and H. Bremmer: The Diffraction of Electromagnetic Waves form an Electrical Point Source Round a Finitely Conducting Sphere, with Applications to Radiotelegraphy and to Theory of the Rainbow, part 1, *Phil. Mag.*, July, 1937; part 2, *Phil. Mag.*, November, 1937.
5. Norton, K. A.: The Propagation of Radio Waves over a Finitely Conducting Spherical Earth, *Phil. Mag.*, June, 1938.
6. Burrows, C. R., and M. C. Gray: The Effect of the Earth's Curvature on Groundwave Propagation, *Proc. IRE*, p. 16, January, 1941.
7. Norton, K. A.: Ground Wave Intensity over a Finitely Conducting Spherical Earth, *Proc. IRE*, p. 623, December, 1941.
8. "The Propagation of Radio Waves through the Standard Atmosphere," Summary Technical Report of the Committee on Propagation, vol. 3, National Defense Research Council, Washington, D.C., 1946, published by Academic Press.
9. Bullington, K.: Radio Propagation at Frequencies above 30 Mc, *Proc. IRE*, p. 1122, October, 1947.
10. "Radio Wave Propagation," Summary Technical Report of the Committee on Propagation of the National Defense Research Committee, Academic Press, Inc., New York, 1949.

11. de Lisle, E. W.: "Computations of VHF and UHF Propagation for Radio Relay Applications," RCA, Report by International Division, New York.
12. Selvidge, H.: Diffraction Measurements at Ultra High Frequencies, *Proc. IRE,* p. 10, January, 1941.
13. McPetrie, J. S., and L. H. Ford: An Experimental Investigation on the Propagation of Radio Waves over Bare Ridges in the Wavelength Range 10 cm. to 10 m, *J. Inst. Elec. Engrs.,* part 3, vol. 93, p. 527, 1946.
14. Megaw, E. C. S.: Some Effects of Obstacles on the Propagation of Very Short Radio Waves, *J. Inst. Elec. Engrs.,* part 3, vol. 95, no. 34, p. 97, March, 1948.
15. Dickson, F. H., J. J. Egli, J. W. Herbstreit, and G. S. Wickizer: Large Reductions of VHF Transmission Loss and Fading by the Presence of a Mountain Obstacle in Beyond-Line-of-Sight Paths, *Proc. IRE,* vol. 41, no. 8, p. 96, August, 1953.
16. Bullington, K.: Radio Propagation Variations at VHF and UHF, *Proc. IRE,* p. 27, January, 1950.
17. CCIR: Documents of the XIth Plenary Assembly, Oslo, 1966; vol. 2, Propagation; Recommendation 370-1; Reports 228-1, 239-1, 244-1, and 264-1.
18. Young, Jr., W. R.: Comparison of Mobile Radio Transmission at 150, 450, 900 and 3700 Mc, *Bell System Tech. J.,* p. 1068, November, 1952.
19. "Report of the Ad Hoc Committee, Federal Communications Commission," vol. 1, May, 1949; vol. 2, July, 1950.
20. Epstein, J., and D. Peterson: An Experimental Study of Wave Propagation at 850 Mc, *Proc. IRE,* p. 595, May, 1953.
21. Smith-Rose, R. L.: A Survey of British Research on Wave Propagation with Particular Reference to Television, *J. Inst. Elec. Engrs.,* part 3A, vol. 99, no. 18, p. 270, 1952.
22. Schelling, J. C., C. R. Burrows, and E. B. Ferrell: *Proc. IRE,* pp. 427-463, March, 1933.
23. Norton, K.: "A Theory of Tropospheric Wave Propagation," FCC Technical Research Division, Report No. 40003, March, 1940.
24. "Tropospheric Propagation and Radio-Meteorology," Central Radio Propagation Laboratory, CRPL-T3, October, 1946.
25. Booker, H. G.: "Elements of Radio Meteorology," *J. Inst. Elec. Engrs.,* part 3A, vol. 93, no. 1, p. 69, 1946.
26. Booker, H. C., and W. E. Gordon: A Theory of Radio Scattering in the Troposphere, *Proc. IRE,* p. 401, April, 1950.
27. Gordon, W. E.: "The Scattering on Radio Waves by Turbulence in the Troposphere," Cornell University Research Report EE 163, September, 1953.
28. Herbstreit, J. W., K. A. Norton, P. L. Rice, and G. E. Schafer: Radio Wave Scattering in Tropospheric Propagation, *Conv. Rec. IRE,* part 2, pp. 85-93, 1953.
29. Barsis, Bean, Herbstreit, Hornberg, and Norton: Propagation of Radio Waves over Land at 1046 Mc, *Natl. Bur. Standards Rept.* 2494.
30. Rice, Longley, Norton, and Barsis: "Transmission Loss Predictions for Tropospheric Communication Circuits," National Bureau of Standards Technical Note 101 (Rev.).
31. "The Effect of Irregular Terrain and Atmospheric on Correlation between Transmission Loss Values," ESSA Report ERL 84.
32. Bean, B. R., and E. J. Dutton: "Radio Meteorology," National Bureau of Standards Monograph 92.
33. Taylor, J. P.: UHF in Portland, *Broadcast News,* p. 16-33, September-October, 1952.
34. Taylor, J. P. More Reports on UHF Coverage, *Broadcast News,* pp. 8-11, January-February 1953.
35. Fink, D. G., J. V. L. Hogan, E. K. Jett, P. F. Siling, and D. B. Smith: Comments on the Proposed Allocation of Television Broadcast Services, *Proc. JTAC,* vol. 4, Sept. 26, 1949.
36. "Radio Spectrum Utilization," Report of the Joint Technical Advisory Committee of the IEEE and EIA. (IEEE 345'E. 47 St., NYC)
37. "Engineering Aspects of Television Allocations" (with supplement), Report of the Television Allocations Study Organization to the FCC.
38. Waldo, G. V.: "Analysis of Measurements and Observations, NYC UHF-TV Project," FCC Report No. R-6303.
39. Damelin, Daniel, Fine, and Waldo: "Development of VHF and UHF Propagation Curves for TV and FM Broadcasting," FCC Report No. R-6602.
40. Federal Communications Commission, Rules and Regulations, Section 3.683(*d*).
41. Standards on Radio Wave Propagation, Measuring Methods, *Proc. IRE.* 1942.

8

Design, Erection, and Maintenance of Antenna Structures

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This is not intended to be a treatise on tower design. The object of this discussion is to give the average broadcaster, owner, manager, or engineer a practical understanding of tower structures. General problems concerning tall structures are discussed in order to aid the broadcast people who are responsible for buying and maintaining towers. Electrical problems will not be discussed.

TOWER COST

The approximate cost of a tower installation is of prime importance for planning purposes. The accompanying curves show approximate costs of typical installations. These curves are intended to show the scale or range of dollars involved. The cheapest tower structure is the simplest one, such as an AM tower. This tower merely holds itself up, with a set of lights. Obviously, anything you add to the tower such as coaxial lines, signs, and so on, will increase the wind load, which in turn increases the weight and cost. It is impossible to show all the different conditions which arise. For example, only a few of the items which will increase cost are:

- Winter erection
- Inaccessible sites
- Foundations in swamps, rock, sand, tide water, or any water
- Heavier wind-design load
- Top hats
- Special insulators
- Electric signs
- Large high-gain antennas
- Large amount of coaxial
- Elevators
- Multiple antennas

Towers over 1,000 ft. usually involve special engineering for the particular conditions required. Hence, the cost of towers over 1,000 ft. is very approximate. People often inquire about the tallest tower which can be built. At the present time, there is no particular engineering reason why towers can not be built up to 3,000 or 4,000 ft. with present-day materials and equipment.

Self-supporting Towers versus Guyed Towers

The obvious advantage of a self-supporting tower is that it requires less ground area at the base of the tower. This often is necessitated because of crowded conditions, such as putting up a tower in the center of a city block, on a roof top, or on a small mountain top. The area required for a typical self-supporting tower will be roughly a square or a triangle somewhere between 7-1/2 and 20 percent of the overall height of the structure, depending on the designer. AM towers tend to be a little more slender than the TV towers. The disadvantage of a self-supporting tower is that, as a general rule, it is more expensive. An additional disadvantage of a self-supporting tower is that the designer does not usually investigate whip or inertia forces. These whip forces tend to be larger in a tall, slender self-supporting tower with a heavy weight on top (such as an antenna) than in a guyed tower.

The obvious advantage of a guyed tower is its cheaper (installed) cost. Most guyed towers today are built with a uniform cross section and, in many instances, a constant weight in cross section. This makes for cheaper fabricating and easier and cheaper stacking during erection. A guyed tower is lighter than a self-supporting tower. The guys, in effect, form a very large base. A guyed tower having less steel is usually cheaper to paint and to maintain, since it has fewer members and the members are easier to reach on the way up and down the tower.

The area required for a guyed tower varies with the designer. Current practice is to place the guy anchors out from the base pier a distance equal to

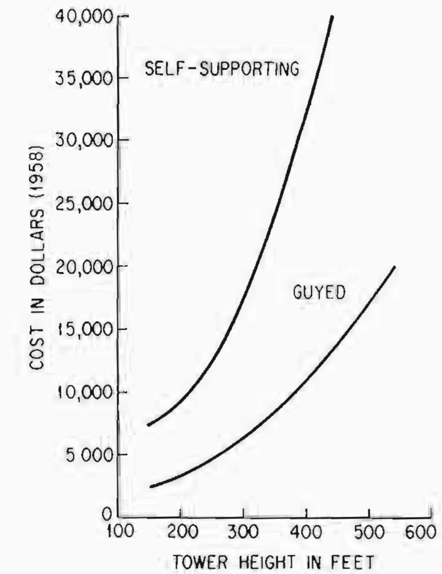


Fig. 1. Approximate installed cost of 30-lb. insulated AM towers. Cost includes tower, foundations, FAA lights, and erection.

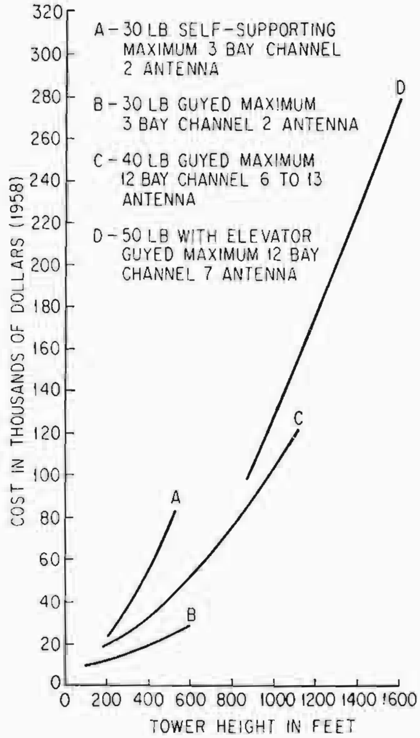


Fig. 2. Approximate installed cost of TV towers. Cost includes tower, foundation, erection, FAA lights, erection of coaxial and antenna.

50 to 100 percent of tower height. The tower designer knows that as he pulls in his guy anchor distance, he increases the down load on the tower and so runs up the size of guys and the size of vertical members. This tends to run up the cost of the tower.

It is not always necessary to buy all the land enclosed by the outline connecting the anchors. Many towers have guys crossing a public road. There are many tower installations where it was necessary to buy or long-lease a small plot at each guy anchor and at the base of the tower.

Tower Material

Most towers today are built from steel for the simple reason that steel is more economical than any other material available at the present time. It is possible to build towers from wood, any number of aluminum alloys, and a number of other materials. Wood is usually uneconomical over 80 or 90 ft. and the broadcast range begins at 150 ft. Aluminum alloys tend to give a lighter but a more expensive tower. The broadcaster usually is more interested in the cost than the weight of the tower. There may be a day when the basic cost of some of these aluminum alloys will come down and steel will go up, so that it may be economical to use these aluminum alloys.

Probably the most commonly used steel is structural carbon steel which comes under ASTM A-36 specifications. The yield of this material is 36,000 psi. It has good elongation and very good working and welding properties. Its base price is relatively cheap.

Pipe is used by some manufacturers. Pipe generally comes under ASTM A-53. This pipe has a yield of about 35,000 psi, depending upon the grade. Pipe is fairly easy to work as a rule and is suitable for welding. Its popularity is due to the fact that it has a low base price. The disadvantage is it comes only in certain specific sizes.

Mechanical steel tubing, both welded and seamless is used in various grades and alloys to

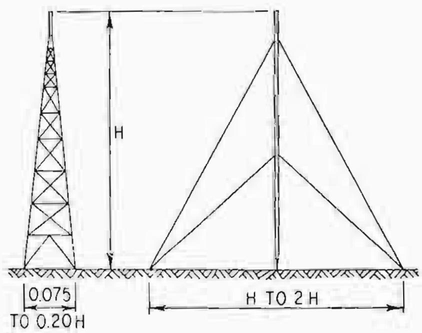


Fig. 3. Relative space requirements for self-supporting and guyed towers.

meet specific requirements. Exacting properties such as tensile strength, ductility, and weldability can be produced. A big advantage of tubing is that both the outside dimensions and the wall thickness can be varied at will by the buyer. The disadvantage of tubing is its relatively high base price.

Taller towers, or towers with exceptionally heavy wind loading generally have solid round leg members, since the heavier loads involved put it out of the range of tubing strength. A wide variety of steels are now available in the industry, ranging from the standard A-36 (36,000 psi yield) to 100,000 psi yields and higher. These higher strengths are obtained by altering the chemical properties (alloy steels) and their cost generally speaking increases with strength. Many other desirable properties for a given application, such as corrosion resistance, weldability and toughness can be obtained through judicious selection of steel types available.

There have been some towers using high carbon strip rolled into Vs. Towers using this material very seldom have welding connections because of the previously mentioned difficulty encountered in welding.

High yields up to 110,000 psi are obtainable from stainless steel in the 17-7 or 18-8 varieties which have good working and welding properties. Although an excellent material, its high cost prohibits its use in commercial tower construction at the present time. It has been used by the U.S. Navy for masts on seagoing ships.

Commercial machine parts usually get high strength by heat-treating higher carbon steel. The higher carbon steel is more difficult to weld. Also, heat treating large, bulky tower columns is uneconomical. For this reason, high-carbon heat-treated steel is very rarely used in tower work.

SHAPE OF MATERIAL

There is no particular magic in any one structural shape. All shapes have their advantages and their disadvantages. The different tower designers have different shape preferences. Different tower manufacturers have different shape-fabricating facilities. It might be interesting to review some of the more commonly used steel shapes.

Steel Angle

The most easily available shape and the one used in great amounts is the structural steel angle. The advantages of a steel angle are its universal availability, low initial cost, ease in fabricating, ease in shipping, ease of galvanizing, and ease of assembly. Because these structural angles make 90° angles, most towers which use angles are four sided. Three-sided towers using angles are possible. The largest single disadvantage of a structural angle shape is that the angle runs up the wind load and, consequently, the weight of the tower, particularly as the height of the tower increases. Almost all towers were made of angles, at one time, when the heights were low. Today most tall towers make use of cylindrical shapes.

A much-used shape is a steel strip which is rolled into a V or some shape approximating a V. The main advantage of a rolled strip is that it is possible to form an approximate 60° angle. This makes it relatively simple to fabricate a triangular cross-sectional tower. The advantages and disadvantages of formed strips are about the same as those of structural angles.

Cylindrical

A solid round steel bar has become popular, particularly in the taller towers. The advantage of a solid bar is that it has low wind resistance for a given cross-sectional area. Its base price is also relatively inexpensive. The solid bar tower tends to run the tower weight up if the designer is not careful.

The advantage of a tube to a tower designer is that it has a circular shape which keeps the wind load down and it gives the tower designer the most efficient material distribution to carry a column load. Tubular towers are usually more efficient and lighter, have fewer parts, and are cleaner looking than those of other shapes. The greatest disadvantage of a tube is its relatively high initial base price for the material.

To sum up shapes, it must be borne in mind there is no particular magic in any of the shapes used. It always amazes people to see different companies using different designs, different types of facilities, and different shapes and coming out with approximately the same tower cost.

TOWER ASSEMBLY

The three principal methods of putting a tower together in the field are bolting, riveting, and welding. The latter two methods are seldom used. Since bolts are used almost universally in tower erection, a discussion of the various types of bolts and bolting practices is in order.

We may also note at this time the advantage of the prefrabricated tower section where most of the assembly work is done in the shop. The expensive erection bolting is then kept to a minimum with a resultant saving in time and cost.

Bolts

High strength ASTM A-325 bolts are generally used in the tower industry. Even higher strength

ASTM A-490 bolts can also be used where higher loads are encountered, in order to hold down the size of the connection.

The properly tightened high-strength bolt exerts a high clamping force, thereby creating a stiffer connection. It is desirable that the high-strength bolts be tightened to at least the minimum tension specified by the manufacturer. The following are the most commonly used methods for torquing high-strength bolts.

1. Torque wrench. An indicator which registers torque is a component part of this wrench.
2. Pneumatic impact wrench. Air pressure is controlled so that the wrench stalls at desired torque.
3. Pneumatic impact wrench with internal automatic cutoff which shuts off air supply when proper torque is reached.
4. The nut is turned to an initial tightness. Then the nut is given prescribed amount of visual turn with the wrench.

Ribbed or Dardelet bolts are sometimes used. These bolts have ribs along the body of the bolt. These ribs dig into the bolted material, provided the holes are undersize. If properly used, they make a rigid connection. They are not popular with erectors because of the extra work involved in driving the bolts into undersized holes. Their effectiveness is lost of holes are not undersized. These bolts require locking devices.

It is mandatory that all bolts and nuts be drawn tight. All nuts (except on high-strength bolts) should be locked in some manner to prevent them from working loose. This can be accomplished in many ways. A simple way is to stake the nuts by upsetting the thread on the bolt after bolt is on. A great variety of patented lock nuts, washers, and devices are available. They all seem to be fairly effective provided they are put on and put on tightly.

Number of Faces on a Tower

The number of faces a tower has is usually dictated by the economy of fabrication and erection. The simplest tower is one which has a circular cross section, which, in effect, has no face at all. Wooden poles would make such a tower, and tall radio towers have been designed out of large-diameter steel or aluminum tubes. An extreme case of the number of faces on a tower would be a tower made up of eight, ten, or even twelve faces. There is no reason why good towers with that number of faces could not be built, and they sometimes are. It should be pointed out that a poorly designed tower is a poorly designed tower and a well-designed tower is a well-designed tower irrespective of the number of faces the tower has. At the present time, most towers are built using either a triangular or a rectangular cross section.

Preassembly by Welding

Some towers are preassembled by welding in the shop. These prefabricated sections may be anywhere from 5 to 30 ft. in length. The length of the section preassembled in the shop is dictated usually by handling, shipping, and erection facilities. The advantage of prefabrication is that it takes some work from the erector in the field and puts it into a better equipped and organized shop. These preassembled sections may be made from material of any shape. The welding gives a stiffer, lighter, and cleaner, subassembly as a general rule.

Erectors like prefabricated sections because they save money by merely stacking sections, having fewer bolts to contend with, and fewer joints to check. The biggest disadvantage of the prefabricated tower is its bulk and resultant increased freight cost. For this reason, prefabricated sections are used in shorter towers. For example, shipping a 1,000-ft. tower in sections 1,000 miles would incur a total freight bill far in excess of the savings in erection. It is not correct to state that a prefabricated or preassembled tower is better than a knocked-down one, or vice versa. Total cost is the measure.

TOWER CONFIGURATION

The Uniform-Cross-Section Radiator

Most people are under the erroneous impression that the uniform cross section in radio towers was dictated by the radiation properties of an AM tower. It is true that the radiator of uniform cross section from top to bottom has radiating properties which an electrical engineer says are easier to predict. But note that self-supporting towers are tapered, although it is possible to build them with a uniform cross section. The electrical engineer simply has to contend with the radiating properties of a tapered structure.

Tapered guyed towers and nontapered self-supporting towers are built but not as a general rule. Most guyed towers are built with constant cross section and most self-supporting towers are tapered because of one simple reason—it is cheaper to build them that way.

Straight Base versus Pivot on a Guyed Tower

A guyed tower may be designed to come straight down at the base pier or to a pivot. Either method is satisfactory providing the conditions encountered are properly engineered. The advantage of a pivot base is that the pivot relieves a large bending moment at the pivot. In Fig. 4 this is graphically illustrated by comparing the mo-

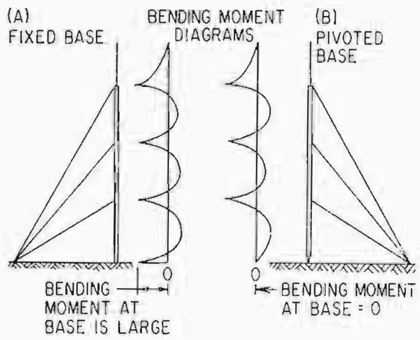


Fig. 4. Effect of a fixed base on a guyed tower.

ment curves of the two types of towers. The pivot saves steel and takes bending off the base insulator, if there is an insulator. The load on a pier is pure down load and the pier is a bit easier to design. The advantage of a straight fixed base is ease in fabrication. The erector can start erecting without using temporary guys. However, the bending moment tends to increase weight, the size of insulators (if any), and the size of the base pier. Also, the pier top must be perfectly level to distribute the load evenly from each tower leg.

Tower Weight

The weight of a tower is quite important. The weight comes into the calculations of the strength of the tower in a very simple manner. The heavier the tower, the greater is the total down load; consequently, more steel is needed and the sizes of the base insulator and base pier go up. In the 200-ft. AM guyed tower range, the weight is relatively a small percentage of the total design load, usually somewhere between 10 and 20 percent. This percentage increases with the height of the tower. In the 1,000-ft. tower range, the weight becomes an appreciable item. Skillful designers of steel towers recognize this fact and make some effort to keep down the dead weight. It is possible to have two towers equally strong and yet with entirely different weights. For example, as a general rule a four-sided tower made up of structural angles will weigh more than a triangular tower using round members and yet the design strength will be about the same in either case. The statement that tower A is stronger than tower B because it is heavier or vice versa is simply not true if both towers are designed to the same specifications.

A heavier tower will generally tend to have larger inertia or whip forces than a lighter tower. Usually these forces are not serious, but they may well be. For example, in a tall, self-supporting tower with a slender ratio and with a heavy antenna on top, whip forces are appreciable.

There is one practical minimum limit to the weight of a tower. The size of the members should not be so small that they are susceptible to damage in transit, during erection, or during maintenance climbing operations later on. Tower members should be rugged enough so that they can be handled as structures and not as fragile china. The average erector with heavy boots should be able to climb the tower without rolling over edges, bending thin members, or kinking

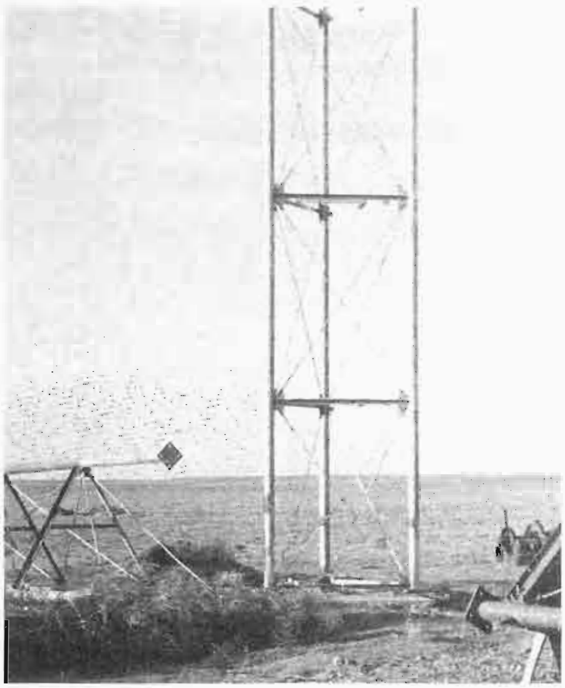
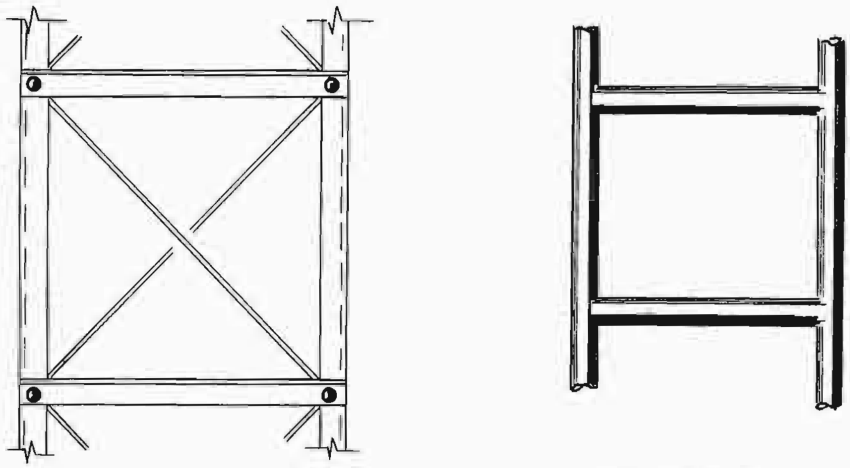


Fig. 5. Photograph showing fixed-base tower.

Fig. 6. Photograph showing tapered-base type tower.



CONVENTIONAL "X" TYPE BRACING

RIGID TYPE FRAME

Fig. 7. Conventional X-type and rigid-frame bracing.

small rods. Most towers used in the broadcast range today have members which are sturdy enough for ordinary usage.

Rigid-frame Trusses

Towers are designed as trusses, either the conventional type X or diagonal bracing or the rigid-frame type. The joints of a rigid-frame type of truss are moment-resisting and are usually welded. Conventional-type trusses are usually bolted at joints, and the joints are considered to be hinged. In rigid-frame trusses, the members have bending stresses as well as axial stresses. Standard methods of analysis can be used for determining the stresses. Rigid-frame trusses tend

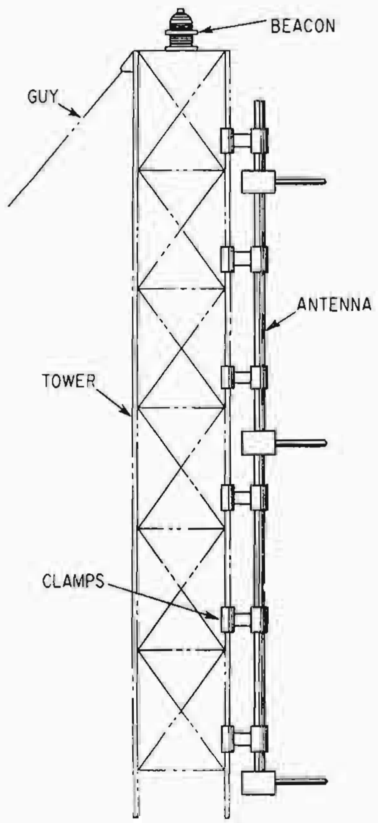


Fig. 8. Side antenna attachment.

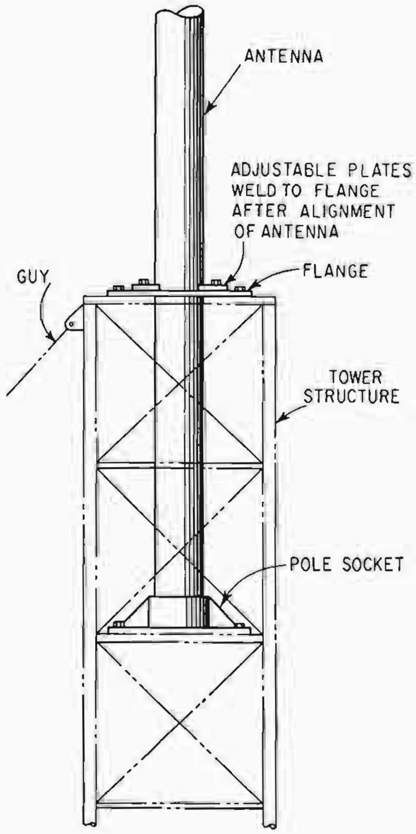


Fig. 9. Telescopic antenna mast attachment.

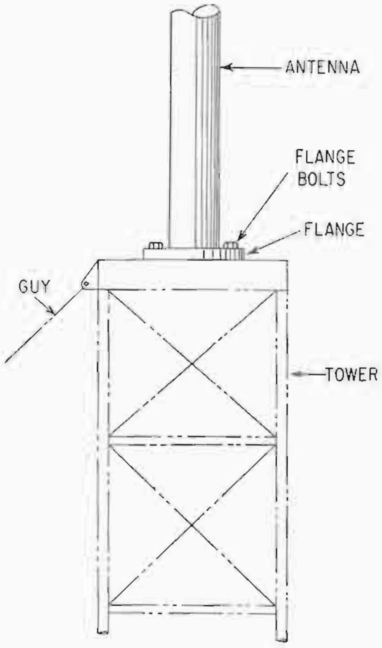


Fig. 10. Flange antenna attachment.

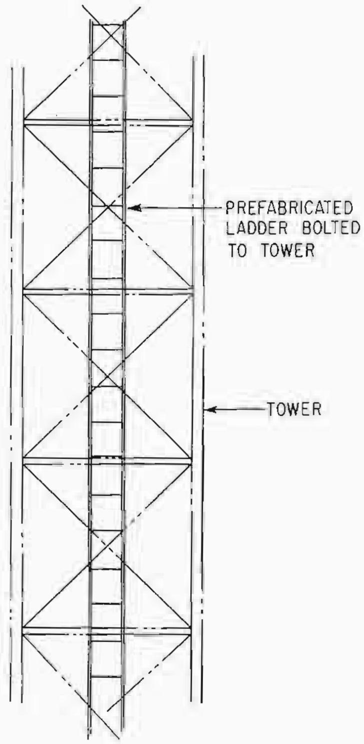


Fig. 11. Ladder mounted on tower face.

to be very clean aerodynamically and offer a minimum resistance to wind. They have also proved themselves quite economical for towers, particularly in the short heights.

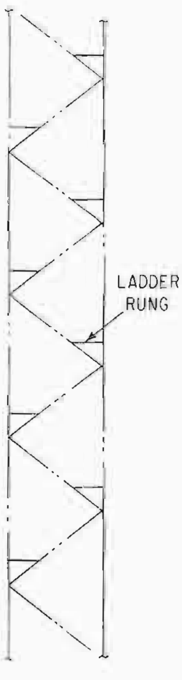


Fig. 12. Ladder steps welded to tower structure.

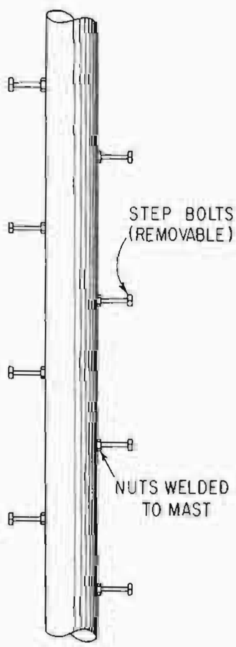


Fig. 13. Step bolts on cylindrical mount.

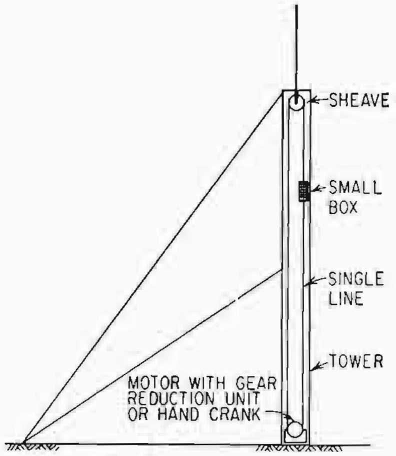


Fig. 14. Dumb-waiter type of lift.

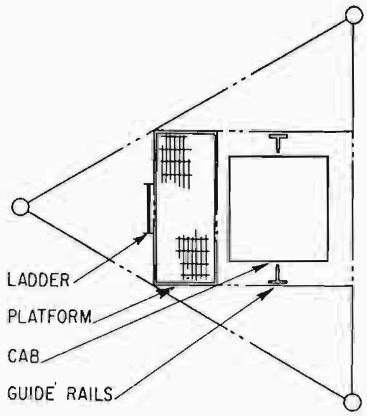


Fig. 15. Typical section through elevator.

TOWER ATTACHMENTS

Antenna

The prime purpose of a TV tower is to support the TV antenna and its feed system. The attachment of the antenna to the tower is a problem, especially when the antenna is large.

Antennas have been mounted on towers in three different methods. One method is to side-mount the antenna onto the tower. In general, when this method is used, the radiating elements are clamped onto the vertical tower members. This method of mounting the antenna has the advantage that the loads caused by the antenna are kept to a minimum and also the antenna loads can be distributed over the tower easily.

A second method of mounting an antenna on a tower is with the telescoping-pole type of mount. The pole telescopes down the center of the tower, the distance depending upon the size of the antenna. At the top of the tower, the pole has some sort of adjustable guide so that it can be plumbed. The bottom of the pole fits into the pole socket. Usually the pole socket is a fixed position and is not adjustable.

The third common type of antenna mount is the flange mount. A flange-type antenna mount suddenly dumps a large overturning moment into the tower. If the moment is large relative to the capacity of the tower as with some TV antennas, the problem can become quite nasty structurally.

Usually it is necessary to install the antenna in a vertical position. The top of the tower or the leveling plates as furnished by some manufacturers should be checked to make sure they are level before actual installation of the antenna.

Climbing Facilities

A tower must have some climbing facilities in order to maintain it and its equipment. Sometimes short towers have the tower members themselves arranged in such a manner that they act as step bars. Various climbing facilities are illustrated in Figs. 11, 12, and 13. When towers are short, step bolts similar to the ones seen on telephone poles are occasionally used. As the tower height increases, these step bolts do not give a feeling of security to the person climbing. As a general rule, ladders are provided on tall towers. Erectors themselves usually prefer a ladder on the face of the tower, since the erector likes to climb on the outside of the tower where he has fewer encumbrances. Most engineers and station people, however, who climb the tower occasionally to check antennas or lights feel safer if the ladder is within the confines of the tower cross section so that the outside of the tower forms, in effect, a natural safety cage. A safety cage is sometimes provided so that it is practically impossible to fall out. Usually, safety cages are not called for, since they add wind load to the tower and, consequently, increase the cost.

On taller towers, some form of hoist or elevator is occasionally used. The simplest arrangement, shown in Fig. 14 is, in effect, a form of dumb waiter.

Tower Elevators

It may take a man 3/4 hr. to climb the full length of a 1,000-ft. tower. If there is any equipment to be lugged up, this adds quite a burden to the climber. For this reason, it is often desirable to install an elevator in towers over 1,000 ft.

The elevator adds to the wind and dead loads, and so, the tower has to be designed originally to carry the elevator. A well-designed elevator embodies the elements noted in Fig. 16. There are many variations of the details required.

An elevator suitable for use in a tower consists of a driving mechanism, car, guide rails, hoisting

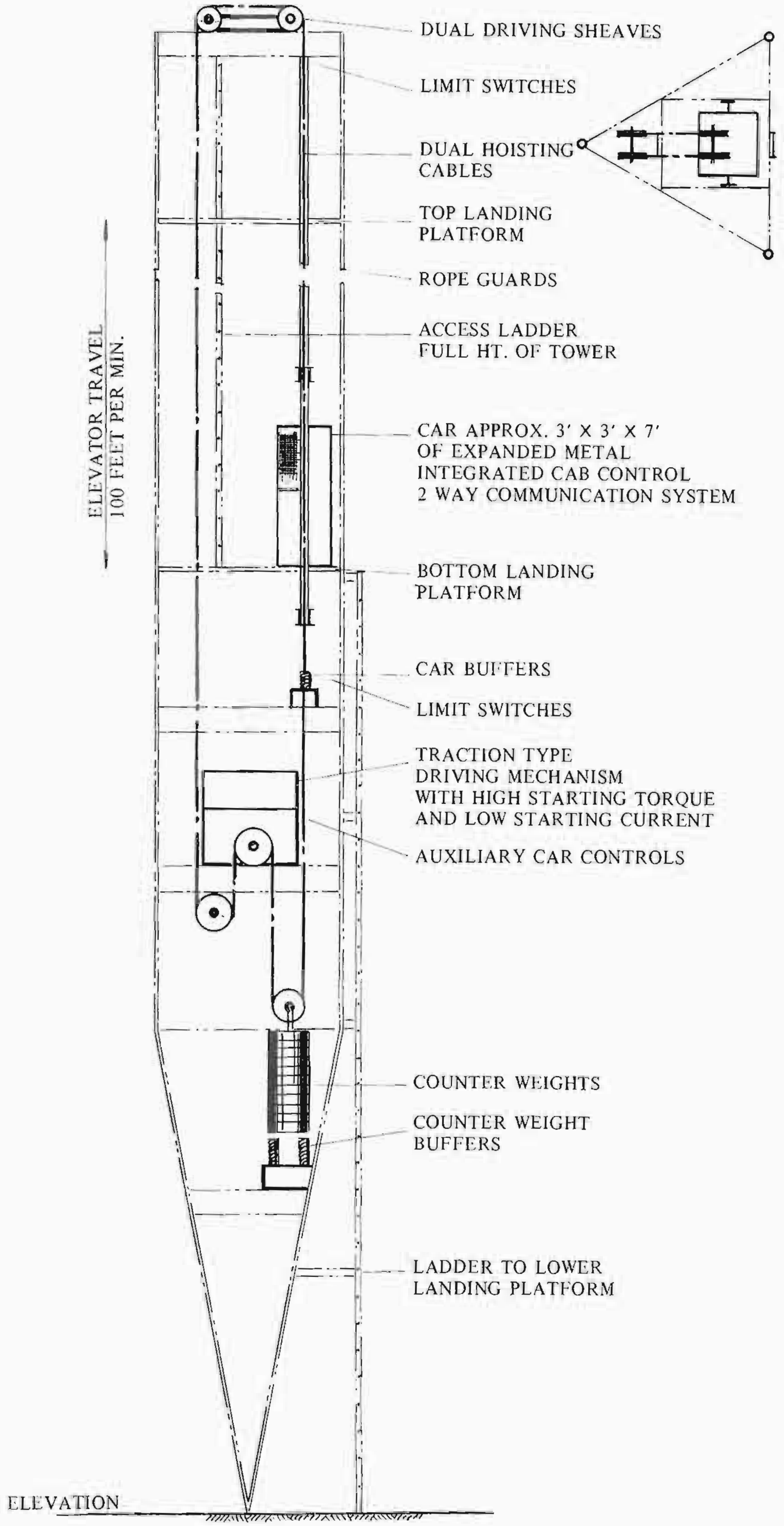


Fig. 16. Typical elevator installation.

cables, counterweights, integral and auxiliary cab controls, and two-way communication system. The guide rails should be machined to provide a smooth, steady ride. The T shape is commonly used, but rounds are used to cut wind loads. The driving mechanism should be a traction type with a high starting torque and low starting current. Rope guards are necessary to prevent entanglement of the hoisting rope in the tower structure during severe wind storms.

Different people prefer cages of different sizes. The tower designer leans toward a small cage; the owner would rather have a large cage. Elevators have a relatively slow rate of climb, simply because it keeps the power requirements and the cost down. The commonly used rate of ascent for elevators today is 100 fpm. Elevators are available with electronic controls and two-way communication systems in cab and tower base so that the operator is able to stop the cage at any height.

Considerable attention is given to safety devices in the design of a tower elevator. For example, in case of hoisting-cable failure, spring-loaded cams automatically are brought into play to freeze the car against the guide rails. Limit switches stop the car motion past either the upper or lower landing platforms should the operator fail to do so. The brakes on the driving mechanism are spring applied, electrically released, and designed to be automatically applied in the event of interruption of power from any cause. A tension device is supplied, limited by moistureproof switches which will cut off power in the event of cable stretch or excessive cable motion. Finally an access ladder is supplied for the full height of the tower to be used as an emergency descent.

TOWER PROTECTION

Galvanizing

Galvanizing is the process of coating metals, usually steel and iron, with zinc. One of the peculiarities of the zinc trade is that this coat is expressed in ounces of zinc for a square foot of surface. Most galvanizing is done via the "hot-dip" method. That is, steel is dunked into a zinc bath and then pulled out. The excess zinc drips off, and a certain thickness of zinc stays on the steel. If a thick coat is desired, the steel is dunked a second or even a third time. This is termed a double or triple hot dip. How does this zinc help? Zinc is higher than steel in the electrochemical series. It means that the zinc tends to be eaten away over an area before the steel does, even if the zinc surface is scratched to expose bare steel. Corrosion of steel is delayed until the adjacent blob of zinc is depleted.

Obviously, the life of the coat depends on the thickness or weight of the zinc coating and the atmosphere. For years, the American Society of Testing Materials has been testing miscellaneous weights of zinc on steel structures in different parts of the country. There are available estimated life curves of zinc coats in various atmospheres, expressed in years versus the coat thickness, in such locations as Pittsburgh, Pa.; Sandy Hook, N.J.; and Ames, Iowa.

Almost all guy strand and wire rope are zinc-coated for the simple reason that the individual wires making up the guy are small and usually run in diameter from 1/16 to 3/16 in., so that corrosion is a critical factor.

Since the zinc coat will impose an additional cost, should one galvanize? This will depend upon conditions. First of all, it is impossible for steel to corrode if the paint is properly kept up. However, there may be installations in certain highly corrosive atmospheres where maintaining the paint will present quite a problem. Those installations are not too frequent. If the broadcaster properly maintains his paint, then this should be adequate. On small, unattended towers where inspection may not be too regular, there is some merit in galvanizing. It is also possible in large, unusual towers where a special dispensation has been obtained to paint only a portion of the tower that it may be worth galvanizing only those portions of the tower which are never painted.

Tubular members, if galvanized, should be galvanized both inside and outside or else the drain holes should be plugged up. Care should be taken to seal the ends of tubes on tubular structures if they are not galvanized. Moisture or oxygen cannot get inside a properly sealed tubular member, and therefore there is no possibility of corrosion on the inside surface.

Painting

FCC Requirements

The Federal Communications Commission has prescribed a set of standards to provide an effective means of indicating the presence of obstructions to air commerce. Radio and TV towers, because of their height, are considered as possible obstructions to air navigation by the Federal Communications Commission and, therefore, must be marked and lighted accordingly.[1]

To comply with these regulations, the towers are painted in contrasting colors of white and international orange in alternate bands for maximum visibility during daylight hours. The exact spacing of these bands is spelled out on the face of the construction permit. The FCC also requires that towers be painted as often as necessary to maintain good visibility. Obviously the painting becomes quite a maintenance problem, and if it were not for this paint regulation, probably the cheapest finish would be a coat of zinc.

[1]Federal Communications Commissions Rules and Regulations, Part 17.

Surface Treatment

Paint will not stick to brand-new galvanized surfaces. The erector should treat the surfaces of the galvanized parts. Some fabricators give galvanized parts a special treatment prior to shipment so that the surface is prepared for painting. Any number of solutions have been made to etch this smooth zinc coat. The simplest and most commonly used treatment is plain vinegar or a weak acetic acid solution which is applied to the surfaces in the field prior to painting. A better solution is as follows:

2 oz. copper chloride
2 oz. copper nitrate
2 oz. sal ammoniac
2 oz. muriatic acid
1 gal. water

Apply with rag or brush to the tower, and allow to dry for 10 hours before applying paint. Galvanizing will first turn black and then a dull gray. Such a treated galvanized surface requires no primer. Another way to treat galvanized sections is to let them weather a period of three months to a year depending on whether the tower is located in a dry or a salty and moist atmosphere.

Application

Paint usually consists of two coats. The outside coat is a hard enamel, either orange or white and sometimes black. The enamel has wearing qualities and is relatively tough. However, enamel does not stick very well to plain steel. For this reason, towers usually have a primer coat. The purpose of the primer coat is to effect a bond between the steel and enamel.

Primer will not stick to a surface which has scaled rust, mud, dirt, oil, or grease. For that reason, the surface has to be fairly clean. If the rust is scaly, it should be wire-brushed off. If the surface is dirty or oily, it should be wiped with a thinner, alcohol, gasoline, or any number of cleaners or detergents. There are many good primers—red lead, iron oxide, zinc cromate, and combinations thereof. The primer should be on the thin side, since a thick primer has a tendency to peel. The primer has no staying qualities; that is, it will not weather very long.

Tests show that international orange and white enamels from most reliable companies are good. The life of the orange and white paint depends upon the location. In the dry desert parts of the United States towers do not require repainting for 10-year stretches. Towers along the seacoast, which are constantly subjected to salt spray and sunshine, require a new coat of paint approximately once a year. There is no fixed rule in the length of the life of the outside coat.

Broadcasters should be cautioned about getting unusually cheap prices for painting or repainting a tower from unknown erectors who happen to be passing through town. These "fast prices" sometimes leave one with a tower where only the bottom 100 ft. are painted beautifully and the rest of the tower is painted on the bottom surfaces only.

On paint maintenance contracts, broadcasters should make sure that the painter has public liability and property damage insurance coverage, since it is very difficult to keep the paint from flying, even in a very small wind. This is a very definite hazard, since neighboring buildings and cars are constantly being covered by flying paint.

TOWER GUYS

Steel Guy Material

Rope and Strand

Tower guys are usually made out of steel rope or steel strand. Both rope and strand are made up of high-strength steel wires. A number of wires spun as a single group is called a strand. A number of strands spun to form a group is called a rope.

The advantage of steel rope is that it is flexible. That is, it is capable of being run over sheaves or pulleys continuously. The disadvantage of rope is that it has a low modulus of elasticity (it is more stretchable than strand) and, as a general rule, it is more expensive than strand. Strand as a rule is preferred in towers because it has a high modulus of elasticity, does not stretch so much as wire rope, and is cheaper per foot for a given strength.

Catalogue value for strand modulus of elasticity is 24 million. This 24 million is a minimum figure. The 24-million figure is fairly consistent and constant. Coiling and uncoiling strand decrease this figure less than 1 percent, but it comes back to the 24 million.

It is the considered opinion of most engineers that there is no such thing as a yield point for strand. The curve falls off gently to a breaking strength. The catalogue values of the ultimate strength or breaking strength of strands are always minimum. The range of breaking strength is usually 2 to 10 percent above catalogue values.

Strand is made from high-carbon cold-worked wire. It is very rugged and very insensitive to notch defect. It will take quite a beating. A good approximation of estimating the percentage of reduction in strength of strand is to note how much wire is cut. For example, if you have 19 wires in a strand and one wire is nicked halfway through, then that strand is subject to a reduction in breaking strength of approximately 1/38 of the catalogue value.

As a rough rule of thumb, it takes 2 percent of the breaking strength of a 19-wire strand to stretch that strand or cable out to its true length. A 1 by 7 strand will require approximately 5 percent of breaking strength.

Prestressing

When a prestressed cable is wound up on a reel and then unwound in the field, there is a negligible amount of length lost. This has been proved many times by checking on long cables for 1,000-ft. towers and on suspension-bridge cables.

Prestressing the guys at a strand manufacturer's plant takes out some of the structural stretch. Most wire manufacturers will pull the guy to 50 percent of ultimate and hold for approximately 1/2 hr. Prestressing will stretch the strand somewhere from 1/10 to 1/4 of 1 percent of the length.

Bird Caging

Bird caging can occur in both manufacturing and in handling in the field. Bird caging prior to shipping is rare. Bird caging in the field is caused by a kink in the strand, unreeling improperly, allowing a large reel to get away, getting a loop in the strand, dropping a guy, or anything that puts wires in compression. Since most strands (19 wires and over) have lays going both ways, there is no method of really fixing a true bird cage. There is no tendency for wires to unravel and bird-cage by themselves. That is, all strands are basically very stable.

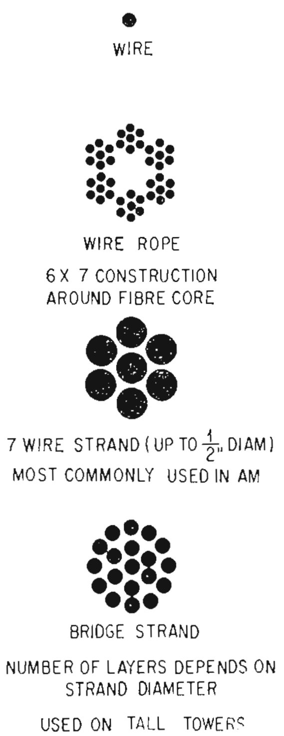


Fig. 17. Composition of typical guy material.

Fatigue

We have never heard of a fatigue failure of wire where it enters a socket on a guyed tower. However, such failures have occurred in sockets which come out on highly loaded shovels where there is continuous large vibration on strands which are constantly highly loaded in tension.

This question arises every now and then when the tower guy has been stretched in a wind storm and you take up the slack: Is the guy breaking strength reduced? The answer is No. For example, strand in preloaded concrete slabs have initial tensions up to 70 percent of the breaking strength, and the working tension of the strand is 50 percent of the breaking strength. Notice that you can take strand and load it to 70, 80, or 90 percent of the breaking strength; unload the strand; and still get 100 percent breaking strength.

Zinc Coat

The usefulness of a zinc coat on a guy comes from the fact that the zinc coat wastes away instead of the load-carrying steel. The zinc does not protect the strand wire indefinitely. The fact that zinc wastes away rather than steel is good. It should be pointed out that the smaller the wire diameter, the thinner is the zinc coat. Using a galvanized socket instead of a black one on the end of a guy will not appreciably increase the life of the guy. It is also for this reason that when you have a corroded clip, the best thing to do is to leave it alone. Corrosion usually starts at the threads where the zinc is stripped, and there is usually enough "meat" in the rest of the clip and in the guys to take care of itself.

AM Guys

Guys on AM towers have to be made nonradiating. The currently accepted method is to break the guys up with insulators into lengths approximately one-seventh of the wavelength on the radiator. Obviously, this breaking up of the guys is a necessary nuisance. People constantly are looking for guy materials which would be nonradiating. To date, such materials as nylon and dacron have too much stretch to be of any practical value. However, in the foreseeable future, it is possible that some such material may be usable. A new polyester film material Mylar bears watching. At the moment it is expensive, but it does not have the great stretch which nylon has.

Guying Arrangement

A three-way guying arrangement where the guys are laid out 120° apart in plan form shown on accompanying Sketch A of Fig. 18 gives the

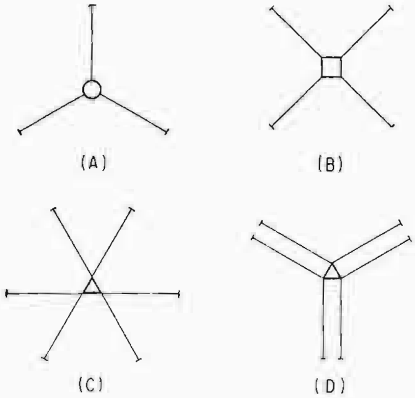


Fig. 18. Commonly used guying arrangements.

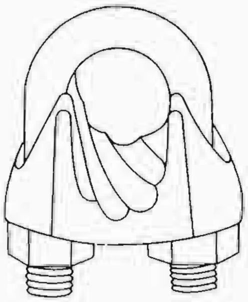


Fig. 19. Wire-rope clip.

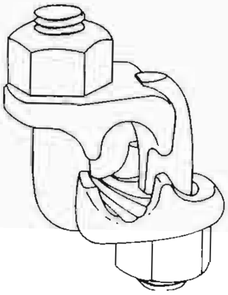


Fig. 20. Laughlin safety clip.

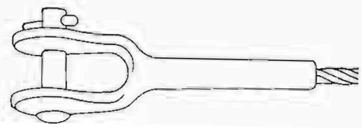


Fig. 21. Swage fittings.

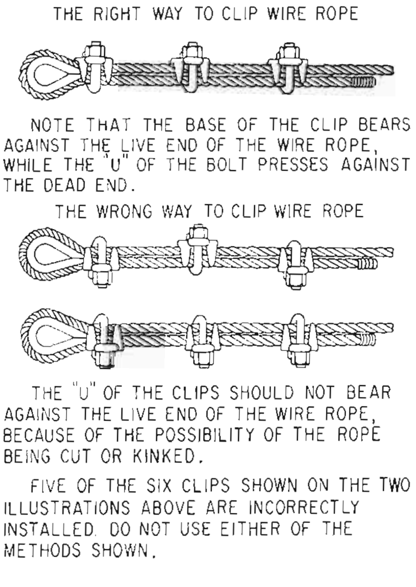


Fig. 22. Proper method of applying rope clips.

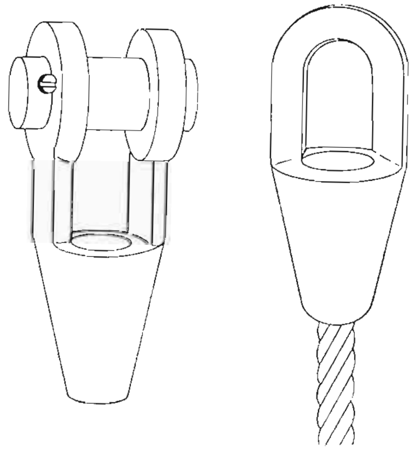


Fig. 23. Wire-rope sockets.

simplest possible guying arrangement which will support a tower in a wind from any direction. This gives the smallest number of guys and usually tends to give you cheaper foundations and a smaller number of insulators.

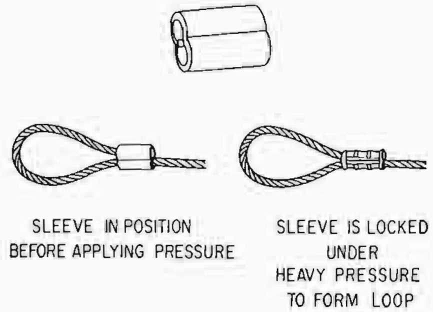


Fig. 24. Nicopress sleeve-type fitting.

A much-used guying arrangement is shown on Sketch B of Fig. 18. A foursided tower has four sets of guys spaced 90° apart in platform.

A guying arrangement such as shown in plan form C (Fig. 18) has been used in tall towers. The disadvantage is the need for more anchors. The advantage is that it tends to save in the column load on the tower and some weight.

A guying arrangement as shown on plan form D (Fig. 18) shows double guys coming off each face. The advantage of this system is that it gives the tower some torsional resistance until the tower has twisted. The disadvantage of plan form D is extra handling by the erector. Most erectors prefer single rather than double guys.

Guy Connections

Clips

The most commonly used guy connections at the insulators are steel clips. These clips are relatively cheap, and they are easily available. They are used by the millions. The efficiency of the clip depends upon drawing the clip up tight. In Fig. 22 showing a properly drawn up clip, you will notice that the yoke must make a definite dent on the surface of the strand. It is also a known fact that after you put load on a guy, you can pull the clip up a little more. Since this is very difficult to do in a guy with many insulators in it (which are made in the field), clip efficiency should not be rated over 80 percent. It is possible to get clip efficiencies in a laboratory over 95 percent. The greatest danger in a clip is that the erector may forget to draw up all clips securely. The best visual inspection that we know of is to check whether the yoke of U part of the clip puts a definite dent in the guy. These clips come in many shapes and forms such as shown. All clips rust sooner or later. When a clip is drawn up, some of the zinc strips off the threads and you have a focal

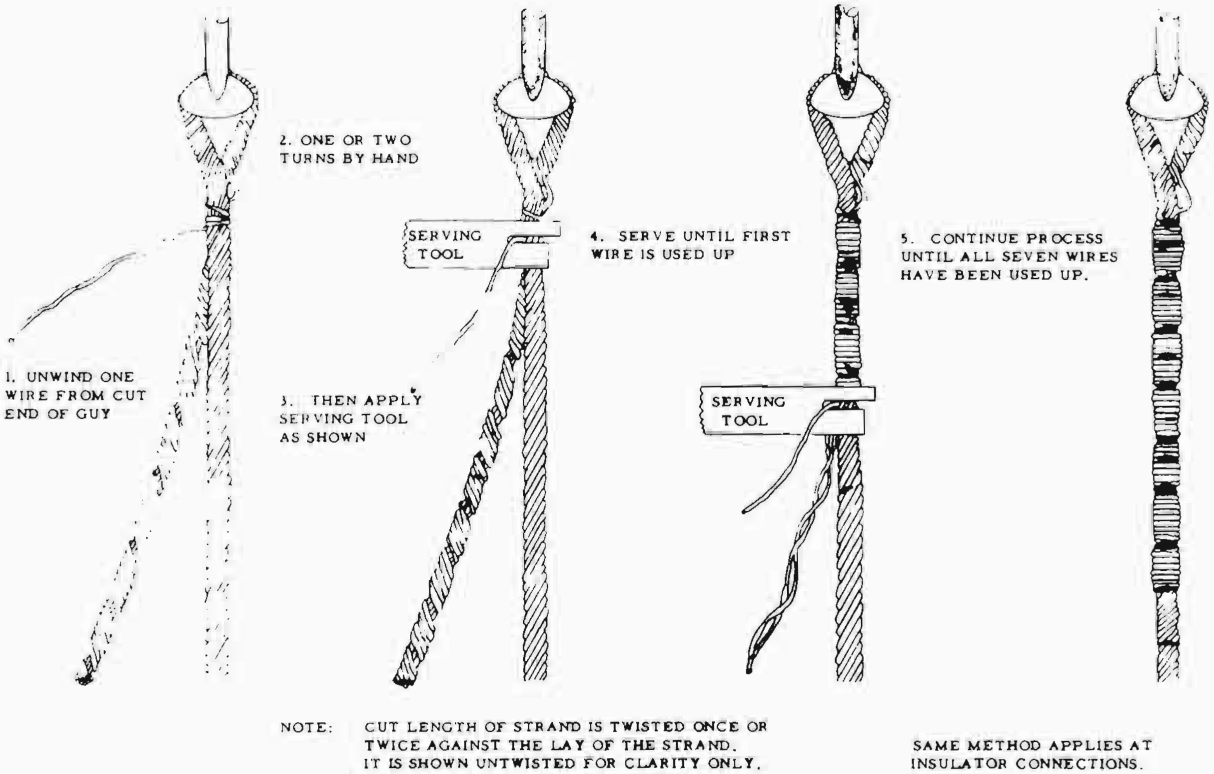


Fig. 25. Serving guy connections.

point of corrosion. Most clips are sturdy and have enough "meat" in them to last for many years. This corrosion depends on the atmosphere in which the tower is sitting. Some erectors have lately been spraying their clips with clear plastic lacquers which come in pressurized cans.

Serving

A neat and clean-looking connection which is very simple to apply has been developed by the power companies in their work. It is the so-called "serving." The several wires are unraveled, then each individual wire is rolled back on the strand. The efficiency of this method is usually in the high 90 percents. It makes a clean connection. It is a safer connection than a clip connection, since you do not run the risk of forgetting to run up the clips tightly. It also does away with the problem of corrosion of the clips.

Sleeves and Sockets

There are several makes of sleeves which are press fittings. This again was developed by power companies. They are good-looking and neat on smaller sized guys.

Large guys usually make use of zinc sockets. On most towers today, the sockets are supplied on the strand by the guy fabricator, since their application takes a certain amount of skill and technique. These sockets are usually made of cast or forged steel.

Preformed Guy Grips

Another relatively new guy end fitting is the preformed guy grip. This grip is essentially a wire loop with a "pig tail" which wraps around the guy end. This pig tail is made of a series of side by side wires which wrap neatly around the guy, and which have an abrasive material which increased the friction and keeps it from pulling loose.

This type grip is generally used with guy diameters 1 in. or under, and combines the desirable characteristics of clipped guys (field installation) and socketed guys (it develops the full strength of the strand, thus requiring a smaller factor of safety than is required for clips). It is generally cheaper than socketing in the sizes mentioned above, although field installation costs will be slightly higher than for socketed guys.

Guy Tension

The proper initial tension in guys is an integral part of tower design and should be determined by the tower manufacturer. Proper guy tension is necessary in order to control the deflection of the tower so that certain specified limits are not exceeded and in order that deflection of the tower does not weaken it.

Common values of initial tension in guys vary between 5 and 25 percent of the breaking strength of the guy, depending on the design and requirements. In general, a low initial tension tends to give a more flexible and lighter tower. A high initial tension tends to give a stiffer and heavier tower. Initial guy tension in a properly designed tower seems to have little effect on the ultimate strength of the tower.

During erection and in maintenance, there is danger of putting too much tension in guys. This overloads the tower as a column and literally pulls the tower down to failure.

Initial tension is seldom specified on small AM and communication towers up to heights of 200 or 300 ft. In these cases where the exact initial tension in guys is not critical from the deflection point of view but is critical in that overload can cause tower failure, tower manufacturers should specify an initial tension and the erector or the maintenance men should check the guy tension by some convenient method such as with a dynamometer.

It is common practice on taller towers with a pivot base that guy tensions are adjusted either so that the tower deflects as a straight line from its base to its top when loaded with the design load or so that the differential deflection at guy points is taken into account in calculating the stresses in the tower members. On these large towers, the erection drawings always specify guy tension and some method of checking it. A number of methods commonly used to measure initial tension in the field are described.

Methods for Determining Guy Tension

Calibrated-rule method. In the calibrated-rule method, two buttons are attached approximately 8 ft. apart to the lower end of the guys. During fabrication of the guys, the required initial tension is applied to the guy. While this load is on the guy, a rule is marked exactly the same as the buttons. In erection, the guy is tightened up until the marks on the buttons line up with the marks on the rule.

Although various stable metals are used to fabricate the rule, this system is subject to errors from several sources. The most likely source of error is the fact that the gauge length (approximately 8 ft.) is relatively small and therefore the change in length of the guy in the 8-ft. length will be very small. The eye cannot see much closer than 0.01 in., and an error of this magnitude would result in a 10 to 20 percent error in the initial guy tension. It is doubtful that the erector in the field would take the trouble to read these calibrations with any great precision.

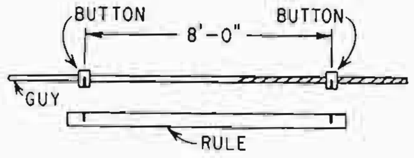


Fig. 26. Calibrated-rule method.

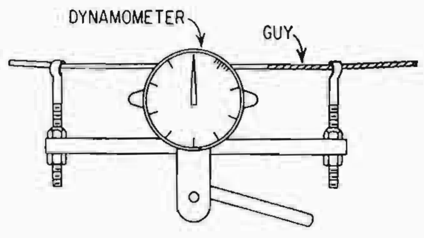


Fig. 27. Shunt-type dynamometer.

Temperature is another factor that must be compensated for, particularly when the linear coefficient of expansion of the guy differs from the rule.

Shunt-type dynamometer. This type of dynamometer or tensiometer is used in determining and maintaining the proper sag or tension in guys. It can be used without breaking-in on the guy to be tested and can be left on the guy until the dial shows the desired reading.

The principle of the shunt dynamometer is based on the relation of the tension in the strand to the force necessary to displace it in a direction perpendicular to the axis of tension.

The dial is graduated from 0 to 100 units and does not read directly in pounds. Tension is determined from graphs specially prepared for each size and type of wire or cable on which the dial reading is plotted against tension in pounds. The manufacturer guarantees the accuracy to within plus or minus 2 percent of the dial reading.

On relatively short towers with small guys, use of a mechanical tensiometer is probably the most practical method to measure guy tensions. On tall towers with large guys, the sag of the guys becomes appreciable and can be used as a measure of guy tension. The guy-sag method is a relatively simple and very practical way to check the guy tension.

Guy sag can be checked with a transit or with a sight bar. We shall briefly describe the sight-bar method. A straight bar made of steel or wood with two hooks is used to make the line of sight parallel to the guy. If the unaided eye cannot see clearly to set the intercept, a telescope can be used as shown in Fig. 28. It is important in making up this sight bar that the line of sight of the bar be parallel to the guy at its point of attachment. This method is quite accurate in setting initial tension when the guys and intercepts are large. For example, a 100-ft. intercept read with 2 ft. has an approximate error of 2 percent. Tension is given by the following formula:

$$T = \frac{WL^2}{2I}$$

The values of the weight of the guy per foot, the span of the guy, and the recommended tension of the guy should be readily available from the tower manufacturer.

Example: 1,000-ft. tower with 1-in. guy strand

L = 1,220 ft.
W = 2.14 lb./ft.
I = 160 ft.

$$T = \frac{(2.14)(1{,}220)^2}{(2)(160)} = 9{,}950 \text{ lb.}$$

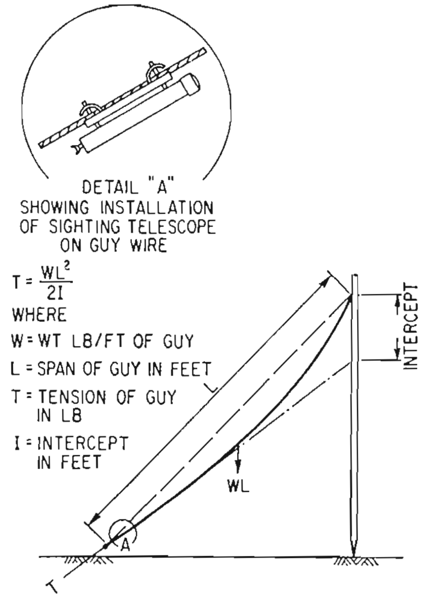


Fig. 28. Use of "sight bar" for determining guy tensions.

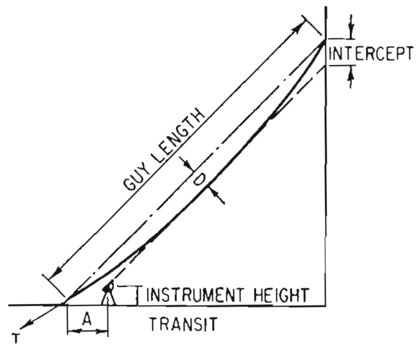


Fig. 29. Transit-intercept method for tensioning guys.

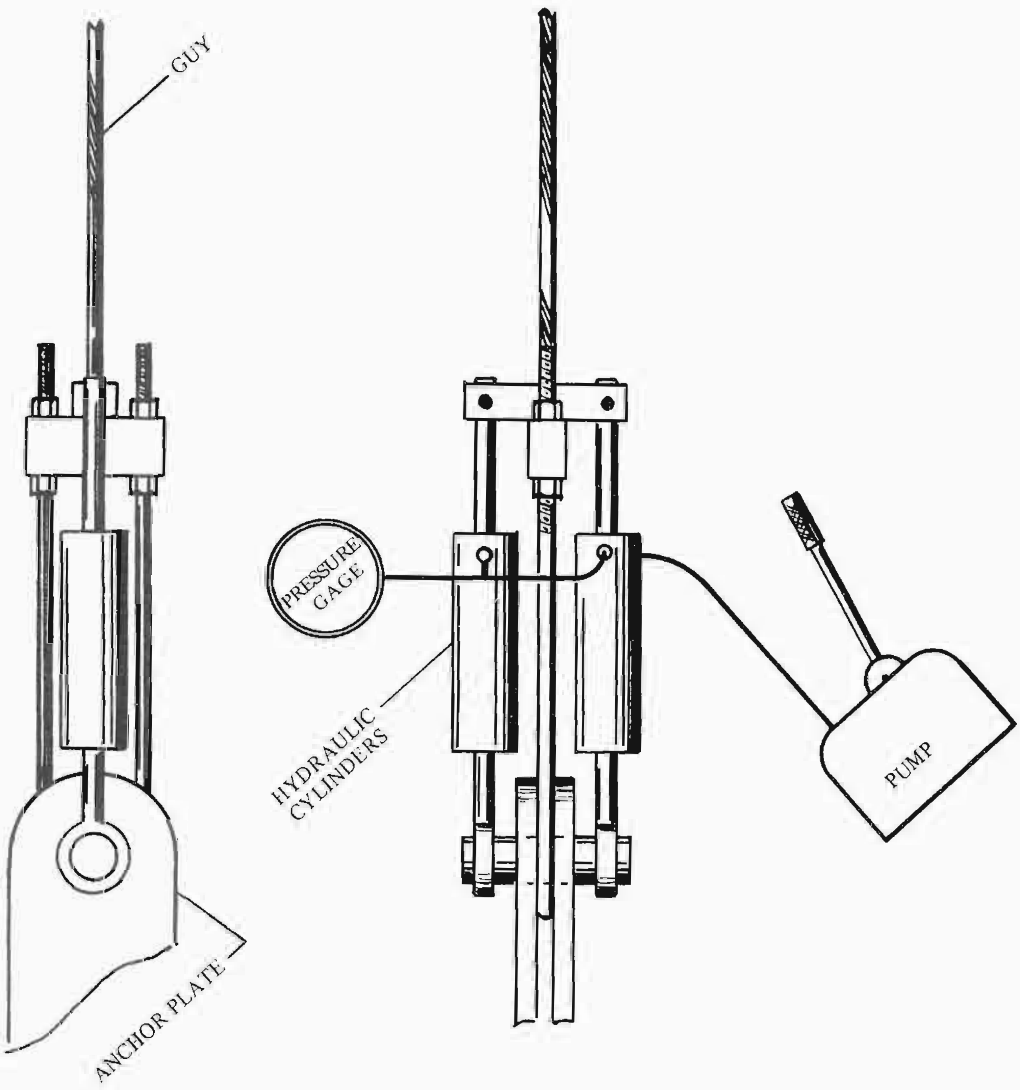


Fig. 30. Hydraulic-cylinder method for measuring guy tensions.

Transit-intercept method for tensioning guys. With guy length and desired tension T known, the sag D is calculated from standard formulas. Again with known instrument height a sight line is established tangent to the guy and ground distance A and tower intercept determined. At erection a transit is set up using these intercepts to establish the line of sight. The guy is then tightened until it becomes tangent to the line of sight.

Hydraulic-cylinder method for measuring guy tensions. The guy is put under the required tension with two push-pull hydraulic cylinders which are usually pumped up by hand. The required tension is read on the pressure gauge. The nuts are pulled up on the U bolt or turnbuckles to hold this tension in the guys. Hydraulic units are then removed. It is recommended that the hydraulic cylinders and gauge be checked accurately prior to use, since there is a tendency for errors to creep into the gauge.

Spring method of tensioning guys. A spring with known deflection characteristics is selected and installed in the guy anchor connection. The guy is tightened until the spring has deflected the desired amount, thereby obtaining the required tension in the guy. A combination tubular spring cover and spacer of predetermined length is normally used to obtain the correct deflection. Caution: Do not continue to tighten the guy after the spacer has bottomed; otherwise, excessive tension will be applied to the guy.

Vibration method of measuring guy tensions. The guy is set properly vibrating by pulling the guy back and forth sideways with the hands. Vibrations are timed with a stop watch. This reading is then substituted in the following formula and the initial tension is calculated.

$$\text{Cycles/min.} = \frac{170T}{L \times (\text{wt./ft. of guy})}$$

where L = length of guy, ft.
T = guy tension, lb.

The vibration method applies to guys of uniform weight and is not applicable to guys with insulators or other concentrated weights. It must be pointed out that this system is only as accurate as the measurement of the frequency of the guys.

Dynamometer method. As shown in Fig. 33, a tension-type dynamometer is mounted between a cable grip and usually a chain hoist. A load is applied to the dynamometer, and when the desired reading is reached, the guy turnbuckle is tightened accordingly. The dynamometer equipment is then removed.

$$S = \sqrt{1{,}000^2 + 700^2} = 1{,}220.6555 \text{ ft.}$$

Given: W = 2.073 lb./ft.–1-in.-diam. guy
T = 10,000 lb.–initial tension

Sag in guy wire with 10,000-lb. tension

$$D = \frac{WS^2 \cos\theta}{8T}$$
$$= \frac{2.073 \times (1{,}220.6555)^2 \times 0.57346}{80{,}000}$$
$$= 22.1411 \text{ ft.}$$

Assume that the guy takes the shape of a parabola

$$L = S + \frac{8D^2}{3S}$$
$$= 1{,}220.6555 + \frac{8(490.2283)}{3{,}661.9665} = 1{,}221.7265 \text{ ft.}$$

Length of guy at 10,000-lb. tension.

Guy Vibration

Although guy vibration is not, as a rule, a serious problem, it may be well to note its effect. Tower guys have been known to vibrate in a few isolated instances. The natural frequency of any tower guy is a function of:

1. The length of the guy
2. The tension in the guy
3. The weight distribution of the guy

A change in any of these constants will change the frequency of the guy. The natural frequency of a guy without ice is different from that with ice simply because the weight of the ice changes the weight distribution of the guy and automatically increases the tension in the guy. Obviously, if a guy begins to vibrate, changing any of these constants, namely, knocking ice off the guy, adding weights to it, shortening its effective length by a bridle, increasing or decreasing its

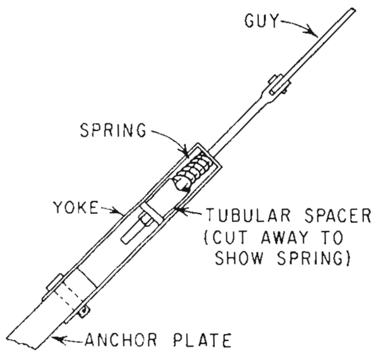


Fig. 31. Spring method of tensioning guys.

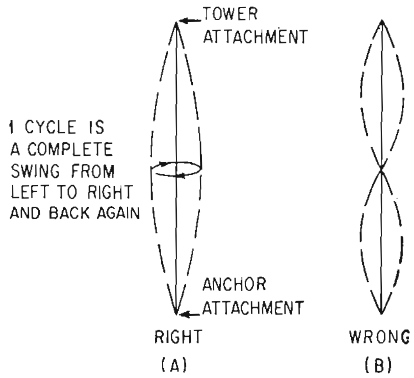


Fig. 32. Vibration method of measuring guy tensions.

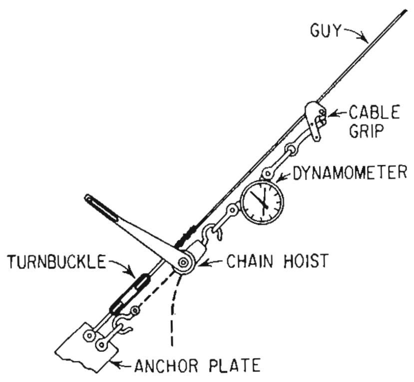


Fig. 33. Dynamometer method.

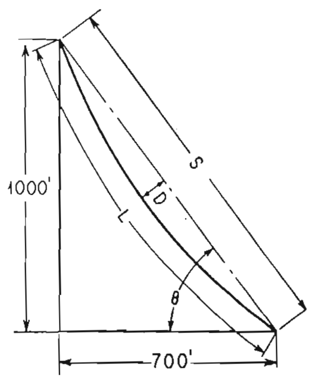


Fig. 34. Method of calculating guy lengths.

tension, should kick the guy out of the vibrating frequency. If long guys are provided with weights which are attached to the guys at irregular intervals, the probability of vibration is theoretically reduced. Insulated towers have these weights already on them in the form of guy insulators. Some towers come with some form of cast-iron weights which are clamped around guys to form the guy dampener. Most tower designers feel that a guy dampener is easy enough to install should you get vibration where no dampeners were specified.

WINDS, WEATHER, AND HAZARDS

Wind Velocity

The Weather Bureau aims to get true wind velocities at a height of approximately 10 m (33 ft.) in open exposure and ten times as far from any obstruction as it is high. The Bureau tries to approach this ideal, but it should be obvious that sometimes it is virtually impossible to find such an exposure for all wind directions in a well-built-up city and even in some airports. The Weather Bureau's figure for true wind is measured over a 1-min. time interval. Some countries use up to 10 min. The Weather Bureau also gives the fastest mile as maximum gust velocity or the peak indication of a pressure tube anemometer. A cup anemometer tends to overregister in a gusty wind. However, this overregistration is very small and never more than a few percent.

Indicated versus True

There is misunderstanding about indicated and true wind velocity. Any figure obtained from a Weather Bureau today or in the last quarter century is a true wind velocity. This true wind velocity is also the indicated velocity. This is because anemometers have been calibrated and the indicated and the true are practically the same. However, in about 1898, the Weather Bureau discovered that the anemometers were registering approximately 25 percent too high. In order to avoid throwing away at least a quarter century of Weather Bureau records already obtained, the Bureau decided to keep on with the figures which were 25 percent high. This continued until about 1924. This means that records prior to 1924 may show an indicated and a true wind velocity differing by approximately 25 percent. Any wind velocities given by a Weather Bureau since that time are true wind velocities.

Since air is a viscous fluid, the ground has a certain amount of "slowing-up" effect on the wind velocity. Another way of putting it, wind velocity tends to increase as height above the ground is increased. Obviously this velocity gradient is not a constant, nor is it easy to express. The Weather Bureau gives the formula shown in Fig. 35 for velocity ratios as expressed in terms of height. The constant N is somewhere between 2 and 7. Although we do not know how much faster it is actually blowing at 1,000 ft. as compared with ground, we are sure that it is blowing faster. For that reason, taller towers should be designed to a slightly higher wind load.

In addition to this wind gradient, there is what the Weather Bureau calls a velocity gradient. This means that in addition to the average maximum wind velocity, there may be superimposed gust velocities for short durations. Much work has been done studying these gusts, and there are some empirical estimates. There is no sure prediction of gusts. It is reasonable to assume that gusts are possible which exceed the maximum wind velocity by a factor between 10 and 30 percent.

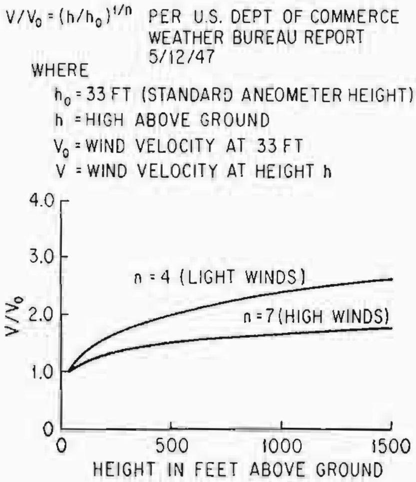


Fig. 35. Variation of wind velocity with height.

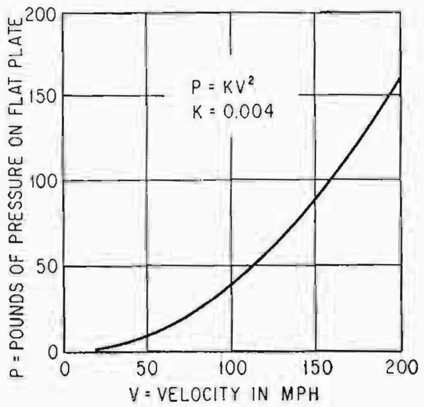


Fig. 36. Wind pressure versus velocity curve.

Hurricanes

Hurricanes are large-diameter tropical storms. These hurricanes usually start out in the Gulf of Mexico or the Caribbean Sea or in the Atlantic Ocean east of the Caribbean. The plotted tracks of past hurricanes cover practically every part of the Gulf of Mexico and the Caribbean Sea and much of the North Atlantic Ocean. They are apt to strike most of the Gulf ports and most of Florida. A good many veer off the southeastern coast of the United States and swing out to sea. However, many of them cruise up through Georgia, the Carolinas, and New England. Hurricanes have a counterclockwise wind system. The strongest winds are somewhere between 75 and 100 mph. Occasionally, they may get up to 150 mph. The eye, or the dead portion of the storm, usually runs about 10 miles in diameter. The outside dimensions of a hurricane which covers the width of the destructive winds could be anywhere from 25 to 400 miles. In the United States, hurricanes reach a peak frequency in August, September, and October. It is possible to design hurricaneproof towers at slight additional cost. The EIA Tower Standard RS-222 shows recommended tower strengths for different heights and locations.

Some hurricanes are accompanied by a strong tide which in some cases can be 10 or 12 ft. high when it reaches the seacoast. In certain bays where there is a narrow channel, this rise may be as high as 50 ft. These waves are certainly unusual, and although towers have been known to be washed away, no attempt has been made to design towers to withstand such tides.

Tornadoes

Tornadoes, or twisters, occur in most parts of the United States. The highest probability of their occurrence seems to be the Mississippi Valley, but one can expect them in the Southwest, Middle West, or Southeast parts of the country. The highest frequency occurs during the months of April, May, and June. A typical tornado starts in the late afternoon, usually moves from the southwest to the northeast, and cuts a path of destruction somewhere between several hundred yards and a mile wide. The winds inside this twister are very high and are believed to exceed 500 mph at times. No attempt is made to design towers to withstand these high wind velocities, but because of the narrow path involved, the probability of a tornado hitting a tower is not too high.

Wind Pressure

The commonly accepted formula for wind pressure is $P = KV^2$. P is wind pressure in pounds per square foot of projected area; K is the wind conversion factor depending on the shape; V is the actual wind velocity in miles per hour. The nominal value for K pressure on flat surfaces is 0.004. Notice that the pressure is proportional to the square of the velocity. If we plot this, we get the curve in Fig. 36. The commonly accepted practice is to use 0.004 for flats and angles and shapes and two-thirds of this value for cylindrical shapes.

Specifications

The EIA specifications for towers were drawn up by representatives of various tower manufacturers. These specifications cover very broadly, but very adequately, all important points in designing steel towers. It is best if broadcasters keep this in mind. There are other specifications probably as good, but they tend only to confuse things. For example, the American Institute of Steel Construction has a set of specifications which were drawn up primarily for large buildings and bridges. It is possible to misuse specifications. For example, AISC reads, "members subject to stresses produced by wind forces may be proportioned for unit stresses 33-1/3 percent greater than those specified for dead and live stresses." The intent of that paragraph was secondary wind bracing for structures with heavy live loads. A tower is not such a structure. This paragraph should not be used in radio-tower design, for if it is carried out to its literal conclusion, it is possible for broadcasters to specify a 30-lb. wind-load AISC tower and obtain approximately a 20-lb. EIA tower.

EIA specifications take a practical look at the method of analysis. EIA recommends that wind loads be expressed in terms of pounds per square foot projected area. Consequently you hear the expression "the tower is a 30-, a 40-, or a 50-lb. tower."

Wind versus Tower Failure

The question often arises, at what wind velocity will a tower fall down? It is very difficult to give an honest answer to that question. Let us take an example: Assume a 40-lb. tower. This means that the tower was designed for a 40-lb. wind pressure on flats, safety factor 1.8, so that the yield of the structure would be approximately at a wind pressure of 40 times 1.8, or 72 lb. Looking at the pressure-wind-velocity curve, 72 lb. equals about 134-mph wind velocity. Theoretically, a wind of 134 mph distributed uniformly over the structure produces yield in a structure, and this usually means failure. But how do we know how fast the wind was blowing on the tower? How do we know that the wind was distributed uniformly over the structure? Probably the best record available is the Department of Commerce Weather Bureau, miles away at a different elevation. For example, assume the anemometer 750 ft. below your tower. Wind velocity at your tower could be 134 mph, but the wind velocity versus height curve in Fig. 35 shows that there is approximately a 1.5 times increase in velocity, or at the anemometer, 750 ft. below, the wind is blowing about 90 mph. If you throw in a 10 percent gust factor, it is possible that the anemometer 750 ft. below your tower registered 80 mph when it was 134 mph at the top of your tower. For this reason, it is very difficult to correlate wind velocities as given by the Weather Bureau miles away from the tower site with the actual wind velocity blowing through the top of the tower. We do know that from past experience, in certain locations, towers designed to certain wind pressures seem to stay up and are adequate. The best indication for any given location is past experience.

Wind Loading

It is interesting to note the effects of installing different items on a tower. By far the greatest single contributor to the load on a tower is the area exposed to the wind. This means that the less area there is exposed to the wind, the less tower is needed to support itself. The simplest tower is a small AM radiator whose function is to support itself, with possibly one small lighting line. The other extreme is where signs, elevators, spare coaxial lines, antennas, and other equipment are installed on the tower. The accompanying graph (Fig. 37) is made in an attempt to show vividly the effect of various items "hanging" on a tower. The tower is a typical clean tower in the 500- to 600-ft. height range with various items being added on, one at a time. Obviously, it is not very difficult to double or even triple the side load on a tower by adding these items. The addition of any single item or article to the tower increases the wind load on it. This, in turn, means that the

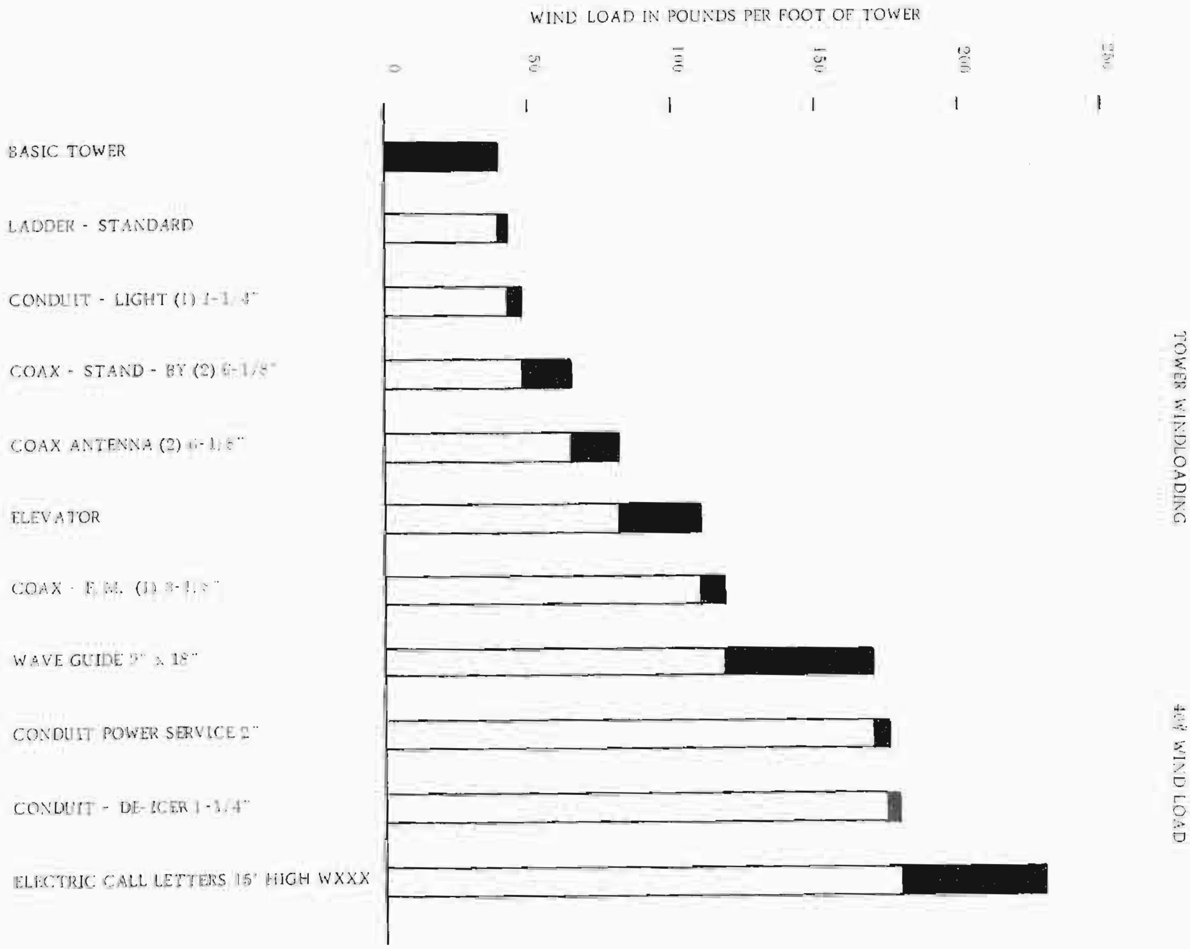


Fig. 37. Wind load in pounds per foot of tower.

tower has to be stronger, heavier, and possibly a little bigger in cross section. This additional cross section increases the wind load, which increases the weight and the cost of the tower. Obviously, you cannot hang all these components on the tower without increasing the weight and cost.

Icing

Ice tends to form on all structures exposed to the elements under certain conditions of humidity and temperature. The temperature is usually a little below freezing, and the air is superladen with moisture. Icing is spotty both in location and in frequency. You usually do not get much ice in dry climates, in very cold weather, or in very warm weather. There has been ice as far south as Atlanta, Ga. To find out how icing conditions are in your locality, ask the engineers at your local power company. Utilities constantly have trouble with ice. Tall towers, around 1,000 ft., tend to get layers of ice farther up the tower. You usually find more ice on mountain tops.

Recently updated EIA Specifications, although not specifying a specific radial ice accumulation for a given area, do call for a minimum 1/2 in. radial ice where applied, and provides for the simultaneous application of wind and ice loads on the tower (including on guys) and accessories. Ice load design has two basic effects on tower design; namely, weight increase and increase in projected wind area. Thus cost will generally increase very appreciably when ice is specified in a design.

Prevention of Icing

A number of ideas on preventing ice formation on towers and guys have been advanced. Heating elements have never been tried to deice the tower as far as we know. Heating elements are used on the antennas, not to prevent damage to the antenna, but rather to prevent damage to the radiating properties. The most practical solution seems to be to make the tower strong enough to carry the ice.

Falling Ice

Ice falling off the structure presents a hazard. A chunk of ice 4 or 5 in. thick falling several hundred feet carries quite a "wollup." Automobiles parked at the base of the tower or even some distance from the base of the tower can be damaged. Ice has been known to break beacons, lights, and microwave gear on the way down. It is certainly a hazard to horizontal runs of coaxial lines. A simple corrugated-iron or wooden shield to deflect the flying ice is adequate. Icing over 1 in. in thickness, except in isolated cases, is rare. Pictures of ice 1 and 2 ft. thick taken on Mount Washington should not be used as a guide in designing a tower.

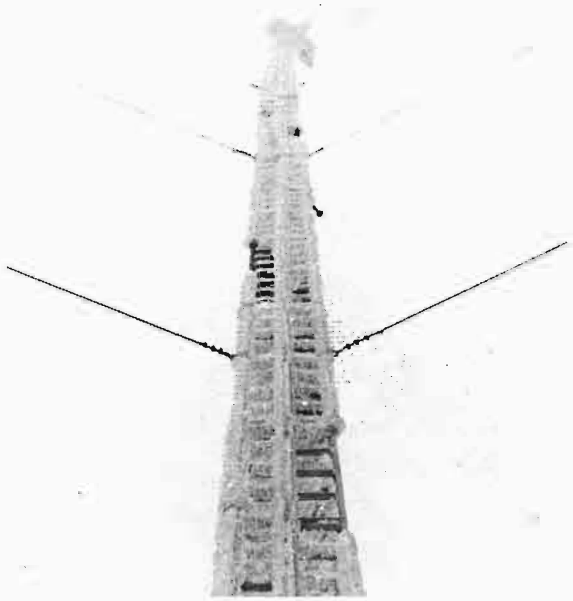


Fig. 38. Ice formation on a tower.

Earthquake Loading

Towers on the West Coast are usually required to meet the Pacific Coast Uniform Building Code for earthquake loadings. This code says as follows:

In determining the horizontal force to be resisted, the following formula shall be used:

$$F = CW$$

where F = horizontal force. lb.
W = total load tributary to the point under consideration
C = 0.05 for towers which are connected to a building
= 0.025 for radio towers which are not supported by a building

This horizontal force F is added directly to the wind load. In a short, light tower, say 200 ft., this does not add an appreciable amount of load to the tower. In a tall, heavy tower, this factor may be considerable.

Atomic Blasts

One of the atomic blasts out in the Nevada flats was made to test a number of civilian defense items. The bomb was set off on a 500-ft. steel tower. Two small cities were built, the first approximately a mile from the blast, the second approximately 2 miles from the blast. Depending on the size of the bomb, all steel within a certain radius is immediately atomized and, for all practical purposes, simply vanishes. So it is impossible to build an atomic bombproof tower. One practical observation was that in the test city, alongside brick and wooden homes which were badly mangled, a guyed 150-ft. AM tower designed as a 30-lb. EIA tower at 250 ft. survived undamaged, although there was evidence of the tower having moved a great deal during the blast. A 100-ft. self-supporting tower, noninsulated, loaded with two-way radio antennas, designed to approximately 20-lb. EIA load, failed at the same site. A very rough conclusion may be that a short guyed 40-ft. EIA tower is approximately a little better than average small buildings. Since the blast gave the tower a violent "jerking about," as it were, the whip or inertia forces must have been high. Consequently, the above conclusion may not be the same for towers which have larger inertia or whip forces. Inertia forces are greater in the case of self-supporting towers and guyed towers with heavy top loads from antenna.

INSULATORS

Base Insulators

Current practice for AM radiators is to have the base of the tower insulated, although there still are some shunt-fed installations.

Most insulators today are made of porcelain. There is no reason why other materials could not be used, such as wood, glass, or fiberglass and other new plastics.

Since current practice is to use porcelain, this discussion will concern porcelain insulators. A designer of porcelain insulators always keeps in mind that porcelain is strong in compression but weak in tension. Therefore, the insulators are always designed so that the load pushes on either a mass of solid porcelain or a cone of porcelain. The designer tries to make sure that there is no bending or tension induced into the porcelain portion of the insulator. Most guyed towers come down to a single-point pivot, and the insulator will have a rounded surface so that the tower can pivot. This is to prevent any bending being induced back into the porcelain, and most of the load is pure compression. Fig. 39 shows a typical installation. Sometimes a rain shield is put over the top of the insulator in an attempt to keep the insulator dry, since the flashover value of dry porcelain is better than that of wet porcelain. However, most rain shields are very ineffective in a driving rain unless they form a complete shroud down and around the porcelain. Since porcelain is fragile and subject to cracking, some care should be exercised in handling it. There have been instances where water has got into the cone, the drain hole has plugged up with dirt, and the water froze and shattered the insulator. This is quite unusual. The cost of base insulators with leakage paths greater than 10 ft. increases rapidly.

The self-supporting tower presents a unique problem in that the base insulator has to transmit either compression or tension from the leg member. The accompanying cross section of a typical push-pull insulator in Fig. 40 shows how this is accomplished. This insulator works in such a way that the upper cone works when the load is down (compression on the pier) and the bottom cone works in compression when the load is an upload on the leg member. These insulators are usually very bulky and expensive, and except for the smaller sizes, delivery and availability are not too good.

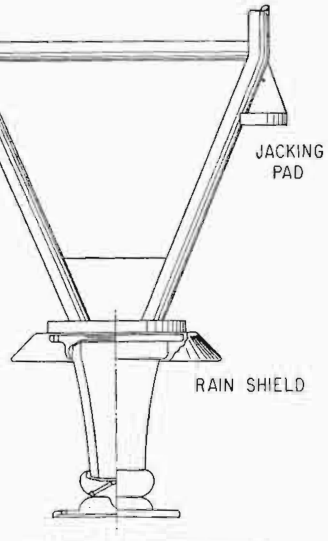


Fig. 39. Typical base insulator for guyed towers.

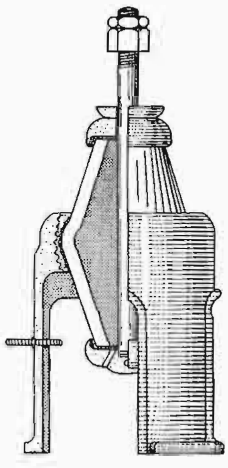


Fig. 40. Push-pull type of insulator for self-supporting towers.

It is perfectly possible to have a three-legged or four-legged guyed tower which is shaped so that it sits on all three or four legs on the pier, in which case, three or four insulators will be required at the base of the tower. Some designers prefer this form, and there is nothing wrong with it provided the insulators are capable of transmitting a certain amount of tension and the foundation pier is absolutely level.

Large special insulators are sometimes used, but they are not typical.

Once in a great while, the porcelain on a base insulator will crack. The crack may be due to an old flaw, an external blow, a lightning hit, or water getting inside the porcelain and freezing. In order to change the base insulator, the tower must be raised slightly. This is not a particularly difficult operation, but it is very critical. Sometimes, on tall towers, jack pads are incorporated into corner legs to facilitate raising the tower.

Raising Base Insulator above Ground

The base insulator of an AM tower is located so that unusual weather will not ground the insulator. Sometimes, 1 or 2 ft. above the ground is adequate. The insulator is usually placed in a concrete pier 3 to 5 ft. tall. Occasionally, insulating may be as much as 25 ft. above the ground as is shown in the accompanying photograph, Fig. 41. Sometimes, in an array of four towers on a sloping piece of ground, it may be desirable to locate all insulators in the same horizontal line. Each tower sits on a pier of a different height. Concrete is generally used up to about 5 to 10 ft.

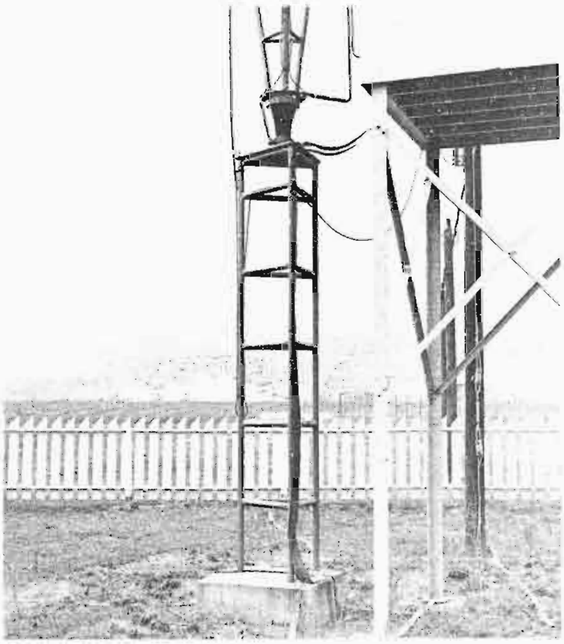


Fig. 41. Example of raising base insulator for flood-water conditions.

Over that height, some sort of steel pier is probably the most economical.

Guy Insulators

Typical guy insulators and guy-insulator assemblies are shown.

The most commonly used guy insulator for AM work is the so-called strain insulator. Since most AM towers are under 300 ft., most towers use these insulators. The insulators were developed by the power companies and are made in large quantities so that they are easily available and the cost per unit is very low. They come with multifins to increase leakage path and are used with strand up to 1/2 in. Another advantage of a strain insulator is that if an insulator cracks, the tower fails safe; that is, the interlocking loops of strand keep the guy intact.

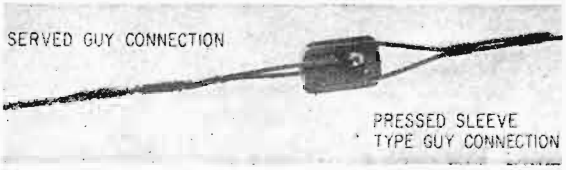


Fig. 42. Typical strain insulator.

Where it is desired to have the insulators capable of being inserted after erection, the open-type insulator is sometimes used. A strand over 1/2 in. is very stiff, and it is very difficult to pull around the insulator. Great care must be taken to make sure that the strand hugs the loop all around its periphery. In other words, the strand must be forced around the grooves on the insulator. If this is not a snug fit at both sides of this insulator, the insulator will tend to cock, the insulators will be loaded at a point rather than over a surface, and the desired mechanical strength will not be obtained.

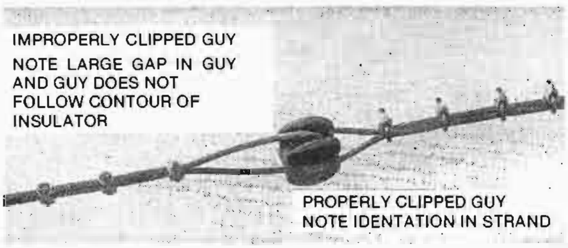


Fig. 43. Improperly and properly clipped guy.

On large guys and when the leakage path is greater than that obtained by strain insulators, the so-called cone insulators are used. This cone insulator is nothing more than a base insulator with a basket around it. You will notice that the load is transmitted through a cone of porcelain in

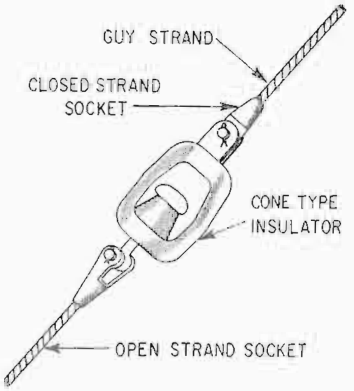


Fig. 44. Cone-type guy insulator.

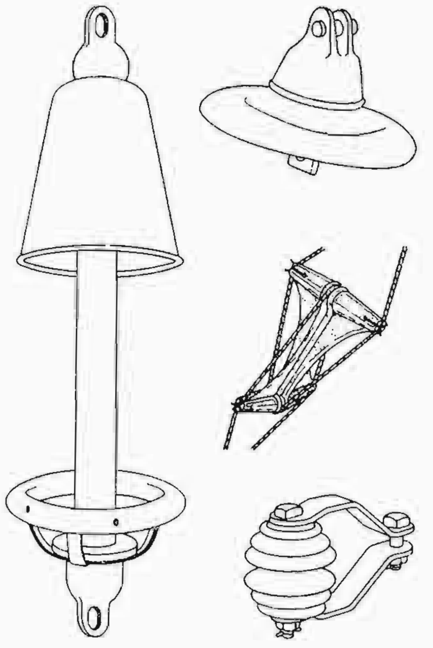


Fig. 45. Miscellaneous guy insulators.

compression. It is interesting to trace the load transmitted through one of these insulators. The load comes down the guy, through the top socket, then around the insulator, through a steel yoke and to the bottom of the cone. All this load so far is tension. The load is transmitted through the porcelain to the top of the cone in compression. The top of the cone has a pivot with a gonglike piece hanging down to pick up the bottom socket. These insulators are large, clumsy, expensive, and not easily available. Also, they do not fail safe.

Several other types of guy insulators which have been used are shown. Porcelain insulators have a very good life. Replacement of cracked strain insulators is not common. For replacement, the guy is dropped or an erector slides down the guy to the point in question.

Sectional Tower Insulators

There are some installations where by sectionalizing a tower it can be used for more than one function. A sectionalized tower can be used to control the AM radiating characteristics of a tall tower. This allows a tall TV tower to be used as an AM tower. This is possible by insulating portions of the tower from one another. As shown in the illustration (Fig. 46), either the pivot type or the push-pull type of insulator can be used to sectionalize a tower. It is desirable to taper the tower for the pivot-type insulator. The push-pull type of insulator is used at each leg member as is used in a self-supporting design. In either case it is necessary to check the shear transfer across the insulator.

With a sectionalized tower, periodic inspections of the insulators are mandatory. A failure in a sectionalizing insulator very likely will cause the tower to fail.

BONDING

An AM tower is a radiator. Hence, it is important that the steel tower acts as one continuous electrical unit. Faying surfaces on a galvanized tower are not painted and as a rule are considered sufficiently bonded through the zinc contact. Two methods of bonding steel towers are shown below.

The weld type of bond is positive, but extreme care must be taken when welding near guys. It is possible to damage guy strand with the molten weld slag. The copper-jumper type of bonding is a bit more troublesome. The holes must be absolutely clean and free from rust and paint. The wedges should be driven in tightly to make good contact and exclude any moisture to preclude any electrolytic action.

LIGHTNING

Since the steel tower is usually the tallest object in its vicinity, it is always the first to be hit by lightning. As a matter of fact, the tower itself forms an electrical umbrella, as it were, for adjacent structures. Since steel is a very good conductor, lightning does not damage the tower or its guys. Although there have been many rumors about lightning shattering concrete foundations, we have never been able to find a

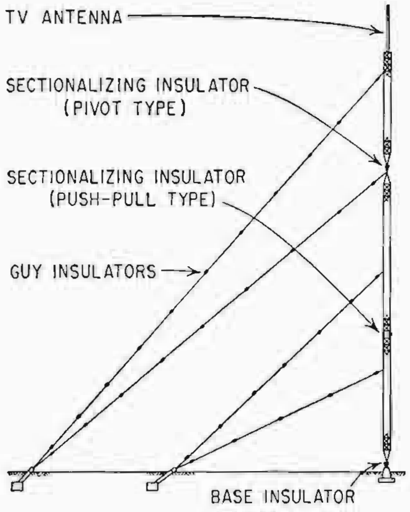


Fig. 46. Example of a sectionalized tower shown with two types of sectionalizing insulators.

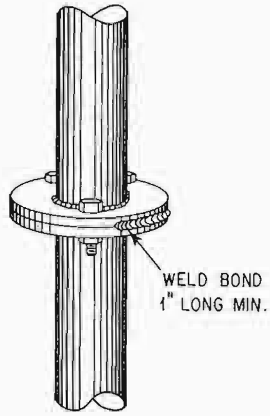


Fig. 47. Weld-type bonding.

record of such an incident. An AM tower, with its screen and radials, automatically makes a very good ground for dissipation of lightning. TV and other towers should be adequately grounded simply as a precaution to keep the lightning path away from the transmitter house. A typical guy cable grounding system is shown in Fig. 49.

Lightning, however, can and has done damage to any and all kinds of electrical equipment on the tower. It seems almost impossible to build a tower where the manufacturer can guarantee that lightning will not knock out pieces of electrical wiring, lamps, junction boxes, etc.

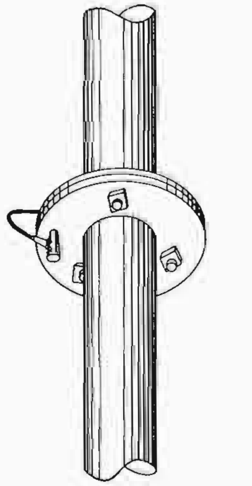


Fig. 48. Jumper-type bonding.

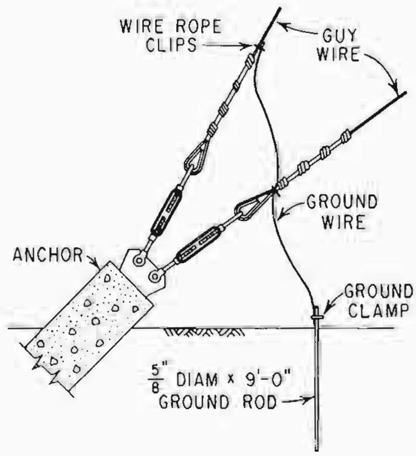


Fig. 49. Grounding at guy anchor.

SOILS, ANCHORS, AND FOUNDATIONS

Soil Exploration

On small towers such as a 200-ft. guyed AM tower, the magnitude of loads is not large enough as a rule to warrant soil exploration, unless, of course, the soil is very sandy or swampy. If the condition of the ground is in doubt and on tall TV installations where the magnitude of load is appreciable, a thorough soil exploration is certainly advisable. In most parts of the country, there are soil engineers who are familiar with the type of soil in a particular location. Test bores are usually made at the tower base and at the anchor foundation locations. At the base of the tower, test bores should be approximately 25 or 35 ft. deep, whereas at the guy anchors, test bores should be a little deeper than the anchor depth.

The purpose of the test bore is to help determine the allowable unit bearing pressure for design. Sometimes, local building codes set their own values for local conditions. There are any number of methods used to study the subsurface conditions. A simple test which permits classification of the soil may or may not be adequate to tell the bearing capacity. For that reason, a test boring log should be turned over to competent soil engineers, who will then convert the data to allowable bearing capacities of the soil. Soil engineers are usually more familiar with local conditions, codes, and geology than others far removed. For purposes of approximation, the allowable bearing values of foundation soils are given in Table 1.

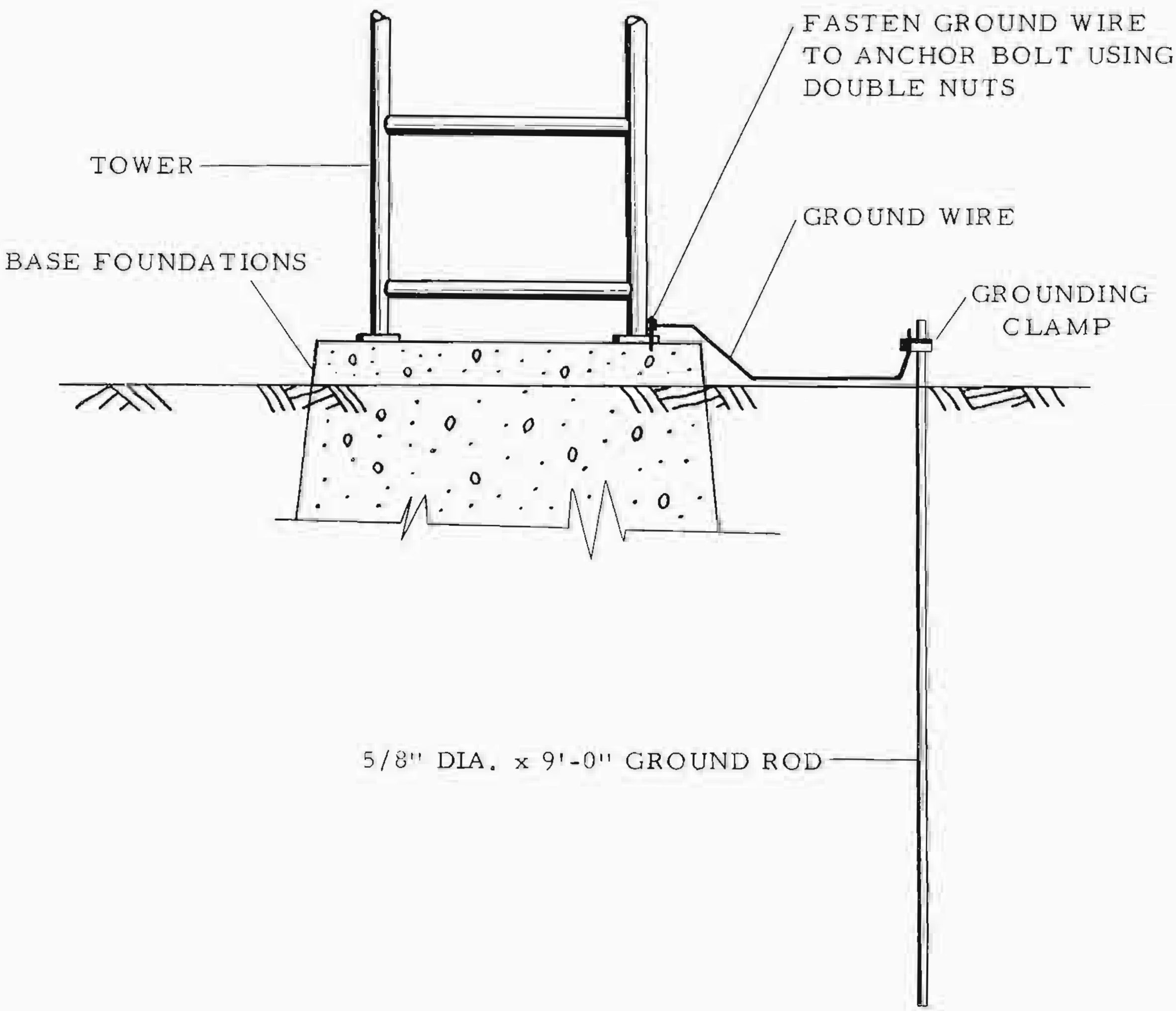


Fig. 50. Grounding at tower.

TABLE 1

Approximate Allowable Bearing Value of Foundation Soils

Soils	Bearing Capacity, Tons per sq. ft. Approximate Depth 3 ft.	Approximate Depth 6 to 10 ft.
Soft silt and mud	0.1–0.2	0.2–0.5
Silt (wet but confined).	1–2	1.5–2
Soft clay	1–1.5	1–1.5
Dense firm clay	2–2.5	2.5–3
Clay and sand mixed firm . . .	2–3	2.5–3.5
Fine sand (wet but confined). .	2	2–3
Coarse sand.	3	3–4
Gravel and coarse sand	4–5	5–6
Cemented gravel and coarse sand	5–6	6–8
Poor rock	7–10	7–10
Sound bedrock	20–40	20–40

A typical log of a boring is shown in Fig. 51. This log is in turn analyzed by a competent soil engineer who will recommend allowable unit bearing pressure for design.

Anchors and Piers

Tower base foundations are usually made of reinforced concrete and are designed to carry the total column load of a tower. The area of the footing should be of sufficient size to prevent detrimental settling of the tower structure.

Anchor foundations, on the other hand, exert little down loads. The vertical component from a guy is resisted by the weight of the concrete and earth overburden. The horizontal component is resisted by friction on the anchor base and by the lateral resistance of soil on the face of the anchor.

At some installations the allowable bearing pressure of the soil is very low or an underlying stratum is exceptionally poor. Serious settling of the foundation may occur under these conditions, and it is advisable to drive piles under the footing.

Figs. 52 to 62 show the many types of base pier and anchor designs for radio and TV towers. Many metal-type anchors for small tower installations are available for different soil conditions, and the illustrations are self-explanatory. The screw-type swamp anchor has a pipe for its shank. The length of the shank is increased by coupling additional pieces of pipe until the screw has been driven into hard soil. Various types of guy anchors are shown.

The photograph in Fig. 63 shows an anchor installation at KOA-TV, Denver. Usually, the small flats on top of hills make a self-supporting tower a must. However, it is possible to install tall guyed towers in rough, mountainous terrain. Naturally, this usually brings about installation problems. Probably the costliest item is making

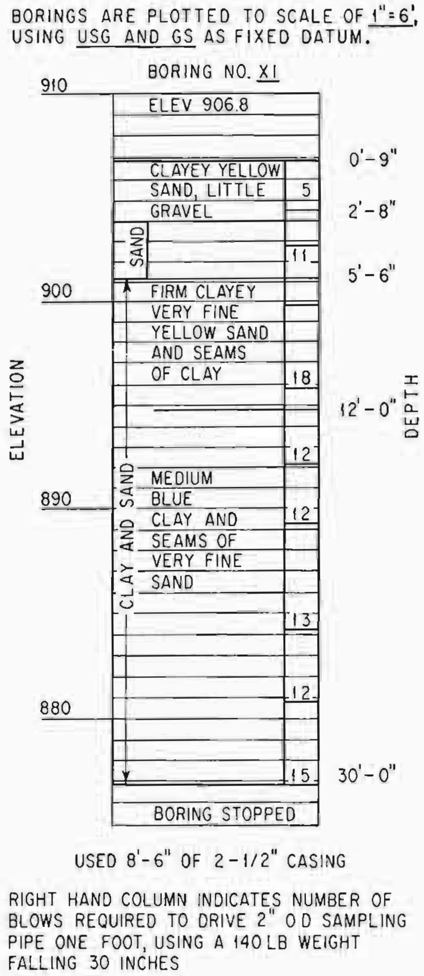


Fig. 51. Typical boring log.

the tower base and each anchor point physically accessible to trucks and erection equipment. Tower designers like to choose sites so that each anchor falls off approximately the same. However, this is not always possible or absolutely necessary.

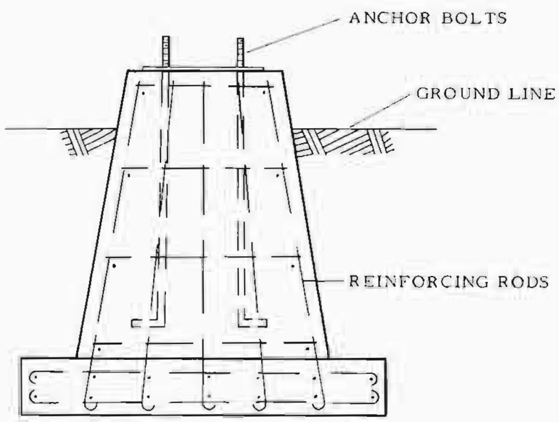


Fig. 52. Typical reinforced-concrete base pier.

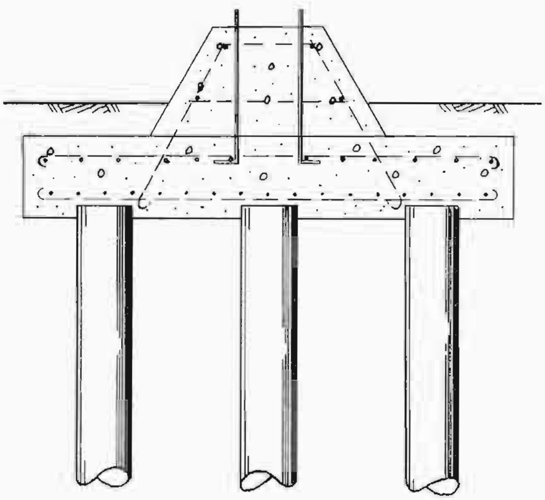


Fig. 53. Base pier of reinforced concrete on piles for use in poor soils.

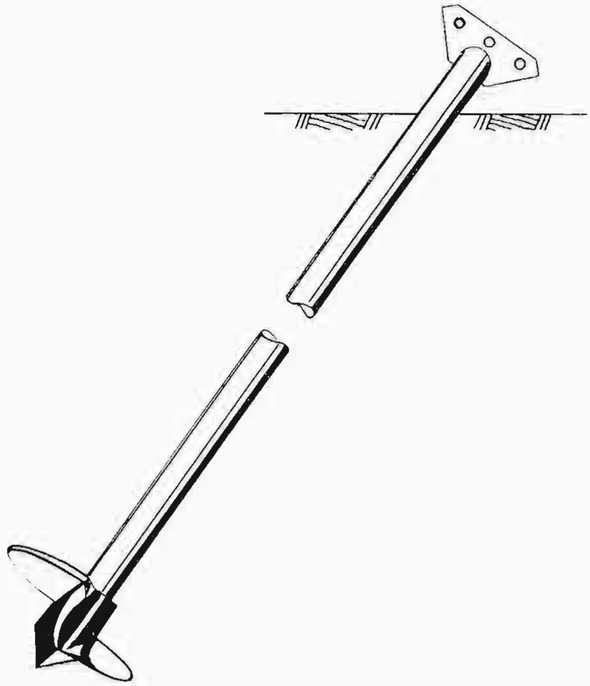


Fig. 54. Screw-type swamp anchor.

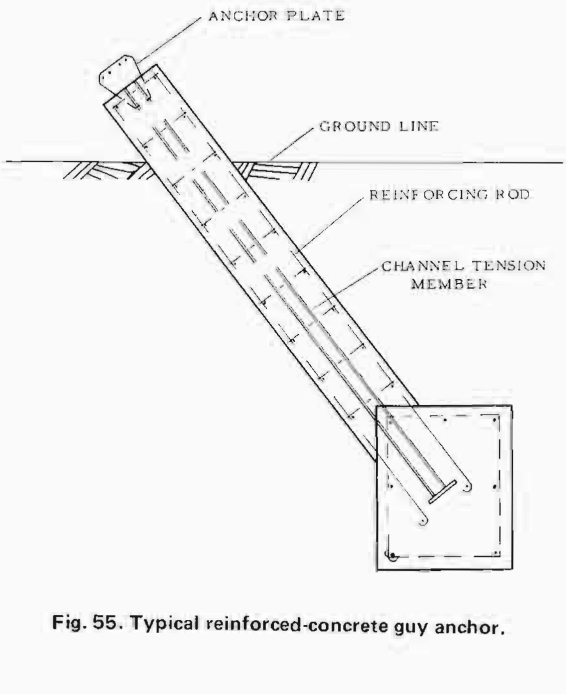


Fig. 55. Typical reinforced-concrete guy anchor.

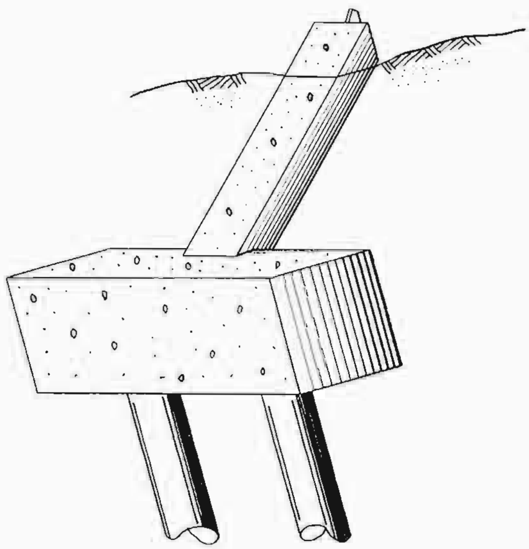


Fig. 57. Reinforced-concrete guy anchor on piles for use in poor soils.

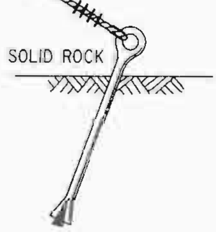


Fig. 56. Wedge-type rock anchor.

Concrete Foundations

Reinforcing

Most foundations are made of reinforced concrete (see Fig. 52). Since the concrete is in a wet plastic state when it is poured, it must be confined until it hardens. Usually, these forms are made of wood. Sometimes in small towers, forms are dispensed with at the anchors simply by digging a hole of rectangular shape and allowing the sides of the earth to give the concrete its shape. On a large tower, the wooden forms run into a considerable amount of money.

Except for tiny foundations, concrete piers and anchors are always reinforced with reinforcing bars of the deformed type of steel. The purpose of these bars is to help carry any tensile stresses in the concrete block, since concrete is essentially a compressive load-carrying material. Deformed steel is used, since the deformed surfaces give a better mechanical bond to the concrete. Since reinforcing bars are universally obtainable, the steel is usually procured locally. The reinforcing bars should be carefully wired and placed to-

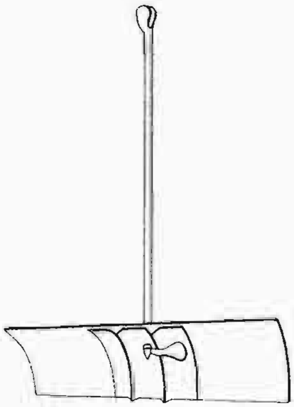


Fig. 58. Two-pieced metal anchor for clay or loam.

Fig. 59. Screw-type earth anchor.

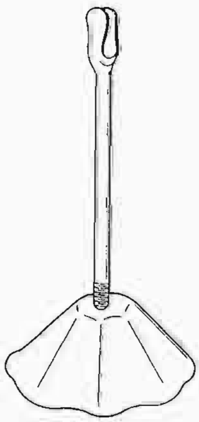


Fig. 60. Cone-type anchor for rocky soils.

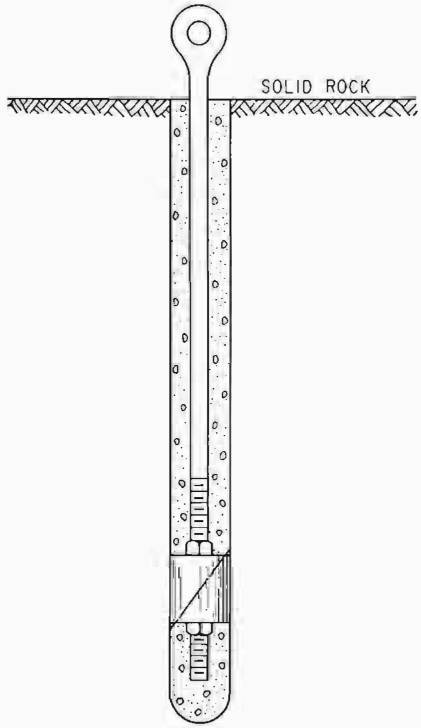


Fig. 61. Expanding rock anchor.

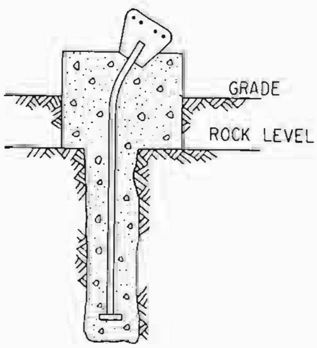


Fig. 62. Concrete-type rock anchor.

gether as called for on the foundation drawing prior to pouring the concrete. Sometimes these bars are welded together into a subassembly.

Mix

The concrete is usually obtainable from a local ready-mix plant. The foundation designer always specifies the proportions of the mix and the water-cement ratio or strength of concrete. These items should be relayed to the supplier of the concrete. A typical mix is 1-2-4, where the numbers 1-2-4 represent the proportions of cement, sand, and gravel. The water-cement ratio is often expressed by specifying approximate compression strength of the concrete after 28 days. A typical strength is 3,000 psi.

Pouring

As the concrete is being poured, precautions should be taken to see that the forms are filled completely. The usual method is simply to poke or churn the concrete with a pole or shovel, especially along the edges of the forms. Care should be taken to see that the steel arms which protrude from the forms are not moved or disturbed by the pouring of the concrete.

On towers where the guys are supplied with fixed lengths, it is most important to know the exact dimensions from the working points at each guy anchor. These are surveyed and determined prior to pouring the concrete. Since the concrete may disturb the steel anchor arms, it is advisable to survey the installed anchors and get a new set of readings locating these work points.

When concrete is poured under water, proper forms and a comparatively dry mix will aid procedure. Where the simple method of depositing the concrete under water directly is not possible, a cofferdam can be built. A cofferdam is a temporary wall structure out of which water is pumped so that work can be carried on in a comparatively dry area.

Freezing

Frozen concrete may not suffer any visible deterioration, but its strength is greatly decreased. Some precautions must be taken during freezing weather. Fresh concrete, when frozen, is easily recognized by its white color, whereas ordinary concrete will remain a slate color. One precaution is to heat the ingredients and water prior to mixing and then cover the poured concrete with layers of hay or straw. Sometimes heat is introduced from a portable heater. Another precaution is adding calcium chloride to the mixture. This generates heat during the setting period.

Fig. 63. Guy anchor installation at KOA-TV, Denver, Colo.

Strength

There are occasions where high strength in concrete foundations at an early age is desired so that the erection of steel can begin at the earliest possible moment or to make possible early reuse of forms. In cold-weather construction, high early strength reduces the time of protection required. High strength at early ages can be achieved by using a type III portland cement usually designated as high-early-strength portland cement or by using richer mixtures of other types of portland cement. The type III cement costs more than the normal portland cement.

Since the important factors which govern the strength of portland cement concrete are the relative proportions of cement and mixing water and conditions during curing, great latitude in obtaining desired strengths at a given period can be obtained by adjusting these factors. Sometimes, calcium chloride is used as an accelerating admixture to increase the rate at which concrete develops its early strength. The calcium chloride is particularly effective in increasing strengths at 1 to 3 days. On the other hand, for a given water content, high-early-strength cements give higher strengths than normal portland cement either with or without the accelerator at the later ages up to about one year.

TOWER ACCEPTANCE

Inspection

Most towers are very simple structures physically. Assuming that the tower was designed by a competent engineer to EIA standards and that the number and size of members called for by the manufacturer are adequate, the job of checking

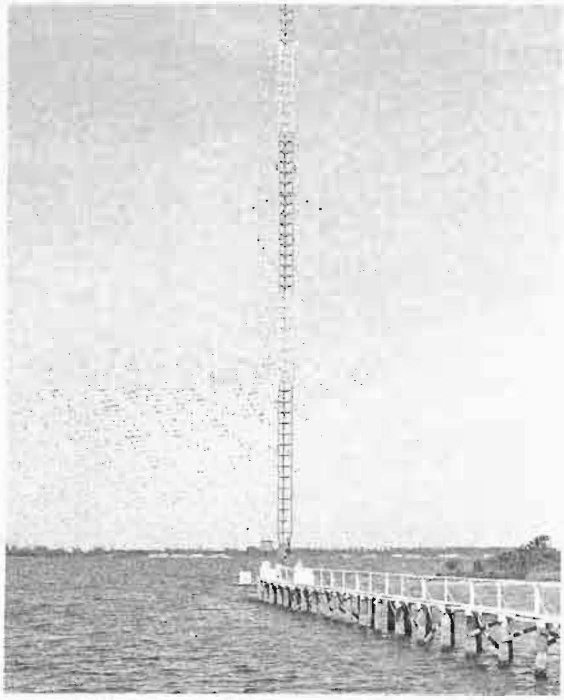


Fig. 64. Photograph of a water installation. The erection costs rise very rapidly. Cofferdams are built prior to pouring the foundations, and the erector must invent ingenious devices to get his material to the base of the tower in the water. The photograph is station WMMB, Melbourne, Fla.

should not be too complicated. The following is a suggested checkoff list:

Tower Inspection Checkoff List

1. Has the site been cleaned of all debris, paint, cans, reels, and miscellaneous erection junk?
2. Is the tower plumb?
3. Is the tower painted properly—international orange and white—per construction permit?
4. Are the bolts pulled up tight?
5. Are all the nuts secured and locked as called for by the manufacturer?
6. Are the turnbuckles safety-wired to prevent back turning?
7. Is the service entrance cable or conduit attached securely?
8. Check anchor distances against tower drawing.
9. Were holes for the foundations dug deep enough as per drawing?
10. Are the anchor holes backfilled? If not, the first rain will make a sizable depression over the anchor.
11. Is the coaxial system tight?
12. Does the lighting system work?
13. Are all the junction boxes secured with watertight gaskets in them?
14. Look at the face of the tower. Is there any appreciable twist in one face?
15. On large towers, check the guy tensions by the method given to you by the manufacturer.
16. Look at all the members from the ground. Are any of them visibly damaged or bent during the course of construction?
17. Did the erector leave any unpaid bills around town that you know of?

Three chronic complaints about erectors are:

1. Shorting in the lighting system
2. Sloppy paint job
3. Leaks and dents in the coaxial system.

General Erection Notes

There is a tendency for the broadcaster to take a long time to decide what tower to buy and then expect an erector on the site before the material has arrived. These boys do not get paid for days they do not work. If they are held up because of lack of material, they resent it! Very often, the broadcaster, with no ill intent, tells the erector that most of the material is on the site and the balance is in transit. This may be true, but unless the last bolt and every piece of coaxial, anchor, and tower is on the site, one can never be sure when it will get there! Less-than-carload shipments are very slow. The erector will cry for extras, and bad feeling begins. You can't blame the erector. Bear in mind that the average erector many times works under adverse conditions and is away from home.

Tower-erection business is very competitive. Most bids are based on the erector's being able to get to the site. He does not necessarily need a four-lane highway, but he should be able to drive the truck to the base of the tower and drive to each anchor. The fact that you can walk on the site does not necessarily mean that it will hold up a truck. He also needs a cleared piece of land to assemble his material.

It is not the erector's responsibility to get a building permit. It is customary for the tower buyer to get all permits simply because they are usually obtained under local conditions which change from town to town all over the country. Sometimes it is a matter of a two-dollar license. In other cases, political intervention or an expensive engineering analysis and approval are required.

Erectors bid on the understanding that they will work regular hours. Overtime is expensive, and one should expect some resentment from the erector when he is asked to work overtime at no extra cost.

It would be wise to allow a somewhat longer time for erection than promised by the erector. He usually thinks in terms of elapsed working days and does not count Sundays, Saturdays, holidays, opening days for fishing, opening days for hunting season, or days or rain, sleet, and high winds.

Often winds are 10 mph on the ground but 30 mph aloft at 700 ft. (see Fig. 35).

Erection work is usually risky work simply because it is off the ground. The more you push the workmen, the more prone to accidents they become. The erector is not going to get paid until he finishes the job, so he, too, is anxious to complete it.

The erector expects electrical power at the base of the tower prior to starting the job. Otherwise, he has trouble getting temporary lights and he will complain.

Erection work is usually thankless and dangerous. Working conditions, because of cold, rain, mud, swamps, rocks, snow, wind, and weather, in general, are never so good as those in an air-conditioned factory. The men have to be of a tougher breed. Understanding their problems helps everyone.

Insurance

If a station decides to hire its own erector to install the tower, it is recommended that the following evidence of insurance from the erector (in the form of certificates) be obtained. The following different insurance certificates are customary today:

1. Workmen's compensation and occupation diseases, including employer's liability insurance. *Limits:* This insurance should be checked with the statutory requirements as applicable in the state in which the work is being performed. Employer's liability should be at least $25,000.

2. Contractor's public liability insurance which covers damage and injury to objects and people not under the care and custody of the contractor. *Limits:* Bodily injury, $15,000/100,000; property damage, $15,000/100,000.

3. Contractor's protective liability insurance protects the contractor with his subcontractors. For example, the contractor may sublet the foundations or sublet the electrical work or paint because of union problems. *Limits:* Bodily injury, $15,000/100,000; property damage, $15,000/100,000.

4. Automobile liability insurance. This covers all motor vehicles owned or leased, including nonownership liability covering contractors' employees' personal cars and trucks. *Limits:* Bodily injury, $100,000; property damage, $100,000.

5. Direct damage insurance. This insurance provides for protection against all risk of the tower, antenna, lines, and the equipment which the erector is working on or material which is in his (erector's) custody until completion of the job. *Limits:* Should be set to cover the value of the tower, lights, coaxial lines, antenna, and any other equipment he is installing, plus erection labor involved.

The owner should have an insurance policy covering any loss to the tower once the tower erection is completed and the customer has accepted the tower. Values are set for replacement values, namely, the price which he has paid for the tower and equipment on the tower plus the cost of erection.

TOWER LIGHTING[1]

Since a tower is a hazard to air navigation, the government prescribes certain warning lights to be installed on the broadcast towers. In general the lighting requirements are spelled out in a pamphlet put out by the FAA called "Standards for Marking and Lighting Obstructions to Air Navigations." However, the exact lighting requirements are given very specifically in detail in the construction permit from the FCC for every station. These specific instructions may differ from the general specifications. Since the maintenance of the tower lights is a never-ending problem, it behooves the station management to see what can be done to keep the lighting requirements down. For example, any tower in the shadow of a taller obstruction, such as a taller building, a taller tower, or a taller hill, can usually be installed without any lighting.

The electrical system is essentially very simple. It consists of a number of lamps which are fed by one or more circuits either 110 or 220 60 cycles alternating current. On AM towers, the RF must be isolated from the 60-cycle current. Circuits are made and broken intermittently by a flasher. A photocell is used to turn the lights on and off automatically at certain light levels.

Maintenance of lighting systems as a rule is fairly simple. Lamps burn out and must be replaced. It is possible to double the lamp-replacement period by installing two lamps at every light requirement and connecting these two lamps with a small relay which turns on lamp 2 upon failure of lamp 1.

The most chronic tower-lighting complaint is water getting into the system and causing shorts. Here again, it is a matter of making sure that all connectors and covers are installed neatly and made watertight. It seems that about as many leaks occur in the conduit system as in the system which uses flexible cable.

Some stations with tall towers have experienced broken glass on beacons due to falling ice and have installed small ice shields over the beacons. Most flashers today use a mercury switch to make and break the circuit. These mercury switches are relatively trouble-free. Flashers which use con-

[1]FCC Docket No. 19331 proposes to change the tower lighting requirements.

tactors for making and breaking a circuit tend to give trouble because contact points burn and pit.

Tall towers requiring several beacons and side lamps are usually fed with several circuits of color-coded TW wire in rigid conduit. Most short AM towers make use of service entrance cable or any number of flexible cables, since this system is cheaper.

Since the beacon is the uppermost point on a tower, it is usually protected with a lightning rod, which reaches a couple of feet above the beacon. Most TV antennas have a lightning rod built into the antenna. As a conservative precaution, it is wise to ground physically in the junction boxes the neutral or ground wire in the lighting system at several levels on the tower.

SIMPLIFIED TOWER DESIGN

Calculating Wind Load

The method of calculating wind load on a tower is given in Sec. 2 of EIA Standard RS-222A. On triangular tower structures, wind pressure is applied to 1.5 of the projected area of all members in one face. Pressure is applied to the projected area of lighting lines. Calculations below are for 30 psf on flat members and 20 psf on round members.

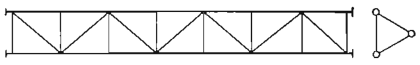


Fig. 65. Typical triangular tower section.

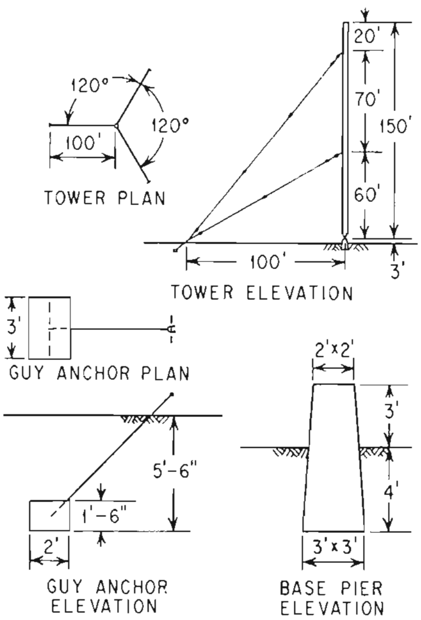


Fig. 66. Tower sample analysis.

1. Tower

Member	External Diameter, in.	Length, in.	Number of pieces	Projected area, ft.^{2}
Cross member 3/4 in. I.P.S.	1.05	16.34	8	0.95
Diagonals 3/4 in. I.P.S.	1.05	39	7	1.99
Verticals 1-1/4 in. I.P.S.	1.66	240	2	5.53
Total projected area				8.47

Wind load:

$$\frac{\text{Projected area} \times 1.5 \times \text{wind pressure}}{20 \text{ ft.}} =$$

$$\frac{8.47 \times 1.5 \times 20}{20} = 12.71 \text{ psf}$$

2. Lights:

$$\text{Total projected area} = \frac{1 \times 20}{12} = 1.67 \text{ sq. ft.}$$

$$\text{Wind load} = \frac{\text{projected area} \times \text{wind pressure}}{20 \text{ ft.}}$$

$$= \frac{1.67 \times 20}{20} = 1.67 \text{ psf}$$

3. Total wind load = 12.71 lb./ft. + 1.67 lb./ft.
= 14.38 lb./ft.

Shear, Moment, and Loading

Obtain shears and moments, considering the tower as a continuous beam. Assume that the points of support deflect as a straight line. Use the moment-distribution or similar method. Allow for eccentric application of the load by the guy. The eccentric moment is the vertical component of the load in the guy multiplied by its distance from the center of the tower.

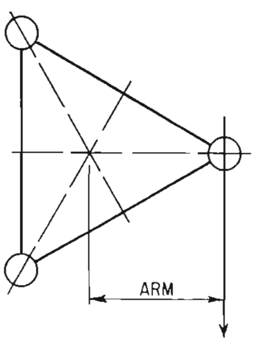


Fig. 67. Shear and moment analysis.

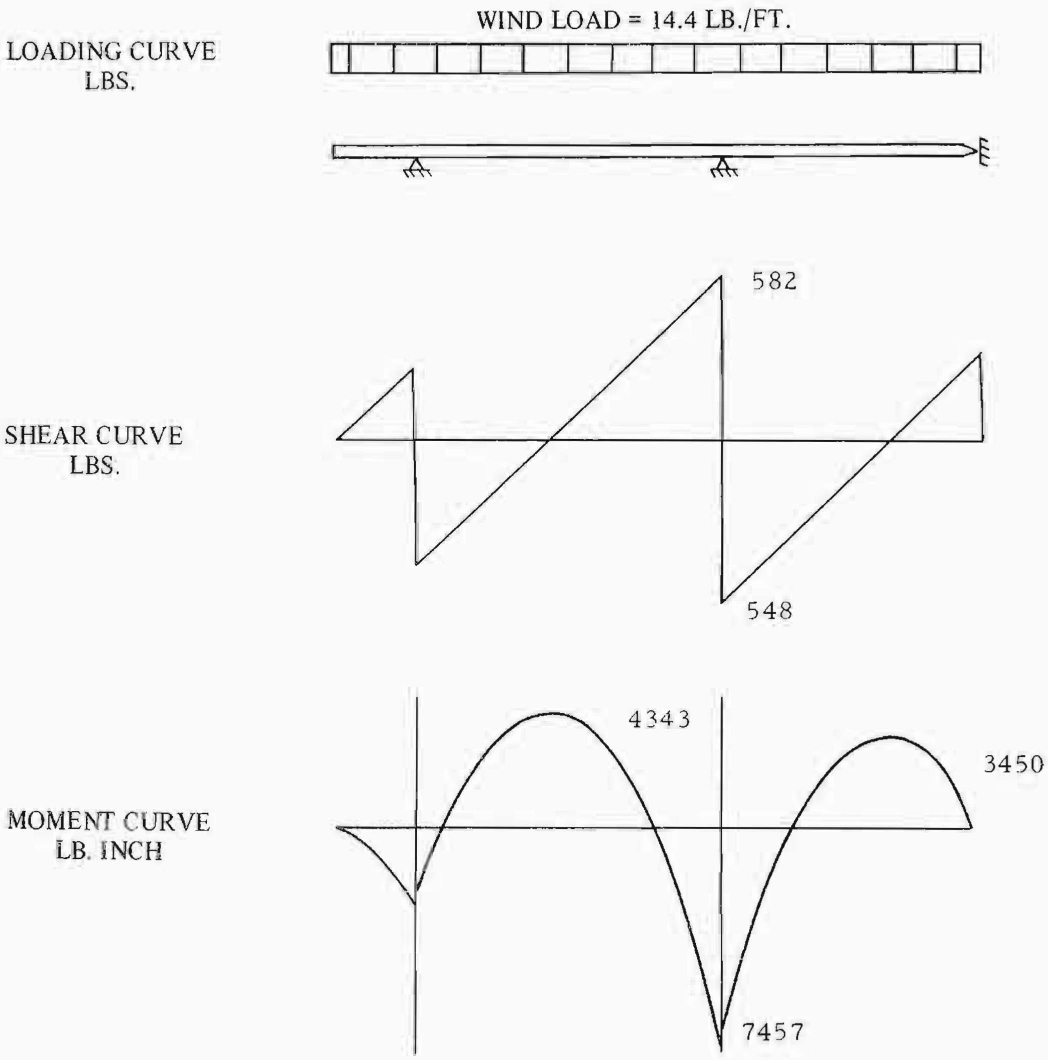


Fig. 68. Loading, shear, and moment curves.

Diagonal Struts

Diagonal struts resist tower shear. Assume that two-thirds of the shear is carried by one face of the tower.

Maximum shear = 582 lb.

$$\text{Load} = 2/3 \times 582 \times \frac{34.1}{18} = 735 \text{ lb.}$$

Check the strength of the member for compression and for tension using allowable stresses (see RS-222A Par. 3.1.1).

Horizontal Struts

The load in horizontal members is equal to the horizontal component of the load in diagonal members.

$$\text{Load} = 735 \times \frac{18}{34.1} = 388 \text{ lb.}$$

Check the strength as for diagonal strut.

Column Load on Tower

The wind direction shown is critical for the column load on the tower. Two guys are on the windward side of the tower and apply a vertical load. Assume that the tension in the leeward guy is negligible, then the load in each guy is

$$\text{Tension} = \text{reaction} \times \frac{\text{length}}{\text{guy radius}}$$

The column load is the sum of the weight plus the vertical components of the guys.

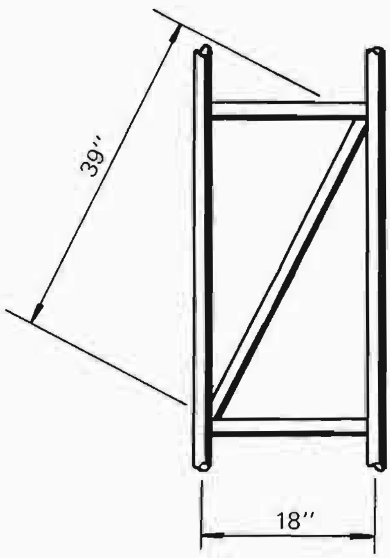


Fig. 69. Diagonal and horizontal struts.

Load in Vertical Member

The vertical members of the tower must be designed for combined compression and bending. The load in a vertical member is equal to the column load divided by 3 plus the chord load due to bending M/d where d is depth. The tower must be checked for tension in the vertical members and for compression. At the point of maximum moment in the first bay, the member is checked as follows:

$$\text{Column Load} = 4{,}423 \text{ lb.}$$

$$\text{Moment} = 3{,}450 \text{ ft.-lb.}$$

$$\text{Load} = \frac{4{,}423}{3} \pm \frac{3{,}450}{1.30}$$

$$= 1{,}474 \pm 2{,}650$$

$$= 4{,}124 \text{ lb. compression}$$

$$= 1{,}176 \text{ lb. tension}$$

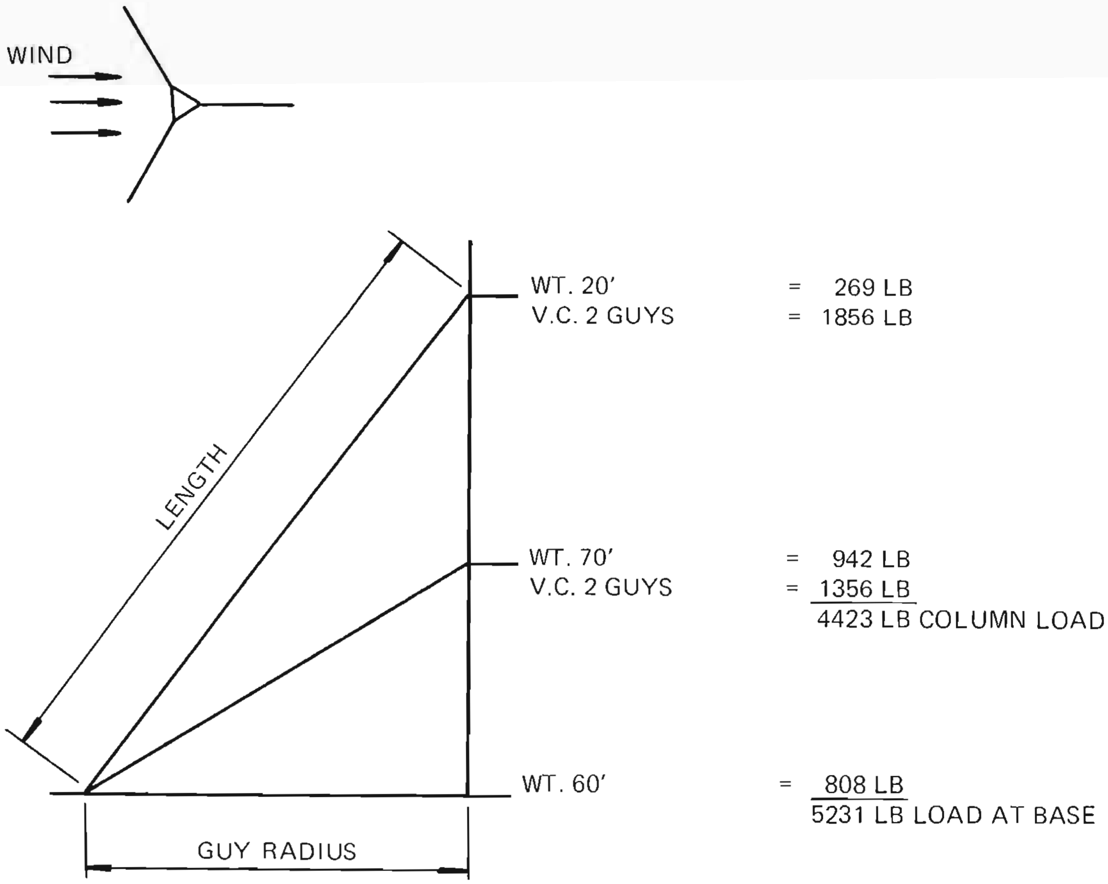


Fig. 70. Column-load analysis.

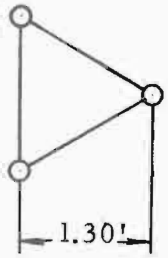


Fig. 71. Vertical-member load.

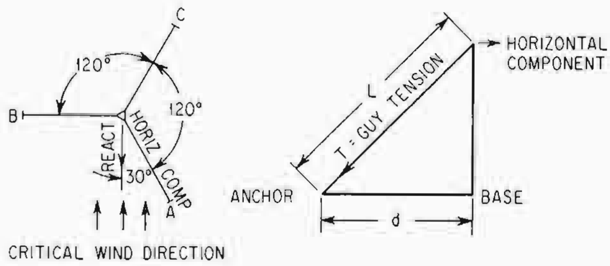


Fig. 72. Critical loads for three-way guying.

Check the strength of the member for compression and for tension, using allowable stresses in RS-222A (Par. 3.1.1).

The tower acting as a column between guys may be critical if the slenderness ratio becomes large. In general, if the ratio of the span between guys divided by the face width of the tower is 40 or less for triangular towers and 50 or less for square towers, column action of the tower is not critical.

Guy Load

The load in guys depends on the guying arrangement and on the direction of the wind. For any number of equally spaced guys, there is a critical wind direction, and this direction must be used to obtain the maximum guy load. Critical loads for three-way guying are shown in Fig. 72.

By statics

$$\text{Horizontal component (guy } A) = \frac{\text{tower reaction}}{\cos 30°}$$

$$\text{Horizontal component} = \frac{R}{0.866} = 1.154R$$

and

$$\text{guy tension} = T = 1.154R \times \frac{L}{d}$$

In practice, especially on tall towers, an allowance is made for wind loads on guys and for erection tension or initial tension in guys. EIA Standard RS-222A (Par 8.2) requires a factor of safety of 2.5, based on the ultimate strength of the guy strand.

For a sample tower, guy loads are as follows:

Guy No.	R, lb.	L, ft.	d, ft.	Crit. guy load, lb.	Guy size, in.	Ultimate strength, lb.	Factory of safety
1	1,130	117	100	1,526	1 X 7 X 1/4 E.H.S.[a]	6,650	4.36
2	714	164	100	1,350	1 X 7 X 1/4 E.H.S.[a]	6,650	4.93

[a]Extruded Hardened Steel.

Foundation Loading

1. Base foundations must be proportioned so that the area of the base is greater than the total column load plus the weight of the concrete pier divided by the allowable soil bearing pressure.
2. By EIA, RS-222A, bearing pressure for normal soil is 4,000 psf.
3. Applied column load = 5,230 lb.
   Weight of concrete pier 44.3 cu. ft. at 140 lb./cu. ft. = 6,200 lb.
   Total load on base = 11,430 lb.
   $$\text{Bearing pressure} = \frac{11{,}430}{3 \times 3} = 1{,}270 \text{ psf}$$
4. Bearing pressure is considerably less than 4,000 psf, and the pier has a large factor of safety.

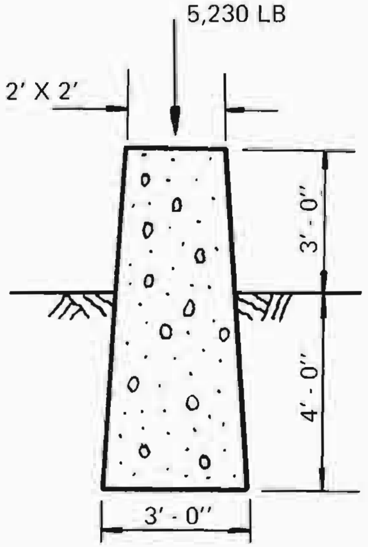


Fig. 73. Base-foundation analysis.

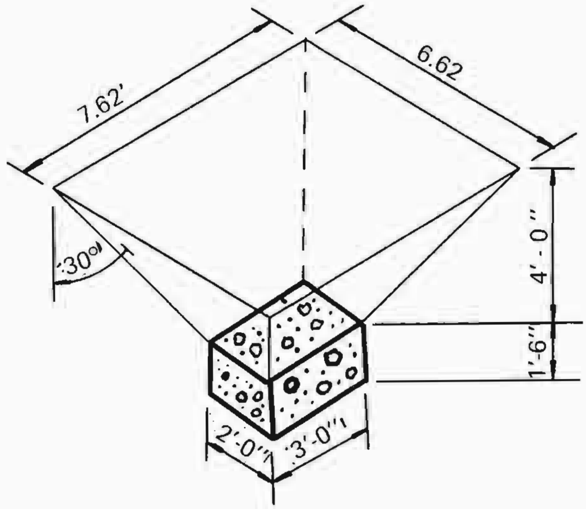


Fig. 74. Guy-anchor analysis.

Guy Anchors

1. Guy anchors are designed for the resultant load of guys when the wind is blowing in the critical direction.

2. Vertical load is resisted by weight of concrete and earth overburden. EIA specifies in uplift that the foundations shall be designed to resist two times more than the applied load assuming that the pier engages a 30° frustrum as an earth overburden. Resistance to horizontal load is provided by friction on the base of the anchor and by lateral resistance of soil on the face of the anchor. Friction on the base is usually small and is neglected. Lateral resistance can be obtained by Rankine's formula for passive resistance:

$$P = wh \frac{1 - \sin \phi}{1 + \sin \phi}$$

where P = resistance, psf
W = unit weight of earth – 100 lb./cu. ft.
h = depth to point considered – 4.75 ft.
ϕ = angle of internal friction of soil assumed to be 30°

$$P = 100h \frac{1 + 0.5}{1 - 0.5} = 300h = 300(4.75)$$
$$= 1{,}425 \text{ psf}$$

3. Allowable uplift on anchors:

For weight of earth:
$4/3(6 + 50.4 + \sqrt{302.4}) = 98.5$ cu. ft.
98.5 cu. ft. X 100 lb./cu. ft. = 9,850 lb. of earth
For weight of concrete:
2 ft. X 3 ft. X 1.5 ft. = 9 cu. ft.
9 cu. ft. X 140 lb./cu. ft. = 1,260 lb. of concrete

$\frac{9{,}850 \text{ lb.}}{11{,}110 \text{ lb.}}$ of earth X 1/2 = 5,555 lb. allowable uplift

4. Allowable horizontal load on anchor

= resistance psf X frontal area
= 1,425 psf X 3 ft. X 1.5 ft.
= 6,420 lb.

9

Standard Broadcast Antenna Systems

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The purpose of this section is to furnish useful information to the engineer, technician, and operator in a broadcasting station. The material is divided into text and handbook types of presentation. An effort has been made to approach each new subject gradually in the text, while in the appendices, design equations and data have been presented in handbook style with the aim of making them most useful to the technician and operating engineer.

First, the single tower is analyzed. It is then used as elements in a two-tower directional-antenna array before going to the more complicated arrays.

Antennas form the dominant theme supported by other items such as coupling networks and monitoring circuits. The topics of adjustments and field measurements are treated in a way thought to be most useful to a man in the field.

The chief purpose of a radio-broadcasting antenna is to radiate the energy supplied by the transmitter efficiently. A simple antenna can do this job quite well. It is usually a vertical tower that radiates the energy equally in all directions along the ground.

A secondary purpose of the antenna system may be to concentrate the amount of radiation in the directions that it is wanted and to restrict the radiation in the directions it is not wanted. This may require a very complicated directional-antenna system if the requirements are great.

The antenna is the last point in the system under the control of the radio-broadcasting station. Radio waves radiated from the transmitting antenna are propagated through space to the receiving antenna. The only control over these propagated waves is in the selection of the antenna site, the polarizations, and the strength of the signals leaving the transmitting antenna. The selection of the antenna site is determined by many considerations, such as ground constants, terrain, distance and direction to populated areas to be served, distance and direction to the areas to be protected, and last but not least the availability of a suitable land area to install the necessary towers and ground system.

For standard broadcast stations, vertical polarization is used because of its superior ground-wave-propagation characteristics and the simplicity of antenna design. The strength of the signal from the transmitting antenna, in any given direction, depends upon the output power of the transmitter and the antenna design. Since the output power is regulated by the Federal Communications Commission for the class of stations involved, the only factors remaining under the engineer's control are the antenna location and design. These factors go hand in hand when designing directional antennas for broadcast purposes.

THE SINGLE-TOWER NONDIRECTIONAL ANTENNA

Current and Voltage Distribution

The vast majority of radio-broadcasting stations have single-tower antennas that are neither top-loaded nor sectionalized. Most of them have an insulator near the ground. Such towers all have a current distribution with a zero value at the top as shown in Fig. 1. The maximum value of current is 90° down from the top on a theoretical antenna, while on all practical antennas it is less than 90° down from the top. This is owing to the fact that the velocity of propagation slows down as the cross section of the tower is increased. For the average uniform-cross-section tower the current maximum is about 84° down from the top.[1]

The general shape of the current distribution on a tower is that of a sine wave given by

$$i_a = I_a \sin (G - y) \qquad [1]$$

Note—Superscript numbers refer to references on page 203.

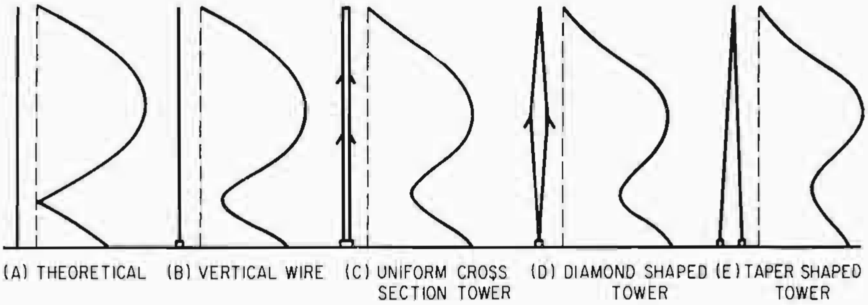


Fig. 1. Practical compared with theoretical current distribution on vertical radiator.

where i_a = current amplitude at distance y above the ground as shown in Fig. 2a, amp
I_a = maximum current amplitude, amp
G = height of antenna, deg
y = height of current element i_a, deg

For most purposes it is entirely satisfactory to consider the current distribution as an exact sine wave through this equation. This is practically true for a vertical wire as shown in Fig. 1b. It is also a good approximation for a uniform-cross-section tower as illustrated in Fig. 1c. For the diamond and tapered types as shown in Fig. 1d and e, the approximation may not be satisfactory.

The general shape of the voltage distribution is very nearly that of a cosine wave as shown in Fig. 2 for the theoretical case and is expressed by the equation

$$e_a = E_a \cos (G - y) \qquad [2]$$

where e_a = voltage amplitude at distance y above the ground as shown in Fig. 2b, volts
E_a = maximum voltage amplitude, volts

and G and y are as defined in Eq. 1. If the tower is not tall enough for the current distribution to have a minimum below the top of the tower, then the maximum value of voltage will be at the top of the tower. It is necessary to visualize the shape of the voltage distribution along the tower because of the need of good insulators at the high-voltage points. If sufficient insulation is not provided in the guy cables or at the tower base, the current may arc-over at these points and disrupt the broadcasting service. If the initial design has poor insulation, then redesign with adequate insulation should be considered.

Some towers are not insulated at the base. Such towers are shunt-fed at some point above the base. This type of tower is less expensive, has no

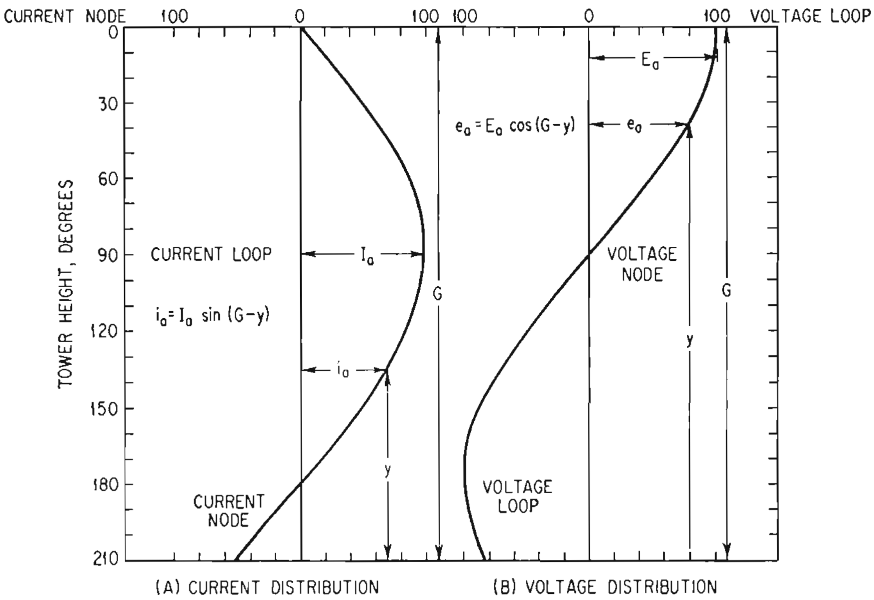


Fig. 2. Theoretical current and voltage distribution on a vertical radiator.

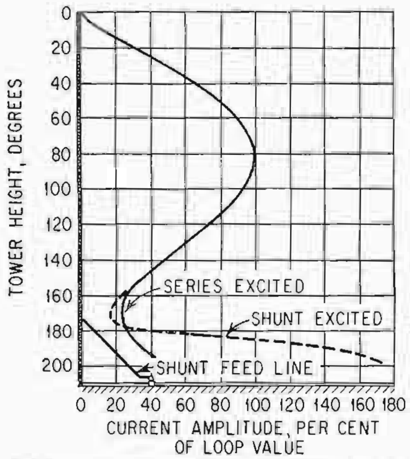


Fig. 3. Experimental current distribution on shunt- and series-fed tower. (Morrison and Smith, *Proc. IRE,* June 1937.)

dangerous base voltage, and is less vulnerable to lightning. The feed line can be used to some extent as the matching network to couple the transmitter or transmission line to the tower. The current distribution above the feed point is essentially the same as for a base-insulated tower.[1] The current below the feed point deviates materially from a sine wave as shown in Fig. 3. This is of little consequence in nondirectional operations. It cannot be tolerated in critical directional-antenna systems because of its effect on deep minima of the radiation pattern.

By proper design the coupling can consist of a slant feed cable with a series capacitor to couple into the transmission line. In general, as the height of the feed point on the tower is raised, the resistance and positive reactance increases. When the horizontal distance to the feed point from the tower base is increased, the resistance and positive reactance decreases. The exact position of the shunt feed line can best be determined by experiment.

The slant cable can consist of two parallel cables properly insulated and having the proper physical dimensions. Such an arrangement can be adjusted to couple directly into a transmission line.

Another method which eliminates the undesirable radiation effects of the slant line is to connect several cables to the tower one-quarter wave ($\lambda/4$) from the base and stretch them down to the ground with insulators at the lower end. These cables form a short-circuited one-quarter-wave ($\lambda/4$) transmission line which is open-circuited at the base, thus making it possible to feed the tower through these cables connected in parallel.

Sectionalized towers have been used for some time and have taken on added importance with the advent of FM and TV broadcasting. A sectionalized tower, in addition to the ordinary base insulator, has one or more insulators in the tower above the base. Very tall towers are often used to support FM and TV antennas in order to achieve the desired height above average terrain for maximum coverage of the FM or TV station. If this is the sole objective, the tower does not have to be sectionalized with insulators.

In some cases a tall tower is sectionalized for the purpose of preventing undesired reradiation when in the vicinity of AM towers, particularly if the other towers are elements of a directional-antenna array. In other cases it is desired to use part or all of the sectionalized tower as active AM radiating elements. This may not be so easy to accomplish as one would expect. Moreover, it requires considerable effort and planning to design the system properly. The Federal Communications Commission will require proof that the antenna system is operating properly, especially if the sectionalized tower is near or part of a directional-antenna array.

Sometimes a tall sectionalized tower is constructed for the purpose of obtaining greater AM broadcast coverage by properly controlling the current distribution on the tower.[2,3] When towers are sectionalized for this purpose, considerable attention is given to the current distributions on the various sections of the tower. This is necessary because the radiation from the current elements on each section must add properly to produce the greatest or optimum field-strength effects. It is well worthwhile to look seriously into these possibilities, even if the tower is to be used for FM and TV operations in addition to AM operation.

Vertical-radiation Characteristic

A nondirectional tower, whether series- or shunt-fed, sectionalized or nonsectionalized, top-loaded or without top loading, has its own vertical-radiation pattern sometimes called its vertical-radiation characteristic. This is simply the amount of signal radiated at all elevation angles above the horizontal plane with respect to the horizontal-plane radiation. Its calculation is usually made using the assumption of sinusoidal current distribution on the radiating portion of the tower.

The current distribution can be controlled by the height and shape of the tower. On a sectionalized tower the magnitude and phase of the current on the lower sections can be controlled with respect to the current on the top section. This permits such a tower to possess a family of vertical-radiation characteristics.[2,3]

The vertical-radiation characteristic of a vertical nonsectionalized, base-insulated tower is given by

$$f(\theta) = \frac{\cos(G \sin \theta) - \cos G}{(1 - \cos G) \cos \theta} \qquad [3]$$

where $f(\theta)$ = vertical radiation characteristic
G = electrical height of antenna, deg
θ = elevation of observation point, deg

The derivation of Eq. 3 is given in Appendix A as a special case for a sectionalized tower when the top section is zero. The curves showing $f(\theta)$ as a function of height were published in several forms in the 4th edition of the "NAB Engineering Handbook."[4] The most useful form is reproduced in Appendix A.

Self-Impedance

A radio tower has a different impedance at every point along its height. Two points are of special interest. One is at the current loop which is the current maximum approximately 90° down from the top of the tower if it is not top-loaded, and the other is at the point where the tower is fed at the base.

Much effort has been made in recent years to find a reliable means of calculating the base impedance of a tower. The average characteristic impedance, usually called Z_0 of the tower appears to play an important role in such calculations.[4]

Assuming a sinusoidal current distribution and the conservation of power between the loop and the base for a simple tower without top loading, the base and loop radiation resistances can be related by the simple equation

$$R_{\text{base}} = \frac{R_{\text{loop}}}{\sin^2 G} \qquad [4]$$

where R_{base} = base radiation resistance, ohms
R_{loop} = loop radiation resistance, ohms
G = height of tower, deg

This equation for base resistance is quite reliable for antenna heights up to 120°. The loop and base radiation resistance along with the theoretical field strength, assuming a perfect ground, are shown in Appendix A.

It should be remembered that any set of calculations may not and usually will not agree with the actual values determined from measurement after the tower has been constructed. For this reason about the best that one can hope for is to make as intelligent an estimate as possible. The base impedance is affected by stray capacity and inductance effects and may be considerably different from the approximate theory when the tower is of the order of a half wave ($\lambda/2$) high.

The loop impedance of a single tower serves an important role by virtue of the fact that the calculated base impedance usually disagrees with the measured value and also because some towers are fed at or near the loop point. For example, a 90° tower fed at its base is also approximately fed at its loop; thus

$$Z_{\text{base}} = Z_{\text{loop}} = 36.6 + j21.3 \qquad [5]$$

where Z_{base} = base impedance, ohms
Z_{loop} = loop impedance, ohms
j = $\sqrt{-1}$, making the second term an inductive reactance

This means that the antenna is series resonant, without reactance, when the height G is slightly less than 90°.

Ground System

A single AM tower is not complete without a ground system. To feed power into such a tower it is common practice to couple the output of the transmitter across the base insulator. The tower base forms one terminal, and the ground system forms the other terminal. Simple antenna theory assumes the ground plane to be a perfect conductor which acts like a mirror plane to the radio waves. In practice it is not a perfect conductor and may introduce a series-ground-loss resistance from a fraction of an ohm to several ohms.

A rather common rule of thumb is to use 2 ohms' loss resistance for the copper-wire ground system consisting of 120 radials 90° long. This ground-loss resistance can be decreased by reducing the E loss due to the electric field and the H loss due to the magnetic field.

When the tower is near a half wavelength in height, there is a voltage maximum at the base with a resulting strong electric field that results in high E losses owing to the displacement current passing from the antenna through the earth to the radial ground wires. This loss can be materially reduced by using an expanded copper screen around the antenna base or increasing the number of radial conductors and placing them very near the surface or under a layer of asphalt pavement which has very low loss for the electric displacement current.

The H loss due to the magnetic field extends out a considerable distance. This loss is due to the radial current which divides between the ground conductors and the earth. It can be decreased by increasing the number of conductors and extending their length. This will cause a larger portion of the current to be in the copper radials where the resistance is very low.

A typical ground system may consist of No. 10 copper wire buried 4 to 12 in. deep. Usually this area is made into meadow or grassland that is mowed often enough to prevent tall grass that

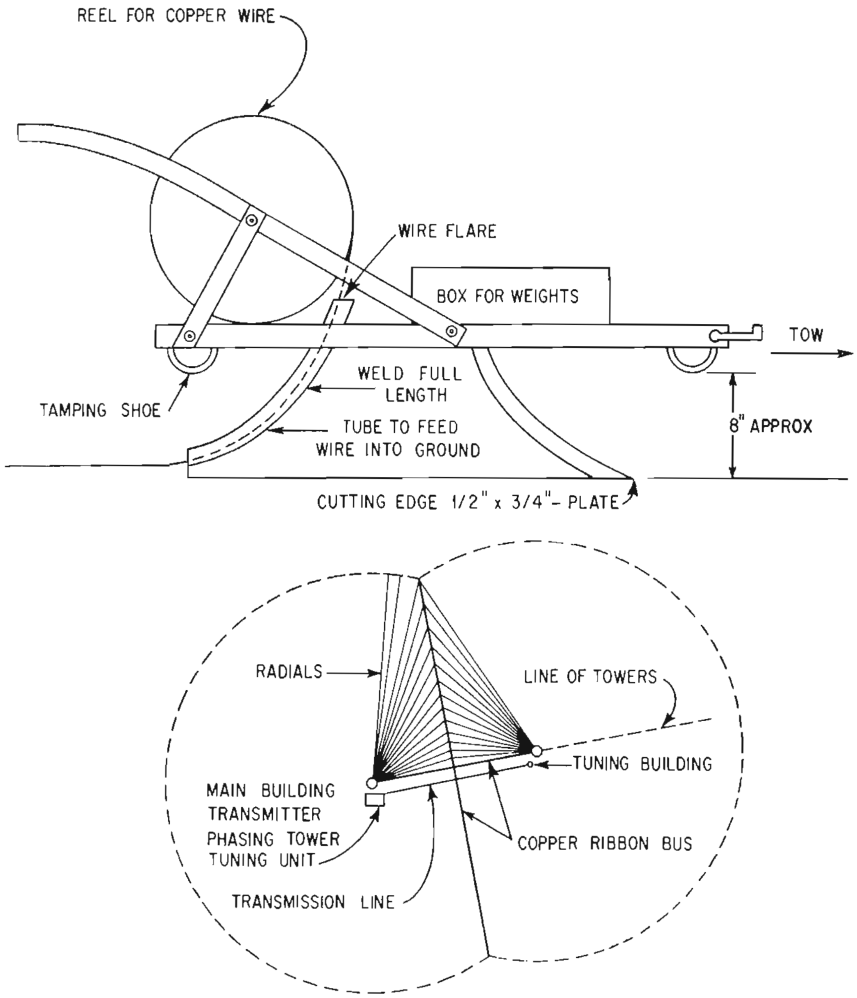


Fig. 4 Design of plow for laying ground wires and typical two-tower ground system.

may cause considerable E loss under certain conditions. If it is necessary to till the soil, the wires must be buried deep enough to avoid mechanical injury.

It is common practice to use a wire plow, as shown in Fig. 4, to lay the ground system. The wire plow consists of a thin vertical steel blade to cut a slit in the ground. At the rear edge of the blade there is a small tube through which the copper wire passes from a wire reel into the ground. The depth of the ground wire can be controlled by the adjustment of the vertical blade with respect to horizontal sled runners or wheels which support the plow mechanism. Soft- or medium-hard-drawn copper wire is easier to handle in the field than hard-drawn copper wire. It can also stand more mechanical stretching before breakage occurs.

The radial wires are usually plowed in, starting from the tower, and driving a tractor pulling the plow toward a guidepost at the edge of the ground system. It is convenient to provide a copper wire or cable ring around the tower base to which each radial ground wire can be mechanically fastened while the radial is being installed. The radial wires must then be soldered or brazed to this ring to provide a good electrical connection. Copper ribbon can then be bonded to the copper ring and run to the ground-system terminal of the antenna. Copper-clad stakes are commonly used to hold the copper ring in place and act as a lightning ground. These stakes are driven down level with the copper ring, and the two are brazed together to form a good electrical connection.

Expanded copper mesh is commonly used inside the copper tie ring or square. Its primary purpose is to terminate the E field. Its secondary job is to carry the radial ground-system current. However, if the amount of copper in the mesh is inadequate, then radial copper straps can be added in this area and bonded to the expanded copper mesh.

Tower Lighting and Painting

The Federal Communications Commission has rules for suitably lighting and painting radio towers so they can be seen from aircraft, thus minimizing their hazard. They are also marked on the aeronautical charts used by aircraft pilots. Part 17, Construction, Lighting and Marking of Antenna Structures, of the FCC Rules and Regulations covers this subject thoroughly.

In brief, it is necessary to provide warning lights at the top and fractional elevation levels of the tower. For tall towers flasher beacons are required at the top and some intermediate levels. For base-insulated towers it is necessary to transfer the a-c power across the base insulator. This is commonly done by RF choke coils, Austin-type power transformers, or the use of quarter-wave ($\lambda/4$) isolating stubs.

Radio towers must be painted with alternate strips of international orange and white paint. The number and width of the strip are covered in the above regulations.

Lightning Protection

Radio towers are vulnerable to lightning; hence it is very important to provide the necessary protection. Lightning rods should be provided at the top of the tower to protect the flasher beacon. Choke coils, large values of resistance, oil-filled insulators, or isolation stubs should be used to drain the static charges across the sectionalizing and base insulators. Ball gaps or horn gaps should be placed across the insulators to carry the high current surges.

The ground system around the tower base should have nonfusible cable or conductor. It is good practice to terminate these cables in copper-clad ground rods not far from the tower base. In some cases the radial ground system itself may be adequate to handle the lightning surges.

An important consideration is the protection of the base current antenna meter and the RF coupling equipment. It is good practice to provide a tower-grounding disconnection switch on the antenna side of the RF coupling equipment for the protection of technical personnel that must maintain it. During operation the antenna terminal of the RF coupling equipment should have a horn-gap path so lightning discharges can be bypassed directly to ground. The lightning paths should be as direct and short as possible to ground.

With regard to the RF antenna meter the best practice is to connect it into the circuit with a double-pole-double-throw (DPDT), make-before-break switch, as shown in Fig. 7a. The meter can then be inserted or removed completely from the circuit during operation. When removed from the circuit, there is very little chance for lightning to injure it because there are no metallic connections to it. The meter is always removed from the circuit except when it is necessary to make a reading. It is sometimes necessary to adjust the length of the shorting loop so it will have the same inductance as the meter loop.

A less expensive and less desirable method is to use a single-pole-double-throw (SPDT), make-before-break switch as shown in Fig. 7b. The least expensive and least desirable method is to use a single-pole (SP) shorting switch as shown in Fig. 7c. The shorting switch shunts most of the current around the RF meter; however, a lightning surge may be sufficient to injure it.

It is difficult to predict what a lightning stroke will do, particularly if it is a direct hit on the tower. The stroke may jump to the transmission-line side of the coupling network; hence it is advisable to provide lightning-protection gaps at the tower end of the transmission line.

Adjustments

A transmission line can usually be coupled into a tower by the use of a series and shunt element. If the tower is in a directional-antenna array, then three tuning components are usually employed so the phase can also be controlled at this point.

Usually it is necessary to design and order the coupling network components before the tower and ground system are installed. In this case sufficient latitude must be allowed for variations of the inductive and capacitive components to match into the tower impedance from the transmitter or transmission line. If the tower and ground system are already installed, antenna input impedance measurements can be made at the operating frequency. It is therefore possible to determine, quite accurately, the value of the components required, but even in this case it is advisable to provide a reasonable tolerance for adjustment in the field.

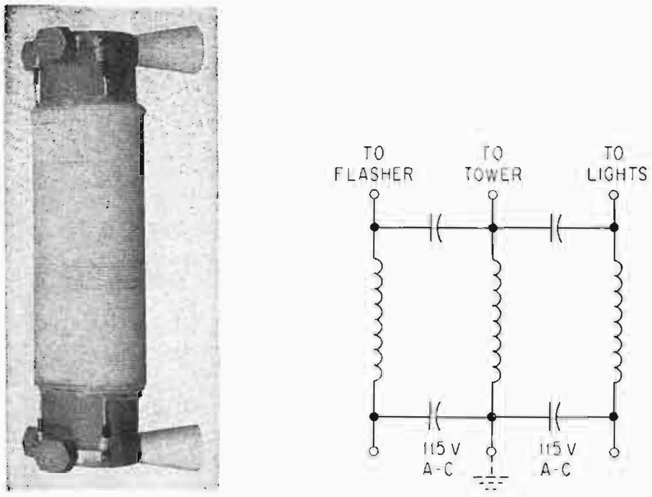
The problem of coupling a transmission line to a sectionalized tower is usually much more involved. The sectionalized tower is, in effect, a collinear vertical directional-antenna system and therefore should be provided with both magnitude and phase control for each of the several elements. For this type of antenna it is usually desired to obtain the optimum vertical-radiation characteristic. If this is done, the results should be checked by field-strength measurements. In this type of antenna it is desirable to provide considerable latitude in variations of the adjustment components.[2,3]

The design information necessary for matching from the transmission line into the antenna is covered in Appendix B.

Inverse Field Strength at 1 Mile

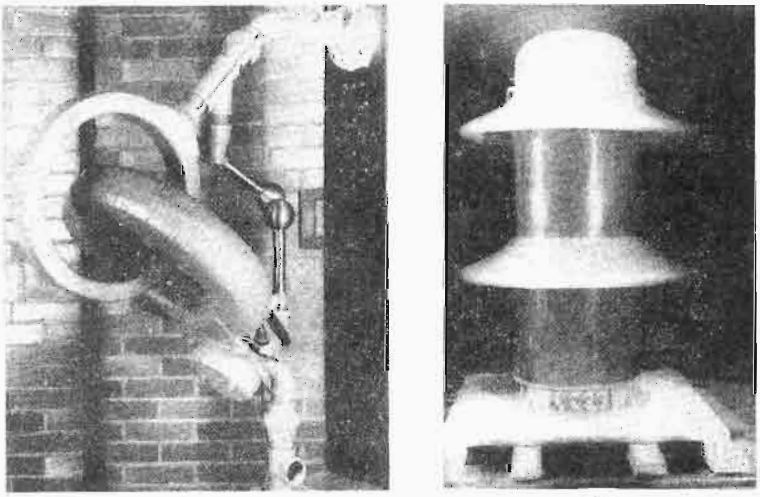
The inverse field strength at 1 mile, sometimes referred to as the unattenuated field strength at 1 mile, is the field strength at 1 mile when the only attenuation is that of distance. It is a theoretical value and is considered primarily for comparison purposes. This concept removes the frequency and ground attenuation effects. Nondirectional- and directional-antenna patterns can be compared on this basis.

The vertical-radiation characteristic, for example, is merely a comparison of the inverse field strength at 1 mile at all elevation angles above the horizontal plane with the inverse field strength at 1 mile in the horizontal plane. When it is necessary to express the radiation from an antenna the value is usually given as the horizontal-plane inverse field strength at 1 mile. It can be expressed either with or without the inherent losses of the antenna system.



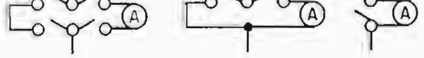
(A) PHOTOGRAPH (B) WIRE DIAGRAM

Fig. 5. Antenna-lighting choke coil.



(*a*) (*b*)

Fig. 6. Austin-type transformers: (a) Air-insulated and (b) Oil-insulated.



(A) DPDT MAKE-BEFORE-BREAK SWITCH

(B) SPDT MAKE-BEFORE-BREAK SWITCH

(C) SP SHORTING SWITCH

Fig. 7. Typical antenna meter switching circuits.

When submitting inverse-field-strength information to the Federal Communications Commission it is common practice to include the antenna-system losses. Nondirectional antennas produce but one such value, since the input power is determined by direct input-power measurements. In other words, the input power is determined by multiplying the measured input resistance by the square of the antenna current measured at the same point. In equation form,

$$P_a = I_a^2 R_a \qquad [6]$$

where P_a = antenna power input, watts
I_a = antenna current, amp
R_a = antenna resistance, ohms

A nondirectional antenna theoretically produces only one value of inverse field strength at 1 mile, which is the same at all horizontal bearings from the antenna. Nondirectional-antenna patterns are graphically described by a circle, the radius of which is the inverse field strength at 1 mile. The pattern of a single-tower radiator is usually considered to be nondirectional. If the feeder is nonsymmetrical, such as in the case of a shunt-fed antenna, or if there are objects which reradiate in the vicinity of the tower, the horizontal pattern will not be circular or nondirectional but will have some directivity.

If the horizontal pattern is directional or nondirectional, its equivalent nondirectional effectiveness can be expressed as the root-mean-square (rms) inverse field strength at 1 mile, or simply its rms value. The rms value is the radius of a circle which has the same area as the pattern formed by all the inverse-field-strength values at 1 mile in all horizontal directions.

A directional-antenna pattern can be quite well described by plotting the inverse-field-strength values at 1 mile at intervals of 10° on polar graph paper. The rms value of the pattern can be obtained by taking the square root of the sum of the squares divided by the number of squared values, thus

$$E_0 = \sqrt{\frac{E_{10}^2 + E_{20}^2 + E_{30}^2 + \cdots + E_{360}^2}{36}} \qquad [7]$$

where E_0 = rms field strength, mv/m
E_{10} = inverse field strength at azimuth angle of 10°, mv/m
E_{20} = inverse field strength at azimuth angle of 20°, mv/m, etc.

The rms value can also be obtained by using a polar planimeter to measure the area and in determining the radius of the circle having the same area. This radius is the rms value of the pattern in the same units used to plot the directional pattern. It is common practice to measure the field strength and plot patterns in millivolts per meter, abbreviated mv/m.

The Federal Communications Commission does not normally require proof of performance measurements on single-tower nondirectional antennas. Therefore measured values of inverse field strength of nondirectional antennas are not in general available to the public at the reference room of the FCC, Washington, D.C. The description of existing towers of nondirectional radio stations is usually not complete except as to height and type. In most directional-antenna proof-of-performance reports it is required to show nondirectional measurements on a single tower in the array either before the other towers are erected or when the other towers are detuned so they will contribute a minimum of reradiation. This information is available at the reference room of the FCC.

Attenuated Field Strength

The attenuated field strength is the amount of signal left after it has been diminished by distance, ground conductivity, ground inductivity, and all other effects encountered by the signal between the antenna and the point of measurement. The field strength is also a function of the operating frequency and unattenuated field strength at 1 mile in the direction from the antenna toward the measuring point.

Only after a tower is constructed is it possible to determine the actual attenuated field strength at any point. Sometimes a test antenna and transmitter are installed at a proposed site to determine more precisely the coverage or interference to be expected. The attenuated field strength is determined by measurement with a field-strength meter properly calibrated and operated.

When the unattenuated rms field strength is needed to prove compliance with minimum requirements, it is necessary to make proof-of-performance measurements on a nondirectional antenna. This consists of a set of attenuated field strength measurements made on each of eight or more radials. The attenuated measurements are then used to determine the unattenuated field strength at 1 mile in the direction of each radial. The manner of taking measurements and the means of analysis are fully described in Part 73 of the FCC Rules and Regulations.

TWO-TOWER DIRECTIONAL ANTENNA

Radiation-Pattern Shape

One purpose of a directional antenna is that of producing a greater radiation in one or more directions than a nondirectional antenna would produce with the same power. Another purpose is to produce a small radiation in one or more directions. The latter consideration is more often required than the former because it is the rule rather than the exception that when a directional antenna is required, its radiation pattern must be so designed that it will not cause interference in any area, thereby depriving that area of one or more existing services. Or if this is not possible, the interference that is created must be limited to population that would feel the impact of losing service least. In other words if interference must be caused to some population, it is more desirable that it be caused to population that already has plenty of service rather than to population that has a meager amount of service or no service at all.

An existing radio station is faced with the same type of interference problem if it desires to change its directional-antenna pattern or if its directional antenna gets out of adjustment. A careful theoretical study of the two-tower directional antenna provides the owner and operator with a very useful tool for maintaining the correct operation.

The two-tower directional antenna, besides being the simplest of directional antennas, is often a basic unit of a three-tower or more array. It may be compared with a single tower in the following respects: The signals produced are but one signal as far as the receiver is concerned. Each tower produces a pattern having an rms value that must be above a specified minimum value according to the FCC rules. The current and voltage distributions on the towers in a directional-antenna array are usually assumed to be sinusoidal and cosinusoidal, respectively, just as they are on a nondirectional antenna. The vertical-radiation characteristic of each tower is defined in exactly the same way. The two-tower operation converges to a single-tower operation if the tower heights are equal, the phasing of the currents in the towers are the same, and the spacing of the two-tower array approaches zero.

This is as far as one can go in comparing the single- and two-tower operations. The two-tower operations are different in the following respects: The spacing of the towers in the two-tower array makes the instantaneous signal of one tower out of phase with the corresponding instantaneous signal for the other tower. This means that the towers can be spaced so that the signal can be made to add or subtract as desired. This, of course, cannot be done with a single tower. Also by means of phasing circuits it is possible to control the instantaneous signals from each of the towers in the two-tower array. Usually the phasing circuit is placed in only one of the tower circuits, since the object of interest is to control the phase of the current in one tower with respect to the phase of the current in the other tower. Furthermore, the magnitude of the current in one tower can be controlled with respect to the magnitude of the current in the other tower. This permits the control of minima depth in the directional antenna pattern. Thus, the spacing, phase, and current ratio controls available in the two-tower array are not available in the single tower, which must have a circular pattern.

To understand better the two-tower directional antenna, consider the following description. Let one tower, say tower 1, be the reference tower and fixed in location. Let the other tower 2 be free to move on a straight line, say due north from tower 1. Let us also by means of the phasing and coupling circuits maintain the same electrical phasing and current magnitude in the two towers. Let us further assume that a person P_n is due north of tower 1 and that another person P_s is due south of tower 1. Now, if tower 2 is gradually moved north, P_n will note that the signal from tower 1 is being received at the same time as before but that the signal from tower 2 is being received sooner. The person P_s will note that the signal from tower 1 is being received at the same time as before but that the signal from tower 2 is being received later. The person P_n might say that the signal from tower 2 leads the signal from tower 1, while the person P_s will say that the signal from tower 2 lags the signal from tower 1.

Actually the persons P_n and P_s can observe only the combination signal from towers 1 and 2. When tower 2 is moved 180° north of tower 1, the person P_n will note an absence of signal. This means that the signal from tower 2 leads the signal from tower 1 by 180°, and since the signals are the same magnitude, they cancel and produce a null effect. The person P_s will also note a null effect which is due to the signal from tower 2 lagging the signal from tower 1 by 180°.

Now, consider person P_e due east and person P_w due west from tower 1 and observing the resulting signal in these directions. They will both note at all times, regardless of the location of tower 2, that both signals arrive at the same time. Hence, the signals are always in phase and add completely. When the towers are spaced 180° and are in phase, it is therefore seen that the pattern has the shape of a figure eight with the lobes east and west and the nulls north and south. This case is illustrated in column 1 of Figs. BC and BI.

One other pattern will be similarly described. Let all the above assumptions hold except that tower 2 is now always phased by means of the electrical phasing circuits to be 90° ahead of tower 1. Now when tower 2 is 90° north of tower 1, the person P_n will note that the signal from tower 2 leads the signal from tower 1 by 180° and therefore complete cancellation occurs, with the result of a null. The person P_s will note that the signal from tower 2 is exactly in phase with the signal from tower 1 and therefore they completely add to form a lobe. The persons P_e and P_w will receive a signal 41 percent greater than the individual signal from tower 1 or 2 because these signals are 90° out of phase. This pattern has the shape of a cardioid with the lobe to the south and the null to the north. This fact can be further explored by referring to column 3, Fig. BC, or column 2, Fig. BH.

The above two patterns just described serve to illustrate the effect of both spacing and phasing. From this it is seen that the pattern shape is affected both by the spacing and phasing. The above discussion pertains only to the pattern shape in the horizontal plane. For the more general case see Appendix B, Two-tower Directional Antennas.

Radiation-Pattern Size

The Federal Communications Commission provides specific amounts of power for the various classes of radio-broadcasting stations. The rules permit the following amounts of power; 100, 250, 500, 1,000, 5,000, 10,000, 25,000, and 50,000 watts. It is therefore necessary to select the value of power to be used and make sure the individual towers will produce enough inverse field strength at 1 mile so the rms of the directional-antenna array will meet minimum radiation requirements of the rules. The pattern used for rms size consideration is the one in the horizontal plane. If the directional antenna is inefficient, the rms pattern may be too small. It is therefore important to be able to determine pattern size.

There are many factors involved in determining the pattern size of a directional-antenna array. The principal ones are phasing, spacing, and height of the towers and the ground-system resistance losses. The pattern size can first be determined assuming no loss in the directional-antenna system. This value is computed from a formula which is based on one tower operating alone, the self-resistance of both towers, the mutual impedance between the two towers, the current ratio, and the relative current phase. The total resistance losses of the directional-antenna system are commonly computed by assigning a series loss resistance to each tower.

The mutual impedance between two towers can be calculated from cumbersome formulas, or it can be found more quickly by graphical means. The mutual impedance between equal-height towers for various spacings is given in Figs. BM and BN. The mutual impedance is referred to the loop, or maximum current position. It is convenient to use the loop values for computation but necessary to use the base mutual-impedance values when tuning up a directional-antenna array.

The procedure for determining pattern size is to use the above factors in the formula, as given in Appendix B, page 210, to calculate the field strength of the reference tower when operating in the directional-antenna array. The field strength from the other tower can then be obtained by applying the field ratio that was used to determine the pattern shape in the horizontal plane. The use of these values of E_1 and E_2 in the horizontal-pattern formula results in the correct-sized pattern.

RMS Field Strength at 1 Mile

It is now possible to calculate the rms field strength of the directional-antenna pattern in the horizontal plane. The appropriate formula in Eq. BN is easy to apply, and the results are accurate. Moreover, these calculations serve as an excellent check on the rms of the plotted pattern which can be measured by using a polar planimeter or Eq. 7.

Monitoring System

Practically all directional antennas have monitoring systems consisting of individual antenna current meters, a common-point input current meter, and an antenna monitor to give the relative phase between the towers. Most directional antennas have antenna meters at each tower base and corresponding remote meters in the transmitter operating room. This makes it possible for the operator on duty to observe the operating conditions continually and make the necessary log entries.

Usually, when the directional antenna is installed, all the antenna meters are calibrated against a meter of known accuracy. Sometimes RF meters are injured in shipment or for some other reason will not give accurate readings. It is good practice to retain an accurate meter so the calibration of all the RF meters can be checked from time to time as needed. The antenna meters at the towers are read daily or weekly, and the remote meters checked for accuracy. Most remote meters are provided with an adjustment so their reading can be made to correspond exactly to the antenna meter.

The calibration of the antenna monitor at the time of the antenna installation is as a rule adequate as long as the monitoring loops and sampling lines stay in good physical and electrical condition. It is important to have an antenna-monitoring system that is more reliable than the directional-antenna system. If the phase readings vary from the licensed value and there is no noticeable change in the antenna current readings, it is advisable to question the antenna monitor before making any readjustments on the directional-antenna system. In such cases the field strength at the monitoring points should be checked. If these readings are normal, the trouble is probably in the antenna-monitor system.

Feeder System

All that is required for a single tower is to match the antenna to the transmission line, and in turn the transmission line must be matched to the transmitter. In most cases the transmitter will match directly into the transmission line, and if the tower is next to the transmitter building, a transmission line is not required. In some cases it is possible to excite the antenna directly from the transmitter output without a transmission line or coupling circuits.

In a directional-antenna feeder system, power-dividing and -phasing networks are required in addition to transmission lines and matching networks. A typical two-tower directional-antenna feeder system is shown in Fig. 8. At least one tower of a two-tower array must have its driving-point impedance transformed to match into a transmission line. The other tower, if not located close to the transmitter, must also be excited through a transmission line.

In a two-tower directional antenna it is necessary to have the required total phase shift from the common point at the transmitter output to each of the towers. The phase shift must be such that the phase of the tower currents meets the design requirements. When a phasing network is employed, it should operate over a favorable control range so the current in tower 2 with respect to the current in tower 1 can be adjusted and maintained at the proper value. In Fig. 8 the current ratio of tower 2 to tower 1 can be adjusted and maintained by the power-dividing network.

It should be pointed out that the phase- and power-division controls are usually not independent because of the mutual-impedance coupling effects between the towers. In other words a change in the phase control may have more effect on the current ratio than on the antenna-monitor reading. The person that must keep the directional-antenna system in adjustment should therefore operate the various controls and obtain a feel of how the system reacts. Before moving any controls, however, the settings should be noted and recorded so it is possible to return to the original operating condition. Here it is assumed that the feeder system is already operating properly. Only persons with the responsibility of operating and maintaining the directional-antenna system need to have this experience.

If the feeder system has been designed and the antenna system is to be tuned up, it is desirable first to determine the feed-point driving-point impedance values. This can be done by following the procedure in Appendix B. It is then necessary to set up the tower coupling networks so they will match into the driving-point impedances determined above. In addition they should have the correct value of phase so the phasing control will be near the center of its range for proper phase of tower 2 with respect to tower 1. The power-dividing network can then be set up to give the approximate division of power, and if there is a matching network between the transmitter and the power divider, it can be set up to give the proper impedance for the transmitter.

A small amount of RF power can now be fed in at the common point, and adjustments made to approximate the required current ratio and phasing between the two towers. If the driving-point impedances at the towers were computed correctly and the tower matching networks were set up properly, it should not be necessary to make any further adjustments at this point other than to add or subtract phase shift.

It should be observed that the driving-point impedances at the towers will not have their correct values until the feeder system is in final adjustment. Therefore, improper meter readings and standing waves on the transmission lines are

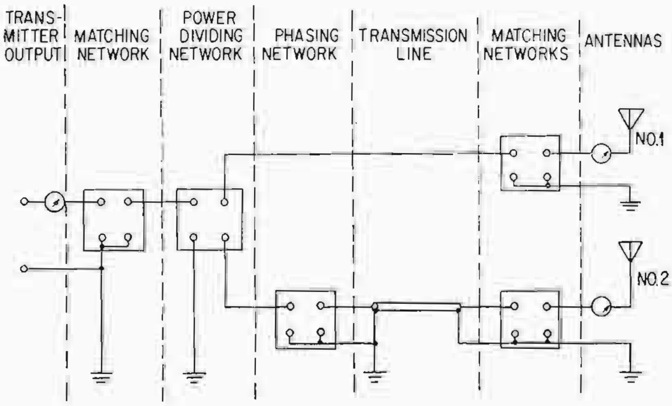


Fig. 8. Block diagram of a directional-antenna feeder system.

to be expected until the final adjustment is approached.

When a directional-antenna array has been correctly adjusted, complete measurement data should be taken before it is turned over to the new user. These data should include not only RF bridge measurements of all components but similar static measurements at several points in the feeder system. These measurements should be made, for example, at the input to each tower impedance-matching network by opening up the transmission line and connecting the RF bridge at this point. Also record open- and short-circuit measurements of all transmission lines.

These measurements can be further supplemented by making dynamic RF voltage readings to ground at a number of points in the feeder system. Also RF current readings should be taken in all network branches.

Then in the event there is a departure from normal performance, the above static and dynamic measurements can be duplicated to assist in the restoration of the feeder system to normal service. This information is particularly helpful if a component becomes defective or is destroyed by lightning.

It is also good practice to make a record of all capacitor and inductor adjustments. It is advisable to mark all coil taps and capacitor settings with lacquer paint. Fingernail polish can be used for this purpose.

Particular attention should be given to make sure that the antenna-monitoring system is in good condition and properly installed. If the sampling lines are of equal length and some of the line must be coiled up, this should be done so that, as nearly as possible, equal lengths are outside the building and will therefore be equally affected by temperature variations. Otherwise, phase variations may occur owing to unequal temperatures of the sampling lines.

The feeder system should be inspected and cleaned regularly. It is advisable to use insect-proof screens over any openings in the housing of feeder system networks. If pressure gauges are used on capacitors or coaxial transmission lines, they should be checked occasionally. These components may be injured if operated without pressure even though the gauge reading appears to be satisfactory.

In the day-to-day operation of a directional-antenna system it should not be necessary to move any controls or make any adjustments. Sometimes temperature and weather conditions will cause slight excursions of the phase and current ratio values. If the tolerance limits are exceeded, then the problem should be analyzed and appropriate corrective measures taken.

DIRECTIONAL ANTENNAS HAVING MORE THAN TWO TOWERS

Comparison with Two-Tower Array

Many directional antennas consist of more than two towers because a two-tower array cannot produce the pattern shape required. It often happens that a two-tower pattern could be used, or it may even be that a nondirectional pattern could be employed if the pattern size were small. Such patterns may be ruled out by the owner because of prestige as to power statements and lack of good service over the urban and rural areas to be covered.

General Case

A general treatment of directional antennas of more than two towers can be limited to an explanation of one tower with respect to a reference point because all other towers are treated in exactly the same manner, since no specific information can be given to distinguish one tower from another. The only facts that need be known about a tower are that it has height, it is sectionalized or not, top-loaded or not, that it has a certain cross-sectional shape and size for each distance above the ground, and that it has a ground system of a specified efficiency. Most of these items have already been discussed.

The important considerations for a general tower in a directional-antenna system are its spacing, phasing, current, and height with respect to the other towers in the array. These four items define its contribution to the radiation characteristics of the array once its individual or single tower characteristics are defined. Hence this general treatment must conclude with an expression that describes the radiation of any tower of a multielement array. This expression is called a vector and is written

$$\dot{E}_k = E_k f_k(\theta) \underline{|\, S_k \cos \phi_k \cos \theta + \Psi_k} \qquad [8]$$

where $\dot{E}_k$ = vector unattenuated inverse field strength at 1 mile for the kth tower while in operation, mv/m

E_k = magnitude of horizontal field strength of kth tower, mv/m

$f_k(\theta)$ = vertical-radiation characteristics of kth tower—always unity y along ground

$\underline{|}$ = vector angle terms are placed in this position. Vector magnitude terms are placed ahead of this angle sign

S_k = spacing of kth tower, deg

ϕ_k = azimuth angle measured clockwise from reference through kth tower, deg

θ = elevation angle from ground or horizontal plane, deg

Ψ_k = electrical phase of current in kth tower, deg

The subscript k was used in this equation to distinguish the radiated field strength of this tower from the other towers in the array. The sum of the vector fields from all the towers gives the total field strength in any direction from the array.

Dropping the subscripts in the above equation for simplicity, the product $Ef(\theta)$ is the magnitude of the vector and $S \cos \varnothing \cos \theta) + \Psi$ is the phase of the vector. The only real value of this general treatment is the meaning it lends to the over-all theory. In fact its understanding is so vital that a clear concept of directional antennas must come from its meaning. As a matter of fact one can treat the whole matter of pattern shape from the vector concept directly without other mathematical complications. If this is done, it is, of course, necessary to know how to add, subtract, multiply, and divide vectors. On the other hand if the mechanism of vectors is not known, one is at a great disadvantage from the start in acquiring a thorough understanding of directional antennas. It is therefore recommended that at least the rudiments of vector analysis be learned by anyone desiring really to understand directional antennas.

Before leaving the general case attention is called to the fact that any directional antenna must be treated as a unit such that the whole operation is considered when any part of the antenna system is changed. For example, it is very important to know how a change in the magnitude or phase of each tower current affects the shape of the pattern, but at the same time it cannot be forgotten that the efficiency is also a factor that must be considered.

The perfect pattern shape and the most efficient operation are seldom attained at the same time. Theoretically this may be possible, but actually the number of towers may be limited or the coverage and protection requirements may have changed after the directional-antenna system was put into operation. Suffice it to say that it is the rule rather than the exception that one or more compromises are necessary before the final operation is attained, and it is best to understand the peculiarities of any particular array so that these compromises can be recognized and dealt with in the most intelligent manner.

Special Cases

Two-Tower Pattern

The simplest equation for a two-tower pattern is

$$E = 2E_2 \cos\left(\frac{S_2}{2} \cos\phi + \frac{\Psi_2}{2}\right) \qquad [9]$$

where E = inverse field strength at 1 mile, mv/m

E_2 = inverse field strength at 1 mile for each tower acting alone, mv/m

$S_2/2$ = spacing from a reference point midway between the two towers, deg

ϕ = azimuth angle measured clockwise from line of towers, deg

$\Psi_2/2$ = electrical time phase of tower 2 and the negative electrical time phase of tower 1, deg

This equation is for the horizontal plane only, and the terms are especially defined to make the equation simple. The tower heights and current values are assumed to be equal or such that $E_1 = E_2$ along the ground. The spacing S_2 is from tower 1 to tower 2, and the phase Ψ_2 is the phase of the current in tower 2 taken with respect to tower 1 (see Fig. 9).

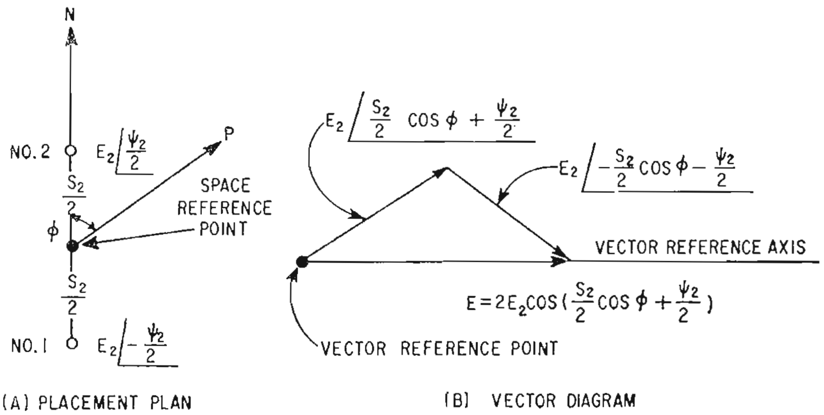


Fig. 9. Simple two-tower case.

Since a two-tower pattern is symmetrical with respect to the line of towers, it is necessary to compute the values for only one side of the line of towers, that is, Ø from 0 to 180°, and these same values can be used on the other side of the line of towers. For example, cos 10° = cos 350°, and hence the value of E will be the same in these two directions.

The shape of the pattern is controlled by proper selection of spacing S_2 and phasing Ψ_2, while the pattern size is controlled by E_2. For null filling or to determine the radiation above the ground plane, it is necessary to use a more general formula.

Three Towers in Line

A three-tower array will be considered from the simultaneous points of view of theory and practical operation. Three towers are either in line or not in line. If they are in line, as in the case of all two-tower patterns, the three-tower pattern must be symmetrical about the line of towers. Consequently, the pattern shape needs to be computed only on one side of the line of towers.

The three towers may be equally spaced or not equally spaced. If vectors alone are used to analyze the operation, it makes little difference where the towers are located, especially if the current values are not chosen for mathematical simplicity. If simplicity is desired, as it often is, the tower spacings should be made equal. This is covered more thoroughly in Appendix C, Fig. CA.

To relate theory and practice consider an array of three towers in line. The field strength produced by each tower can be represented by a vector at any point in space. The sum of the three vectors at the point is the total field strength produced by the entire array. This sum, or resultant field strength, is itself a vector and can be determined mathematically when all the parameters of the three-tower array are known. The size, or magnitude, of the resultant vector is the all-important part of the resultant field strength as far as the radio receiver is concerned. This is because the receiver does not detect the phase angle; it simply responds to the magnitude of the resultant vector and detects the information on it. The magnitude of the resultant vector at the receiver depends upon the magnitude and phase of the current on each of the three towers, which amounts to a total of six parameters.

The observation that there are six parameters in a three-tower array, which can vary independently of one another, makes it clear that it is necessary to understand which ones are being changed when the array is being adjusted. Otherwise, the possibility of making the wrong adjustment is very great. On the other hand when a desired correction is made by changing the appropriate parameter, the result cannot be wrong. This view is somewhat optimistic because theory does not hold exactly in practice where actual conditions involve the necessity of making compromises. For example, it is not difficult to change a parameter to get a certain field strength at a given point but in so doing the field strength may be adversely affected elsewhere.

An understanding of the directional antenna is quite easily acquired through vector analysis, but in actual field practice it is almost always more efficient to convert the vectors to an ordinary algebraic expression of the field strength at 1 mile. When this is done, the theoretical effects of a change in any one parameter can be quickly determined. The algebraic equations for a three-tower-in-line array are given in Appendix C, Fig. CC.

Three Towers Not in Line

The above treatment of three towers in a straight line should and did receive first consideration because of the number of such directional-antenna arrays in existence. Three towers not in line, sometimes referred to as a dog-leg array, deserves serious consideration because of the number of such arrays that are in existence and because such three-tower patterns naturally fit the predominately unsymmetrical requirements.

There are a number of ways to select the reference point and the reference line in the three-tower array. Only one will be treated here for the sake of clarity and briefness. It is believed to have more significance than other choices because it can be related to the two-tower treatment already covered and to the four-tower paralellogram array.

Further discussion of three towers not in line follows the treatment of the four-tower parallelogram array; hence it is treated as a corollary in Appendix C, Fig. CD.

Four-Tower Parallelogram

Many directional-antenna systems have four towers located at the corners of a parallelogram. The chief reason for the popularity of this type of array is the ease with which the pattern shape can be designed to meet complicated requirements. The design procedure is straightforward, and the computations are relatively easy. Because of these advantages it is surmised that some four-tower arrays have been designed and constructed where three-tower arrays would do the job. This does not necessarily imply that the three-tower array would do a better job. The four-tower array may have better stability in operation and make it possible to modify the pattern without change in tower location, and the efficiency may be better.

When the multiplication form of the four-tower array is used, it can be designed piecemeal by first selecting one two-tower design that will provide the necessary protection in two directions. Then another two-tower array can be selected to protect in two other directions. If the parallelogram design is used, these patterns can be multiplied together and achieve the necessary protection in all four specified directions. The design details are given in Appendix C, Fig. CB.

Arrays of More than Four Towers

It is not believed advisable to go further into the discussion of special cases where more than four towers are involved. If an owner or operator of a multielement array desires to adjust or understand a specific directional-antenna system, it is anticipated that he will take one of two courses: employ a competent consultant to do the work or become sufficiently proficient himself to do the job.

Suffice it to say here that in general the adding of more towers in an array permits protection in more directions or greater protection over wider angles and may in some cases be used to increase the field strength in some directions. The more complicated arrays are usually made up of combinations of two-tower units, and in some cases three-tower units are used. For example, an eight-tower array may be made up of four two-tower units, or a nine-tower array may be made up of three three-tower units.

GENERAL CONDITIONS AND PLANT LAYOUT

The entire plant should be considered from a number of points of view prior to detail study if an existing broadcast station is in need of adjustments or if the broadcast plant is to be built from its beginning.

The location of the transmitter building with respect to the towers is important from the standpoint of access to the transmitter from the road, and if the common point of the directional-antenna system is in the transmitter building, the building should be close to the towers to minimize RF transmission-line losses. If the transmitter building must be located some distance from the towers, it is advisable to feed the RF power over a transmission line to a common point located so that the RF lines from this point to the towers will have a minimum of loss.

The ground-system design for a new directional-antenna array should be laid out such that the copper will be used to best advantage to minimize E and H losses. This does not necessarily mean that a radial system under each tower is the best layout. A study of the H field or ground-current direction at a number of points will help decide how the copper wire should be placed. If the ground system has been installed for some time, it may have deteriorated somewhat. In such cases it is advisable to check for corrosion and mechanical failure of the conductors. The extent of the ground system should be checked against the original construction permit for completeness.

The transmission line, if above the ground, should have a ground strap buried in the ground below it, and this strap should be tied into the ground conductor system. This buried ground strap should be bonded to the ground side of the transmission line at regular intervals.

A general survey of the feeder system in an existing plant will involve not only the location of the matching, phasing, and power-division networks but obtaining information concerning possible inefficiencies and inconveniences in operating arrangements and adjustment controls.

The antenna monitor should be the most reliable indicator of the current of the various towers. If this is not the case, steps should be taken to improve its operation. The location of remote indicating meters should be checked along with their calibration against the antenna ammeters. If any question exists about the current magnitudes, then all the antenna and common-point meters should be calibrated against a meter of known accuracy.

It is good practice to become familiar with the procedure for warming up the transmitter, including starting and stopping operations. This will protect the equipment. Safety precautions, especially when high power is involved, should be obeyed rigorously. It is much better to spend a little more time than to have someone injured or killed.

All tuning controls, including variable capacitors and inductors, should be noted. All taps and settings should be recorded. A complete set of meter and antenna-monitor readings should be recorded before any adjustments are made on an existing system.

The tower lighting, tower insulation, lighting-control circuits, or the phase-monitoring system may require preliminary alterations before tower-impedance or common-point-impedance measurements are made.

The number of transmitters available for regular, auxiliary, or emergency operation should be inspected with regard to switching circuits and studied with regard to the possibility of improvements in convenience and efficiency.

REQUIRED PREADJUSTMENT INFORMATION

Preliminary Computations

Base Driving-Point Impedance

The loop impedance values can be computed or estimated, and from this information the base driving-point impedances of all towers can be estimated as outlined in Appendix B.

Base Driving-Point Currents

Knowing the power and driving-point impedances it is possible to estimate the base driving-point currents. Consideration should be given to the conservation of power principle between the loop and base values as discussed in Appendix B.

Characteristic Impedance of Transmission Lines

In a new or old system it is good practice to measure the characteristic impedance of all transmission lines. This can sometimes be done by measuring the open- and short-circuit impedances and determining the characteristic impedance from the equation

$$Z_0 = \sqrt{Z_{OC} Z_{SC}} \qquad [10]$$

where Z_0 = characteristic impedance, ohms
Z_{OC} = open-circuit impedance, ohms
Z_{SC} = short-circuit impedance, ohms

These values may all contain resistance terms when measured with an RF bridge. When the transmission line is near 90° in length, this method gives very good results. However, when the line is near 180° in length, the open-circuit values will be very large and the short-circuit values will be very small, with the result that Z_0 from the above equation may not be very accurate.

Another method, quite good and acceptable in practice, is to use a decade resistance box at one end of the line and measure the impedance looking in at the other end of the line. Then plot the decade box resistance along the x axis of graph paper and the measured RF bridge input impedance magnitude along the y axis. Where this curve intersects a 45° diagonal line in the first quadrant is located the characteristic impedance magnitude.

This method works quite well for any length of line. Of course, as the line becomes very long, the variation of resistance at the far end will have less and less effect, because if the line is of infinite length, the input impedance will look like the characteristic impedance regardless of the value of load resistance.

This method can be refined in accuracy by first measuring with the RF bridge the values of the decade box resistance. Usually decade resistance boxes have an inductive reactance component that may vary with resistance-value settings. In such cases it may be desirable to parallel the decade resistance box with a small variable capacitor that is adjusted to make the load terminals of the decade box look like a pure resistance. With such refinements it is usually possible to obtain very good results in the field.

Matching Networks

With the above information at hand the transmission line to tower matching networks can be adjusted to transfer the transmission-line-impedance to the driving-point-impedance value. An L section is usually adequate unless the design requires a different amount of phase shift.

The system should be designed for the least amount of phase shift possible consistent with good operating practice because in this way the system efficiency can be maximized.

If it is not convenient to set up dummy driving-point impedances and measure the network from the transmission-line end, then a resistor equal to the characteristic impedance of the transmission line can be connected across the line side of the matching network. The network can then be adjusted until the RF bridge looking in at the tower terminals sees the conjugate value of the driving-point impedance. This means that when the network is connected at this point in a normal fashion, the reactance of the driving-point impedance will be resonated with the reactance of its conjugate value. The resistance of the conjugate impedance is equal to the resistance of the driving-point impedance. Hence the condition for maximum power transfer is achieved.

Probably the only other matching network will be between the power divider and the transmitter. This is the last network to be adjusted. It may be either before or after the common point where the power input to the directional antenna is measured. Usually it is after the common point in order that the common-point input will be a pure resistance at the operating frequency. The loss in this network is then charged against the directional-antenna system, since it is beyond the common point of power measurement.

Phase-Shifting Networks

Usually the phase-shifting networks are designed to operate into the characteristic impedance of the transmission line. Hence, they can be connected directly and maintain an impedance match. It is rather common practice to place the phase-shifting networks in the lines that handle the least amount of RF power, thus minimizing the RF power loss of the feeder system. The transmission line or tower that takes the most power can be run directly to the power-dividing network.

It is usually easier to vary the phase by ganging the rollers of coils rather than using variable capacitors. For this condition a T section would be chosen for a 90° ± 10° phase-retarding network and a π section would be chosen for a 90° ± 10° phase-advancing network as shown in Appendix B, Fig. BZ.

If it is necessary to vary a capacity element, it is sometimes more convenient to place a small fixed capacitor in series with a variable coil so that the series combination will have the correct value at the operating frequency. If the filtering or harmonic properties also have to be considered, this combination may not be satisfactory.

It is important to make sure that the rotating wiping contacts on the phase shifters are in good mechanical condition to wipe smoothly and make good electrical contact continuously. The contacts should feel nearly as cool as the other parts after the equipment has been in operation; otherwise there is too much resistance at the contacts.

Power-Dividing Networks

The power-dividing network usually accepts power from the transmitter output and feeds the proper amounts into transmission lines and phase-shifting networks. For maximum efficiency it is good practice to feed the largest amount of power directly into the transmission line, thus avoiding the power loss in the phase-shifting network.

If power-handling dummy driving-point-impedance loads are used the power divider can be adjusted approximately before connecting to the towers. If this procedure is followed, the approximate value of phase can be inserted if the phase sampling is done at the input to the dummy loads. For L sections in parallel the resistance input to the individual L sections must have the value of resistance needed to absorb the correct ratio of the total power delivered from the common point.

For example, in a two-tower array, the L section resistance inputs can be written

$$R_1 = \frac{V^2}{P_1} \qquad [11]$$

$$R_2 = \frac{V^2}{P_2} \qquad [12]$$

where R_1 = resistance into L section leading to tower 1, ohms
R_2 = resistance into L section leading to tower 2, ohms
V = voltage between common point and ground, volts
P_1 = power to tower 1, watts
P_2 = power to tower 2, watts

The common-point resistance can be written

$$R = \frac{R_1 R_2}{R_1 + R_2}$$

where R is the common-point resistance in ohms.

Component Ratings

The current through and the voltage across each component in the feeder system should be computed to determine the required rating. This information provides a means of choosing the most economically sized component in a new installation. These computations will show up components in an existing system which are underrated and should be changed.

The current rating of capacitors are given by the manufacturer and should not be exceeded during operation for the most adverse temperature and poor adjustment conditions. The voltage ratings are also given by the manufacturer and should be high enough to comply with any surges that may arise, including lightning. The lightning-protection devices should be good enough to allow for reasonable economy in deciding the maximum voltage rating.

The current and voltage rating of coils are related to the voltage gradient between turns of the coil. The distance between conductor centers in adjacent turns should be roughly twice the diameter of the conductor, and the conductor diameter must comply with good engineering standards as to coil losses.

Coarse Adjustments

Meter Calibrations

All meters should be checked for accuracy against meters which are of known accuracy. Calibration charts should be made up for meters that do not register correctly. The current-sampling system on each tower should be checked for accuracy.

Antenna-Monitor System

The antenna monitor should be checked for accuracy. The tower-sampling loops can be placed in parallel and checked for zero phase when the same field is sampled. If tower input currents are sampled, the same current can be sampled by two sampling units to check for accuracy.

Another method is to establish a null off the end of two towers and read the phase which is known quite accurately by theory for this condition. This can be done by setting up a field strength set at some distance and walk the two-tower phase and power-division controls to give a deep null. This also gives an excellent check on unity field-strength ratio. It is helpful to have two-way communication to expedite these measurements.

Common-Point Impedance

After the array is approximately adjusted, it is advisable to measure the common-point input impedance. It may be desired at this time to make input matching network adjustments so a pure resistance load will be presented to the transmitter at the operating frequency.

After final adjustment of the array the common-point input impedance must be measured across a band of frequencies to meet FCC requirements and check on characteristics that may cause objectionable distortion. It is desirable to have a relatively constant value of resistance over the modulation-frequency range.

Low-Power Operation

After the common-point impedance has been adjusted properly, low power can be fed into the system and all meters checked for predicted readings. If errors have been made in the computations, the adjustment will probably be incorrect.

Field-Strength Check

After the array is in reasonable adjustment, it is timely to check the field strength. Usually a nondirectional proof is made by running at least eight radials to determine the rms value and the attenuation in the various directions and establish suitable monitoring points in critical directions.

These measurements will probably indicate what changes are necessary to meet the requirements in the construction permit. Any change in adjustment should be followed by appropriate field-strength measurements properly logged so that further adjustments are always in the correct direction.

As the desired pattern is approached and the feeder system comes into proper adjustment, the full input power can be used.

Fine Adjustments

These adjustments are simply a continuation of the tuning to arrive at the final values. More exact and extensive information is gathered with regard to how the controls affect the field-strength measurements, particularly along radials in the direction of the various minima.

The final adjustment of the array is decided upon after enough information is gathered to show what adjustment of the array gives the desired over-all results. The final adjustment may involve compromises in optimum field strength between the various minima and critical bearings concerned with protection.

During this phase the monitoring points are usually selected. The value of monitoring-point readings should be recorded along with the other meter readings of the system.

When the final pattern adjustments have been made, careful attention is given to establishing the exact power at the common point. The resistance and reactance versus frequency measurements are then run for the common point.

Final Operating Adjustment

With the antenna system operating properly, all meter readings are recorded and maintained while the field-strength measurements are made to prove the shape and size of the horizontal pattern.

The monitoring points have to be photographed in order to provide a reliable means of finding their exact location in the future. The field strength at the monitoring points should be checked at least daily while making the proof of performance field-strength measurements.

The field-strength radial measurements are plotted on FCC logarithmic paper and analyzed to determine the unattenuated field strength at 1 mile. These values are then plotted on polar coordinate paper, and a planimeter can then be used to determine the rms value. This should agree closely with the predicted value.

If only a skeleton or partial proof is required, sufficient directional measurements must be made at points used in the original proof to show by means of ratios between the two measurements at each location that the pattern is basically unchanged. If the average of the ratios for each radial, usually about 5, is between 0.8 and 1.2, it is considered that the pattern is unchanged. If the average deviates outside this range on two or more radials, the array probably needs further adjustment.

MULTIPURPOSE ANTENNA SYSTEMS

Two-Pattern Arrays

Many directional-antenna systems have a different day and night pattern. Usually the nighttime pattern requires deeper minima and in many cases different locations of the towers or more towers in the array.

In the layout and design of such a system the problem should be carefully analyzed and the simplest layout used consistent with good engineering practice. Many times the same matching networks can be used with a day-night transfer relay to change coil turns and capacity values as required for the two conditions of operation.

It is good practice to provide pilot-light circuits to indicate when all RF relays are in their correct positions. If power is applied to a system with the relays not in proper positions, some components may be injured and the transmitter may not be working into a matched load.

Two Transmitters Using Same Towers

There are a number of cases where an antenna system is used by more than one station. If, for example, two radio transmitters use the same towers, it is necessary to add RF filter circuits so energy will not be fed from the output of one transmitter back to the output of the other transmitter and produce cross-modulation products. If this happens, the program of the other radio station will be heard in the background.

In the feeder-system design for two transmitters using the same towers it is usually possible to design the networks such that the T, τ, or L sections perform the necessary filtering action in addition to the required impedance transformation and phase-shift functions.

The metering circuits must also be filtered so they will not respond to the undesired frequency. If a meter has two RF currents of different frequencies, it will give an rms response providing it is not frequency-sensitive.

REFERENCES

1. Morrison, J. F., and P. E. Smith: The Shunt Excited Tower, *Proc. IRE*, vol. 25, pp. 673-696, June, 1937.
2. Jeffers, C. L.: An Antenna for Controlling the Nonfading Range of Broadcasting Stations, *Proc. IRE*, vol. 36, pp. 1426-1431, November, 1948.
3. Smith, Carl E., D. B. Hutton, and W. G. Hutton: Performance of Sectionalized Broadcasting Towers, *IRE Trans.*, pp. 22-34, December, 1955.
4. Smith, Carl E.: "Theory and Design of Directional Antenna Systems," Cleveland Institute of Electronics, Inc., Cleveland, Ohio, 1951. (Where this reference is cited, it is understood that it was lifted from the 4th edition of the "NAB Handbook." Hence that reference is also cited.
5. Smith, Carl E.: "Directional Antenna Patterns," Cleveland Institute of Electronics, Inc., Cleveland, Ohio, 1946. Book contains over 15,000 systematized patterns.
6. Everitt, W. L., and G. E. Anner: "Communication Engineering," McGraw-Hill Book Company, Inc., New York, 1956.
7. Everitt, W. L.: Coupling Networks, *Communications (N.Y.)*, vol. 18, p. 12, September, 1938, p. 12, October, 1938.
8. Stewart, A. C.: Radio Frequency Networks, "NAB Engineering Handbook," 4th edition.
9. Terman, F. E.: "Radio Engineers' Handbook," McGraw-Hill Book Company, Inc., New York, 1943.
10. Laport, E. A.: "Radio Antenna Engineering," McGraw-Hill Book Company, Inc., New York, 1952.
11. Brown, G. H.: Directional Antennas, *Proc. IRE*, vol. 25, pp. 78-145, January, 1937.
12. Schelkunoff, S. A.: "Antennas: Theory and Practice," John Wiley & Sons, Inc., New York, 1952.
13. Schelkunoff, S. A.: "Advanced Antenna Theory," John Wiley & Sons, Inc., New York, 1952.
14. Williams, Paul H.: "Antenna Theory and Design," vol. I, Foundations of Antenna Theory; vol. II, The Electrical Design of Antennae, Sir Isaac Pitman & Sons, Ltd., London, 1950.
15. King, Ronald W. P.: The Theory of Linear Antennas, Harvard University Press, Cambridge, Mass. 1956.

APPENDIX A
SINGLE-TOWER ANTENNAS

Theoretical Vertical-Radiation Characteristics

Formulas

Sectionalized Top-loaded Tower. The current distribution on the bottom section of the tower as shown in Fig. A is given by

$$i_a = I_a \sin (G - y) \qquad [A\text{-}1]$$

The current distribution on the top section is given by

$$i_c = I_c \sin (H - y) \qquad [A\text{-}2]$$

At the insulator height $y = A$, $I_c = i_a$, $G - A = B$, and

$$I_c \sin (H - A) = I_a \sin B \qquad [A\text{-}3]$$

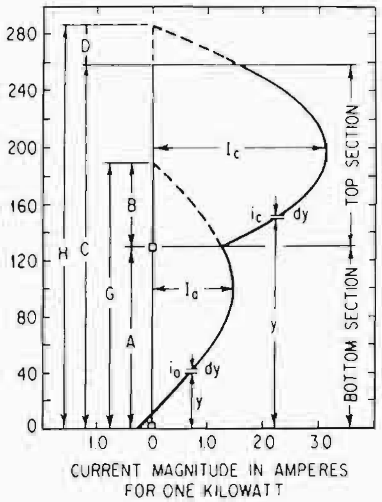


Fig. AA. Theoretical current distribution on a top-loaded sectionalized tower.

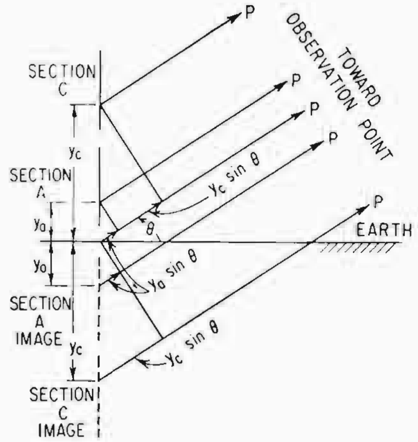


Fig. AB. Geometry to determine field from sectionalized tower with images.

or
$$I_c = \frac{\sin B}{\sin (H - A)} I_a \qquad \text{[A-4]}$$

The inverse field or unattenuated field strength toward at 1 mile the observation point P at an elevation angle θ produced by a vertical element dy at the base of the antenna would be $dy \cos \theta$. The field from any other similar element of the antenna or its image would have a phase different from zero as depicted in Fig. B. The addition of these vector fields from an element and its image on sections A and C is shown in Fig. ACa and b, respectively. It is noted that the sine components cancel. The total field at the point P is, therefore,

$$E_\theta = K 2 I_a \cos\theta \left[\int_0^A i_a \cos (y \sin\theta)\, dy + \int_A^C i_c \cos (y \sin\theta)\, dy \right] \qquad \text{[A-5]}$$

where K is a constant such that E_θ will be in the units desired. K cancels out in $f(\theta)$. Substituting from Eqs. A-1, A-2 and A-4, performing the indicated integration, and dividing the result by itself when $\theta = 0$ give

$$f(\theta) = \frac{\cos B \cos (A \sin\theta) - \cos G + \dfrac{\sin B \cos (H - C) \cos (C \sin\theta)}{\sin (H - A)} - \dfrac{\sin B \sin\theta \sin (H - C) \sin (C \sin\theta)}{\sin (H - A)} - \dfrac{\sin B \cos (H - A) \cos (A \sin\theta)}{\sin (H - A)}}{\cos\theta \left\{ \cos B - \cos G + [\sin B / \sin (H - A)] (\cos \overline{H - C} - \cos \overline{H - A}) \right\}} \qquad \text{[A-6]}$$

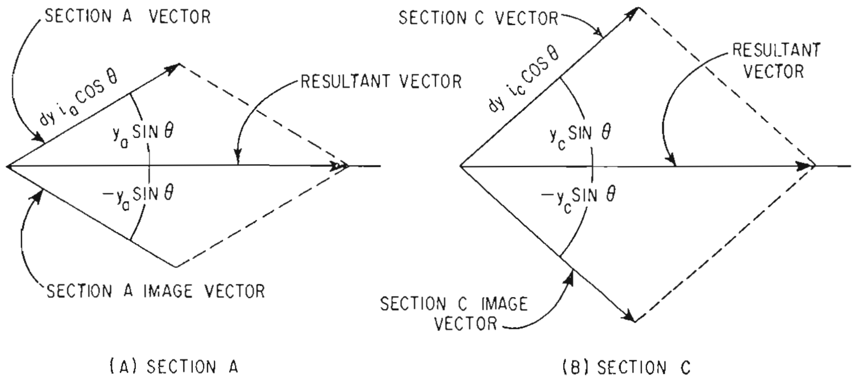


Fig. AC. Vector diagrams of field strength at point *P*.

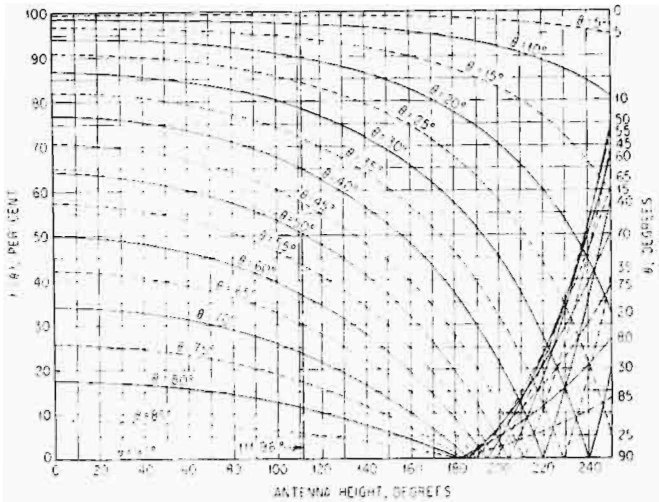


Fig. AD. Vertical-radiation charateristic as a function of electrical tower height for various values of elevation angle.

This is the vertical-radiation-characteristic equation for a two-section sectionalized tower. The same procedure can be applied if more than two sections are involved.

Top-loaded Tower. Referring to Fig. A-1 it is noted that the sectionalized antenna can be reduced to a nonsectionalized top-loaded antenna by making the top section of zero length but at the same time arranging for top loading such that B is unchanged. This can be done by letting $C = A$ and $H = C$ in Eq. (A-6), which then reduces to

$$f(\theta) = \frac{\cos B \cos(A \sin\theta) - \cos G - \sin B \sin\theta \sin(A \sin\theta)}{\cos\theta(\cos B - \cos G)} \qquad \text{[A-7]}$$

This is the vertical-radiation characteristic for a top-loaded tower of height A and top-loaded to a height of $G = A + B$.

Ordinary Vertical Tower. The ordinary tower without top loading can be obtained from Eq. (A-6) by letting $C = A$, $H = C$, and $B = 0$ or in Eq. (A-7) by letting $A = G$ and $B = 0$ to obtain

$$f(\theta) = \frac{\cos(G \sin\theta) - \cos G}{\cos\theta(1 - \cos G)} \qquad \text{[A-8]}$$

This is the same as Eq. 3 in the text. Table A gives values of $f(\theta)$ for a useful range of tower heights, and Fig. D gives this information in graphical form.

Theoretical Self-Impedance and Radiation

It is useful to know the theoretical loop and base resistance of a vertical radiator. This information is presented graphically in Fig. AE along with the theoretical inverse field strength at 1 mile.

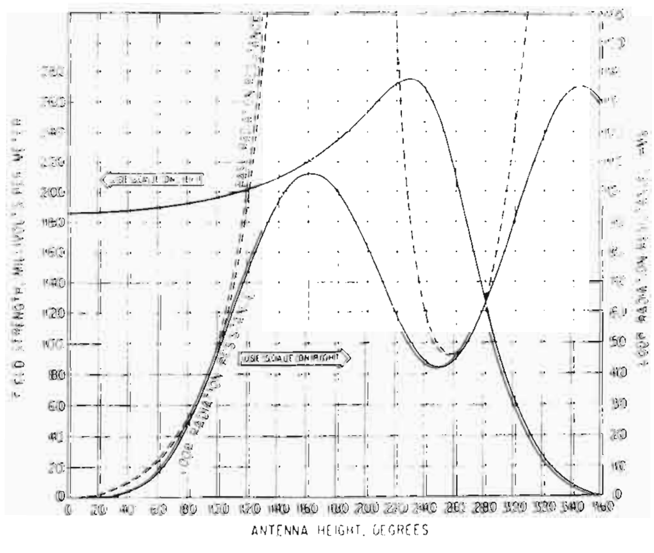
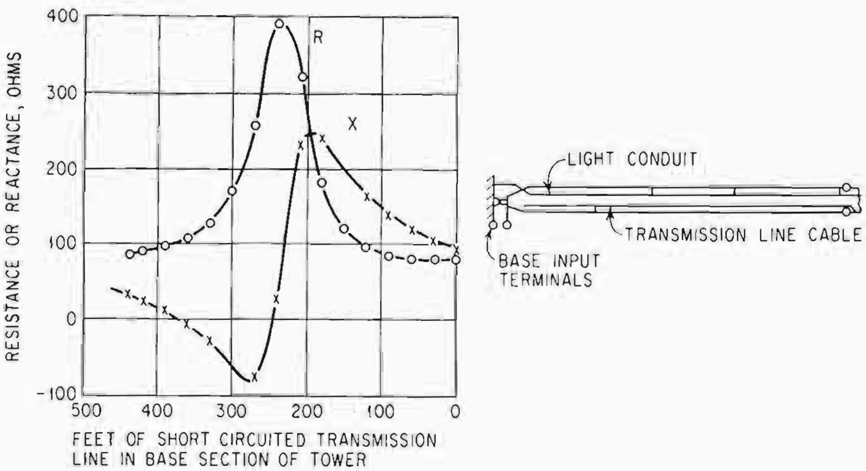
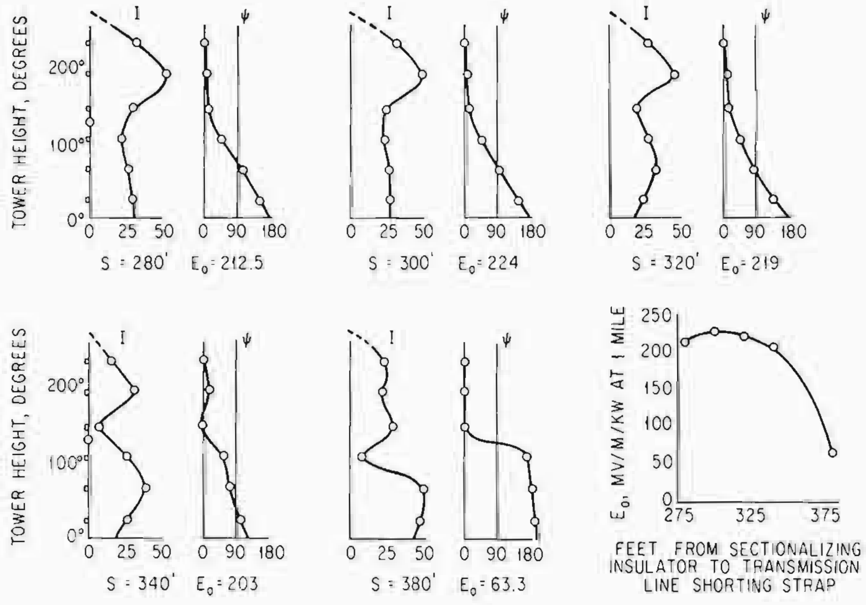


Fig. AE. Inverse field strength at 1 mile for 1 kw, loop and base radiation resistance as a function of tower height over a perfectly conducting earth.

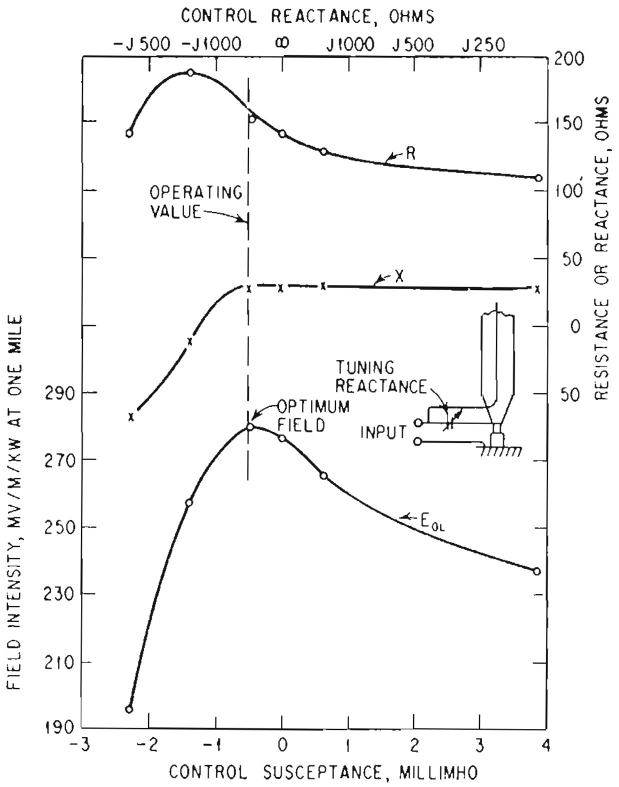


(A) - BASE IMPEDANCE OF 258° TOWER AS A FUNCTION OF LOADING REACTANCE ACROSS SECTIONALIZING INSULATOR

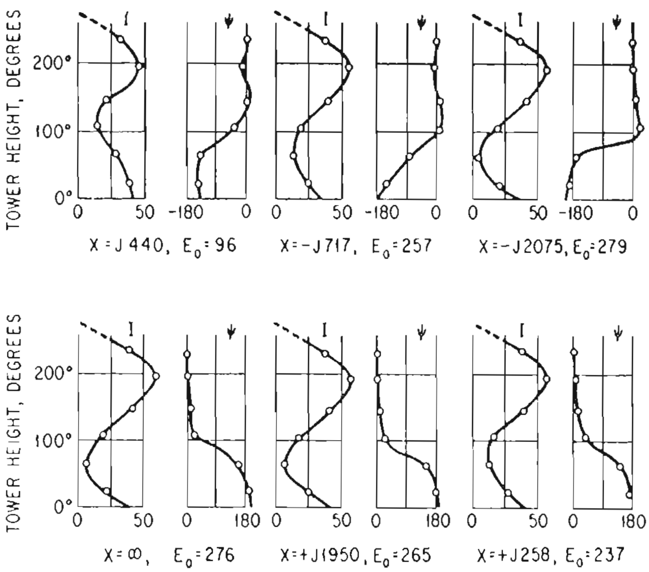


(B) - CURRENT AND PHASE DISTRIBUTION ON 258° TOWER AS FUNCTION OF LOADING REACTANCE ACROSS SECTIONALIZING INSULATOR IN TERMS OF SHORTED TRANSMISSION LINE LENGTHS

Fig. AF. Performance of sectionalized tower with a top section excited through reactance element from bottom section.



(A) INPUT IMPEDANCE AND FIELD STRENGTH OF TOP LOADED SECTIONALIZED 258° TOWER AS FUNCTION OF TUNING REACTANCE



(B) CURRENT AND PHASE DISTRIBUTION ON 258° TOWER AS FUNCTION OF TUNING REACTANCE AT BASE OF TOWER

Fig. AG. Performance of sectionalized tower with top and bottom sections excited independently.

Table A-1. Vertical-radiation Characteristic $f(\theta)$

$\theta°$	Tower height, $G°$								
	0	5	10	15	20	25	30	35	40
0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
5	0.9962	0.9962	0.9962	0.9961	0.9961	0.9961	0.9960	0.9960	0.9959
10	0.9848	0.9848	0.9847	0.9846	0.9845	0.9843	0.9841	0.9839	0.9836
15	0.9659	0.9659	0.9657	0.9655	0.9653	0.9649	0.9644	0.9639	0.9632
20	0.9397	0.9394	0.9393	0.9390	0.9386	0.9379	0.9372	0.9362	0.9351
25	0.9063	0.9062	0.9058	0.9054	0.9047	0.9037	0.9026	0.9012	0.8996
30	0.8660	0.8658	0.8654	0.8648	0.8638	0.8626	0.8610	0.8592	0.8571
35	0.8192	0.8188	0.8186	0.8176	0.8164	0.8148	0.8129	0.8106	0.8080
40	0.7660	0.7658	0.7653	0.7642	0.7628	0.7610	0.7587	0.7561	0.7530
45	0.7071	0.7069	0.7062	0.7051	0.7035	0.7014	0.6989	0.6960	0.6925
50	0.6428	0.6423	0.6418	0.6406	0.6390	0.6368	0.6341	0.6309	0.6272
55	0.5736	0.5732	0.5726	0.5714	0.5697	0.5674	0.5647	0.5615	0.5577
60	0.5000	0.4947	0.4990	0.4979	0.4961	0.4940	0.4914	0.4882	0.4846
65	0.4226	0.4222	0.4217	0.4203	0.4191	0.4171	0.4143	0.4117	0.4084
70	0.3420	0.3412	0.3412	0.3404	0.3390	0.3372	0.3351	0.3325	0.3297
75	0.2588	0.2579	0.2584	0.2575	0.2564	0.2550	0.2533	0.2513	0.2490
80	0.1736	0.1695	0.1732	0.1727	0.1720	0.1710	0.1697	0.1684	0.1668
85	0.0871	0.0844	0.0869	0.0869	0.0864	0.0858	0.0852	0.0844	0.0836

$\theta°$	45	50	55	60	65	70	75	80	85
0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
5	0.9958	0.9957	0.9956	0.9955	0.9953	0.9952	0.9950	0.9948	0.9946
10	0.9832	0.9830	0.9824	0.9819	0.9815	0.9809	0.9804	0.9795	0.9788
15	0.9625	0.9617	0.9607	0.9597	0.9585	0.9573	0.9559	0.9544	0.9527
20	0.9339	0.9325	0.9309	0.9289	0.9272	0.9251	0.9227	0.9200	0.9173
25	0.8978	0.8957	0.8934	0.8908	0.8879	0.8848	0.8813	0.8776	0.8735
30	0.8546	0.8519	0.8487	0.8453	0.8416	0.8375	0.8328	0.8278	0.8224
35	0.8050	0.8015	0.7977	0.7934	0.7887	0.7836	0.7779	0.7718	0.7651
40	0.7485	0.7449	0.7410	0.7358	0.7305	0.7244	0.7180	0.7109	0.7103
45	0.6886	0.6769	0.6791	0.6735	0.6675	0.6608	0.6536	0.6457	0.6372
50	0.6230	0.6186	0.6130	0.6073	0.6009	0.5936	0.5862	0.5777	0.5686
55	0.5535	0.5486	0.5427	0.5373	0.5308	0.5236	0.5159	0.5075	0.4984
60	0.4804	0.4759	0.4705	0.4648	0.4587	0.4518	0.4441	0.4361	0.4271
65	0.4042	0.4002	0.3954	0.3898	0.3843	0.3779	0.3710	0.3630	0.3556
70	0.3263	0.3216	0.3190	0.3141	0.3089	0.3031	0.2970	0.2906	0.2842
75	0.2463	0.2433	0.2400	0.2363	0.2323	0.2279	0.2232	0.2181	0.2127
80	0.1649	0.1629	0.1622	0.1576	0.1557	0.1515	0.1492	0.1457	0.1408
85	0.0826	0.0816	0.0804	0.0791	0.0777	0.0761	0.0739	0.0726	0.0707

$\theta°$	90	95	100	105	110	115	120	125	130
0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
5	0.9944	0.9942	0.9939	0.9937	0.9934	0.9931	0.9927	0.9923	0.9919
10	0.9781	0.9770	0.9760	0.9749	0.9738	0.9725	0.9712	0.9697	0.9681
15	0.9509	0.9489	0.9468	0.9445	0.9420	0.9393	0.9363	0.9337	0.9297
20	0.9143	0.9110	0.9074	0.9035	0.8993	0.8947	0.8898	0.8845	0.8788
25	0.8691	0.8642	0.8590	0.8534	0.8473	0.8407	0.8336	0.8259	0.8175
30	0.8165	0.8102	0.8033	0.7959	0.7878	0.7791	0.7698	0.7597	0.7489
35	0.7579	0.7501	0.7417	0.7320	0.7228	0.7122	0.7000	0.6886	0.6754
40	0.6946	0.6855	0.6759	0.6656	0.6541	0.6420	0.6288	0.6157	0.5999
45	0.6279	0.6180	0.6073	0.5958	0.5834	0.5702	0.5560	0.5408	0.5245
50	0.5591	0.5487	0.5373	0.5253	0.5124	0.4987	0.4838	0.4689	0.4511
55	0.4886	0.4781	0.4669	0.4548	0.4419	0.4281	0.4134	0.3977	0.3809
60	0.4178	0.4078	0.3969	0.3854	0.3730	0.3600	0.3460	0.3310	0.3151
65	0.3470	0.3378	0.3279	0.3174	0.3061	0.2942	0.2813	0.2680	0.2536
70	0.2766	0.2687	0.2598	0.2509	0.2413	0.2311	0.2203	0.2091	0.1969
75	0.2067	0.2007	0.1937	0.1866	0.1790	0.1709	0.1623	0.1533	0.1437
80	0.1377	0.1331	0.1281	0.1237	0.1180	0.1130	0.1064	0.1005	0.0941
85	0.0686	0.0664	0.0640	0.0614	0.0588	0.0559	0.0529	0.0497	0.0464

Table A-1. Vertical-radiation Characteristic $f(\theta)$ (*Continued*)

θ°	Tower height, G°							
	135	140	145	150	155	160	165	170
0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
5	0.9915	0.9910	0.9905	0.9899	0.9893	0.9886	0.9878	0.9870
10	0.9663	0.9645	0.9624	0.9602	0.9577	0.9551	0.9522	0.9491
15	0.9259	0.9219	0.9175	0.9127	0.9075	0.9019	0.8956	0.8889
20	0.8725	0.8657	0.8584	0.8504	0.8418	0.8324	0.8222	0.8110
25	0.8085	0.7988	0.7883	0.7769	0.7645	0.7511	0.7366	0.7207
30	0.7372	0.7245	0.7108	0.6961	0.6801	0.6628	0.6440	0.6237
35	0.6612	0.6460	0.6293	0.6118	0.5926	0.5720	0.5496	0.5254
40	0.5837	0.5664	0.5477	0.5276	0.5060	0.4828	0.4577	0.4305
45	0.5070	0.4882	0.4681	0.4466	0.4235	0.3979	0.3719	0.3432
50	0.4330	0.4137	0.3932	0.3710	0.3473	0.3219	0.2948	0.2657
55	0.3631	0.3440	0.3237	0.3020	0.2786	0.2542	0.2278	0.1996
60	0.2981	0.2802	0.2611	0.2407	0.2190	0.1960	0.1713	0.1451
65	0.2382	0.2222	0.2051	0.1867	0.1675	0.1469	0.1256	0.1019
70	0.1838	0.1716	0.1555	0.1399	0.1237	0.1065	0.0881	0.0687
75	0.1335	0.1227	0.1114	0.0994	0.0866	0.0732	0.0590	0.0439
80	0.0868	0.0796	0.0719	0.0634	0.0547	0.0458	0.0359	0.0256
85	0.0428	0.0390	0.0351	0.0309	0.0265	0.0218	0.0169	0.0117
θ°	175	180	185	190	195	200	205	210
0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
5	0.9861	0.9851	0.9840	0.9828	0.9815	0.9801	0.9784	0.9766
10	0.9455	0.9418	0.9375	0.9330	0.9278	0.9222	0.9159	0.9089
15	0.8815	0.8733	0.8645	0.8547	0.8438	0.8319	0.8186	0.8038
20	0.7988	0.7855	0.7708	0.7548	0.7370	0.7175	0.6958	0.6718
25	0.7034	0.6845	0.6638	0.6412	0.6168	0.5888	0.5585	0.5250
30	0.6015	0.5774	0.5510	0.5222	0.4907	0.4561	0.4179	0.3757
35	0.4991	0.4706	0.4395	0.4057	0.3687	0.3283	0.2839	0.2350
40	0.4013	0.3696	0.3353	0.2979	0.2573	0.2129	0.1645	0.1112
45	0.3122	0.2788	0.2427	0.2036	0.1612	0.1152	0.0650	0.0103
50	0.2344	0.2008	0.1646	0.1256	0.0834	0.0378	−0.0118	−0.0657
55	0.1658	0.1370	0.1022	0.0649	0.0247	−0.0186	−0.0655	−0.1161
60	0.1171	0.0873	0.0553	0.0211	−0.0155	−0.0550	−0.0973	−0.1431
65	0.0772	0.0509	0.0228	−0.0071	−0.0391	−0.0733	−0.1100	−0.1494
70	0.0481	0.0261	0.0029	−0.0220	−0.0483	−0.0765	−0.1065	−0.1388
75	0.0280	0.0111	−0.0069	−0.0259	−0.0461	−0.0676	−0.0905	−0.1150
80	0.0148	0.0033	−0.0089	−0.0218	−0.0354	−0.0499	−0.0633	−0.0818
85	0.0062	0.0004	−0.0057	−0.0122	−0.0191	−0.0264	−0.0341	−0.0424
θ°	215	220	225	230	235	240	245	250
0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
5	0.9746	0.9723	0.9697	0.9668	0.9635	0.9597	0.9551	0.9504
10	0.9011	0.8925	0.8826	0.8580	0.8586	0.8442	0.8275	0.8084
15	0.7873	0.7689	0.7481	0.7247	0.6981	0.6679	0.6333	0.5935
20	0.6450	0.6151	0.5815	0.5438	0.5010	0.4525	0.3970	0.3334
25	0.4877	0.4462	0.3997	0.3475	0.2887	0.2220	0.1462	0.0593
30	0.3291	0.2772	0.2188	0.1548	0.0821	0.0000	−0.0931	−0.1992
35	0.1810	0.1214	0.0551	−0.0188	−0.1016	−0.1946	−0.2997	−0.4191
40	0.0529	−0.0117	−0.0814	−0.1620	−0.2501	−0.3489	−0.4599	−0.5853
45	−0.0498	−0.1156	−0.1881	−0.2683	−0.3572	−0.4562	−0.5671	−0.6917
50	−0.1243	−0.1885	−0.2588	−0.3363	−0.4216	−0.5163	−0.6216	−0.7394
55	−0.1711	−0.2310	−0.2962	−0.3677	−0.4462	−0.5327	−0.6285	−0.7351
60	−0.1924	−0.2461	−0.3040	−0.3674	−0.4364	−0.5125	−0.5958	−0.6882
65	−0.1918	−0.2375	−0.2880	−0.3406	−0.3989	−0.4625	−0.5322	−0.6089
70	−0.1733	−0.2107	−0.2503	−0.2935	−0.3402	−0.3909	−0.4463	−0.5069
75	−0.1411	−0.1691	−0.1992	−0.2315	−0.2664	−0.3042	−0.3452	−0.3899
80	−0.0992	−0.1182	−0.1380	−0.1600	−0.1826	−0.2079	−0.2346	−0.2639
85	−0.0511	−0.0605	−0.0705	−0.0812	−0.0927	−0.1051	−0.1185	−0.1330

Sectionalized Tower Measurements

Two cases of interest are presented in Figs. AF and AG. In Fig. AF, it will be noted that the maximum field strength is 224 mv/m for 1-kw input when the tower is driven at the base and an inductive reactance in the form of a short-circuited transmission line is connected across the sectionalizing insulator. The current and phase distribution are of particular interest for this condition. A standing wave of varying amplitude exists on the top section with very little phase shift, while on the lower section a traveling wave characterized by a constant amplitude and progressive phase shift is evident.

When both the upper and lower tower sections are driven as shown in Fig. AG, the maximum inverse field strength for 1-kw input is 279 mv/m. In this case there is a very rapid phase shift of 180° and the current drops to a very low value. At the bottom of the tower there is a build-up of current that is approximately 180° out of phase with the current on the top section. It is this combination that reduces high angle radiation and is responsible for the strong ground-wave field strength.

APPENDIX B
TWO-TOWER DIRECTIONAL ANTENNAS

Pattern Formulas

General Equation

The inverse field strength from a two-tower directional antenna as shown in Fig. BA is given by

$$E = E_1 f_1(\theta) \sqrt{2F} \Big/ \sqrt{\frac{1+F^2}{2F} + \cos(S\cos\phi\cos\theta + \Psi)} \qquad \text{[B-1]}$$

where E = inverse field strength at 1 mile, mv/m
E_1 = inverse field strength at 1 mile from tower 1 when operating in array, mv/m
$f_1(\theta)$ = vertical-radiation characteristic of tower 1

$$F = \frac{E_2 f_2(\theta)}{E_1 f_1(\theta)} \qquad \text{[B-2]}$$

= ratio of field strength from tower 2 to tower 1

where E_2 = inverse field strength at 1 mile from tower 2 when operating in array, mv/m
$f_2(\theta)$ = vertical-radiation characteristic of tower 2
S = spacing between tower 2 and tower 1, deg
ϕ = azimuth angle from line of towers, deg
θ = elevation angle, deg
Ψ = electrical phase angle of current in tower 2 with respect to tower 1, deg

The above terms as shown in Fig. BB are written without subscripts where possible for a simple two-tower array. When more than two towers are involved, the term F in Eq. B-2 is written F_{21} to designate the ratio between tower 2 and tower 1. Similarly, the spacing would be marked S_{21}, which is the distance from tower 2 to tower 1 that is located at the space reference point. The electrical phase in general is written Ψ_{21} to designate the phase of the current in tower 2 with respect to tower 1.

Minimum-Depth Term

The minimum-depth term by definition is

$$\frac{1+F^2}{2F} \qquad \text{[B-3]}$$

Because of its significance in Eq. B-1, Table A has been prepared. This table lists the values of F, $1/F$, F^2, and the minimum-depth term. The minimum-depth term is unchanged if $1/F$ is used in the place of F.

An inspection of the radicand in Eq. B-1 shows that E in the minima can be made larger than zero providing the minimum-depth term is not completely canceled by the cosine term. The exact size of E in the minima can be fixed by choice of the value of the minimum-depth term. Conversely, if the equation for E is in the form of Eq. B-1 and if F is also given, then Table B-1 can be used to check the accuracy of the formula quickly. If F is not given, it can be found from the table.

General Value of Field Ratio

The general form of F is given in Eq. B-2. The values of $f(\theta)$ for various tower heights are given in Appendix A, Fig. AD and Table A. Hence, in the design of a two-tower directional antenna, it is convenient first to select the value of the minimum-depth term. The corresponding value of F can be found in Appendix B, Table A, and by Eq. B-2 the ratio of E_2 over E_1 can be determined. This procedure can be reversed to check a given equation.

For pattern computations, it is convenient to fix θ and vary ϕ; thus the information can be used to meet the requirement in Paragraph 3.150 of Part 3, FCC Rules. The data required are field strength E as a function of azimuth angle ϕ for 5° intervals of elevation angle θ from 0 to 60°.

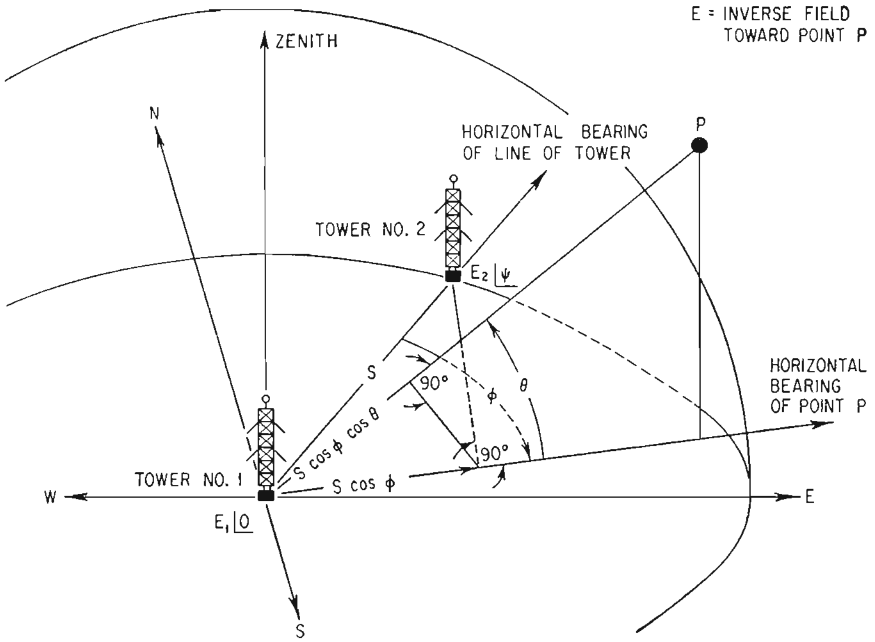


Fig. BA. Space view of two-tower directional antenna.

Horizontal-Plane Equation

In the ground plane Eq. B-1 reduces to

$$E = E_1 \sqrt{2F} \sqrt{\frac{1 + F^2}{2F} + \cos(S \cos \phi + \Psi)} \quad \text{[B-4]}$$

where F is the ratio of E_2 over E_1 for equal or unequal height towers. Thus Eq. B-4 can be used for $\theta = 0$ and Eq. B-1 can be used at elevation angles up to 60° as required by the above rules.

If the ratio of E_2 over E_1 is given but E has not been expressed in the form of Eq. B-1 or B-4, it is convenient to use Table A to obtain the values to be used in the above equations.

The minimum-depth term usually appears more than once in directional-antenna-pattern equations for arrays having more than two towers. Three towers in line and parallelogram arrays can use two or more of the multiplication radicands given in Eq. B-1.

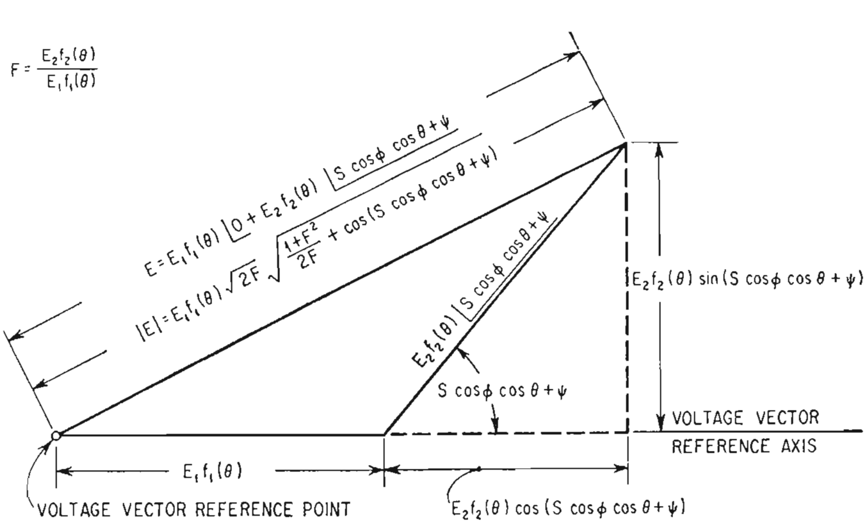


Fig. BB. Voltage vector diagram for two-tower directional antenna.

Systematization of Two-Tower Patterns

The systematization has been divided into relatively large steps of 45° for phasing and spacing in Figs. BC to BF. The spacing extends to four wavelengths or 1,440°. The more useful range of spacing up to one wavelength is given in small steps of 15° for both spacing and phasing in Figs. BG to BL.

Pattern Size

Field Strength of Reference Tower

In order to determine the pattern size, it is rather common practice to compute the value of field strength that the reference tower will radiate when operating in the directional-antenna array. This value can then be used in Eq. B-1 to determine the pattern shape at the correct size. The value of E_1 can be computed from the following equation, sometimes called the loop impedance formula, thus

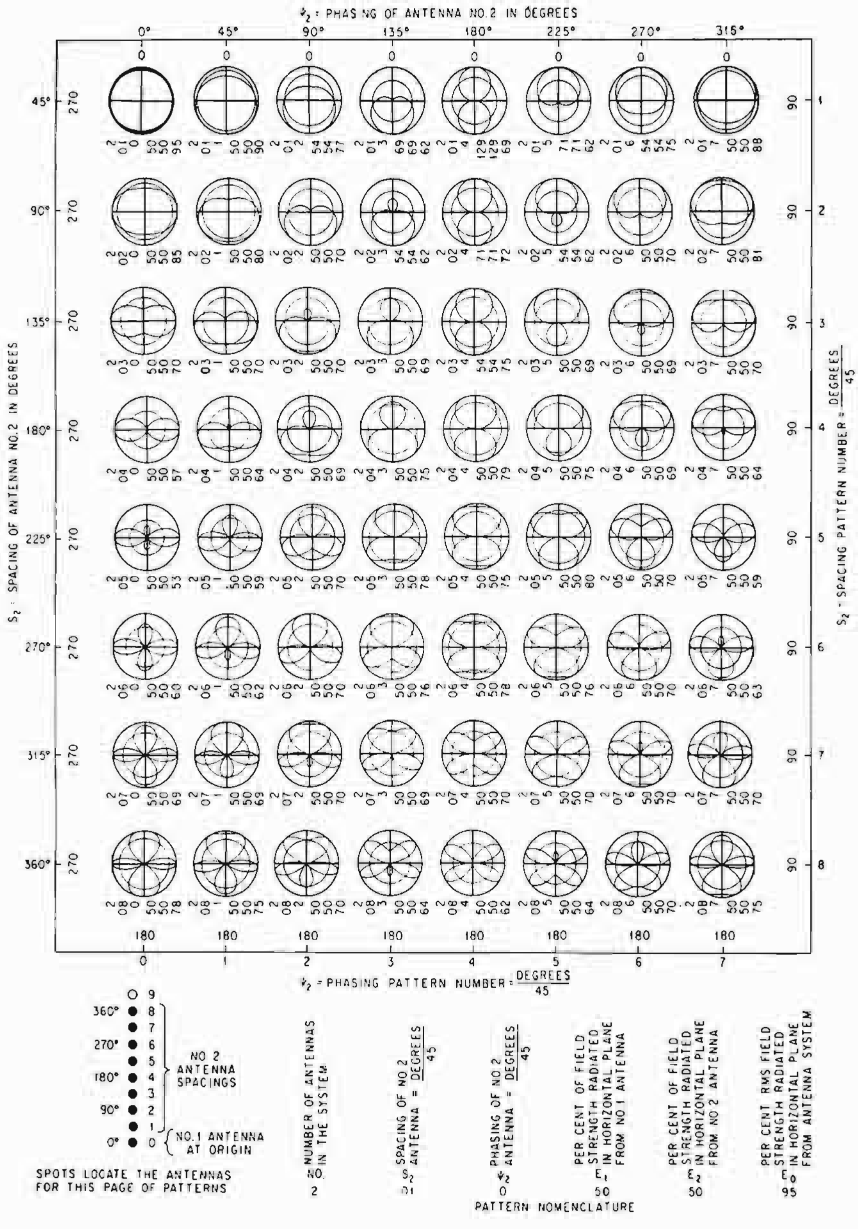


Fig. BC. Systematization of two-tower patterns in steps of 45 to 1,440°.

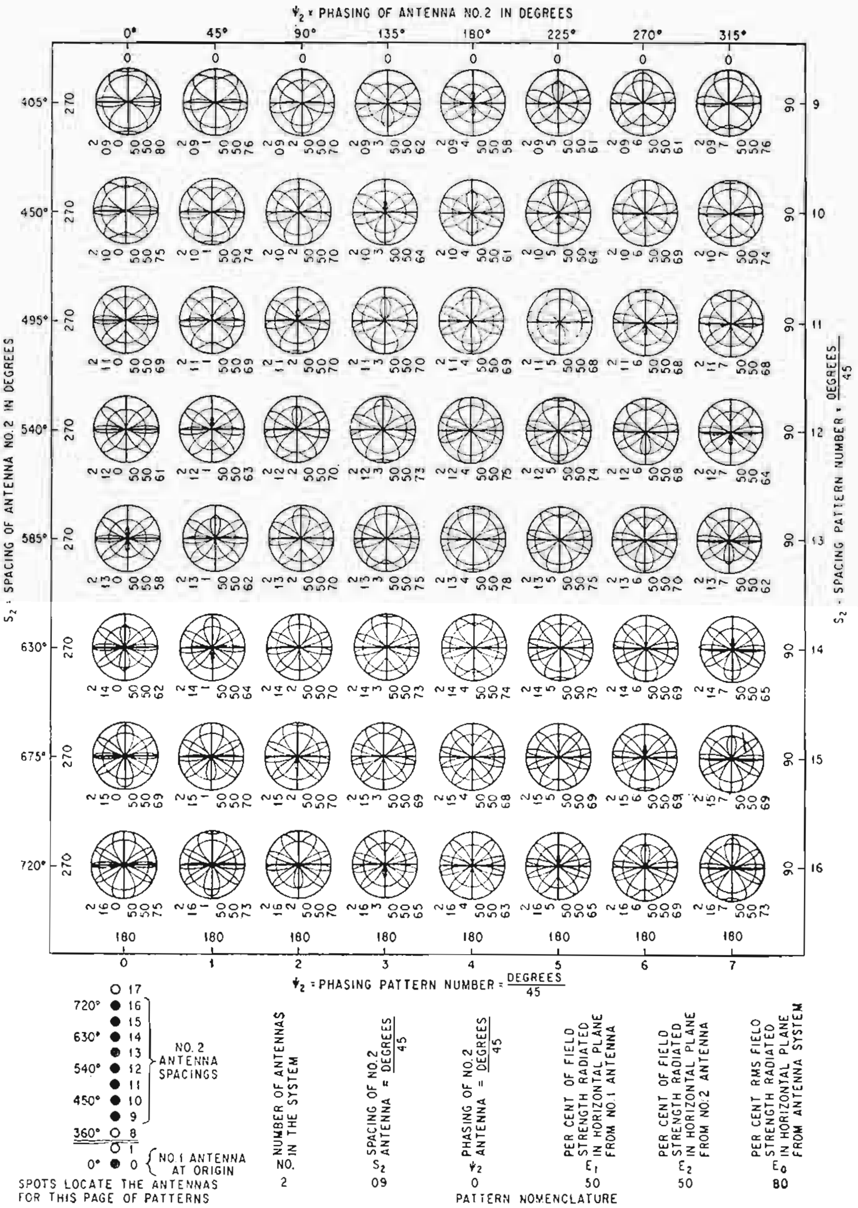


Fig. BD. Systematization of two-tower patterns in steps of 45 to 1,440°.

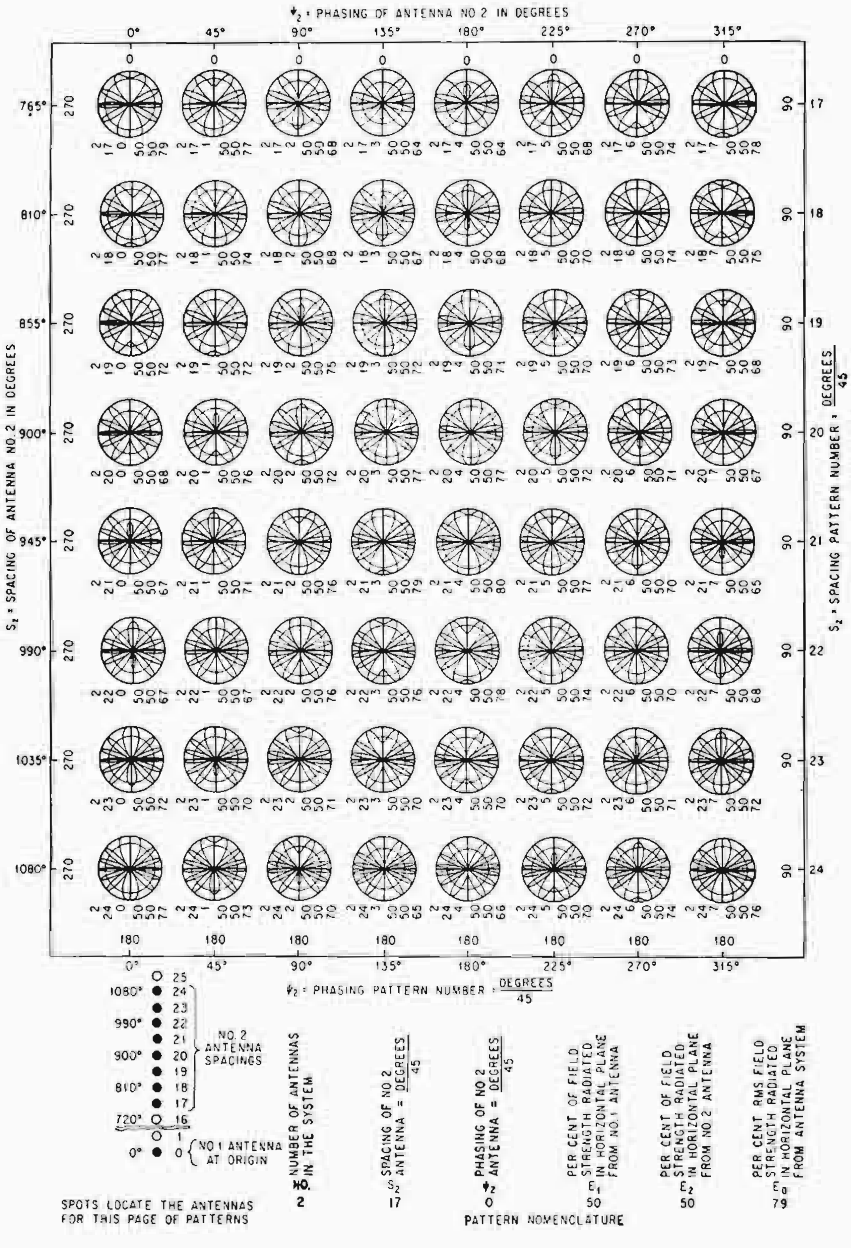


Fig. BE. Systematization of two-tower patterns in steps of 45 to 1,440°.

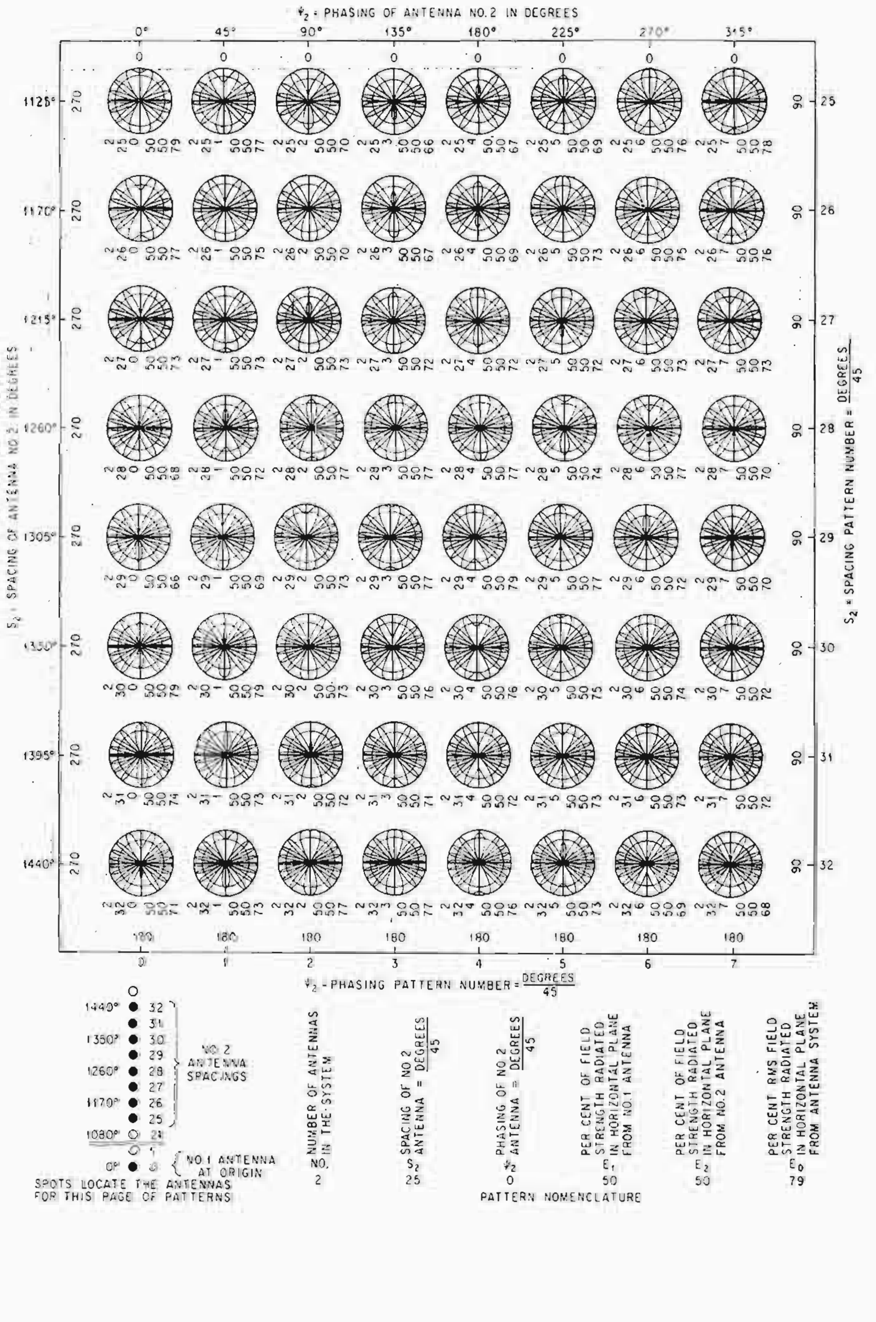


Fig. BF. Systematization of two-tower patterns in steps of 45 to 1,440°.

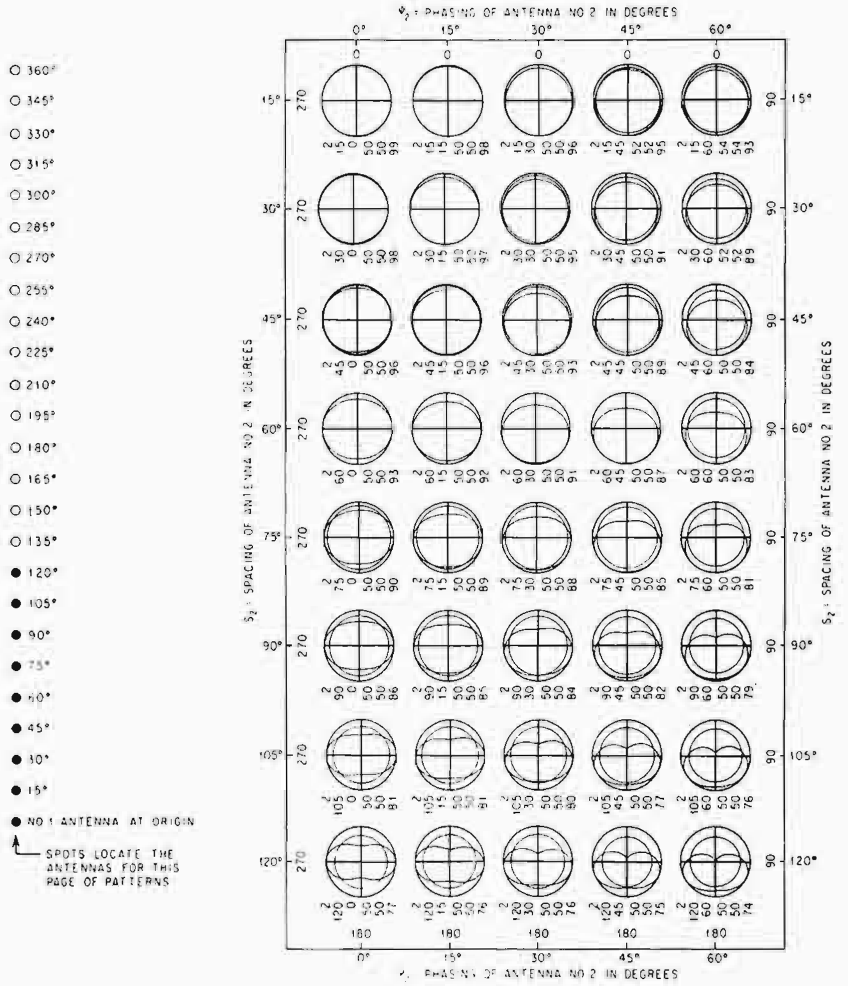


Fig. BG. Systematization of two-tower patterns in steps of 15 to 360°.

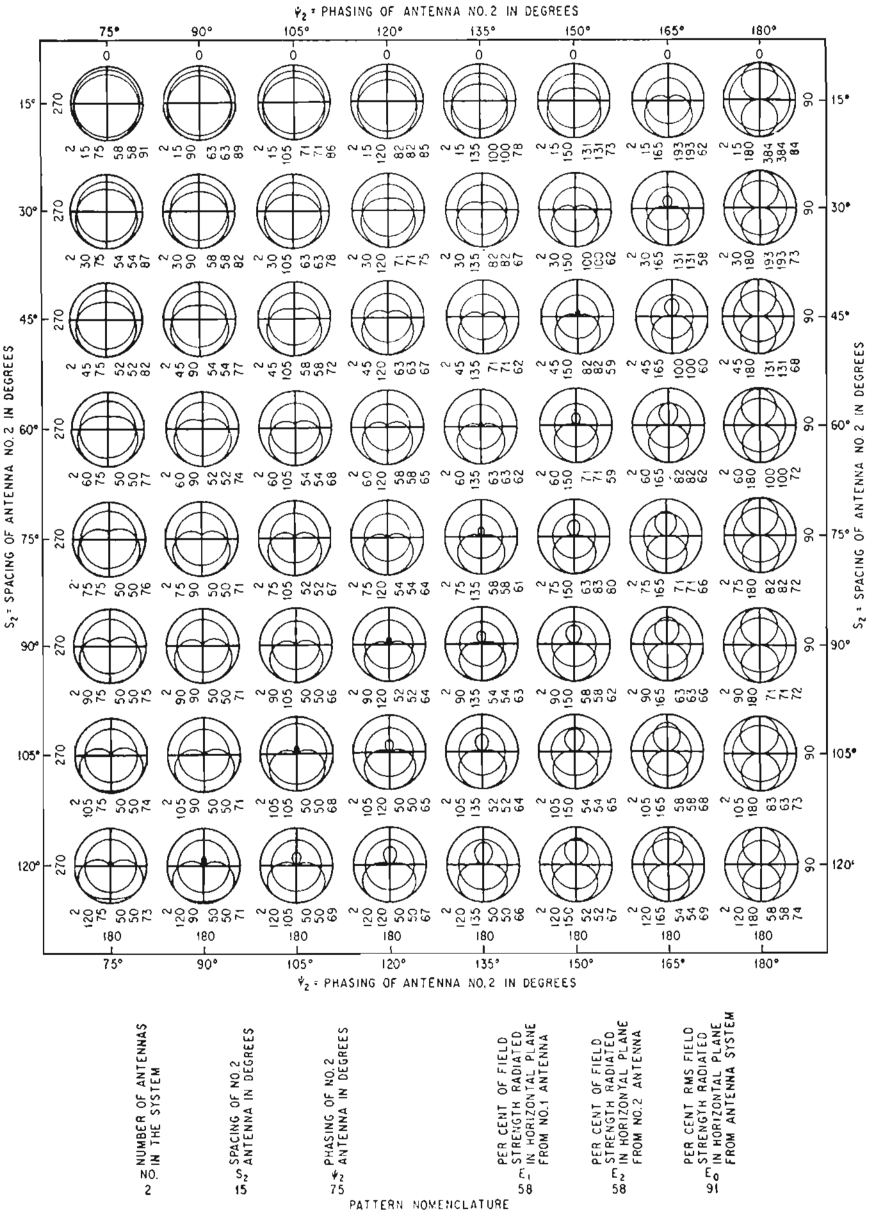


Fig. BH. Systematization of two-tower patterns in steps of 15 to 360°.

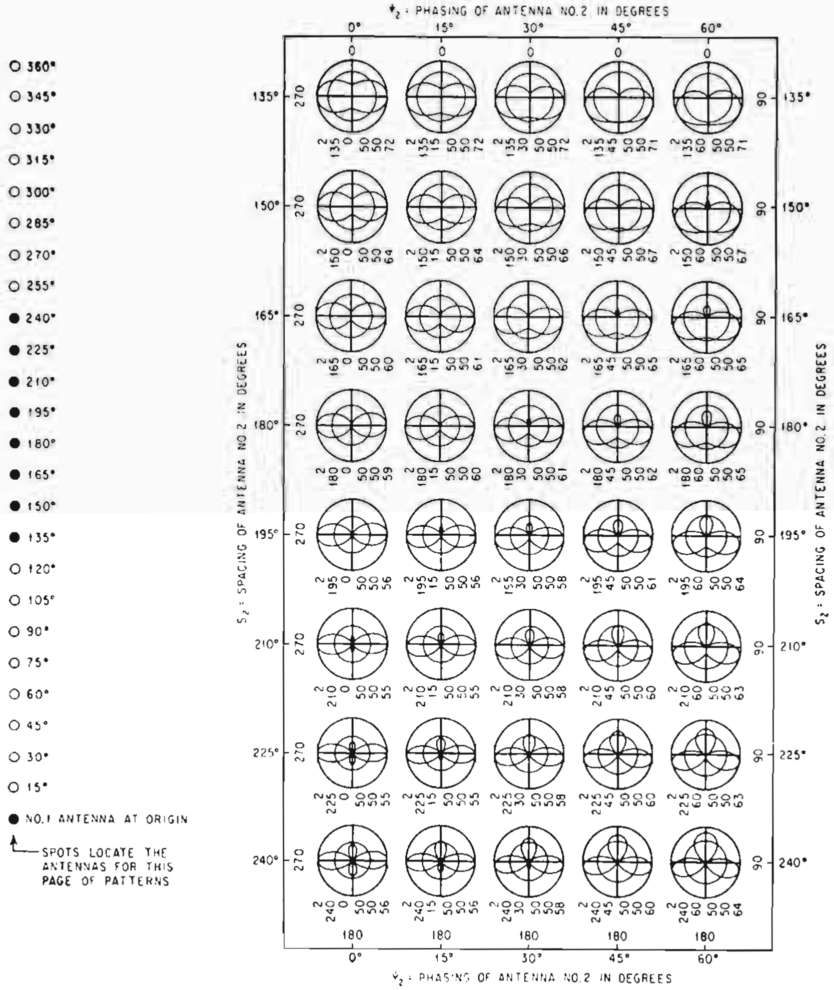


Fig. BI. Systematization of two-tower patterns in steps of 15 to 360°.

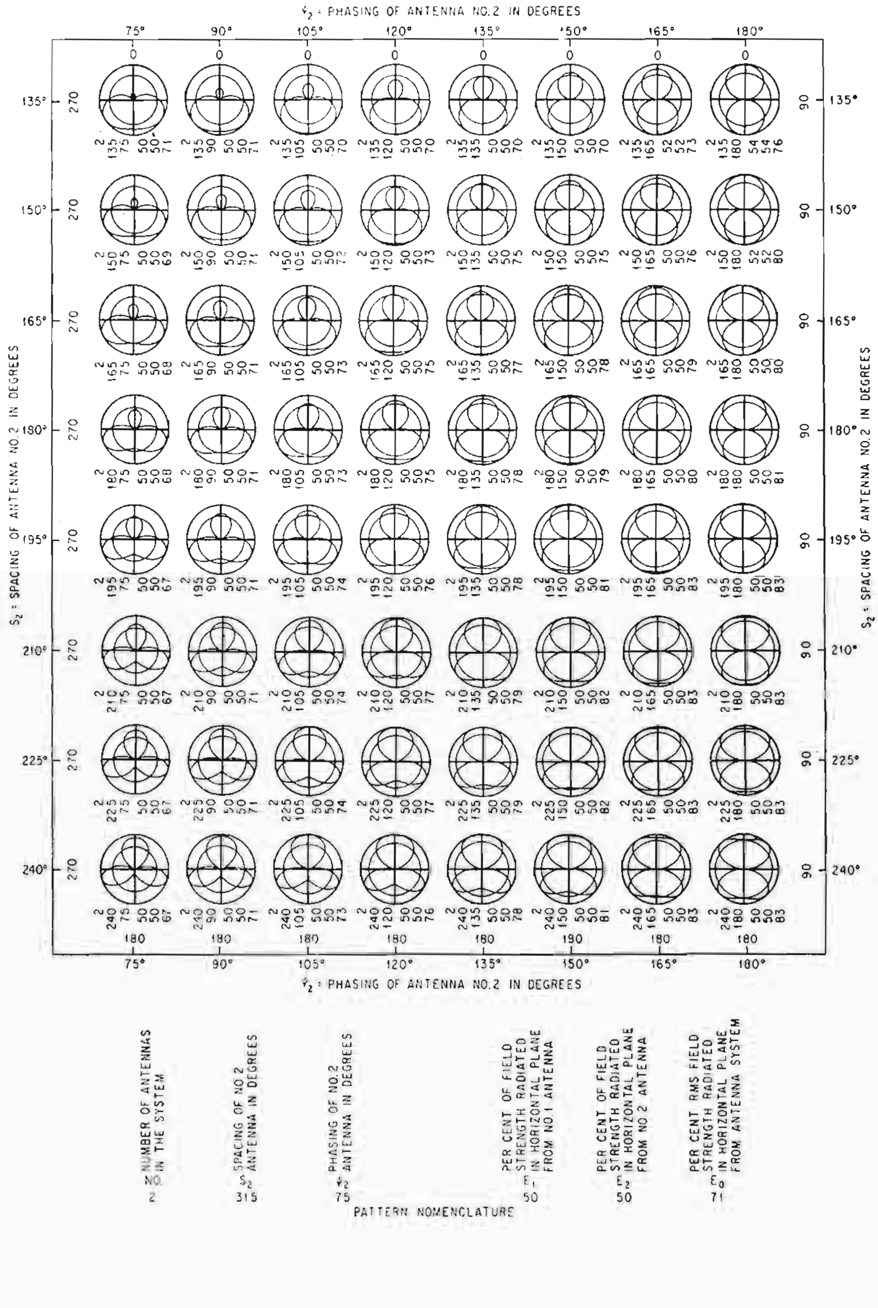


Fig. BJ. Systematization of two-tower patterns in steps of 15 to 360°.

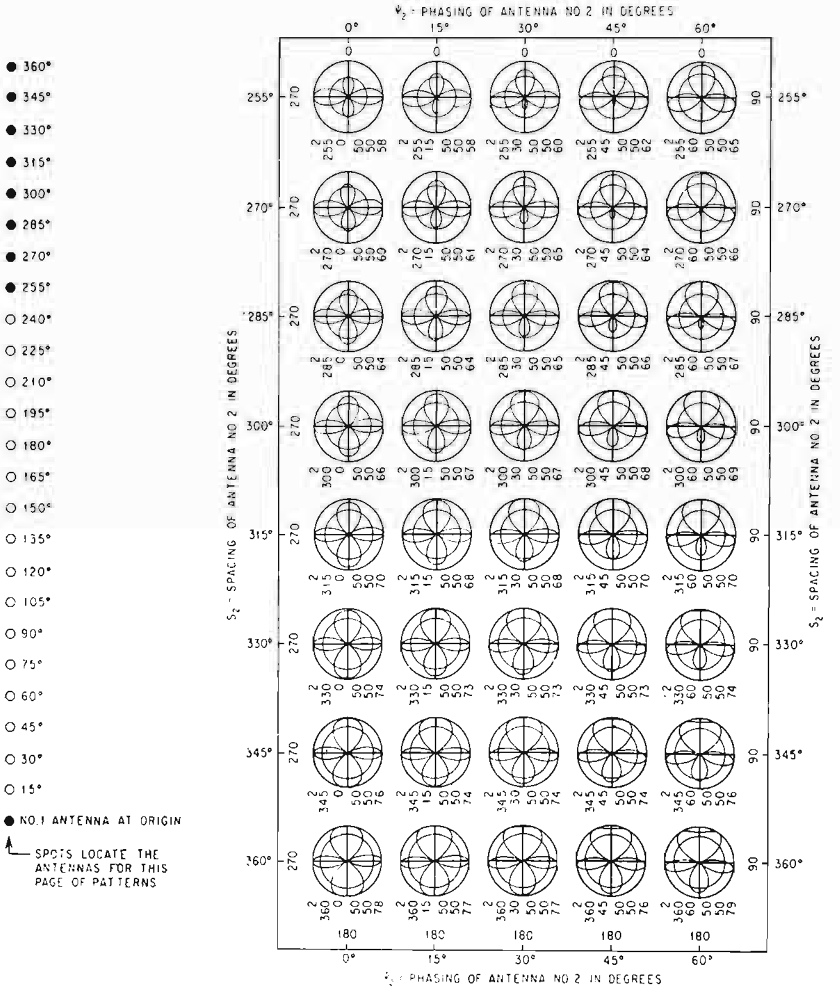


Fig. BK. Systematization of two-tower patterns in steps of 15 to 360°.

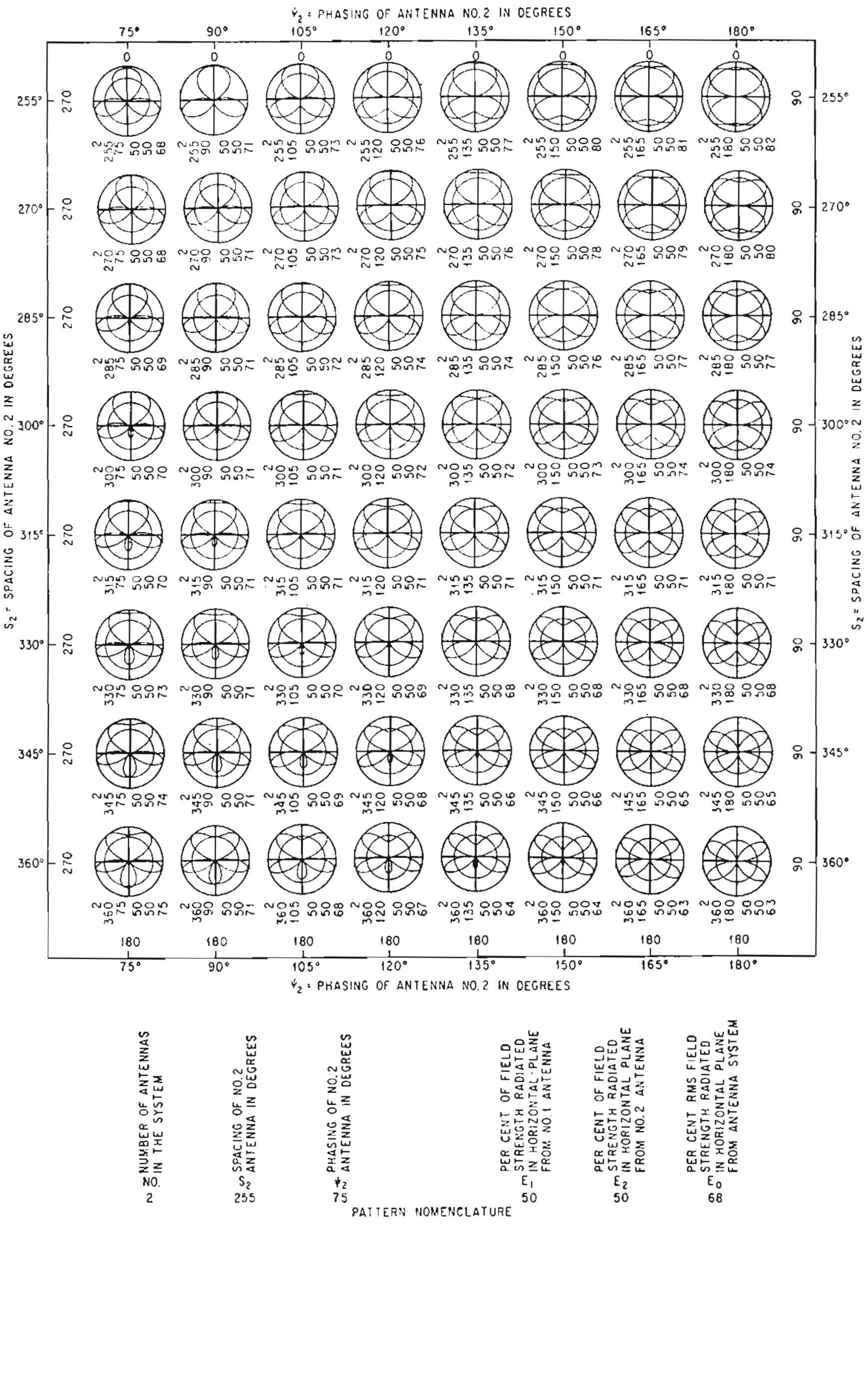


Fig. BL. Systematization of two-tower patterns in steps of 15 to 360°.

$$E_1 = E_{1s}\sqrt{\frac{R_{11}}{R_1 + M^2 R_2}}$$

$$= E_{1s}\sqrt{\frac{R_{11}}{(R_{11} + R_{L1} + R_{C1}) + M^2 (R_{22} + R_{L2} + R_{C2})}} \qquad \text{[B-5]}$$

where E_1 = inverse field strength at 1 mile for tower 1 while operating in the array, mv/m
E_{1s} = inverse field strength at 1 mile for tower 1 operating alone as a standard reference antenna, mv/m
R_{11} = loop self-resistance of tower 1, ohms
R_{L1} = loss resistance assumed at loop of tower 1, ohms
R_{C1} = coupled resistance at loop of tower 1 from other towers while array is in operation, ohms
R_{22} = loop self-resistance of tower 2, ohms
R_{L2} = loss resistance assumed at loop of tower 2, ohms
R_{C2} = coupled resistance at loop of tower 2 from other towers while array is in operation, ohms
M = ratio of current at loop of tower 2 divided by current at loop of tower 1

The values of E_{1s}, R_{11}, and R_{22} can be obtained from Fig. A-5 for simple towers that are not sectionalized or top-loaded. For other types of towers these values must be assumed or calculated. The values of R_{L1} and R_{L2} are usually assumed to be 2 ohms each.

Coupled-Resistance Formula

The values of coupled resistance from the other towers are given by

$$R_{C1} = MZ \cos(\Psi + \gamma) \qquad \text{[B-6]}$$

$$R_{C2} = \frac{Z}{M}\cos(-\Psi + \gamma) \qquad \text{[B-7]}$$

where Z = magnitude of loop impedance between the two towers, ohms
M = magnitude of current ratio of loop current in tower 2 divided by tower 1
γ = angle of loop mutual impedance, deg
Ψ = electrical phase angle of current in tower 2 with respect to tower 1, deg

These equations can be used with reasonable accuracy for simple nonloaded towers.

The above equations are written without the use of magnitude signs and subscripts for the sake of simplicity. The exact vector expressions are

$$Z_{21} = |Z_{21}| \underline{|\gamma_{21}} \qquad \text{[B-8]}$$

and

$$M_{21} = \frac{I_2}{I_1} = |M_{21}| \underline{|\Psi_{21}} \qquad \text{[B-9]}$$

where the currents are vector values having magnitude and phase angle. The current values in this equation are determined when the directional antenna is designed.

Mutual-Impedance Curves

The value of mutual impedance for most tower heights and spacing is given in Fig. BM. The loop mutual impedance between quarter-wave towers is shown in Fig. B-BN. These values can be used in the above equations for coupled resistance. For towers of unequal height the mutual impedance can be computed or reference can be made to curves already computed.[4]

Top-Loaded and Sectionalized Towers

The preceding equations can be applied to top-loaded and sectionalized towers but with considerable complication. The field strength E_{1s} and the self-resistance R_{11} are in general not available. They can be found in the literature for a few special cases.[3] The mutual impedance between sectionalized towers likewise is not readily available. It must be calculated for any special case if it is to be determined accurately. It is easier to determine the mutual effects by graphical solutions to the necessary accuracy.

Horizontal-Plane RMS Field Strength

The rms field strength for a two-tower array can be determined from

$$E_0 = E_1\sqrt{1 + F^2 + 2F\cos\Psi J_0(S)} \qquad \text{[B-10]}$$

where E_0 = rms in verse field strength at 1 mile, mv/m
E_1 = inverse field strength at 1 mile for reference tower 1 while operating in array, mv/m
F = ratio of magnitude of field strength from tower 2 divided by tower 1
Ψ = electrical phase of field from tower 2 with respect to tower 1, deg
$J_0(S)$ = Bessel function of first order for tower spacing S

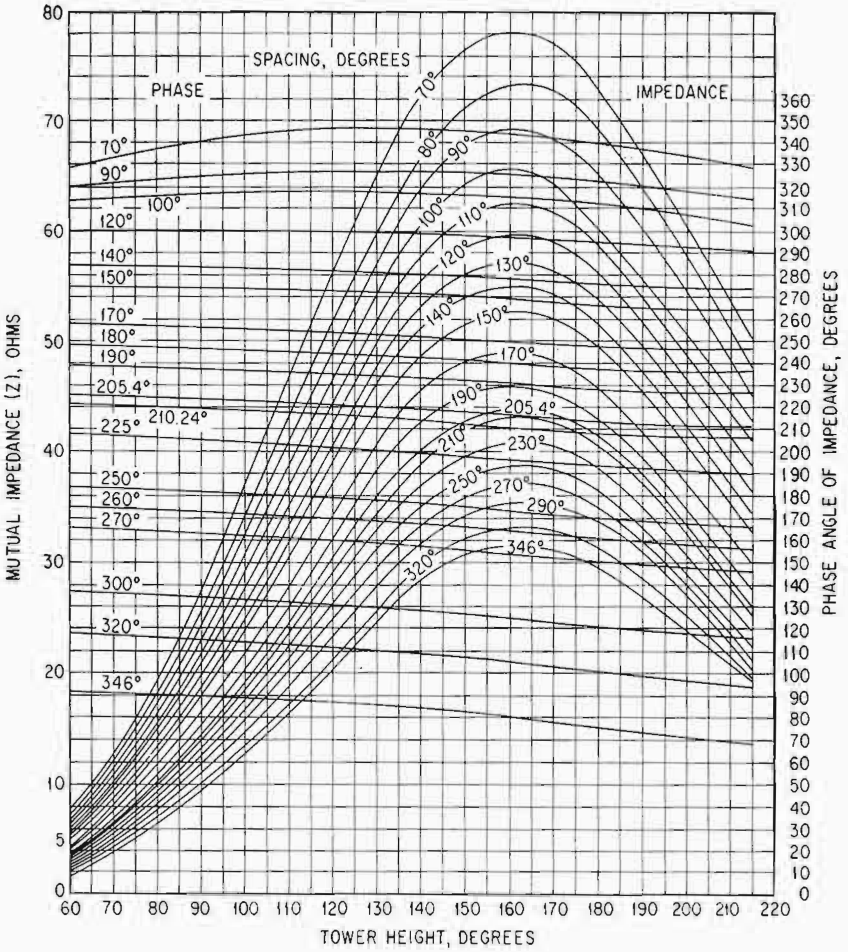


Fig. BM. Loop mutual impedance and phase angle between two towers of equal height.

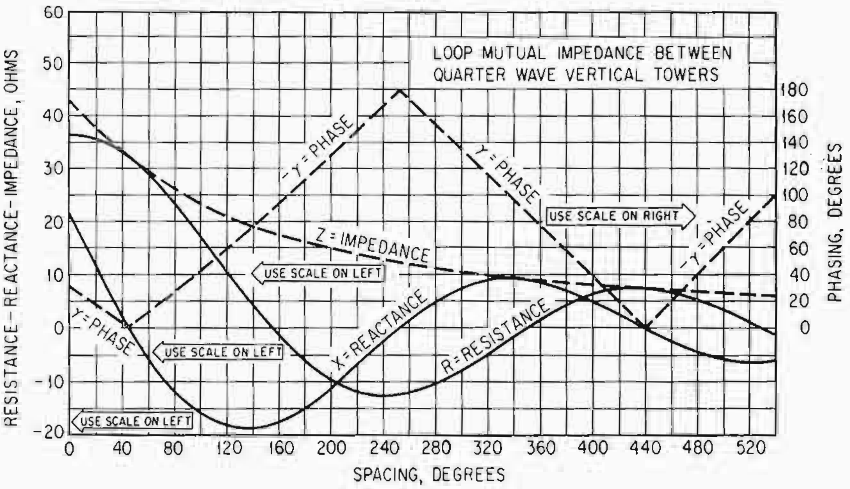


Fig. BN. Loop mutual impedance between quarter-wave vertical towers.

Usually the teams F and M are identical. However, with unequal-height towers and top-loading or sectionalized towers these ratios may have different values. Table B can be used to obtain the desired Bessel-function values. Interpolation can be used if necessary.

Horizontal RMS Field-Strength and Power Gain

The field-strength gain of any directional-antenna array can be written

$$\sqrt{g_0} = \frac{E_0}{E_{1s}} \qquad \text{[B-11]}$$

where $\sqrt{g_0}$ = field-strength gain by definition in the horizontal plane
E_0 = rms inverse field strength at 1 mile, mv/m
E_{1s} = inverse field strength at 1 mile for tower 1 operating alone as a standard reference antenna, mv/m

The power gain for a two-tower array is given by

$$g_0 = \frac{1 + F^2 + 2F\cos \Psi J_0(S)}{1 + F^2 + 2F\cos \Psi (R_{12}/R_{11})} \qquad \text{[B-12]}$$

where g_0 = directivity or power gain
F = ratio of magnitude of field strength from tower 2 divided by tower 1
Ψ = electrical phase of field from tower 2 with respect to tower 1, deg
$J_0(S)$ = Bessel function of first kind and zero order for tower spacing S
R_{12} = mutual loop resistance between towers, ohms
R_{11} = loop-radiation self-resistance of tower 1, ohms

It is of interest to know whether a particular antenna system is a gainer or a loser as compared with a standard reference antenna. This can be determined by the following:

$$E_0 = E_{1s}\sqrt{g_0} \qquad \text{[B-13]}$$

Now, if 90° towers are used and the field ratio $F = 1$, Eq. B-12 substituted in Eq. B-13 gives

$$E_0 = 195\sqrt{\frac{1 + \cos \Psi J_0(S)}{1 + \cos \Psi (R_{12}/36.6)}} \qquad \text{[B-14]}$$

The solution of this equation is shown in Fig. B-15 for various values of tower current phasing and tower spacing. It gives the theoretical field without loss for 1-kw operation.

Power to Provide System Losses

Because of losses in the transmission lines and matching, phasing, and power-division networks, plus other losses in the system such as resistance losses in the tower and ground system and dielectric losses in the insulators, an overfeeding of power is allowed by FCC at the common point.

The calculation of the amount of overfeeding of power at the common point is made as follows:

For stations with directional antennas authorized to radiate 5 kw of power or less, the measured

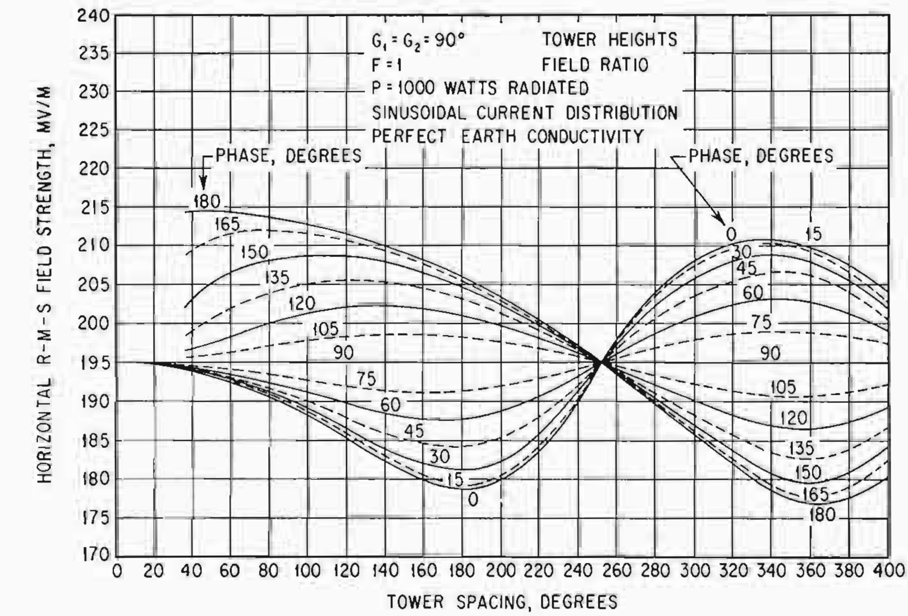


Fig. BO. Horizontal rms field strength of two-tower directional antenna.

common-point resistance is assumed to be 92.5 percent of its measured value, and for all other directional antennas, it is assumed to be 95 percent. This arbitrary reduction in resistance amounts to increasing the current at the common point by $1/\sqrt{0.925} = 1.0389$, or approximately a 4 percent increase for values of transmitter power up to and including 5 kw. For transmitters with power above 5 kw the antenna current can be increased $1/\sqrt{0.95} = 1.0252$, or approximately a 2.5 percent increase.

Another way of saying this is that for a 1-kw station 1,081 watts can be fed in at the common point, while for a 50-kw station 52,105 watts can be fed in at the common point. For the 1-kw station there is 81 watts available for feeder-system loss, and in the 50-kw station there is 2,105 watts available for feeder-system loss.

Feeder System

Loop and Base, Impedance and Current

The first approximation of the base resistance of an ordinary base-insulated tower that is not top-loaded or sectionalized is given by

$$R_b = \frac{R_a}{\sin^2 G} \qquad \text{[B-15]}$$

where R_b = base resistance of tower, ohms
R_a = loop resistance of tower, ohms
G = electrical height of tower, deg

The first approximation of the base current for the above tower is

$$I_b = I_a \sin G \qquad \text{[B-16]}$$

where I_b = base current of tower, amp
I_a = loop current of tower, amp

These equations are consistent with the theory that the power at the loop is equal to the power at the base; that is,

$$I_b^2 R_b = I_a^2 R_a \qquad \text{[B-17]}$$

These equations are most accurate for single towers operating alone where the cross section is small and uniform so the current distribution will be approximately sinusoidal.

A second approximation of the base impedance depends upon the tower acting like a transmission line from the loop to the base and is given by

$$Z_b = Z_0 \frac{Z_a \cos(G - 90) + jZ_0 \sin(G - 90)}{Z_0 \cos(G - 90) + jZ_a \sin(G - 90)} \qquad \text{[B-18]}$$

where Z_b = base impedance of tower, ohms
Z_a = loop impedance of tower, ohms
Z_0 = average characteristic impedance of tower, ohms
G = electrical height of tower, deg

A second approximation for the base current also depends upon the tower acting like a transmission line and is written

$$I_b = |I_a| \left[\sin G + j\frac{R_a}{2Z_0}(1 - \cos G)\right] \qquad \text{[B-19]}$$

where I_b = complex value of tower base current, amp
$|I_a|$ = magnitude of tower loop current, amp
R_a = loop resistance of tower, ohms

Z_0 and G are defined following Eq. B-18. The first term in this equation is a sinusoidal term corresponding to Eq. B-16, which corresponds to the antenna current that causes the radiation. The second term is the feed current which supplies the radiated power from the base to the loop. It should be noted that this equation does not give the phase of the base current with respect to the loop current. This change in phase between the loop and base current is expressed by the more general equation

$$I_y = |I_a| \left[\sin(G - y) + j\frac{R_a}{2Z_0}(\cos y - \cos G)\right] \qquad \text{[B-20]}$$

where I_y is the current at any height y on the tower in amperes. The other terms are defined in Eq. B-19. Equation B-20 reduces to Eq. B-19 when $y = 0$. It gives the phase as well as the magnitude of the current at any point on the tower; hence at the current loop,

$$I_a = |I_a| \left[1 + j\frac{R_a}{2Z_0}(\cos y - \cos G)\right] \qquad \text{[B-21]}$$

The difference in the phase of the current I_a in Eq. B-21 and the current I_b in Eq. B-19 is the additional phase shift that must be provided for in the feeder system.

Conservation of power between the loop and base may not exist in Eqs. B-18 and B-19 as it does in Eqs. B-15 and B-16. However, Eqs. B-18 and B-19 usually give a better answer for the base impedance values when the towers are operating in a directional-antenna system.

These equations can be used in the feeder-system design. However, it is advisable to provide adequate range so proper adjustments can be made when the system is put into operation.

Networks for Matching Impedances

General. A directional-antenna system usually requires impedance-matching networks at several points such as from the transmission lines to the towers and perhaps from the transmitter to the common point of the antenna feeder system. These networks are usually made up of lumped constants in the form of L, T, or π sections.

If an impedance load is not a pure resistance, it can be made to look like a pure resistance by adding a reactance element in series or parallel that will make the load either series- or parallel-resonant. If this is done, the treatment of the impedance-matching networks can be simplified. Therefore in this section networks to match between pure resistance values of R_1 and R_2 will be treated.

L Sections. An L section is the simplest way to match between two resistors R_1 and R_2. It is made up of an inductor for Z_2 and a capacitor for Z_3 with a small, fixed phase lag depending upon the ratio $r = R_1/R_2$. Or it can be constructed with a capacitor for Z_2 and an inductor for Z_3 with a small phase advance as shown in Figs. P and Q.

The phase shift in an L section is fixed by the ratio $r = R_1/R_2$. This is because there are only two reactance elements. The size of the shunt element across R_1 controls the size of R_2, while the series element is used to resonate the circuit so only resistance appears at the R_2 terminals.

The design equations for an L section matching between resistors R_1 and R_2 are

$$Z_2 = \pm jR_2\sqrt{r-1} = \pm j\frac{R_1}{a} \qquad \text{[B-22]}$$

$$Z_3 = \mp j\frac{R_1}{\sqrt{r-1}} = \mp j\frac{R_1}{b} \qquad \text{[B-23]}$$

$$\cos\beta = \frac{1}{\sqrt{r}} \qquad \text{[B-24]}$$

where Z_1 = reactance of series arm, ohms
Z_2 = reactance of shunt arm, ohms
R_1 = larger terminating resistance, ohms
R_2 = smaller terminating resistance, ohms
r = R_1/R_2 ratio
β = phase shift, deg

The $\pm j$ in Eq. B-22 and $\mp j$ in Eq. B-23 means simply that if $+j$ or an inductor is used for Z_1, then $-j$ or a capacitor must be used for Z_3.

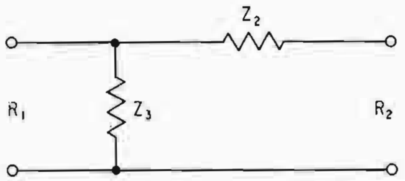


Fig. BP. General L-section impedance-matching network.

T and π Sections. T and π sections made up of reactance arms are widely used in the directional-antenna feeder systems. With the three reactance elements it is possible to control the amount of phase shift in addition to the input and output resistance values.

The efficiency of such a network is implicitly determined by the ratio $r = R_1/R_2$ and the phase shift β. There is no choice between T and π sections, whether advancing or retarding the phase, as far as efficiency is concerned. The loss increases with the ratio r and tends to increase for very small or very large phase shifts. For very high transformation ratios r of, say, 10 or more, it is advisable to use two or more sections in tandem. This will increase the stability and reduce the loss.

The design equations for a T or π section are:

$$a = \frac{r\sin\beta}{\sqrt{r} - \cos\beta} \qquad \text{[B-25]}$$

$$b = \sqrt{r}\sin\beta \qquad \text{[B-26]}$$

$$c = \frac{\sqrt{r}\sin\beta}{1 - \sqrt{r}\cos\beta} \qquad \text{[B-27]}$$

where a = design factor as shown in Figs. R and S
b = design factor as shown in Figs. R and S
c = design factor as shown in Figs. R and S
r = R_1/R_2 ratio, greater than 1
β = phase shift, deg

The graphs of a, b, and c are shown in Figs. T through X where r is assumed to be equal or greater than unity. The terminals at R_1 can be placed at either the load or generator end of the section; hence the above equations can be applied to any case.

It is interesting to note that these design curves also apply for the L section where $a = r/\sqrt{r-1}$, $b = \sqrt{r-1}$, and $c = \infty$.

Transmission Lines

General. Most directional antennas require one or more RF transmission lines. They are usually operated nonresonant, which means that the load is made equal to the characteristic impedance of the transmission line. In this case the wave travels from the transmitter end to the load end and is completely absorbed by the load; therefore, there are no standing waves on the line. For this condition of operation the power loss and standing waves on the line are a minimum.

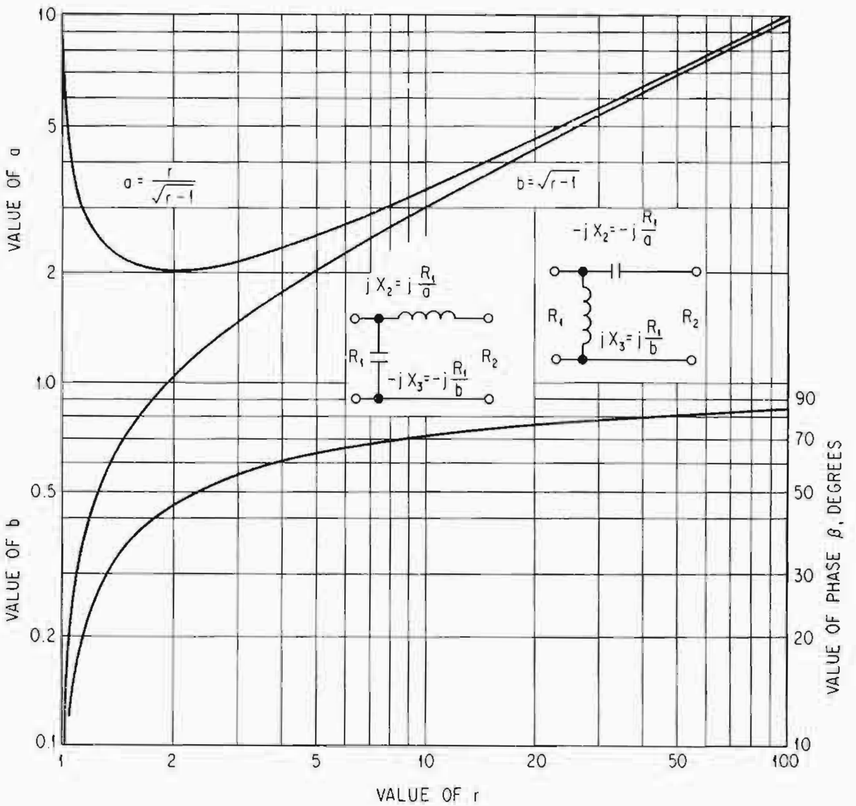


Fig. BQ. L-section design chart.

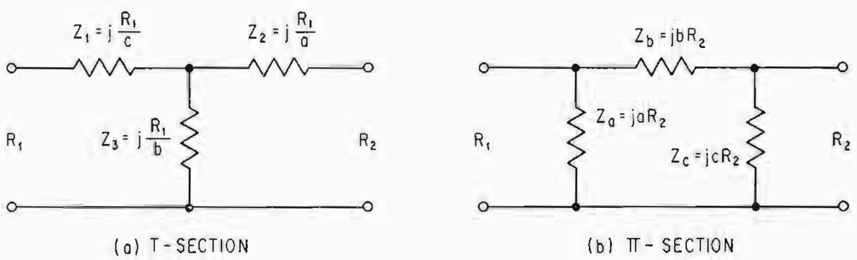


Fig. BR. General T- and π section impedance-matching network.

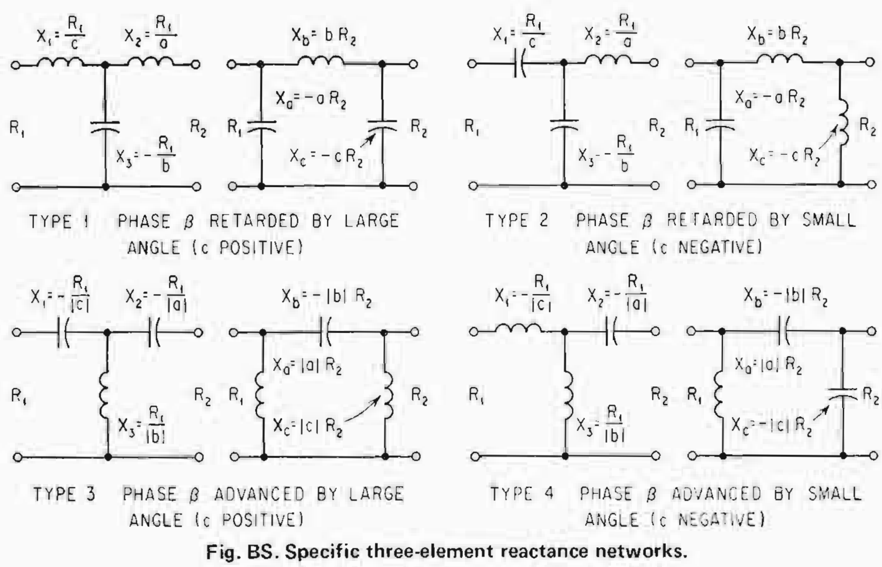


Fig. BS. Specific three-element reactance networks.

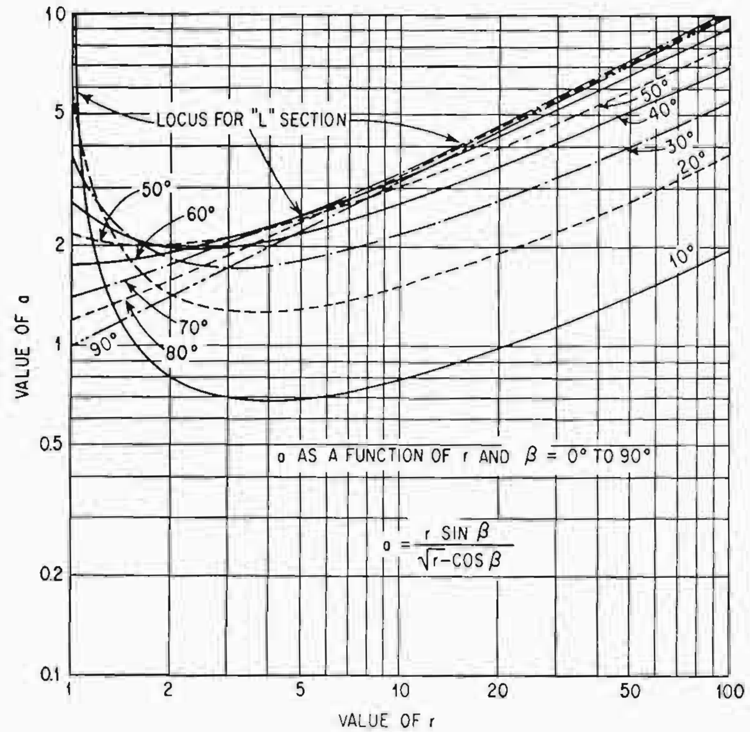


Fig. BT. Design chart for a as function of r and $\beta = 0$ to 90°.

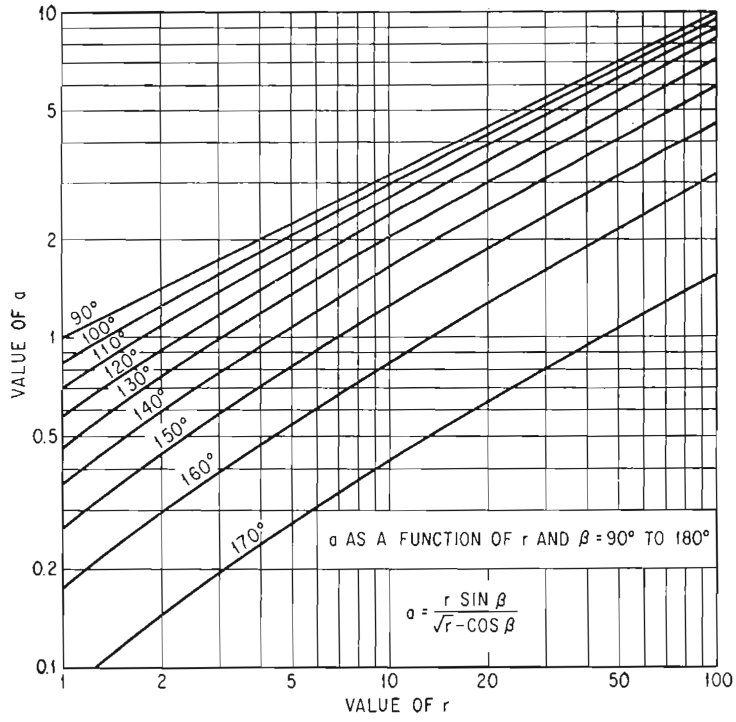


Fig. BU. Design chart for a as function of r and $\beta = 90$ to 180°.

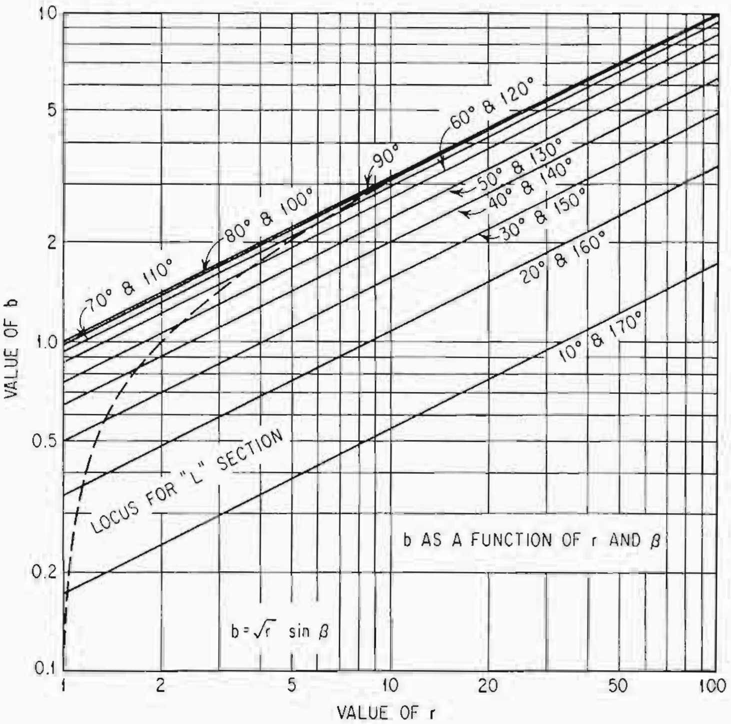


Fig. BV. Design chart for b as a function of r and β.

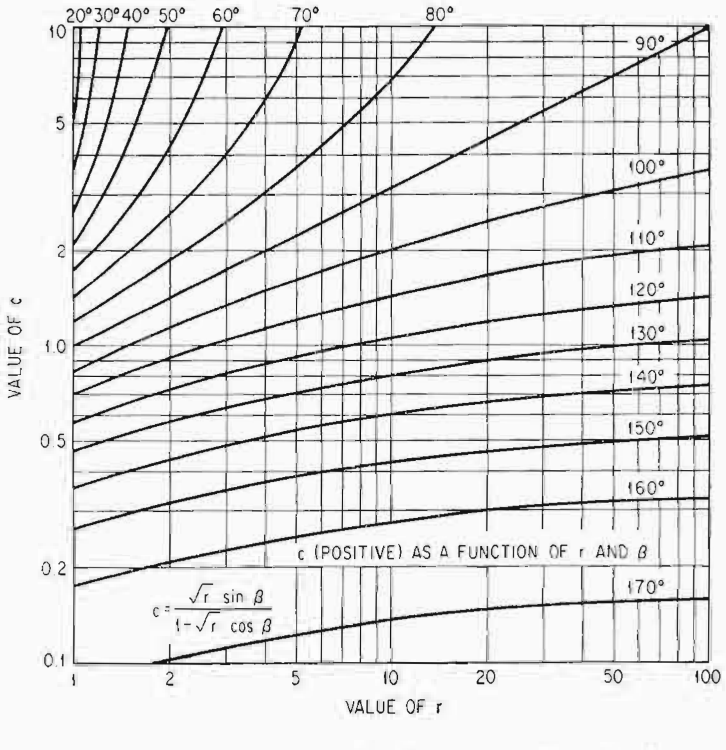


Fig. BW. Design chart for c (positive) as a function of r and β.

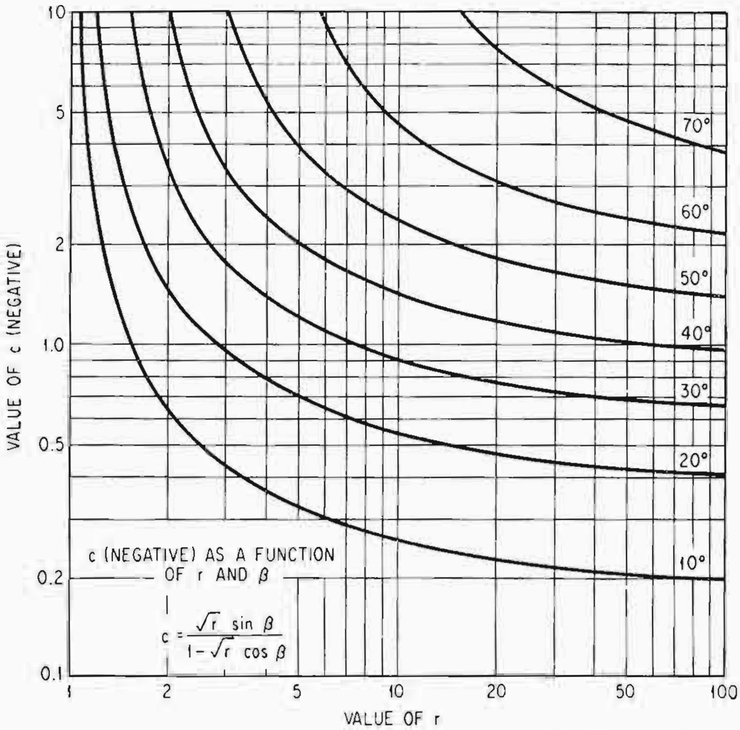


Fig. BX. Design chart for c (negative) as function of r and β.

The general equations for the voltage and current at the sending and receiving end of a transmission line are

$$E_s = E_r \cosh \sqrt{ZY}\,l + I_r Z_0 \sinh \sqrt{ZY}\,l \qquad \text{[B-28]}$$

$$I_s = I_r \cosh \sqrt{ZY}\,l + \frac{E_r}{Z_0} \sinh \sqrt{ZY}\,l \qquad \text{[B-29]}$$

where E_s = sending end voltage, volts
E_r = receiving end voltage, volts
$Z = R + j\omega L$ = series impedance per unit length, ohms
$\gamma = G + j\omega C$ = shunt admittance per unit length, ohms
l = length of line in same units as Z and γ
$Z_0 = \sqrt{Z/Y}$ = characteristic impedance, ohms
$\gamma = \sqrt{ZY}$ = propagation constant, or hyperbolic angle per unit length, radians

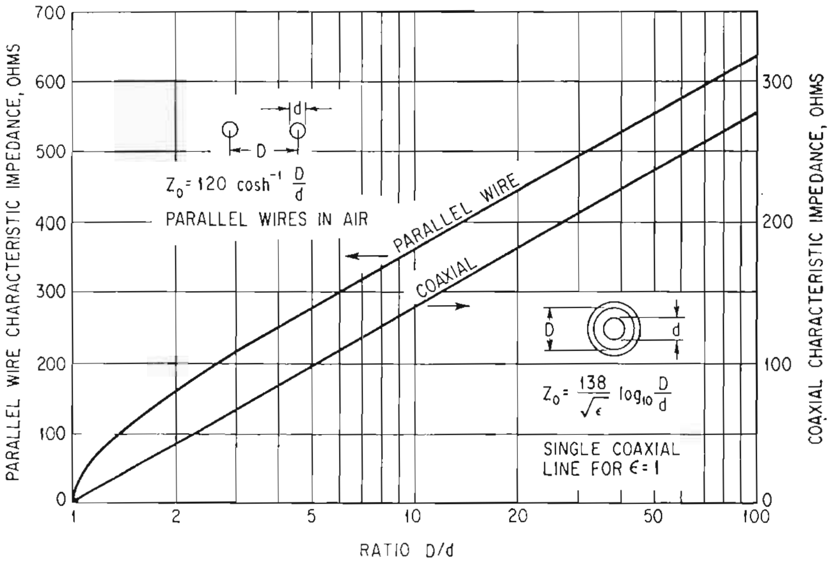


Fig. BY. Characteristic impedance of coaxial and two-wire transmission lines.

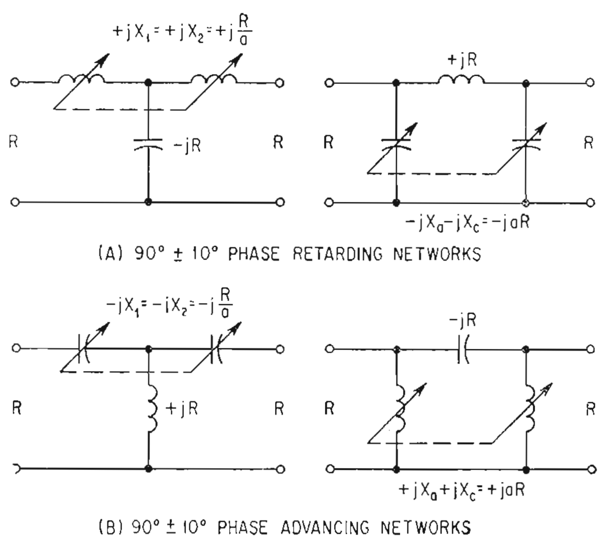


Fig. BZ. Phase-shifting networks.

Characteristic impedance. The characteristic impedance at radio frequency can be taken as a pure resistance,

$$Z_0 = \sqrt{\frac{L}{C}} \qquad \text{[B-30]}$$

where L = inductance per unit length, henrys
C = capacitance per unit length, farads

For a single coaxial transmission line this equation can be written

$$Z_0 = \frac{138}{\sqrt{\epsilon}} \log_{10} \frac{D}{d} \qquad \text{[B-31]}$$

where ϵ = dielectric constant
D = inside diameter of outer conductor
d = outside diameter of inner conductor in the same units as D

For a parallel two-wire transmission line the characteristic impedance is

$$Z_0 = 120 \cosh^{-1} \frac{D}{d} \qquad \text{[B-32]}$$

where D = spacing between conductor centers
d = diameter of conductors in same units as D

The characteristic impedance of coaxial and two-wire transmission lines is shown in Fig. Y.

Propagation constant. The other factor of interest is the propagation constant given by

$$\sqrt{ZY} = \gamma = \alpha + j\beta \qquad \text{[B-33]}$$

where γ = propagation constant, radians per unit length
α = attenuation constant, nepers per unit length
β = phase constant, radians per unit length

Usually the attenuation in the line can be neglected in the design of directional antennas, particularly if the line is designed for low loss and is operated nonresonant.

The phase shift in an air-dielectric line will be only a few percent less than would occur in free space. For a coaxial line with ceramic beads the velocity factor is 0.85, while with solid polyethylene insulation the velocity factor is approximately 0.66. For two-wire lines insulated with ceramic spacers at intervals of a few feet the velocity factor is about 0.975. These factors must be taken into consideration when determining the phase shift in transmission lines of a directional-antenna system.

Phase-Shifting Networks

In addition to the necessary phase shift in the networks and transmission lines of a feeder system, it is usually desirable to have a phase-shift network the control on which shifts the phase with little or no impedance transformation. This is readily accomplished in a 90° T or π section that has unity impedance transformation, $r = 1$, between input and output terminals.

In such a 90° T or π section the reactance arms all have the same magnitude and are equal to $R = R_1 = R_2$. The shunt arm in the T section or the series arm in the π section is held constant while the other two arms are varied in unison to shift the phase (see Figs. BZ and BA).

The value of the reactance in the series arms of a T section is

$$Z_1 = Z_2 = \pm jR\,\frac{1-\cos\beta}{\sin\beta} = \pm j\,\frac{R}{a} \qquad \text{[B-34]}$$

where $Z_1 = Z_2$ = series-arm reactance, ohms
$R = R_1 = R_2$ = terminating resistances, ohms
β = phase shift, deg

and the shunt arm of the T section is

$$Z_3 = \mp jR\,\frac{1}{\sin\beta} = \mp j\,\frac{R}{b} \qquad \text{[B-35]}$$

where Z_3 is the shunt-arm reactance in ohms and the other values are given above.

The value of the resistance in the shunt arms of a π section is

$$Z_a = Z_c = \pm jR\,\frac{\sin\beta}{1-\cos\beta} = \pm jaR \qquad \text{[B-36]}$$

where $Z_a = Z_c$ = shunt-arm resistance, ohms
$R = R_1 = R_2$ = terminating resistances, ohms
β = phase shift, deg

and the series arm of the π section is

$$Z_b = \mp jR\sin\beta = \mp jbR \qquad \text{[B-37]}$$

where Z_b is the series-arm reactance in ohms and the other values are defined above.

The phase shift for the approximation that $b = 1$ gives good answers for $\pm 10°$ and can be written

$$\beta = \cos^{-1}\left(1 - \frac{R}{X_1}\right) = \cos^{-1}\left(1 - \frac{R}{X_a}\right) \qquad \text{[B-38]}$$

where X_1 and X_a are the reactance values as shown in Fig. Ba and the other values are defined above for the T- and π-section phase-shifting network.

Power-Dividing Networks

The driving-point impedance at the base of each tower in a directional-antenna system must be fed the correct amount of power to make the array operate properly. The usual practice is to provide a power-dividing network near the common-point input to the feeder system as shown in Fig. 8.

Typical power-dividing networks are shown in Fig. Ba. Terminals 1 and 2 are the output terminals to towers 1 and 2, respectively. The transmitter is connected directly or through a matching section to the terminals marked IN. A common practice is to start with the phase at the antenna loop current and compute the phase shift back through the matching networks, transmission lines, and phase shifters to the output of the power divider. In case the power division is nearly equal and the feed lines need to be out of phase, the push-pull circuit in Fig. Ba-a may be suitable. Where the feeder lines are in phase the series- or parallel-resonant circuits of Fig. Ba-b or c are applicable. In some cases the feed lines may be in quadrature phase, so the circuit of Fig. Ba-d can be used. If the power input to the feeder lines is known, then L sections can be designed to give the proper division as shown in Fig. Ba-e.

Small and Large Values of Variable Reactance

The design of a feeder system should be such that adjustments can be made with ease in the field. Some ideas are given here that may be of help in new designs or modifications of existing designs to make them easier to adjust.

If a very low value of capacitive reactance is required, it can be obtained easily by placing an inductor in series with a capacitor as shown in Fig. Ca-a. This arrangement makes it easy to obtain equivalent capacity values up to infinity when the circuit becomes series-resonant. Thus, it is possible to obtain values of inductive or capacitive reactance near zero values. This arrangement is often used in the shunt or series arms of a T or π section, so the correct value can be easily obtained. It is usually more satisfactory than providing a variable capacitor. In this arrangement care must be taken not to exceed the current rating of the capacitor. This discussion neglects the resistance component, which is usually very small.

Sometimes it is necessary to obtain an inductive reactance larger than the reactance of available inductors. In such cases it is possible to parallel the coil with a very small capacitor. If the capacitor tap on the coil is moved as shown in Fig. Bc-b, the desired value of inductive reactance can be achieved.

Adjustments

Theoretical Mesh Circuit Equation

In order to understand the operation of a directional-antenna system, it is desirable to understand how the circuit performs theoretically. With this understanding, it is easier to make the necessary adjustments. For a two-tower array the input terminals of the two towers can be considered to be a mesh circuit; hence the following simultaneous equations apply:

$$V_1 = I_1Z_{11} + I_2Z_{12} \qquad \text{[B-39]}$$

$$V_2 = I_1Z_{21} + I_2Z_{22} \qquad \text{[B-40]}$$

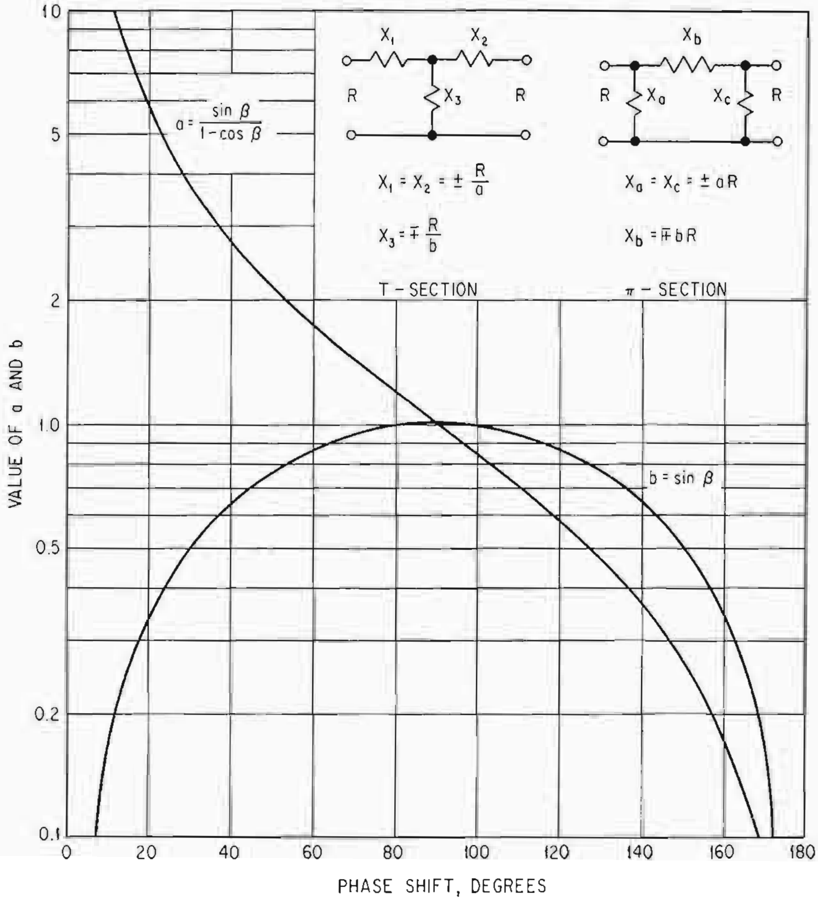


Fig. Ba. Phase-shifting-network curves.

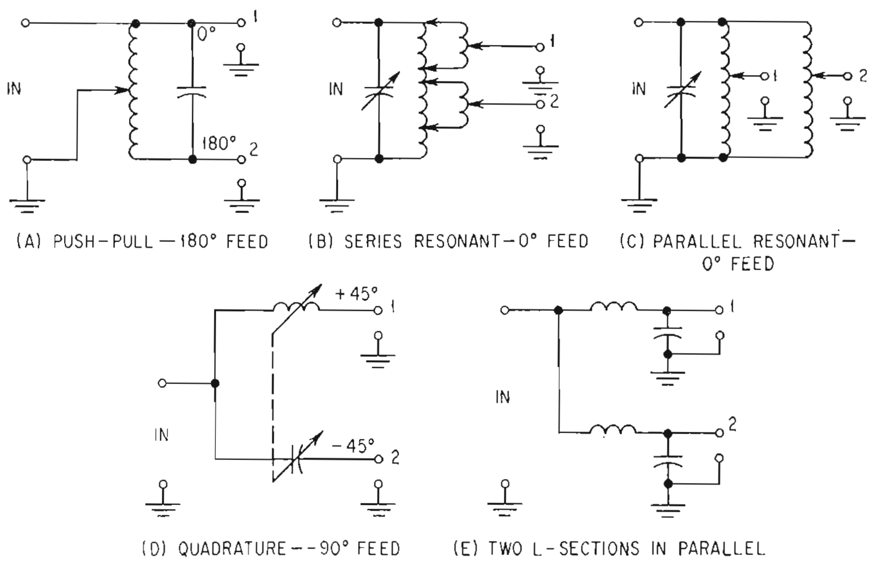


Fig. Bb. Typical power-dividing networks.

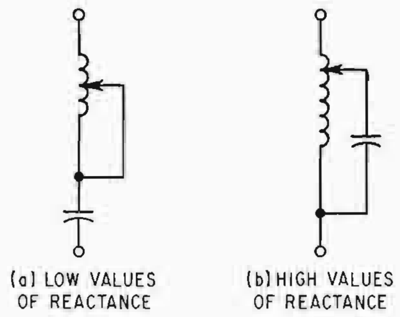


Fig. Bc. Methods of varying reactance.

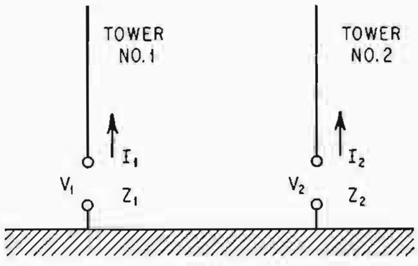


Fig. Bd. Two-tower input terminals.

where V_1 and V_2 = vector effective voltage at input terminals of towers 1 and 2 respectively, volts
I_1 and I_2 = vector effective current at input terminals of towers 1 and 2 respectively, amp
Z_{11} and Z_{22} = self-impedance of towers 1 and 2 respectively, ohms
$Z_{12} = Z_{21}$ = mutual impedance between towers 1 and 2, ohms

All the terms in the above mesh equations are complex quantities.

From this set of simultaneous equations it is possible to define the driving point impedance of each tower, thus

$$Z_1 = \frac{V_1}{I_1} = Z_{11} + \frac{I_2}{I_1} Z_{12} \qquad \text{[B-41]}$$

$$Z_2 = \frac{V_2}{I_2} = \frac{I_1}{I_2} Z_{12} + Z_{22} \qquad \text{[B-42]}$$

where Z_1 = driving-point impedance of tower 1 while array is in operation, ohms
Z_2 = driving-point impedance of tower 2 while array is in operation, ohms

The resistance component R_1 of Z_1 and R_2 of Z_2 is pure radiation resistance if there is no loss in the system. The directional-antenna system can be designed using this theoretical basis, and then from a knowledge of the system losses the driving-point impedances can be estimated with fair accuracy. (See Fig. Bd.)

Measured Base Self-Impedance

If the towers are approximately 90° high or less and the spacing is not very close, then the self-impedance can be measured by leaving the terminals of tower 2 open while measuring the impedance of tower 1 with an RF bridge at the operating frequency. This can be seen by inspecting Eq. B-41, where $I_2 = 0$; hence only Z_{11} will be measured for this condition.

Similarly, Z_{22} can be measured by leaving the terminals of tower 1 open while measuring at the terminals of tower 2.

Measured Base Mutual Impedance

This can be done by inserting a variable reactance in series with the terminals of tower 2 when the terminals of tower 1 are open and adjusting it so that only a pure resistance R_{22} remains. This can be done with an RF bridge. Tower 2 is now tuned to resonance at the operating frequency.

The next step is to drive tower 1 with a suitable voltage at the operating frequency and note the currents in towers 1 and 2 when tower 2 is tuned to resonance.

From these measurements the magnitude of the mutual impedance to a first approximation is

$$|Z_{12}| = -\frac{|I_2|}{|I_1|} R_{22} \qquad \text{[B-43]}$$

The angle of the mutual impedance can best be approximated by using theoretical information. If the loop mutual-impedance phases are used, they must be delayed by the effective electrical distance of the loop above the tower base. If base mutual-impedance phases are used, they also must be delayed by the same effective electrical distance because they do not provide for time delay of the current to reach the loop position.

If the phase-monitoring system has been installed and is calibrated to read properly, it can be used to measure the phase of I_2 with respect to I_1 and thus provide the necessary phase angle of Z_{12}. This is a good way to check the theoretical values. It may be even a better check on the antenna-monitor calibration.

The theoretical value of the magnitude of Z_{12} written $|Z_{12}|$ can be used in lieu of the above measured value. If the towers are near 180° in height, it is advisable to measure the mutual impedance. Also, if the spacing is less than 90°, the mutual-impedance values should be measured. In other words if the mutual impedance is large, it should be measured for best results.

Estimated Base Driving-Point Impedance

The driving-point impedance Z_1 can now be estimated by using the above values of Z_{11} and Z_{12} along with the current ratio:

$$M_{21} = \frac{I_2}{I_1} \qquad \text{[B-44]}$$

as specified in the directional-antenna design. When these values are substituted in Eq. B-41, the driving-point impedance for tower 1 while the array is in operation results.

Similarly it is possible to obtain the driving-point impedance for tower 2.

Estimated Base Driving-Point Current

Assuming no loss in the tower, insulators, or ground system, the authorized power input must be

$$P = |I_1|^2 R_1 + |I_2|^2 R_2 \qquad \text{[B-45]}$$

Since the ratio of current is known, we can write

$$|I_1| = \frac{P}{R_1 + |M_{21}|^2 R_2} \qquad \text{[B-46]}$$

and then,

$$|I_2| = |I_1|\,|M_{21}| \qquad \text{[B-47]}$$

The above authorized power does not include the power allowed by FCC for feeder-system losses.

Feeder-System Adjustment

A good way to set up the feeder system is to make up dummy driving-point impedance loads with the aid of an RF bridge. If small components are available, only RF bridge measurements can be used. If larger resistors are used which will not change value when heated up with power, then the whole feeder system can be set up and adjusted for the correct power division using dummy driving-point impedance loads.

It is possible to adjust each transmission line to the tower input network using the dummy load, since the tower input impedance will not have the correct value until the whole directional-antenna system is operating properly. After these matching networks are adjusted with the RF bridge, it should not be necessary to make any further adjustments at this point. The networks at the towers can then be connected, and the completion of the feeder-system adjustments can usually be made at the common point where the power division and phasing controls are located.

Tower with Negative Resistance

In some directional-antenna systems a tower will have a negative resistance at the driving point. This means that power must be removed from the tower terminals. While the initial adjustments are made, this power can be dissipated, but for the final operation it is usually desirable to feed this power back into the system in order to maintain high efficiency.

In Fig. Be-a the antenna system is properly adjusted to give the required pattern shape but the power from tower 2 is being dissipated into a driving-point impedance with a negative resistance component. If the driving-point impedance of the negative tower is matched into a transmission line, this power can be fed back to the common-point input point as shown in Fig. Be-b. It is necessary to adjust the phase and magnitude of the feedback voltage properly so it will equal the magnitude and phase of the voltage where the feedback system is connected at the common point. Then the two circuits can be connected in parallel. The feedback system is used to control the phase and magnitude of the feedback voltage. When the feedback voltage is connected across the common-point input terminals, the input resistance will increase because the negative resistance in parallel with a positive resistance will have a resistance value larger than the positive resistance value alone.

In the design of the feeder system it is usually possible simply to tap on to the power-dividing network in the usual manner with the circuit to the tower having a negative resistance. In this case the phase shifts must be figured in the reverse direction owing to the reverse direction of power flow.

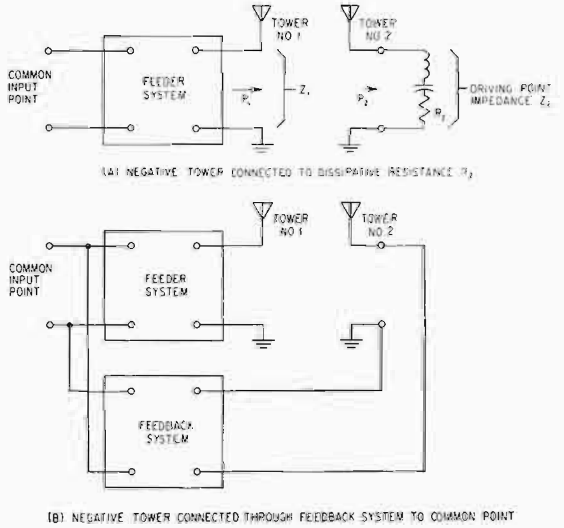


Fig. Be. Addition of power from tower with negative resistance.

TABLE A
Minimum-Depth Term[a]

F	$\frac{1}{F}$	F^2	$\frac{1+F^2}{2F}$	F	$\frac{1}{F}$	F^2	$\frac{1+F^2}{2F}$
0.995	1.0050	0.99002	1.00001	0.745	1.3422	0.55502	1.0436
0.990	1.0101	0.98010	1.00005	0.740	1.3513	0.54760	1.0457
0.985	1.0152	0.97022	1.00011	0.735	1.3605	0.54022	1.0478
0.980	1.0204	0.96040	1.00020	0.730	1.3698	0.53290	1.0499
0.975	1.0256	0.95062	1.00032	0.725	1.3793	0.52562	1.0522
0.970	1.0309	0.94090	1.00046	0.720	1.3888	0.51840	1.0544
0.965	1.0363	0.93122	1.00063	0.715	1.3986	0.51122	1.0568
0.960	1.0417	0.92160	1.00083	0.710	1.4084	0.50410	1.0592
0.955	1.0471	0.91202	1.00106	0.705	1.4184	0.49702	1.0617
0.950	1.0526	0.90250	1.00132	0.700	1.4285	0.49000	1.0643
0.945	1.0582	0.89302	1.0016	0.695	1.4388	0.48302	1.0669
0.940	1.0638	0.88360	1.0019	0.690	1.4492	0.47610	1.0696
0.935	1.0695	0.87422	1.0023	0.685	1.4598	0.46922	1.0724
0.930	1.0752	0.86490	1.0026	0.680	1.4705	0.46240	1.0753
0.925	1.0810	0.85562	1.0030	0.675	1.4814	0.45562	1.0782
0.920	1.0869	0.84640	1.0035	0.670	1.4925	0.44890	1.0812
0.915	1.0929	0.83722	1.0039	0.665	1.5037	0.44222	1.0844
0.910	1.0989	0.82810	1.0045	0.660	1.5151	0.43560	1.0875
0.905	1.1049	0.81902	1.0050	0.655	1.5267	0.42902	1.0909
0.900	1.1111	0.81000	1.0056	0.650	1.5384	0.42250	1.0942
0.895	1.1173	0.80102	1.0062	0.645	1.5503	0.41602	1.0977
0.890	1.1236	0.79210	1.0068	0.640	1.5625	0.40960	1.1012
0.885	1.1299	0.78322	1.0075	0.635	1.5748	0.40322	1.1049
0.880	1.1363	0.77440	1.0082	0.630	1.5873	0.39690	1.1086
0.875	1.1428	0.76562	1.0089	0.625	1.6000	0.39062	1.1125
0.870	1.1494	0.75690	1.0097	0.620	1.6129	0.38440	1.1164
0.865	1.1560	0.74822	1.0105	0.615	1.6260	0.37822	1.1205
0.860	1.1627	0.73960	1.0114	0.610	1.6393	0.37210	1.1246
0.855	1.1695	0.73102	1.0123	0.605	1.6528	0.36602	1.1289
0.850	1.1764	0.72250	1.0132	0.600	1.6666	0.36000	1.1333
0.845	1.1834	0.71402	1.0142	0.595	1.6806	0.35402	1.1378
0.840	1.1904	0.70560	1.0152	0.590	1.6949	0.34810	1.1425
0.835	1.1976	0.69722	1.0163	0.585	1.7094	0.34222	1.1472
0.830	1.2048	0.68890	1.0174	0.580	1.7241	0.33640	1.1521
0.825	1.2121	0.68062	1.0186	0.575	1.7391	0.33062	1.1571
0.820	1.2195	0.67240	1.0197	0.570	1.7543	0.32490	1.1621
0.815	1.2269	0.66422	1.0210	0.565	1.7699	0.31922	1.1675
0.810	1.2345	0.65610	1.0223	0.560	1.7857	0.31360	1.1728
0.805	1.2422	0.64802	1.0236	0.555	1.8018	0.30802	1.1784
0.800	1.2500	0.64000	1.0250	0.550	1.8181	0.30250	1.1841
0.795	1.2578	0.63202	1.0264	0.545	1.8348	0.29702	1.1899
0.790	1.2658	0.62410	1.0279	0.540	1.8518	0.29160	1.1959
0.785	1.2738	0.61622	1.0294	0.535	1.8691	0.28622	1.2021
0.780	1.2820	0.60840	1.0310	0.530	1.8867	0.28090	1.2084
0.775	1.2903	0.60062	1.0327	0.525	1.9047	0.27562	1.2149
0.770	1.2987	0.59290	1.0343	0.520	1.9230	0.27040	1.2215
0.765	1.3071	0.58522	1.0361	0.515	1.9417	0.26522	1.2284
0.760	1.3157	0.57760	1.0379	0.510	1.9607	0.26010	1.2354
0.755	1.3245	0.57002	1.0397	0.505	1.9802	0.25502	1.2426
0.750	1.3333	0.56250	1.0417	0.500	2.0000	0.25000	1.2500

* $(1 + F^2)/2F$ where either F or $1/F$ is the ratio of the inverse field strengths.

TABLE A
Minimum-Depth Term (*Continued*)

F	$\frac{1}{F}$	F^2	$\frac{1+F^2}{2F}$	F	$\frac{1}{F}$	F^2	$\frac{1+F^2}{2F}$
0.495	2.0202	0.24502	1.2576	0.345	2.8985	0.11902	1.6218
0.490	2.0408	0.24010	1.2654	0.340	2.9411	0.11560	1.6406
0.485	2.0618	0.23522	1.2734	0.335	2.9850	0.11222	1.6600
0.480	2.0833	0.23040	1.2817	0.330	3.0303	0.10890	1.6802
0.475	2.1052	0.22562	1.2901	0.325	3.0769	0.10562	1.7010
0.470	2.1276	0.22090	1.2988	0.320	3.1250	0.10240	1.7225
0.465	2.1505	0.21622	1.3078	0.315	3.1746	0.09922	1.7448
0.460	2.1739	0.21160	1.3170	0.310	3.2258	0.09610	1.7679
0.455	2.1978	0.20702	1.3264	0.305	3.2786	0.09302	1.7918
0.450	2.2222	0.20250	1.3361	0.300	3.3333	0.09000	1.8167
0.445	2.2471	0.19802	1.3461	0.295	3.3898	0.08702	1.8424
0.440	2.2727	0.19360	1.3564	0.290	3.4482	0.08410	1.8691
0.435	2.2988	0.18922	1.3669	0.285	3.5087	0.08122	1.8969
0.430	2.3255	0.18490	1.3778	0.280	3.5714	0.07840	1.9257
0.425	2.3529	0.18062	1.3890	0.275	3.6363	0.07562	1.9557
0.420	2.3809	0.17640	1.4005	0.270	3.7037	0.07290	1.9869
0.415	2.4096	0.17222	1.4123	0.265	3.7735	0.07022	2.0193
0.410	2.4390	0.16810	1.4245	0.260	3.8461	0.06760	2.0531
0.405	2.4691	0.16402	1.4371	0.255	3.9215	0.06502	2.0883
0.400	2.5000	0.16000	1.4500	0.250	4.0000	0.06250	2.1250
0.395	2.5316	0.15602	1.4633	0.245	4.0816	0.06002	2.1633
0.390	2.5641	0.15210	1.4770	0.240	4.1666	0.05760	2.2033
0.385	2.5974	0.14822	1.4912	0.235	4.2553	0.05522	2.2451
0.380	2.6315	0.14440	1.5058	0.230	4.3478	0.05290	2.2889
0.375	2.6666	0.14062	1.5208	0.225	4.4444	0.05062	2.3347
0.370	2.7027	0.13690	1.5364	0.220	4.5454	0.04840	2.3827
0.365	2.7397	0.13322	1.5524	0.215	4.6511	0.04622	2.4331
0.360	2.7777	0.12960	1.5689	0.210	4.7619	0.04410	2.4860
0.355	2.8169	0.12602	1.5859	0.205	4.8780	0.04202	2.5415
0.350	2.8571	0.12250	1.6035	0.200	5.0000	0.04000	2.6000

TABLE B
Bessel Function, J_0 $(S \cos \theta)$

$S°$	Elevation angle, $\theta°$								
	0°	10°	20°	30°	40°	50°	60°	70°	80°
1	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
2	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
3	0.999	0.999	0.999	0.999	1.000	1.000	1.000	1.000	1.000
4	0.999	0.999	0.999	0.999	0.999	0.999	1.000	1.000	1.000
5	0.998	0.998	0.998	0.999	0.999	0.999	1.000	1.000	1.000
6	0.997	0.997	0.998	0.998	0.998	0.999	0.999	1.000	1.000
7	0.996	0.996	0.997	0.997	0.998	0.998	0.999	1.000	1.000
8	0.995	0.995	0.996	0.996	0.997	0.998	0.999	0.999	1.000
9	0.994	0.994	0.995	0.995	0.996	0.997	0.998	0.999	1.000
10	0.992	0.993	0.993	0.994	0.996	0.997	0.998	0.999	1.000
11	0.991	0.991	0.992	0.993	0.995	0.996	0.998	0.999	1.000
12	0.989	0.989	0.990	0.992	0.994	0.996	0.997	0.999	1.000
13	0.987	0.988	0.989	0.990	0.992	0.995	0.997	0.998	1.000
14	0.985	0.986	0.987	0.989	0.991	0.994	0.996	0.998	1.000
15	0.983	0.983	0.985	0.987	0.990	0.993	0.996	0.998	0.999
16	0.981	0.981	0.983	0.985	0.985	0.992	0.995	0.998	0.999
17	0.978	0.979	0.981	0.984	0.987	0.991	0.994	0.997	0.999
18	0.976	0.976	0.978	0.982	0.985	0.990	0.994	0.997	0.999
19	0.973	0.974	0.976	0.980	0.986	0.989	0.993	0.997	0.999
20	0.970	0.971	0.973	0.977	0.982	0.987	0.992	0.996	0.999
21	0.967	0.968	0.971	0.975	0.980	0.986	0.992	0.996	0.999
22	0.964	0.965	0.968	0.973	0.973	0.985	0.991	0.996	0.999
23	0.960	0.961	0.965	0.970	0.977	0.983	0.970	0.975	0.999
24	0.957	0.958	0.962	0.967	0.974	0.982	0.985	0.995	0.999
25	0.953	0.954	0.958	0.965	0.972	0.980	0.988	0.994	0.999
26	0.949	0.951	0.955	0.962	0.970	0.979	0.987	0.994	0.998
27	0.945	0.947	0.953	0.959	0.968	0.977	0.986	0.994	0.998
28	0.941	0.943	0.948	0.956	0.965	0.976	0.985	0.993	0.998
29	0.937	0.939	0.944	0.953	0.963	0.974	0.984	0.993	0.998
30	0.933	0.935	0.940	0.949	0.960	0.972	0.983	0.992	0.998
31	0.928	0.930	0.936	0.946	0.958	0.970	0.982	0.992	0.998
32	0.924	0.926	0.932	0.942	0.955	0.968	0.981	0.991	0.998
33	0.919	0.921	0.928	0.939	0.952	0.966	0.979	0.990	0.998
34	0.914	0.916	0.924	0.935	0.945	0.964	0.978	0.990	0.997
35	0.905	0.912	0.919	0.931	0.941	0.962	0.977	0.985	0.997
36	0.904	0.907	0.915	0.927	0.943	0.960	0.976	0.989	0.997
37	0.899	0.901	0.910	0.923	0.940	0.957	0.974	0.986	0.997
38	0.893	0.896	0.905	0.919	0.937	0.955	0.973	0.987	0.997
39	0.888	0.891	0.900	0.915	0.933	0.953	0.971	0.987	0.997
40	0.882	0.885	0.895	0.911	0.930	0.950	0.970	0.986	0.996
41	0.876	0.880	0.890	0.906	0.926	0.948	0.968	0.985	0.996
42	0.870	0.874	0.885	0.902	0.923	0.945	0.967	0.984	0.996
43	0.864	0.868	0.880	0.897	0.919	0.943	0.965	0.984	0.996
44	0.858	0.862	0.874	0.892	0.915	0.940	0.963	0.983	0.996
45	0.852	0.856	0.868	0.888	0.913	0.937	0.962	0.982	0.995
46	0.845	0.850	0.862	0.883	0.908	0.935	0.960	0.981	0.995
47	0.839	0.843	0.857	0.878	0.904	0.932	0.958	0.980	0.995
48	0.832	0.837	0.851	0.873	0.900	0.929	0.957	0.980	0.995
49	0.825	0.830	0.845	0.868	0.896	0.926	0.955	0.979	0.994
50	0.818	0.823	0.838	0.862	0.891	0.923	0.953	0.978	0.994

TABLE B
Bessel Function, J_0 (S cos θ) (*Continued*)

$S°$	Elevation angle, $\theta°$								
	0°	10°	20°	30°	40°	50°	60°	70°	80°
51	0.812	0.817	0.832	0.857	0.887	0.920	0.951	0.977	0.994
52	0.804	0.810	0.826	0.851	0.883	0.917	0.949	0.976	0.994
53	0.797	0.803	0.820	0.846	0.878	0.913	0.947	0.975	0.994
54	0.790	0.796	0.813	0.840	0.874	0.910	0.945	0.974	0.993
55	0.783	0.789	0.807	0.835	0.869	0.907	0.943	0.973	0.993
56	0.775	0.782	0.800	0.829	0.865	0.904	0.941	0.972	0.993
57	0.767	0.774	0.793	0.823	0.860	0.900	0.939	0.971	0.993
58	0.760	0.767	0.786	0.817	0.855	0.897	0.937	0.970	0.992
59	0.752	0.759	0.779	0.811	0.850	0.893	0.935	0.969	0.992
60	0.744	0.751	0.772	0.805	0.845	0.890	0.933	0.968	0.992
61	0.736	0.743	0.765	0.799	0.840	0.886	0.930	0.967	0.991
62	0.728	0.735	0.758	0.792	0.835	0.883	0.928	0.966	0.991
63	0.720	0.728	0.750	0.786	0.830	0.879	0.926	0.965	0.991
64	0.712	0.720	0.743	0.780	0.825	0.875	0.923	0.964	0.991
65	0.703	0.712	0.735	0.773	0.820	0.871	0.921	0.963	0.990
66	0.695	0.703	0.728	0.766	0.815	0.867	0.919	0.962	0.990
67	0.686	0.695	0.720	0.760	0.810	0.863	0.916	0.960	0.990
68	0.678	0.686	0.712	0.753	0.804	0.860	0.914	0.959	0.989
69	0.669	0.678	0.704	0.746	0.798	0.856	0.911	0.958	0.989
70	0.660	0.669	0.696	0.739	0.792	0.851	0.909	0.957	0.989
71	0.652	0.661	0.688	0.732	0.787	0.847	0.906	0.956	0.988
72	0.642	0.652	0.680	0.725	0.781	0.843	0.904	0.954	0.988
73	0.634	0.643	0.672	0.718	0.776	0.839	0.901	0.953	0.988
74	0.625	0.635	0.664	0.711	0.770	0.835	0.898	0.952	0.987
75	0.615	0.626	0.656	0.703	0.764	0.830	0.896	0.950	0.987
76	0.606	0.617	0.648	0.697	0.758	0.826	0.893	0.949	0.987
77	0.597	0.607	0.639	0.689	0.752	0.822	0.890	0.948	0.986
78	0.588	0.599	0.631	0.682	0.746	0.818	0.887	0.947	0.986
79	0.578	0.589	0.622	0.674	0.740	0.813	0.884	0.945	0.986
80	0.569	0.580	0.613	0.667	0.734	0.808	0.882	0.944	0.985
81	0.559	0.571	0.605	0.659	0.728	0.804	0.879	0.943	0.985
82	0.550	0.561	0.596	0.652	0.722	0.799	0.876	0.941	0.985
83	0.540	0.552	0.587	0.644	0.715	0.794	0.873	0.939	0.984
84	0.531	0.543	0.579	0.636	0.709	0.790	0.870	0.938	0.984
85	0.521	0.535	0.570	0.628	0.702	0.785	0.867	0.937	0.983
86	0.511	0.524	0.561	0.620	0.696	0.780	0.864	0.935	0.983
87	0.502	0.515	0.552	0.612	0.689	0.775	0.861	0.934	0.983
88	0.492	0.505	0.543	0.604	0.683	0.770	0.858	0.933	0.982
89	0.482	0.495	0.534	0.596	0.678	0.766	0.854	0.931	0.982
90	0.472	0.486	0.525	0.588	0.670	0.761	0.851	0.929	0.981
91	0.462	0.476	0.516	0.580	0.663	0.756	0.848	0.928	0.981
92	0.452	0.466	0.506	0.572	0.656	0.751	0.845	0.926	0.981
93	0.442	0.456	0.497	0.564	0.649	0.746	0.842	0.924	0.980
94	0.432	0.447	0.488	0.556	0.643	0.741	0.839	0.923	0.980
95	0.422	0.437	0.479	0.547	0.636	0.735	0.835	0.921	0.979
96	0.412	0.427	0.470	0.539	0.629	0.730	0.832	0.920	0.979
97	0.402	0.417	0.461	0.531	0.622	0.725	0.829	0.918	0.978
98	0.392	0.407	0.451	0.522	0.615	0.720	0.825	0.916	0.978
99	0.382	0.397	0.442	0.514	0.608	0.714	0.822	0.915	0.977
100	0.372	0.387	0.432	0.506	0.601	0.709	0.818	0.913	0.977

TABLE B
Bessel Function, J_0 ($S \cos \theta$) (*Continued*)

$S°$	Elevation angle, $\theta°$								
	0°	10°	20°	30°	40°	50°	60°	70°	80°
101	0.361	0.377	0.423	0.497	0.594	0.703	0.815	0.911	0.977
102	0.352	0.367	0.414	0.489	0.587	0.698	0.812	0.909	0.976
103	0.341	0.357	0.404	0.480	0.579	0.693	0.808	0.908	0.976
104	0.331	0.347	0.395	0.471	0.572	0.687	0.804	0.906	0.975
105	0.321	0.337	0.385	0.463	0.565	0.682	0.801	0.904	0.975
106	0.311	0.327	0.375	0.454	0.558	0.676	0.797	0.902	0.974
107	0.301	0.317	0.366	0.446	0.551	0.671	0.793	0.900	0.974
108	0.290	0.307	0.356	0.437	0.543	0.665	0.790	0.899	0.973
109	0.281	0.297	0.347	0.428	0.536	0.660	0.786	0.897	0.973
110	0.270	0.287	0.337	0.419	0.528	0.654	0.783	0.895	0.972
111	0.260	0.277	0.328	0.411	0.521	0.648	0.779	0.893	0.972
112	0.250	0.267	0.318	0.402	0.513	0.642	0.775	0.891	0.971
113	0.240	0.257	0.309	0.393	0.506	0.636	0.771	0.890	0.971
114	0.230	0.247	0.299	0.385	0.498	0.630	0.767	0.888	0.970
115	0.220	0.237	0.290	0.376	0.491	0.625	0.763	0.886	0.970
116	0.210	0.227	0.280	0.367	0.484	0.619	0.760	0.884	0.969
117	0.200	0.217	0.271	0.359	0.476	0.613	0.756	0.882	0.969
118	0.190	0.208	0.261	0.350	0.468	0.607	0.752	0.880	0.968
119	0.180	0.198	0.252	0.341	0.461	0.601	0.748	0.878	0.968
120	0.170	0.188	0.242	0.332	0.453	0.596	0.744	0.876	0.967
121	0.160	0.178	0.233	0.323	0.445	0.590	0.740	0.874	0.967
122	0.150	0.168	0.223	0.314	0.438	0.584	0.736	0.872	0.966
123	0.140	0.158	0.214	0.306	0.430	0.578	0.732	0.870	0.965
124	0.130	0.148	0.204	0.297	0.422	0.572	0.728	0.868	0.965
125	0.120	0.139	0.195	0.288	0.415	0.565	0.724	0.866	0.964
126	0.111	0.129	0.185	0.279	0.407	0.559	0.720	0.864	0.964
127	0.101	0.120	0.176	0.270	0.400	0.553	0.716	0.861	0.963
128	0.092	0.110	0.167	0.261	0.392	0.547	0.712	0.859	0.963
129	0.082	0.101	0.158	0.253	0.384	0.541	0.707	0.857	0.962
130	0.072	0.091	0.148	0.244	0.376	0.535	0.703	0.855	0.961
131	0.063	0.082	0.139	0.235	0.368	0.529	0.699	0.853	0.961
132	0.053	0.072	0.129	0.227	0.360	0.522	0.695	0.851	0.960
133	0.044	0.063	0.120	0.218	0.353	0.516	0.690	0.848	0.960
134	0.035	0.053	0.111	0.209	0.345	0.510	0.686	0.846	0.958
135	0.026	0.044	0.102	0.201	0.337	0.503	0.682	0.844	0.958
136	0.017	0.035	0.093	0.192	0.329	0.497	0.678	0.842	0.958
137	0.007	0.026	0.094	0.183	0.321	0.491	0.673	0.840	0.957
138	−0.002	0.017	0.075	0.175	0.314	0.485	0.669	0.837	0.957
139	−0.011	0.008	0.066	0.166	0.308	0.478	0.665	0.835	0.956
140	−0.020	−0.001	0.058	0.158	0.299	0.472	0.660	0.833	0.955
141	−0.029	−0.010	0.049	0.149	0.291	0.466	0.656	0.830	0.955
142	−0.037	−0.019	0.040	0.141	0.283	0.459	0.652	0.828	0.954
143	−0.046	−0.028	0.031	0.132	0.275	0.453	0.647	0.826	0.954
144	−0.055	−0.036	0.022	0.124	0.267	0.446	0.642	0.823	0.953
145	−0.064	−0.045	0.013	0.115	0.259	0.440	0.638	0.821	0.952
146	−0.072	−0.053	0.005	0.107	0.252	0.434	0.634	0.819	0.952
147	−0.080	−0.062	−0.003	0.099	0.244	0.427	0.629	0.817	0.951
148	−0.088	−0.070	−0.012	0.090	0.236	0.420	0.625	0.814	0.950
149	−0.097	−0.078	−0.020	0.082	0.229	0.414	0.620	0.812	0.950
150	−0.105	−0.087	−0.029	0.073	0.221	0.408	0.615	0.809	0.949

TABLE B
Bessel Function, J_0 ($S \cos \theta$) (*Continued*)

$S°$	Elevation angle, $\theta°$								
	0°	10°	20°	30°	40°	50°	60°	70°	80°
151	−0.113	−0.095	−0.037	0.065	0.213	0.401	0.611	0.807	0.948
152	−0.121	−0.103	−0.045	0.057	0.205	0.395	0.606	0.805	0.947
153	−0.129	−0.111	−0.053	0.049	0.198	0.388	0.602	0.802	0.947
154	−0.137	−0.119	−0.062	0.040	0.190	0.382	0.597	0.800	0.946
155	−0.145	−0.126	−0.070	0.032	0.183	0.375	0.592	0.797	0.945
156	−0.153	−0.134	−0.078	0.024	0.175	0.368	0.587	0.795	0.945
157	−0.160	−0.142	−0.085	0.017	0.167	0.362	0.583	0.792	0.944
158	−0.167	−0.149	−0.093	0.009	0.160	0.356	0.578	0.790	0.943
159	−0.175	−0.157	−0.101	0.001	0.152	0.349	0.573	0.787	0.943
160	−0.182	−0.164	−0.108	−0.007	0.145	0.343	0.569	0.785	0.942
161	−0.189	−0.172	−0.116	−0.015	0.137	0.336	0.564	0.782	0.941
162	−0.196	−0.179	−0.123	−0.023	0.130	0.330	0.559	0.780	0.940
163	−0.203	−0.186	−0.131	−0.030	0.122	0.323	0.555	0.777	0.940
164	−0.210	−0.193	−0.138	−0.037	0.114	0.317	0.550	0.774	0.939
165	−0.217	−0.200	−0.146	−0.045	0.107	0.310	0.545	0.772	0.938
166	−0.223	−0.207	−0.153	−0.053	0.100	0.303	0.541	0.769	0.937
167	−0.230	−0.213	−0.159	−0.060	0.093	0.297	0.536	0.767	0.937
168	−0.236	−0.220	−0.167	−0.068	0.085	0.290	0.531	0.764	0.936
169	−0.242	−0.226	−0.173	−0.075	0.078	0.284	0.526	0.761	0.935
170	−0.249	−0.232	−0.180	−0.082	0.070	0.277	0.521	0.759	0.935
171	−0.255	−0.239	−0.187	−0.089	0.063	0.271	0.516	0.756	0.934
172	−0.261	−0.245	−0.194	−0.097	0.056	0.264	0.511	0.753	0.933
173	−0.266	−0.251	−0.200	−0.104	0.049	0.258	0.506	0.751	0.932
174	−0.272	−0.257	−0.207	−0.111	0.042	0.251	0.502	0.748	0.932
175	−0.278	−0.263	−0.213	−0.118	0.035	0.245	0.497	0.746	0.931
176	−0.283	−0.269	−0.220	−0.125	0.027	0.238	0.492	0.743	0.930
177	−0.289	−0.274	−0.226	−0.131	0.020	0.232	0.487	0.740	0.929
178	−0.294	−0.279	−0.232	−0.138	0.013	0.226	0.482	0.737	0.928
179	−0.299	−0.285	−0.238	−0.145	0.006	0.219	0.477	0.735	0.927
180	−0.304	−0.290	−0.244	−0.151	−0.001	0.212	0.472	0.732	0.927
181	−0.309	−0.295	−0.249	−0.158	−0.008	0.206	0.467	0.729	0.926
182	−0.314	−0.300	−0.255	−0.164	−0.015	0.200	0.462	0.726	0.925
183	−0.319	−0.305	−0.261	−0.171	−0.022	0.193	0.457	0.723	0.924
184	−0.323	−0.310	−0.266	−0.177	−0.028	0.187	0.452	0.721	0.923
185	−0.328	−0.315	−0.272	−0.183	−0.035	0.180	0.447	0.718	0.923
186	−0.332	−0.319	−0.277	−0.190	−0.041	0.174	0.442	0.715	0.922
187	−0.336	−0.324	−0.282	−0.196	−0.048	0.167	0.437	0.712	0.921
188	−0.340	−0.328	−0.287	−0.202	−0.055	0.161	0.432	0.709	0.920
189	−0.344	−0.332	−0.292	−0.208	−0.061	0.155	0.427	0.706	0.919
190	−0.348	−0.336	−0.297	−0.214	−0.068	0.148	0.422	0.704	0.918
191	−0.351	−0.340	−0.302	−0.219	−0.074	0.142	0.417	0.701	0.918
192	−0.355	−0.344	−0.307	−0.225	−0.081	0.136	0.412	0.698	0.917
193	−0.358	−0.348	−0.311	−0.231	−0.087	0.129	0.407	0.695	0.916
194	−0.362	−0.352	−0.316	−0.236	−0.094	0.123	0.402	0.692	0.915
195	−0.365	−0.355	−0.320	−0.242	−0.100	0.117	0.397	0.689	0.914
196	−0.368	−0.359	−0.324	−0.247	−0.106	0.110	0.392	0.686	0.913
197	−0.371	−0.362	−0.328	−0.252	−0.113	0.104	0.387	0.683	0.913
198	−0.374	−0.365	−0.332	−0.257	−0.119	0.098	0.382	0.680	0.912
199	−0.376	−0.368	−0.336	−0.262	−0.125	0.092	0.377	0.677	0.911
200	−0.379	−0.371	−0.340	−0.267	−0.131	0.086	0.372	0.674	0.910

TABLE B
Bessel Function, J_0 (S cos θ) (*Continued*)

$S°$	Elevation angle, $\theta°$								
	0°	10°	20°	30°	40°	50°	60°	70°	80°
201	−0.381	−0.374	−0.344	−0.272	−0.137	0.079	0.367	0.671	0.909
202	−0.383	−0.376	−0.347	−0.277	−0.143	0.073	0.361	0.668	0.908
203	−0.386	−0.379	−0.351	−0.282	−0.149	0.067	0.356	0.665	0.907
204	−0.388	−0.381	−0.354	−0.287	−0.154	0.061	0.351	0.662	0.906
205	−0.390	−0.383	−0.357	−0.292	−0.160	0.055	0.346	0.659	0.905
206	−0.391	−0.385	−0.360	−0.296	−0.166	0.049	0.341	0.656	0.904
207	−0.393	−0.387	−0.363	−0.301	−0.172	0.043	0.336	0.653	0.904
208	−0.394	−0.389	−0.366	−0.305	−0.177	0.037	0.331	0.650	0.903
209	−0.396	−0.391	−0.369	−0.309	−0.183	0.031	0.326	0.647	0.902
210	−0.397	−0.393	−0.372	−0.313	−0.188	0.025	0.321	0.644	0.901
211	−0.398	−0.394	−0.374	−0.317	−0.193	0.019	0.316	0.641	0.900
212	−0.399	−0.396	−0.377	−0.321	−0.199	0.013	0.311	0.638	0.899
213	−0.400	−0.397	−0.379	−0.325	−0.204	0.007	0.306	0.635	0.898
214	−0.401	−0.398	−0.382	−0.329	−0.209	0.001	0.301	0.632	0.897
215	−0.401	−0.399	−0.384	−0.333	−0.214	−0.004	0.296	0.629	0.896
216	−0.402	−0.400	−0.386	−0.336	−0.220	−0.010	0.291	0.626	0.895
217	−0.402	−0.401	−0.388	−0.340	−0.225	−0.016	0.285	0.623	0.894
218	−0.403	−0.401	−0.389	−0.343	−0.230	−0.022	0.280	0.620	0.893
219	−0.403	−0.402	−0.391	−0.346	−0.235	−0.027	0.275	0.616	0.892
220	−0.403	−0.402	−0.393	−0.350	−0.239	−0.032	0.270	0.613	0.892
221	−0.403	−0.403	−0.394	−0.353	−0.244	−0.038	0.265	0.610	0.891
222	−0.402	−0.403	−0.395	−0.356	−0.249	−0.044	0.260	0.607	0.890
223	−0.402	−0.403	−0.397	−0.359	−0.254	−0.049	0.255	0.604	0.889
224	−0.402	−0.403	−0.398	−0.362	−0.258	−0.055	0.250	0.601	0.888
225	−0.401	−0.403	−0.399	−0.364	−0.263	−0.061	0.245	0.597	0.887
226	−0.400	−0.402	−0.400	−0.367	−0.267	−0.066	0.240	0.594	0.886
227	−0.399	−0.402	−0.400	−0.370	−0.272	−0.072	0.235	0.591	0.885
228	−0.398	−0.401	−0.401	−0.372	−0.276	−0.077	0.230	0.588	0.884
229	−0.397	−0.401	−0.402	−0.374	−0.280	−0.083	0.225	0.585	0.883
230	−0.396	−0.400	−0.402	−0.377	−0.284	−0.088	0.220	0.581	0.882
231	−0.395	−0.399	−0.402	−0.379	−0.288	−0.093	0.215	0.578	0.881
232	−0.393	−0.393	−0.403	−0.381	−0.292	−0.099	0.210	0.575	0.880
233	−0.392	−0.397	−0.403	−0.383	−0.296	−0.104	0.205	0.572	0.879
234	−0.390	−0.396	−0.403	−0.385	−0.300	−0.109	0.200	0.568	0.878
235	−0.389	−0.395	−0.403	−0.387	−0.304	−0.114	0.195	0.565	0.877
236	−0.387	−0.393	−0.402	−0.388	−0.308	−0.119	0.190	0.562	0.876
237	−0.385	−0.391	−0.402	−0.390	−0.312	−0.124	0.185	0.559	0.875
238	−0.383	−0.389	−0.402	−0.391	−0.315	−0.129	0.180	0.555	0.874
239	−0.380	−0.388	−0.401	−0.393	−0.319	−0.134	0.175	0.552	0.873
240	−0.378	−0.386	−0.401	−0.394	−0.322	−0.139	0.170	0.549	0.871
241	−0.376	−0.384	−0.400	−0.395	−0.326	−0.144	0.165	0.546	0.870
242	−0.373	−0.382	−0.399	−0.397	−0.329	−0.149	0.160	0.543	0.869
243	−0.371	−0.380	−0.398	−0.398	−0.333	−0.154	0.155	0.540	0.868
244	−0.368	−0.377	−0.397	−0.399	−0.336	−0.159	0.150	0.536	0.867
245	−0.365	−0.375	−0.396	−0.399	−0.339	−0.164	0.145	0.533	0.866
246	−0.363	−0.372	−0.395	−0.400	−0.342	−0.168	0.140	0.530	0.865
247	−0.359	−0.370	−0.393	−0.401	−0.345	−0.173	0.135	0.526	0.864
248	−0.356	−0.367	−0.392	−0.401	−0.348	−0.178	0.130	0.523	0.863
249	−0.353	−0.364	−0.390	−0.402	−0.351	−0.183	0.125	0.520	0.862
250	−0.350	−0.361	−0.389	−0.402	−0.353	−0.187	0.120	0.516	0.861

TABLE B
Bessel Function, J_0 (S cos θ) (*Continued*)

$S°$	Elevation angle, $\theta°$								
	0°	10°	20°	30°	40°	50°	60°	70°	80°
251	−0.346	−0.358	−0.387	−0.402	−0.356	−0.192	0.116	0.513	0.860
252	−0.343	−0.355	−0.385	−0.403	−0.359	−0.196	0.111	0.510	0.859
253	−0.339	−0.352	−0.383	−0.403	−0.361	−0.201	0.106	0.506	0.858
254	−0.335	−0.349	−0.381	−0.403	−0.364	−0.205	0.101	0.503	0.857
255	−0.332	−0.346	−0.379	−0.403	−0.366	−0.209	0.097	0.500	0.856
256	−0.328	−0.342	−0.377	−0.402	−0.368	−0.214	0.092	0.496	0.855
257	−0.324	−0.339	−0.374	−0.402	−0.371	−0.218	0.087	0.493	0.854
258	−0.320	−0.335	−0.372	−0.402	−0.373	−0.222	0.082	0.489	0.852
259	−0.316	−0.331	−0.369	−0.401	−0.375	−0.226	0.077	0.486	0.851
260	−0.312	−0.327	−0.367	−0.401	−0.377	−0.231	0.072	0.483	0.850
261	−0.307	−0.324	−0.364	−0.400	−0.379	−0.235	0.067	0.479	0.849
262	−0.303	−0.320	−0.361	−0.400	−0.380	−0.239	0.063	0.476	0.848
263	−0.299	−0.316	−0.358	−0.399	−0.382	−0.243	0.058	0.472	0.847
264	−0.294	−0.312	−0.356	−0.398	−0.384	−0.247	0.053	0.469	0.846
265	−0.290	−0.307	−0.353	−0.397	−0.386	−0.251	0.049	0.466	0.844
266	−0.285	−0.303	−0.350	−0.396	−0.387	−0.255	0.044	0.462	0.843
267	−0.280	−0.299	−0.346	−0.395	−0.389	−0.259	0.039	0.459	0.842
268	−0.276	−0.294	−0.343	−0.393	−0.390	−0.262	0.035	0.455	0.841
269	−0.271	−0.290	−0.340	−0.392	−0.391	−0.266	0.030	0.452	0.840
270	−0.266	−0.285	−0.336	−0.391	−0.393	−0.270	0.026	0.449	0.839
271	−0.261	−0.281	−0.333	−0.389	−0.394	−0.274	0.021	0.446	0.838
272	−0.256	−0.276	−0.330	−0.387	−0.395	−0.277	0.017	0.442	0.837
273	−0.251	−0.271	−0.326	−0.385	−0.396	−0.281	0.012	0.439	0.835
274	−0.246	−0.267	−0.322	−0.384	−0.397	−0.284	0.007	0.435	0.834
275	−0.241	−0.262	−0.318	−0.382	−0.398	−0.288	0.003	0.432	0.833
276	−0.235	−0.257	−0.314	−0.380	−0.399	−0.291	−0.002	0.429	0.832
277	−0.230	−0.252	−0.310	−0.378	−0.399	−0.294	−0.006	0.425	0.831
278	−0.225	−0.247	−0.306	−0.376	−0.400	−0.298	−0.011	0.422	0.830
279	−0.219	−0.242	−0.302	−0.374	−0.401	−0.301	−0.015	0.418	0.829
280	−0.214	−0.236	−0.298	−0.372	−0.401	−0.304	−0.020	0.415	0.827
281	−0.208	−0.231	−0.294	−0.370	−0.402	−0.307	−0.024	0.411	0.826
282	−0.203	−0.226	−0.289	−0.367	−0.402	−0.311	−0.028	0.408	0.825
283	−0.197	−0.221	−0.285	−0.365	−0.402	−0.314	−0.033	0.404	0.824
284	−0.192	−0.215	−0.281	−0.362	−0.402	−0.317	−0.037	0.401	0.823
285	−0.186	−0.210	−0.276	−0.360	−0.403	−0.320	−0.042	0.397	0.822
286	−0.181	−0.205	−0.272	−0.357	−0.403	−0.323	−0.046	0.394	0.820
287	−0.175	−0.199	−0.267	−0.354	−0.403	−0.326	−0.050	0.390	0.819
288	−0.169	−0.194	−0.263	−0.351	−0.403	−0.328	−0.055	0.387	0.818
289	−0.163	−0.188	−0.258	−0.349	−0.403	−0.331	−0.059	0.384	0.817
290	−0.157	−0.182	−0.253	−0.346	−0.402	−0.334	−0.063	0.380	0.816
291	−0.151	−0.177	−0.248	−0.343	−0.402	−0.337	−0.068	0.377	0.814
292	−0.146	−0.171	−0.243	−0.340	−0.402	−0.339	−0.072	0.373	0.813
293	−0.140	−0.166	−0.238	−0.336	−0.401	−0.342	−0.076	0.370	0.812
294	−0.134	−0.160	−0.233	−0.333	−0.401	−0.344	−0.080	0.366	0.810
295	−0.128	−0.154	−0.228	−0.330	−0.400	−0.346	−0.084	0.363	0.809
296	−0.122	−0.148	−0.223	−0.326	−0.400	−0.349	−0.089	0.359	0.808
297	−0.116	−0.143	−0.218	−0.323	−0.399	−0.351	−0.093	0.356	0.807
298	−0.110	−0.137	−0.213	−0.320	−0.398	−0.354	−0.097	0.352	0.805
299	−0.104	−0.131	−0.208	−0.316	−0.397	−0.356	−0.101	0.349	0.804
300	−0.098	−0.125	−0.203	−0.313	−0.396	−0.358	−0.105	0.345	0.803

TABLE B
Bessel Function, J_0 (S cos θ) (*Continued*)

$S°$	Elevation angle, $\theta°$								
	0°	10°	20°	30°	40°	50°	60°	70°	80°
301	−0.092	−0.119	−0.198	−0.309	−0.395	−0.360	−0.109	0.342	0.802
302	−0.086	−0.113	−0.192	−0.305	−0.394	−0.362	−0.113	0.338	0.801
303	−0.080	−0.107	−0.187	−0.301	−0.393	−0.364	−0.117	0.335	0.799
304	−0.076	−0.101	−0.182	−0.298	−0.392	−0.366	−0.121	0.332	0.798
305	−0.068	−0.095	−0.176	−0.294	−0.391	−0.368	−0.125	0.328	0.797
306	−0.062	−0.090	−0.171	−0.290	−0.390	−0.370	−0.129	0.325	0.796
307	−0.056	−0.084	−0.165	−0.286	−0.388	−0.372	−0.133	0.321	0.794
308	−0.050	−0.078	−0.160	−0.282	−0.387	−0.374	−0.137	0.318	0.793
309	−0.044	−0.072	−0.155	−0.278	−0.385	−0.376	−0.141	0.314	0.792
310	−0.038	−0.066	−0.149	−0.273	−0.384	−0.377	−0.145	0.311	0.791
311	−0.032	−0.060	−0.144	−0.269	−0.382	−0.379	−0.149	0.307	0.789
312	−0.026	−0.054	−0.138	−0.265	−0.380	−0.380	−0.152	0.304	0.788
313	−0.020	−0.048	−0.133	−0.261	−0.379	−0.382	−0.156	0.300	0.787
314	−0.014	−0.042	−0.127	−0.256	−0.377	−0.383	−0.160	0.297	0.786
315	−0.008	−0.036	−0.122	−0.252	−0.375	−0.385	−0.163	0.293	0.784
316	−0.002	−0.030	−0.116	−0.248	−0.373	−0.386	−0.167	0.290	0.783
317	0.004	−0.024	−0.110	−0.243	−0.371	−0.387	−0.171	0.286	0.781
318	0.010	−0.018	−0.104	−0.239	−0.369	−0.389	−0.175	0.283	0.780
319	0.016	−0.013	−0.099	−0.234	−0.367	−0.390	−0.178	0.279	0.779
320	0.022	−0.007	−0.093	−0.229	−0.365	−0.391	−0.182	0.276	0.777
321	0.028	−0.001	−0.088	−0.225	−0.363	−0.392	−0.185	0.273	0.776
322	0.034	0.005	−0.082	−0.220	−0.360	−0.393	−0.189	0.269	0.775
323	0.039	0.011	−0.076	−0.215	−0.358	−0.394	−0.192	0.266	0.773
324	0.045	0.017	−0.071	−0.211	−0.356	−0.395	−0.196	0.262	0.772
325	0.051	0.023	−0.065	−0.206	−0.353	−0.396	−0.200	0.259	0.771
326	0.056	0.028	−0.059	−0.201	−0.351	−0.397	−0.203	0.255	0.770
327	0.062	0.034	−0.053	−0.196	−0.348	−0.397	−0.206	0.252	0.768
328	0.068	0.040	−0.048	−0.191	−0.345	−0.398	−0.210	0.248	0.767
329	0.073	0.046	−0.042	−0.186	−0.343	−0.399	−0.213	0.245	0.766
330	0.079	0.051	−0.037	−0.182	−0.340	−0.399	−0.217	0.241	0.764
331	0.085	0.057	−0.031	−0.177	−0.337	−0.400	−0.220	0.238	0.763
332	0.090	0.062	−0.025	−0.172	−0.334	−0.400	−0.223	0.234	0.762
333	0.095	0.068	−0.020	−0.167	−0.331	−0.401	−0.227	0.231	0.760
334	0.101	0.073	−0.014	−0.162	−0.328	−0.401	−0.230	0.227	0.759
335	0.106	0.079	−0.009	−0.157	−0.325	−0.402	−0.233	0.224	0.758
336	0.111	0.084	−0.003	−0.152	−0.322	−0.402	−0.236	0.221	0.756
337	0.116	0.090	0.003	−0.147	−0.319	−0.402	−0.239	0.218	0.755
338	0.122	0.095	0.008	−0.141	−0.316	−0.402	−0.242	0.214	0.754
339	0.127	0.100	0.014	−0.136	−0.313	−0.403	−0.245	0.211	0.752
340	0.132	0.106	0.020	−0.131	−0.310	−0.403	−0.249	0.207	0.750
341	0.137	0.111	0.025	−0.126	−0.307	−0.403	−0.252	0.204	0.749
342	0.142	0.116	0.031	−0.121	−0.303	−0.403	−0.255	0.200	0.748
343	0.147	0.121	0.036	−0.116	−0.300	−0.403	−0.258	0.197	0.746
344	0.151	0.126	0.042	−0.111	−0.297	−0.403	−0.261	0.193	0.745
345	0.156	0.131	0.047	−0.105	−0.293	−0.402	−0.263	0.190	0.744
346	0.161	0.136	0.052	−0.100	−0.290	−0.402	−0.266	0.187	0.742
347	0.166	0.141	0.058	−0.095	−0.286	−0.402	−0.269	0.183	0.741
348	0.170	0.146	0.063	−0.090	−0.282	−0.402	−0.272	0.180	0.740
349	0.175	0.151	0.068	−0.084	−0.279	−0.401	−0.275	0.176	0.738
350	0.170	0.155	0.073	−0.079	−0.275	−0.401	−0.278	0.173	0.737

TABLE B
Bessel Function, J_0 ($S \cos \theta$) (*Concluded*)

$S°$	Elevation angle, $\theta°$								
	0°	10°	20°	30°	40°	50°	60°	70°	80°
351	0.184	0.160	0.079	−0.074	−0.271	−0.400	−0.281	0.169	0.735
352	0.188	0.164	0.084	−0.069	−0.268	−0.400	−0.283	0.166	0.734
353	0.192	0.169	0.089	−0.064	−0.264	−0.399	−0.286	0.163	0.732
354	0.197	0.173	0.094	−0.058	−0.260	−0.399	−0.289	0.159	0.731
355	0.201	0.178	0.099	−0.053	−0.257	−0.398	−0.291	0.156	0.730
356	0.205	0.182	0.104	−0.048	−0.253	−0.397	−0.294	0.152	0.729
357	0.209	0.187	0.109	−0.043	−0.249	−0.397	−0.297	0.149	0.727
358	0.213	0.191	0.114	−0.038	−0.245	−0.396	−0.299	0.146	0.726
359	0.216	0.194	0.119	−0.033	−0.241	−0.395	−0.302	0.142	0.724
360	0.220	0.199	0.124	−0.027	−0.237	−0.394	−0.304	0.139	0.723
361	0.224	0.203	0.128	−0.022	−0.233	−0.393	−0.307	0.136	0.722
362	0.228	0.207	0.133	−0.017	−0.228	−0.392	−0.309	0.132	0.720
363	0.231	0.211	0.138	−0.012	−0.224	−0.391	−0.312	0.129	0.719
364	0.234	0.215	0.143	−0.006	−0.220	−0.390	−0.314	0.125	0.717
365	0.238	0.218	0.147	−0.001	−0.216	−0.389	−0.316	0.122	0.716
366	0.241	0.222	0.152	0.004	−0.212	−0.388	−0.319	0.119	0.714
367	0.244	0.226	0.156	0.009	−0.208	−0.387	−0.321	0.116	0.713
368	0.247	0.229	0.161	0.014	−0.204	−0.386	−0.323	0.113	0.712
369	0.250	0.233	0.165	0.019	−0.199	−0.384	−0.325	0.109	0.710
370	0.253	0.236	0.170	0.024	−0.195	−0.383	−0.327	0.106	0.708
371	0.256	0.239	0.174	0.029	−0.191	−0.381	−0.330	0.103	0.707
372	0.259	0.242	0.178	0.034	−0.186	−0.380	−0.332	0.099	0.705
373	0.262	0.245	0.182	0.039	−0.182	−0.378	−0.334	0.096	0.704
374	0.264	0.248	0.186	0.044	−0.178	−0.377	−0.336	0.093	0.702
375	0.267	0.251	0.190	0.049	−0.173	−0.375	−0.338	0.089	0.701
376	0.269	0.254	0.194	0.054	−0.169	−0.374	−0.340	0.086	0.700
377	0.271	0.257	0.198	0.059	−0.164	−0.372	−0.342	0.083	0.698
378	0.274	0.260	0.202	0.064	−0.160	−0.370	−0.344	0.079	0.697
379	0.276	0.262	0.206	0.069	−0.156	−0.369	−0.346	0.076	0.695
380	0.278	0.265	0.210	0.074	−0.151	−0.367	−0.348	0.073	0.694
381	0.280	0.267	0.213	0.079	−0.147	−0.365	−0.349	0.070	0.692
382	0.282	0.270	0.217	0.084	−0.142	−0.363	−0.351	0.066	0.691
383	0.283	0.272	0.220	0.088	−0.138	−0.361	−0.353	0.063	0.689
384	0.285	0.274	0.224	0.093	−0.133	−0.359	−0.355	0.060	0.688
385	0.287	0.276	0.227	0.097	−0.128	−0.357	−0.357	0.057	0.686
386	0.288	0.278	0.230	0.102	−0.124	−0.355	−0.358	0.053	0.685
387	0.290	0.280	0.233	0.107	−0.119	−0.353	−0.360	0.050	0.684
388	0.291	0.282	0.237	0.111	−0.115	−0.351	−0.362	0.047	0.682
389	0.292	0.284	0.240	0.116	−0.110	−0.349	−0.363	0.044	0.681
390	0.293	0.285	0.243	0.120	−0.106	−0.347	−0.365	0.040	0.679
391	0.295	0.287	0.246	0.125	−0.101	−0.345	−0.366	0.037	0.678
392	0.296	0.288	0.249	0.129	−0.097	−0.342	−0.368	0.034	0.676
393	0.296	0.290	0.251	0.134	−0.092	−0.340	−0.369	0.031	0.675
394	0.297	0.291	0.254	0.138	−0.087	−0.338	−0.371	0.028	0.673
395	0.298	0.292	0.257	0.142	−0.082	−0.335	−0.372	0.025	0.671
396	0.298	0.294	0.259	0.146	−0.078	−0.333	−0.374	0.021	0.670
397	0.299	0.295	0.262	0.151	−0.073	−0.331	−0.375	0.018	0.668
398	0.299	0.296	0.264	0.155	−0.069	−0.328	−0.376	0.015	0.667
399	0.300	0.297	0.267	0.159	−0.064	−0.326	−0.378	0.012	0.665
400	0.300	0.297	0.269	0.163	−0.060	−0.323	−0.379	0.009	0.664

TABLE B
Bessel Function, J_0 (S cos θ) (*Concluded*)

$S°$	Elevation angle, $\theta°$								
	0°	10°	20°	30°	40°	50°	60°	70°	80°
401	0.300	0.298	0.271	0.167	−0.055	−0.321	−0.380	0.006	0.662
402	0.300	0.298	0.273	0.171	−0.050	−0.318	−0.381	0.003	0.661
403	0.300	0.299	0.275	0.175	−0.046	−0.315	−0.382	0.000(−)	0.659
404	0.300	0.299	0.277	0.179	−0.041	−0.313	−0.383	−0.003	0.658
405	0.300	0.300	0.279	0.183	−0.036	−0.310	−0.385	−0.006	0.656
406	0.299	0.300	0.281	0.186	−0.032	−0.307	−0.386	−0.009	0.655
407	0.299	0.300	0.283	0.190	−0.027	−0.304	−0.387	−0.012	0.653
408	0.298	0.300	0.284	0.194	−0.023	−0.302	−0.388	−0.016	0.652
409	0.298	0.300	0.286	0.198	−0.018	−0.299	−0.389	−0.019	0.650
410	0.297	0.300	0.287	0.201	−0.013	−0.296	−0.390	−0.022	0.648
411	0.296	0.300	0.289	0.204	−0.009	−0.293	−0.390	−0.025	0.647
412	0.296	0.299	0.290	0.208	−0.004	−0.290	−0.391	−0.028	0.645
413	0.295	0.299	0.291	0.211	0.000(+)	−0.287	−0.392	−0.031	0.644
414	0.294	0.298	0.293	0.215	0.005	−0.284	−0.393	−0.034	0.642
415	0.292	0.298	0.294	0.218	0.009	−0.281	−0.394	−0.037	0.641
416	0.291	0.297	0.295	0.221	0.014	−0.278	−0.394	−0.040	0.639
417	0.290	0.297	0.295	0.224	0.018	−0.275	−0.395	−0.043	0.638
418	0.289	0.296	0.296	0.227	0.023	−0.272	−0.396	−0.046	0.636
419	0.287	0.295	0.297	0.230	0.027	−0.269	−0.396	−0.049	0.635
420	0.286	0.294	0.298	0.233	0.032	−0.266	−0.397	−0.052	0.633

APPENDIX C DIRECTIONAL ANTENNAS HAVING MORE THAN TWO TOWERS

A Three-Tower-in-Line-Array Pattern Shape

Three towers in line spaced an equal distance between adjacent towers and with the end towers having equal inverse fields and phasings that are equal but opposite in sign are shown in Fig. CA-1. The resultant inverse field strength at 1 mile in the direction of any point P in the horizontal plane is shown in the vector diagram of Fig. CA-b. The resultant vector E always lies along the vector reference axis. This simplifies the pattern computations.

The resultant inverse field strength E at 1 mile in the direction of point P in the horizontal plane is given by

$$E = E_1\underline{|0} + E_2\underline{|\beta_2} + E_3\underline{|\beta_3} \qquad \text{[C-1]}$$

where E = resultant inverse field strength at 1 mile, mv/m
E_1 = inverse field strength from tower 1 at 1 mile while array is in operation, mv/m
E_2 = inverse field strength from towers 2 and 3 at 1 mile while array is in operation, mv/m

$$\beta_2 = -\beta_3 = S_2 \cos\phi + \Psi_2 \qquad \text{[C-2]}$$

where S_2 = spacing from tower 1 to 2 and 3, deg
ϕ = azimuth angle to observation point P, deg
Ψ_2 = phase of tower 2 with respect to tower 1, deg

The magnitude of E in the above equation can be written

$$E = E_1(1 + 2F_2 \cos\beta_2) \qquad \text{[C-3]}$$

where $F_2 = E_2/E_1$. This equation is in convenient form for computing the horizontal pattern. It can also be used to determine the effect of any change in the design parameters. For example, for a given spacing $S_2 = 90°$ and direction $\phi = 60°$, the equation can be written

$$E = E_1[1 + 2F_2 \cos(45 + \Psi_2)] \qquad \text{[C-4]}$$

If $F_2 = 0.5$, then the equation becomes

$$E = E_1[1 + \cos(45 + \Psi_2)] \qquad \text{[C-5]}$$

Now when Ψ_2 is selected properly, E can be made to have any value from 0 to $2E_1$. If E is to be zero at 60 and 300°, since the pattern is symmetrical,

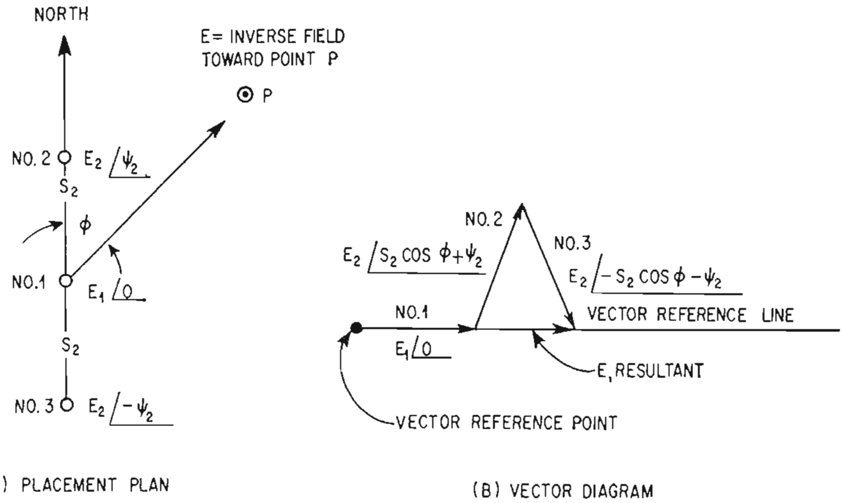


Fig. CA. Three-tower-in-line array.

then $\cos(45 + \Psi_2) = -1$ or $\Psi_2 = 135°$. For this condition the horizontal-pattern equation is written:

$$E = E_1 [1 + \cos(90 \cos\phi + 135)] \qquad \text{[C-6]}$$

When ϕ is varied from 0 to 180°, the complete pattern can be determined because it is symmetrical around the line of towers.

In general a three-tower-in-line array will produce a pattern with four nulls. Actually the pattern of Eq. C-6 has four nulls, but two occur at $\phi = 60°$, and two occur at $\phi = 300°$. This results in wider angles of low field strength at these two bearings than would be the case with single nulls.

The multiplication form for three towers in line is a more useful form and in the horizontal plane is written

$$E = 2E_1 \sqrt{F_2F_3} \left[\left(\frac{1 + F_2^{\,2}}{2F_2} + \cos\beta_2 \right) \left(\frac{1 + F_3^{\,2}}{2F_3} + \cos\beta_3 \right) \right]^{1/2} \qquad \text{[C-7]}$$

where
$F_2 = E_2/E_1$
$F_3 = E_2/E_1$
$\beta_2 = S_2 \cos\phi + \Psi_2$
$\beta_3 = -S_2 \cos\phi - \Psi_3$

and the other values are defined above. Each parenthesis term in Eq. C-7 gives the pattern shape for two towers. The resulting pattern is produced by multiplying these terms together and taking the square root. With this design the direction of the nulls can be controlled for each pair of towers, the center tower in this case acting like two towers. If F_2 and F_3 are other than unity, a minimum rather than a null will result. Thus it is possible to fill in one pair of nulls independently of the other set.

Attention is directed to the minimum-depth terms

$$\frac{1 + F_2^{\,2}}{2F_2} \quad \text{and} \quad \frac{1 + F_3^{\,2}}{2F_3}$$

which can be determined from Appendix B, Table A. The actual values of F_2 and F_3 or their reciprocal values can be used to obtain the same result. If the actual reciprocal values are used to make adjustments in the field, this fact should be made clear in the report to FCC and there should be no objection on their part.

Four-Tower Parallelogram-Array Pattern Shape

General Case

The plan configuration of a four-tower parallelogram array is shown in Fig. B along with the related vector diagram. The general equation for the pattern can be written

$$\text{[C-8]}$$

$$E = E_1 f_1(\theta)[1 + F_2^{\,2} + F_3^{\,2} + F_4^{\,2} + 2F_2 \cos\beta_2 + 2F_3 \cos\beta_3 + 2F_4 \cos\beta_4 + 2F_2F_4 \cos(\beta_2 - \beta_4) + 2F_2F_3 \cos(\beta_2 - \beta_3) + 2F_3F_4 \cos(\beta_3 - \beta_4)]^{1/2}$$

where E = inverse field strength at 1 mile in direction of point P, mv/m
$\beta_2 = S_2 \cos(\phi_2 - \phi)\cos\theta + \Psi_2$
$\beta_3 = S_3 \cos(\phi_3 - \phi)\cos\theta + \Psi_2$
$\beta_4 = S_4 \cos(\phi_4 - \phi)\cos\theta + \Psi_2$

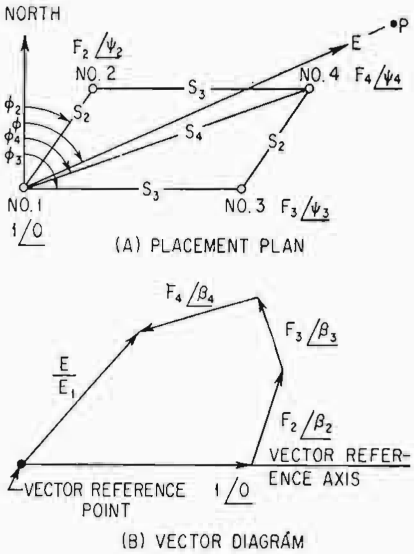


Fig. CB. General parallelogram array.

$$F_2 = \frac{E_2 f_2(\theta)}{E_1 f_1(\theta)}$$

$$F_3 = \frac{E_3 f_3(\theta)}{E_1 f_1(\theta)}$$

$$F_4 = \frac{E_4 f_4(\theta)}{E_1 f_1(\theta)}$$

E_1, E_2, E_3, and E_4 = inverse field strength at 1 mile, produced by towers 1 to 4, respectively when, the array is in operation, mv/m

$f_1(\theta)$, $f_2(\theta)$, $f_3(\theta)$, and $f_4(\theta)$ = vertical radiation characteristic of towers 1 to 4, respectively

This equation is valid for towers of unequal height but is of a form seldom used. if the restriction $\beta_4 = \beta_2 + \beta_3$ and $F_4 = F_2 F_3$ is applied, Eq. C-8 can be written

$$E = 2E_1 f_1(\theta) \sqrt{F_2 F_3} \left[\left(\frac{1 + F_2^2}{2F_2} + \cos\beta_2 \right) \left(\frac{1 + F_3^2}{2F_3} + \cos\beta_3 \right) \right]^{1/2} \qquad \text{[C-9]}$$

where the terms are defined above.

It is noted that tower 4 must have the following field ratio:

$$F_4 = F_2 F_3 = \frac{E_2 f_2(\theta) E_3 f_3(\theta)}{E_1^2 f_1^2(\theta)} \qquad \text{[C-10]}$$

If $E_1 = E_2 = E_3$, then the vertical-radiation characteristics of tower 4 must be

$$f_4(\theta) = \frac{f_2(\theta) f_3(\theta)}{f_1^2(\theta)} \qquad \text{[C-11]}$$

Since all $f(\theta)$ values are unity along the ground, this condition cannot be detected in the horizontal plane. However, if the parallelogram array is operated at night when high angle radiation is involved, it is necessary to compute the radiation at various elevation angles and the above equation must be considered.

The greatest practical value of Eq. C-9 is that it gives information concerning the exact location of the four minima, two for each of the two-tower patterns unless spacings greater than 180° are used, and in such cases there may be four minima per two-tower pattern. This information is useful in the design and adjustment of the parallelogram array. It comes from the condition when $\beta = 180°$.

Then the minimum-depth terms give useful information concerning the value of field strength to be expected in these directions. They are helpful in shaping the pattern to meet the design requirements.

The expression inside the brackets completely defines the pattern shape. The factor $2E_1 f_1(\theta)\sqrt{F_2 F_3}$ outside the bracket defines the pattern size, especially the term E_1, which will be evaluated in a later section of this appendix.

Special Three-Tower-in-Line Case

If tower 2 is placed on top of tower 3, a three-tower-in-line array will result as shown in Fig. C-2. This arrangement is redrawn in Fig. C-3.

Special Three Towers Not in Line

If in Eq. C-8 the condition that $F_4 = 0$ is imposed, the equation reduces to

$$E = E_1 f_1(\theta) \left[2F_2 \left(\frac{1 + F_2^{\,2}}{2F_2} + \cos\beta_2 \right) + 2F_3 \left(\frac{1 + F_3^{\,2}}{2F_3} + \cos\beta_3 \right) - 1 + 2F_2F_3 \cos(\beta_2 - \beta_3) \right]^{1/2} \qquad \text{[C-12]}$$

This equation is essentially an addition formula for a three-tower-not-in-line array as shown in Fig. CD plus the variable term $2F_2F_3 \cos(\beta_2 - \beta_2) - 1$. The -1 merely translates the sum of the other three terms to the left one unit. Hence it remains only to find how the pattern changes with the addition of the two patterns plus the term $2F_2F_3 \cos(\beta_2 - \beta_3)$. The effect of change in parameter values can be noted in the computations. The information can be very useful in making adjustments on this type of array.

Pattern-Size Determination

Four-Tower Array

The equation to determine the field strength from the reference tower 1 is

$$E_1 = E_{1S} \sqrt{\frac{R_{11}}{R_1 + M_{21}^{\,2}R_2 + M_{31}^{\,2}R_3 + M_{41}^{\,2}R_4}} \qquad \text{[C-13]}$$

where E_1 = inverse field strength at 1 mile in horizontal plane from tower 1 while operating in the array, mv/m

E_{1S} = inverse field strength at 1 mile in horizontal plane from tower 1 operating alone, mv/m

R_1, R_2, R_3, and R_4 = driving-point resistance values at input terminals of towers 1 to 4 respectively, ohms

M_{21}, M_{31}, and M_{41} = loop-current ratios of towers 2, 3 and 4 to tower 1, respectively

Only magnitude values are used in the above equation. The driving-point resistances, as in Eq. B-5, are made up of self-, mutual-, and loss-resistance terms.

They can be written

$$R_1 = R_{11} + R_{L1} + R_{C1} \qquad \text{[C-14]}$$

$$R_2 = R_{22} + R_{L2} + R_{C2} \qquad \text{[C-15]}$$

$$R_3 = R_{33} + R_{L3} + R_{C3} \qquad \text{[C-16]}$$

$$R_4 = R_{44} + R_{L4} + R_{C4} \qquad \text{[C-17]}$$

where R_{11}, R_{22}, R_{33}, and R_{44} = self-loop radiation resistance of towers 1 to 4, respectively, ohms

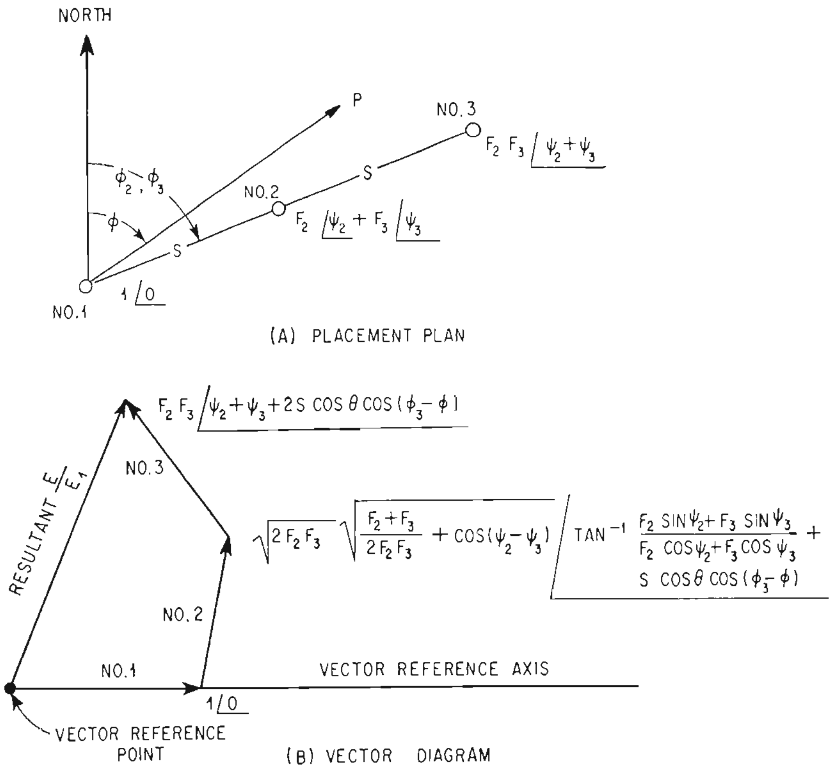


Fig. CC. Special three-tower-in-line array.

R_{L1}, R_{L2}, R_{L3}, and R_{L4} = loop-loss resistance of towers 1 to 4, respectively, ohms

R_{C1}, R_{C2}, R_{C3}, and R_{C4} = loop-coupled resistance of towers 1 to 4, respectively, ohms

In Eq. C-13 the value of E_{1s}, R_{11}, R_{22}, R_{33}, and R_{44} can be obtained from Appendix A, Fig. E, R_{L1}, R_{L2}, R_{L3}, and R_{L4} are usually assumed to be 2 ohms for towers 90° high or taller. The values of coupled resistance can be obtained from the mutual-impedance terms in mesh circuit equations, which can be written

$$R_{C1} = M_{21}Z_{12}\cos(\Psi_{12}+\gamma_{12}) + M_{31}Z_{13}\cos(\Psi_{13}+\gamma_{13}) + M_{41}Z_{14}\cos(\Psi_{14}+\gamma_{14}) \quad \text{[C-18]}$$

$$R_{C2} = M_{12}Z_{21}\cos(\Psi_{21}+\gamma_{21}) + M_{33}Z_{23}\cos(\Psi_{23}+\gamma_{23}) + M_{42}Z_{24}\cos(\Psi_{24}+\gamma_{24}) \quad \text{[C-19]}$$

$$R_{C3} = M_{13}Z_{31}\cos(\Psi_{31}+\gamma_{31}) + M_{23}Z_{32}\cos(\Psi_{32}+\gamma_{32}) + M_{43}Z_{34}\cos(\Psi_{34}+\gamma_{34}) \quad \text{[C-20]}$$

$$R_{C1} = M_{14}Z_{41}\cos(\Psi_{41}+\gamma_{41}) + M_{24}Z_{42}\cos(\Psi_{42}+\gamma_{42}) + M_{34}Z_{43}\cos(\Psi_{43}+\gamma_{43}) \quad \text{[C-21]}$$

where Z_{pq} = Z_{qp} = magnitude of loop mutual impedance between tower p and tower q, ohms

γ_{pq} = γ_{qp} = angle of loop mutual impedance between tower p and tower q, deg

Ψ_{pq} = $-\Psi_{qp}$ = electrical phasing of tower q with respect to tower p, deg

The loop coupled reactance X_{C1}, X_{C2}, X_{C3}, and X_{C4} of towers 1 to 4, respectively can be calculated from Eqs. C-18 to C-21 by replacing cos by sin throughout. The coupled reactance values are not needed for the determination of the size of E_1. However, they are useful when it comes to determining the driving-point impedances and setting up the matching networks at the towers.

The mutual-impedance terms required above for ordinary equal-height towers are shown in Fig. B-14. The mutual impedance between top-loaded towers may be assumed equal to the mutual impedance between the same towers not top-loaded in most cases.

The above equations can also be applied to top-loaded sectionalized towers but with major problems. The radiation E_{1s} and self-resistance values are not readily available in general. Also, the mutual impedances must be calculated except for special cases which are available.

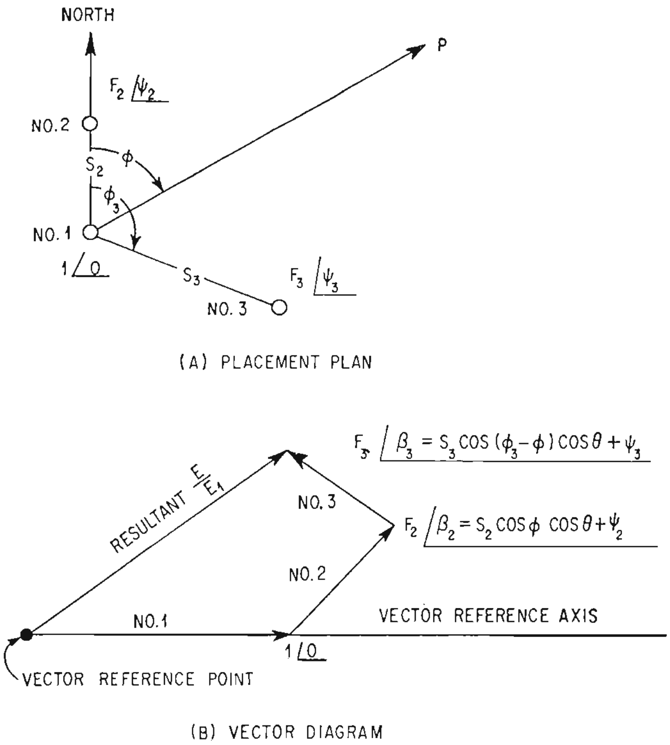


Fig. CD. Special three-tower-not-in-line case.

When E_1 is determined by Eq. C-13, the pattern can be plotted to its exact size.

Three-Tower Array

The equation to determine the field strength for a three-tower array can be written

$$E_1 = E_{1s}\sqrt{\frac{R_{11}}{R_1 + M_{21}{}^2R_2 + M_{31}{}^2R_3}} \qquad \text{[C-22]}$$

where the values are defined following Eq. C-13. The terms involving tower 4 in Eqs. C-18, C-19, and C-20 will vanish.

Horizontal-Plane RMS Field Strength of Four-Tower Array

The equation for the rms field strength in the horizontal plane of a four-tower array is

$$\begin{aligned} E_0 = E_1[1 &+ F_2{}^2 + F_3{}^2 + F_4{}^2 \\ &+2F_2 \cos \Psi_{12}J_0(S_{12}) \\ &+2F_3 \cos \Psi_{13}J_0(S_{13}) \\ &+2F_4 \cos \Psi_{14}J_0(S_{14}) \\ &+2F_2F_3 \cos \Psi_{23}J_0(S_{23}) \\ &+2F_2F_4 \cos \Psi_{24}J_0(S_{24}) \\ &+2F_3F_4 \cos \Psi_{34}J_0(S_{34})]^{1/2} \end{aligned} \qquad \text{[C-23]}$$

where
- E_0 = rms inverse field strength in horizontal plane, mv/m
- E_1 = inverse field strength at 1 mile produced by tower 1 while operating in array, mv/m,
- F_2, F_3, and F_4 = inverse field-strength ratios of towers 2, 3 and 4 to tower 1, respectively.
- Ψ_{pq} = electrical phasing of tower q with respect to tower p as designated by the subscript numbers, deg
- S_{pq} = spacing of tower q to tower p as designated by the subscript numbers, deg
- $J_0(S_{pq})$ = Bessel function of first kind and zero order of the spacing as designated by the subscripts and given in Appendix B, Table B.

A good check on the arithmetic is to measure the pattern area with a planimeter.

For a four-tower parallelogram array Eq. C-23 reduces to

$$\begin{aligned} E_0 = E_1[1 &+ F_2{}^2 + F_3{}^2 + F_4{}^2 \\ &+2(F_2 + F_3F_4) \cos \Psi_{12}J_0(S_{12}) \\ &+2F_4 \cos \Psi_{14}J_0(S_{14}) \\ &+2F_2F_3 \cos \Psi_{23}J_0(S_{23}) \\ &+2(F_3 + F_2F_4) \cos \Psi_{13}J_0(S_{13})]^{1/2} \end{aligned} \qquad \text{[C-24]}$$

where the terms are defined following Eq. C-23.

Horizontal-Plane RMS Field Strength of Three-Tower Array

The equation for the rms field strength in the horizontal plane of a three-tower array is

$$\begin{aligned} E_0 = E_1[1 &+ F_2{}^2 + F_3{}^2 \\ &+2F_2 \cos \Psi_{12}J_0(S_{12}) \\ &+2F_3 \cos \Psi_{13}J_0(S_{13}) \\ &+2F_2F_3 \cos \Psi_{23}J_0(S_{23})]^{1/2} \end{aligned} \qquad \text{[C-25]}$$

where the terms are defined following Eq. C-23.

For the special three-tower-in-line array of Fig. C-1 the above equation reduces to

$$\begin{aligned} E_0 = E_1[1 &+ 2F_2{}^2 \\ &+4F_2 \cos \Psi_{12}J_0(S_{12}) \\ &+2F_2{}^2 \cos (2\Psi_{12})J_0(2S_{12})]^{1/2} \end{aligned} \qquad \text{[C-26]}$$

where the terms are defined following Eq. C-23.

10

Power Dividers for Directional Antenna Systems

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GENERAL

A directional antenna system is a complex network of radiators, branching, and coupling circuits that are integrated into a single closely coupled system. Radio frequency energy is fed to the individual radiating elements of the array or system in the proper proportions and phase angle relationship to produce the desired radiation pattern. The control of the amount of power flowing to each radiator and its phase angle relationship to that in the other radiators is the function of a system of networks for dividing the power, shifting its phase, and matching the various impedances encountered in the array. This feeder system should have a degree of flexibility and a range of adjustment that permits this function to be accomplished at the initial tune up and at any time that the performance of the system is affected by external changes.

TYPICAL FEEDER SYSTEM

A block diagram of a typical feeder system is shown in Fig. 1. The power divider is a branching circuit that divides the total transmitter power between the individual radiators. The proportions in which this power is divided is determined by parameters of the array. Power division can be accomplished by a variety of different circuit configurations and generally takes a form that is determined by the personal preference of the designer or the engineer who is responsible for the initial tune up.

The power divider is often preceded by a matching network to give a more precise and wider range of adjustment of the input impedance of the feeder system and to provide a degree of isolation to the input impedance from short term variations occurring in the array.

The phase control of phase shifting networks are generally lagging T networks. They usually have unit impedance transformation, and have a characteristic impedance equal to that of the transmission lines that they feed. It is expedient to use networks which shift the phase by 90° since greater excursions of phase around this value can be obtained without affecting the characteristic impedance seriously. However, the actual phase shift used is dictated by the overall phase requirements of the entire system and it is not always possible to use a shift of 90° in all of the networks. It is wise, however, to manipulate the phases to affect a shift of as near 90° in as many networks as is possible.

The primary purpose of the antenna matching networks is to transform the complex operating impedance of the antennas to the characteristic impedance of the transmission lines that feed them. This impedance is a function of the antenna's self-impedance, the mutual impedances between the antenna, and the phase and magnitude of the field radiated from the antenna.[1,2] In some arrays, the impedance of one or two antennas may have a negative resistive component. This requires that the feed system provide for feeding power from the antenna back to the power divider. The phase shift in these networks is a part of the overall phase problem and must be considered along with that of the phase shfting networks and the transmission lines.

Design of networks that have specific transformation and phase properties has been discussed by several authors.[2]

POWER DIVIDERS

Any power divider is a form of one of the basic circuits shown in Fig. 2, or a combination of several of them. No matter which of these basic circuits is used, the input impedance is a complex impedance that may be transformed to any value of input resistance that is desired. The load

[1]Superscript numbers in text refer to references at the end of the chapter.

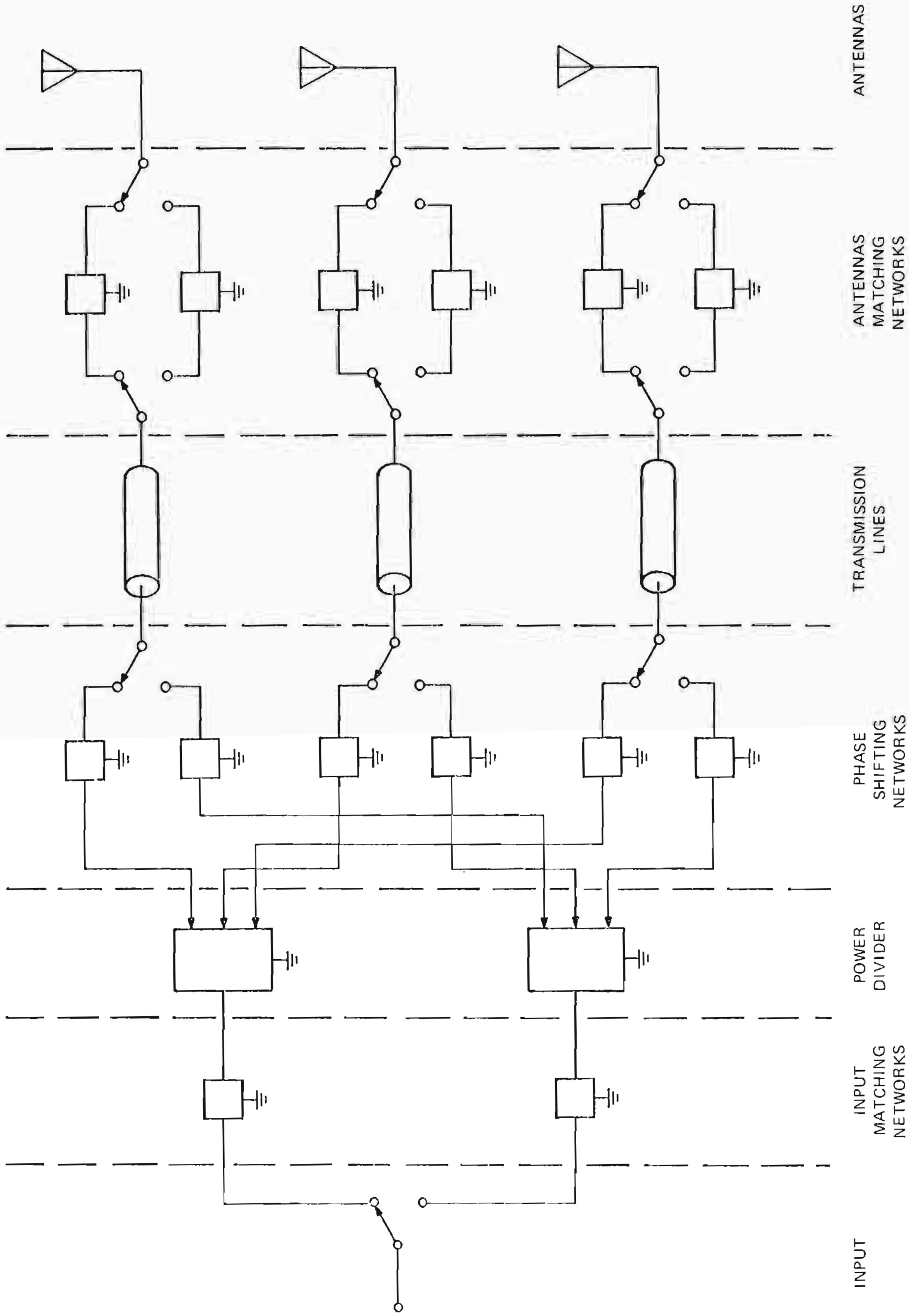

Fig. 1. Typical directional antenna feeder system.

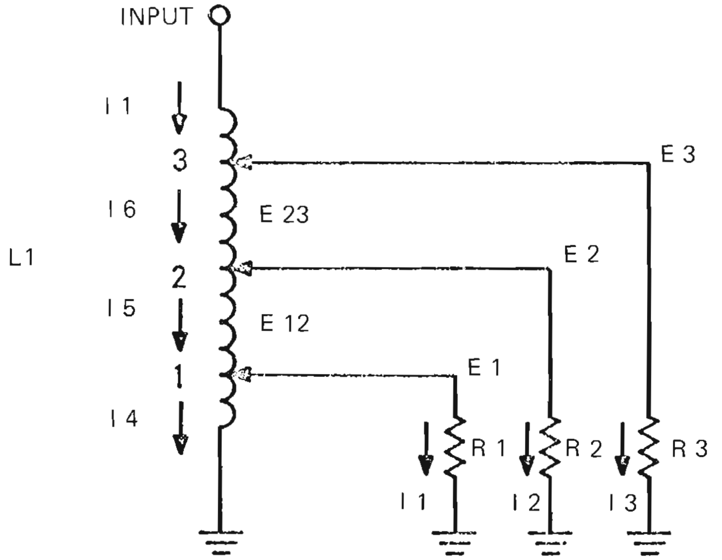

FIG. 2A. SERIES POWER DIVIDER

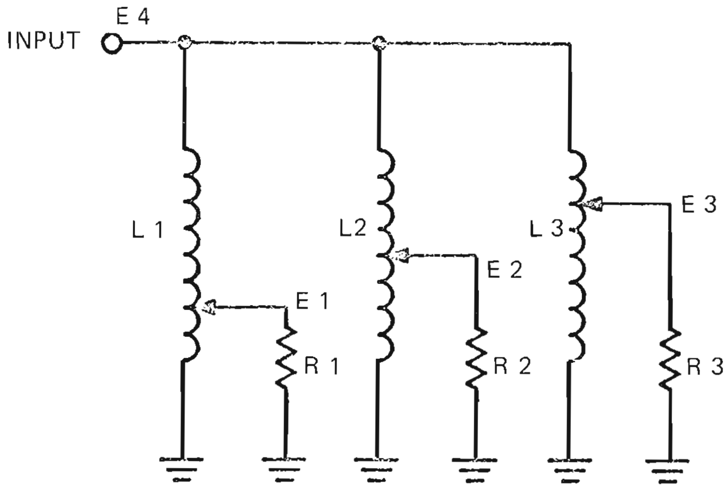

FIG. 2B. SHUNT POWER DIVIDER

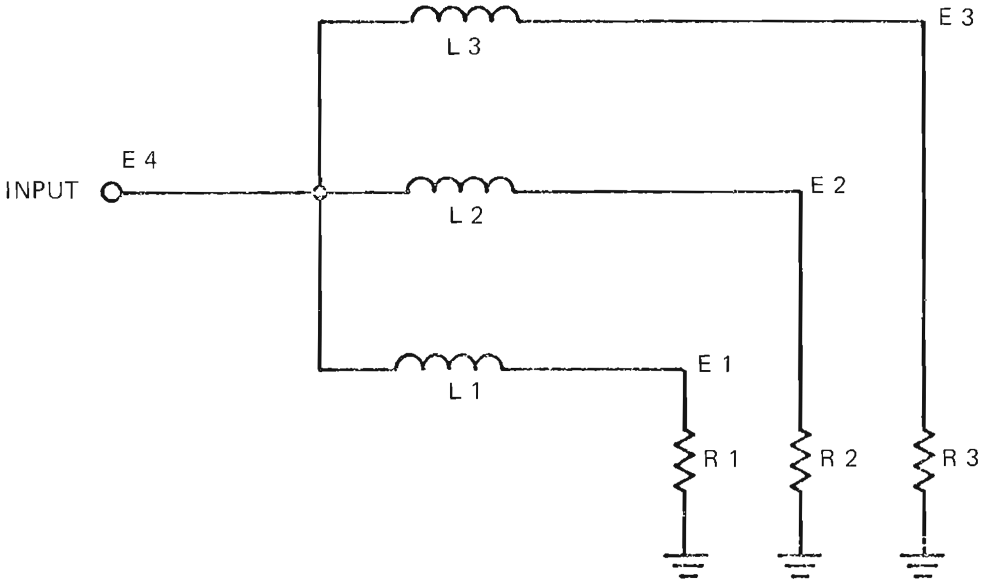

FIG. 2C. HYBRID (SHUNT SERIES) POWER DIVIDER

Fig. 2.

resistances R_1, R_2, and R_3 are the input impedances of the phase shifting networks that feed each of the lines to the antenna. Assuming that the lines are properly terminated and the phase shifting networks have a unity transformation ratio, the resistance of the loads is equal to the characteristic impedance of the lines. The voltage developed across each load is equal to the square root of the product of the power fed to the antenna and the impedance of the lines. The phase relationship between these voltages depends upon the transformation that occurs within the power divider.

The magnitude of the phase difference between these voltages is greater where the voltage difference is greater and less where the voltage difference is less, being zero when the voltages are equal. An exception to this rule occurs when a tower with a negative resistance exists and power is fed into the power divider from this tower. Phase difference may be reduced by increasing the circulating current in the divider, but, higher losses occur and a compromise between phase difference and efficiency must be reached.

DESIGN OF POWER DIVIDERS

The design of power dividers of the type shown in Fig. 2a by algebraic methods is tedious and time consuming. However, it can be accomplished easily and quickly by graphical means.[1] The accuracy of this method is as good as design by the use of a slide rule and it gives a good visual representation of the currents and voltages involved and their relationship to each other. Design errors and poor assumptions can be recognized and corrections can be quickly made.

In the examples shown, vectors with closed arrowheads represent currents and those with open arrowheads represent voltages. If rectangular coordinate paper is used, the printed divisions on the paper can be used for the magnitude of the vectors and a divider and straight edge used to transfer them to the vectors. If plain paper is used, an electrical engineers scale is used for decimal scale divisions and different scales may be used for voltages and currents.

Fig. 3 is a vector diagram of the voltages and currents found in the power divider of Fig. 2a. From antenna impedance and power division calculations,[1,2] the amount of power flowing to each of the loads is known and knowing the resistance of the loads, the magnitudes of the currents and voltages can be calculated. Since the loads are assumed to be resistive, the currents and voltages are in phase for a given load.

The current and voltage I_1 and E_1 for the load with the least power are laid out as shown in the diagram. The current in the bottom end of the inductor, I_4, is determined by the voltage, E_1, and

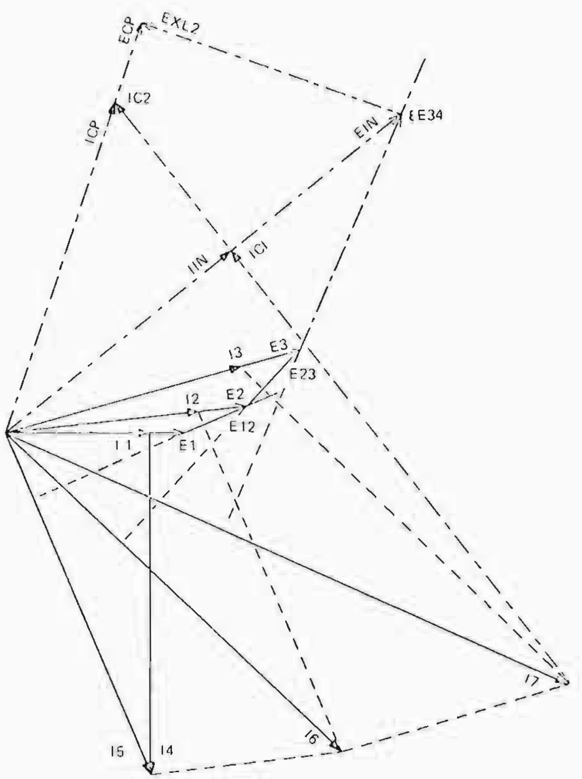

Fig. 3. (Scales I-50 E-20).

the reactance of that portion of the inductor. Since the value of this reactance has not been determined, a value of the magnitude of I_4 can be assigned to it. The relative phase of the currents in all the loads is dependent on the magnitude of this current so some care should be used when assigning a value to it. The magnitude of this current should be two to four times the value of I_1 and if I_1 is relatively small, I_4 should be chosen to be at least as large or slightly larger than I_3, the current in the load receiving the most power.

The vector sum of I_1 and I_4 is I_5, the current flowing in the inductor above the number 1 tap. The voltage developed across the portion of the coil between taps 1 and 2 leads I_5 by 90°. The voltage E_{12} is added vectorially to E_1 at right angles to I_5 to a distance from the source equal to E_2. E_2 and I_2 are then laid out on the diagram and I_2 and I_5 added vectorially to give I_6. The voltage E_{23} across taps 2 and 3 leads I_6 by 90° and is laid out to extend E_2 in a direction which is at right angles to I_6 to a distance from the source equal to E_3. This procedure is continued for as many loads as are required, in this case three, until the current into the top end of the coil and the total voltage across R_3 are determined. In our diagram, these are I_7 and E_3.

The resistive component of the impedance seen at the input (at tap 3) is then

$$R = \frac{P}{I_7^2} \text{ where } P \text{ is the total transmitter power.}$$

The magnitude of the impedance at the input is

$$Z = \frac{E_3}{I_7^2}.$$

The reactive component of this impedance is

$$X_L = +j Z \sin \cos^{-1} \frac{R}{Z}.$$

The Q of the power divider is then

$$Q = \frac{X_L}{R}$$

and may be extended to any greater value desired by increasing the amount of reactance above the upper tap. The Q of the circuit would also be greater if I_4 were initially given a higher value.

The circuit may be resonated to produce the desired input resistance. The input resistance is

$$R_{in} = (Q^2 + 1) R.$$

Since R has been determined, Q may be extended to result in the desired value for R_{in}. The value of Q then is

$$Q = \sqrt{\frac{R_{in}}{R} - 1}$$

The resonating capacitor has a reactance of

$$-j x_C = -j \frac{R_{in}}{Q}$$

R_{in} may be adjusted to the value desired for a common point resistance or may be transformed to that value by means of an L or T network.[3,4]

Problem: Design a power divider for a 3-tower directional array where the power of 10 kilowatts is divided and fed to the antennas in the following proportions, 1,800 watts, 3,200 watts, 5,000 watts by means of transmission lines of 50-ohm impedance. See Fig. 4.

The voltages at the loads are

$$E_1 = \sqrt{PR} = \sqrt{1800 \times 50} = 300 \text{ volts}$$

$$E_2 = \sqrt{PR} = \sqrt{3200 \times 50} = 400 \text{ volts}$$

$$E_3 = \sqrt{PR} = \sqrt{5000 \times 50} = 500 \text{ volts}$$

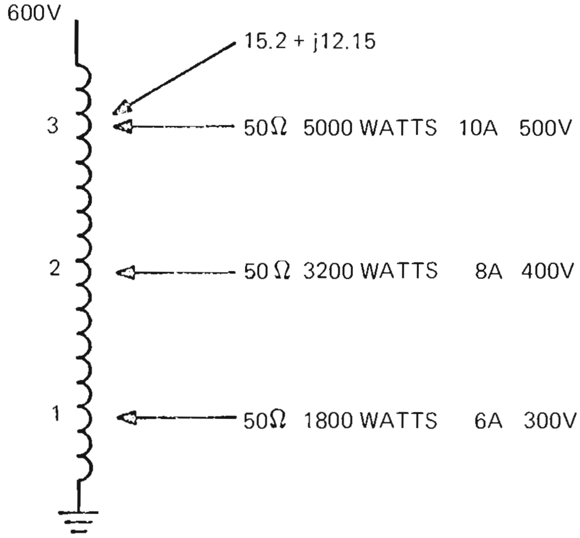

Fig. 4.

The current in the loads are

$$I_1 = \sqrt{\frac{P}{R}} = \sqrt{\frac{1800}{50}} = 6 \text{ amperes}$$

$$I_2 = \sqrt{\frac{P}{R}} = \sqrt{\frac{3200}{50}} = 8 \text{ amperes}$$

$$I_3 = \sqrt{\frac{P}{R}} = \sqrt{\frac{5000}{50}} = 10 \text{ amperes}$$

Referring to Fig. 3, the scale used for current is 50 divisions per inch and voltage scales are 20 per inch. Draw E_1, 300 volts, and I_1, 6 amperes, and add I_4, 14 amperes lagging I_1 by 90°. The value of I_4 was chosen arbitrarily. The vector sum of I_1 and I_4 is labeled I_5 and has a value of 15.2 amperes.

E_{12} is drawn from the end of E_1 and is perpendicular to I_5. E_2 is drawn to coincide with E_{12} at a point where E_2 has a value of 400 volts. A pair of dividers may be used for this purpose. I_2 is drawn along E_2 to a length of 8 amperes. I_2 and I_5 are added vectorially resulting in a value of 19.1 amperes for I_6. The procedure is continued until I_7 id determined and a value of 25.7 amperes is measured.

The input resistance then is

$$R = \frac{P}{I_7^2} = \frac{10000}{(25.7)^2} = 15.2 \text{ ohms}$$

The magnitude of the impedance is

$$Z = \frac{E_3}{I_7} = \frac{500}{25.7} = 19.45 \text{ ohms}$$

The reactive component of the impedance is

$$X_L = +j\,Z \sin(\cos^{-1}\frac{R}{Z}) = +j\,19.45 \sin(\cos^{-1}\frac{15.2}{19.45})$$

$$= j\,12.15 \text{ ohms.}$$

The common point impedance may then be adjusted to 50 ohms or a value larger than this and then transformed to 50 ohms by an L or T network.

For example, adjust the input impedance to 70 ohms and then transform to 50 ohms using an L network as shown in Fig. 5.

The Q of the circuit is

$$Q = \sqrt{\frac{R_{in}}{R} - 1} = \sqrt{\frac{70}{15.2} - 1} = 1.9$$

The resonating capacitor has a reactance of

$$X_{C1} = -j\frac{R_{in}}{Q} = -j\frac{70}{1.9} = -j\,36.8$$

To resonate the circuit, the inductive reactance of the divider must be adjusted to

$$+j\,X_L = +j\,RQ = +j\,(15.2)\,(1.9) = +j\,28.9$$

Since at tap 3 we have a reactance of $+j$ 12.15, the value of reactance to be added is 28.9 – 12.15 = 16.75.

The reactance of the inductor to be added above tap 3 is $+j$ 16.75 ohms.

The total reactance of L_1 may be determined by adding up the reactance of all of its parts. These are determined by dividing the voltage across each part by the current through it and adding them together, thus

$$j\frac{E_1}{I_4} = j\frac{300}{15} = j\,21.4$$

$$j\frac{E_{12}}{I_5} = j\frac{105}{15.2} = j\,6.92$$

$$j\frac{E_{23}}{I_6} = j\frac{125}{19.1} = j\,6.55$$

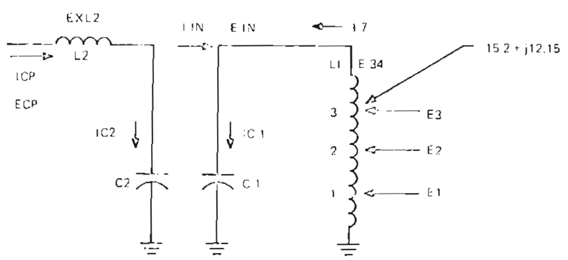

Fig. 5.

Total reactance is

$$j\,X_L = j\,21.4 + j\,6.92 + j\,6.55 + j\,16.75 = 51.62.$$

The components of the L matching network are designed as follows:

$$X_{L2} = +j\,R(\text{common point})\,Q_2$$

$$X_{C2} = -j\frac{R_{in}}{Q_2}$$

Q_2 is the Q of the L network and is

$$Q_2 = \sqrt{\frac{R_{cp}}{R_{in}} - 1} = \sqrt{\frac{70}{50} - 1} = .633$$

Then the reactance of L_2 is

$$X_{L2} = +j\,(50)\,(.633) = +j\,31.6$$

$$X_{C2} = \frac{-j\,(70)}{.633} = -j\,110.5.$$

The reactance of C_1 and C_2 may be combined into one value

$$X_c = \frac{1}{\frac{1}{-jX_{C1}} + \frac{1}{-jX_{C2}}} = \frac{1}{\frac{1}{-j36.8} + \frac{1}{-j110.5}} = -j27.6$$

The vector diagram for the power divider Fig. 3 has been extended to show the graphical design of the rest of the circuit as we have just designed it.

Currents and voltages at the divider input and the common point input for the total power are

$$I_{cp} = \sqrt{\frac{P_t}{R_{cp}}} = \sqrt{\frac{10000}{50}} = 14.14 \text{ amperes}$$

$$E_{cp} = \sqrt{P_T\,R_{cp}} = \sqrt{(10000)\,(50)} = 707 \text{ volts}$$

$$I_{in} = \sqrt{\frac{P_T}{R_{in}}} = \sqrt{\frac{10000}{70}} = 11.95 \text{ amperes}$$

$$E_{in} = \sqrt{P_T R_{in}} = \sqrt{(10{,}000)\,(70)} = 837 \text{ volts}$$

The current I_7 in the divider and the current in C_1 add vectorially to give us the current into the resonated divider I_{in} and the current in C_1, I_{C1}, is leading the voltage across it by 90°. Since the current I_{in} and E_{in} are in phase, resonant condition, they are drawn as shown in Fig. 3. E_{in} is 837 volts and when drawn as shown will coincide with E_{34} which is the voltage from tap 3 to the top of the inductor and is drawn perpendicular to I_7, the current in the top end of the inductor.

I_{C2} is added to I_{C1} for the total capacitor current. The common point current I_{cp} is 14.14 amperes and is drawn to add vectorially with I_{C2}, determining the length of I_{C2}. The voltage at the common point E_{cp} is drawn in phase with I_{cp} and has a magnitude of 707 volts. Since the common point current flows through $L2$ the voltage E_{XL2} developed across $L2$ will lead the current by 90°. The vector sum of E_{in} and E_{XL2} is E_{cp}.

The magnitude of these vector currents and voltages may be scaled and their ratio determined to give the reactance of $L2$ and C ($C1 + C2$)

$$X_{L2} = +j\,\frac{E_{XL2}}{I_{cp}} = +j\,\frac{445}{14.14} = +j\,31.6$$

$$X_c = -j\,\frac{E_{in}}{I_c} = -j\,\frac{837}{30.3} = -j\,27.6$$

These values agree with those determined earlier.

Problem: Design a power divider for a three-tower directional array where the power of 10 kilowatts is divided and fed to the antennas in the following proportion: 7800 watts, 3200 watts, -1000 watts. Transmission line impedance is 50 ohms. The solution of this problem will be covered only far enough to illustrate the procedure necessary to accommodate the negative power flow.

The load currents and voltages are

$$E_1 = \sqrt{(1000)(50)} = 224 \text{ volts}$$

$$E_2 = \sqrt{(3200)(50)} = 400 \text{ volts}$$

$$E_3 = \sqrt{(7800)(50)} = 625 \text{ volts}$$

$$I_1 = \sqrt{\frac{1000}{50}} = 4.47 \text{ amperes}$$

$$I_2 = \sqrt{\frac{3200}{50}} = 8 \text{ amperes}$$

$$I_3 = \sqrt{\frac{7800}{50}} = 12.5 \text{ amperes.}$$

Since P_1 is negative, either the current or voltage must be negative. A negative current results in a better phase angle relationship between output powers so the design will consider only a negative current for I.

The circuit diagram is shown in Fig. 6 and the vector diagram in Fig. 7. Symbols used in Fig. 2 are used in this example and the procedure is the same as used in the first problem except that now I_1 is negative so the vector is drawn in a direction opposite that of the voltage E_1. The outputs are more nearly in phase in this example. This is due to

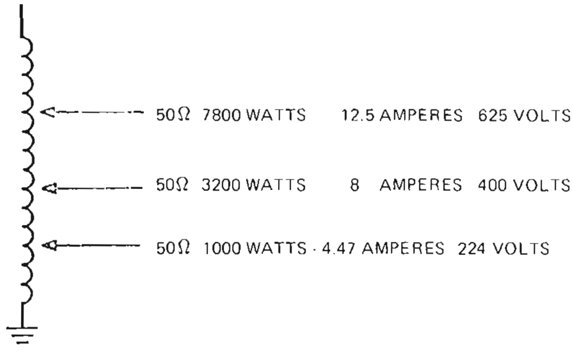

Fig. 6.

the effect of the negative current flow, I_1. I_7 in this example is 21.7 amperes and the input resistance is

$$R = \frac{P}{I_7^2} = \frac{10000}{(21.7)^2} = 21.3 \text{ ohms.}$$

The magnitude of the impedance at tap 3 is

$$Z = \frac{E_3}{I_7} = \frac{625}{21.7} = 28.8 \text{ ohms.}$$

The reactive component of the impedance is

$$X_L = j\,Z \sin\ \cos^{-1}\frac{R}{Z} = +j\,28.8 \sin\ \cos^{-1}\frac{21.3}{28.8}$$

$$= +j\,19.4 \text{ ohms.}$$

The divider impedance of $21.3 + j\,19.4$ may then be transformed to the desired common point impedance, as was done in the first example.

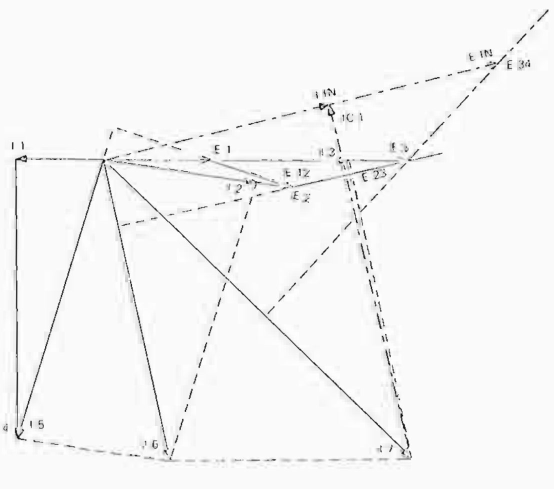

Fig. 7.

SHUNT POWER DIVIDER

The shunt power divider, as shown in Fig. 2b consists of a group of variable inductors in parallel between the common input point and ground. The loads are connected from the variable taps to ground and each is adjustable from maximum voltage to zero voltage. The impedance at the input of each of these branches depends upon the position of the tap and is a pure reactance when the tap is at the minimum position and an impedance consisting of the reactance of the total inductor in shunt with the load resistance at the maximum position. Both the total reactance of the inductor and the resistance of the load are fixed quantities for any given application. The series input impedance of each branch is determined by finding the series impedance of the load resistance and the portion of the inductor in shunt with it and adding to this series impedance the reactance of the remainder of the coil. The solution of this problem is complicated by the fact that all of these branches must be connected to a common voltage source and develop a voltage at its output that is proportional to a specified power output.

A series-parallel conversion chart is a valuable tool for the solution of the problem. This chart is illustrated in Fig. 8 and consists of a family of resistance circles on the x axis and a family of reactance circles on the y axis superimposed on rectangular grid lines. The solution of the series impedance of a reactance and resistance in parallel is accomplished by selecting the parallel resistance circle and following it to the point where it coincides with the parallel reactance circle. The vertical distance of this point from the x axis represents the series reactance and the horizontal distance from the y axis represents the series resistance. There remains, however, the reactance of the remainder of the inductor above the tap which must be added to the series reactance of the impedance for the shunt position. The locus of all of the impedance points, as the tap is moved from the top to the bottom of the inductor, is a curve beginning at the junction of the load resistance circle and the circle representing the total reactance of the inductor, terminating on the y axis at the end of this same reactance circle. A family of these curves for values to total coil reactances of from $+j50$ to $+j150$ ohms and a load resistance of 50 ohms have been drawn on the conversion chart.

The procedure for the design of a shunt power divider will be demonstrated by an example.

Problem: Design a shunt power divider, Fig. 9, for a three-tower directional array where the total power of 10 kilowatts is divided and fed to the antennas in the following proportions, 1,800 watts, 3,200 watts and 5,000 watts by means of transmission lines of 50-ohm impedance. The total reactance of each of the variable inductors is as assumed to be $+j100$ ohms. We then use the curve connecting the end points of the 100 ohm reactance circle where it coincides with the y axis at one end and the 500 ohm resistance circle at the other end. This curve is the locus of all values of branch input impedance as a 50-ohm load connection is moved from the top to the bottom of the 100-ohm inductor. A reference must now be established for one of the branches to which the other branches are related.

When the load of one of the branches is set at the top of the inductor, the branch parallel resistance is 50 ohms and the branch parallel reactance is $+j100$ ohms. The series resistance is 40 ohms and the series reactance is $+j20$ ohms. This position is shown on Fig. 8. It is desirable however to move the operating point down the coil to allow for adjustment latitude. Adjustment to Point 1, Fig. 8, results in a parallel resistance, Rp, of 70 ohms and a parallel reactance, X_p, of 75 ohms.

If the antenna receiving the most power (5,000 watts) is connected to this tap, the input voltage required is

$$E = \sqrt{PR_p} = \sqrt{5000 \times 70} = 591.6 \text{ volts.}$$

This voltage then is the input voltage for all of the branches.

The parallel resistance for the other branches may then be determined by

$$Rp = \frac{E^2}{p}$$

For the second branch, the parallel resistance is

$$Rp = \frac{(591.6)^2}{3200} = 109.4 \text{ ohms}$$

and for the third branch, the parallel resistance is

$$Rp = \frac{(591.6)^2}{1800} = 194.4 \text{ ohms.}$$

The points on our locus curve corresponding to these parallel resistance values are shown as Point 2 and Point 3. The parallel reactances for these points are read from the chart and are $+j73$ and $+j80$, respectively.

We then have three parallel resistance values and three parallel reactance values which when in shunt result in the input impedance.

The resistance values are again 70, 109.4, and 194.4 ohms. Combined in parallel, they are

$$Rp \text{ in} = \frac{1}{\dfrac{1}{Rp_1} + \dfrac{1}{Rp_2} + \dfrac{1}{Rp_3}}$$

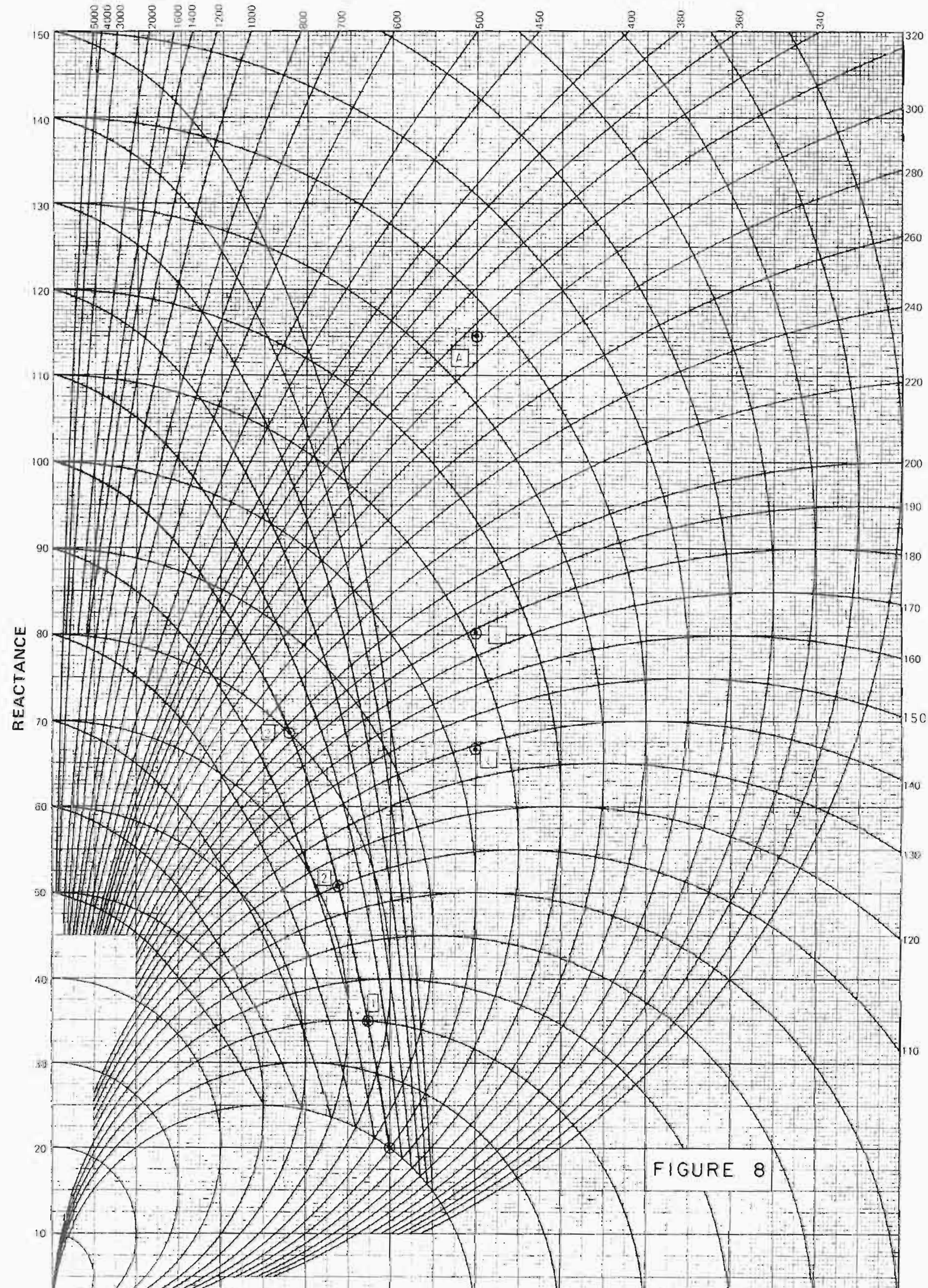

Fig. 8. A series-parallel conversion chart. The X axis is a family of resistance circles and Y axis is a family of reactance circles.

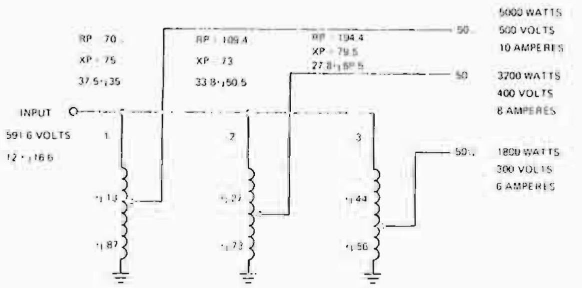

Fig. 9.

$$= \frac{1}{\frac{1}{70} \quad \frac{1}{109.4} \quad \frac{1}{194.4}} = 35 \text{ ohms.}$$

The reactance values are again $+j75$, 73, and 80 ohms. Combined in parallel they are

$$Xp \text{ in} = \frac{1}{\frac{1}{+j75} \quad \frac{1}{+j73} \quad \frac{1}{+j80}} = j25.3.$$

The total power is

$$P = \frac{E^2}{R} = \frac{(591.6)^2}{35} = 10{,}000 \text{ watts.}$$

The parallel resistance of 35 ohms and reactance of $+j25.3$ are then converted to series resistance and reactance

$$R_S = \frac{Rp \;\; Xp^2}{Rp^2 + Xp^2} = \frac{(35) \;\; (25.3)^2}{(35)^2 + (25.3)^2} = 12 \text{ ohms}$$

$$X_S = \frac{Rp^2 \;\; Xp}{Rp^2 + Xp^2} = \frac{(35)^2 \;\; (25.3)}{(35)^2 + (25.3)^2} = +j16.6 \text{ ohms.}$$

The series impedance is $12 + j16.6$ ohms.

If all of the taps are moved up on the inductors, the series resistance is raised. If larger inductors are used, the series resistance is also raised. This series impedance may then be transformed to a common point impedance by adding series inductance and resonating the circuit with a shunt capacitor as was done in the examples for a series power divider. The input impedance may be transformed to any higher value desired and then transformed to the common point by means of an L or T network, as was done in an earlier example.

The phase angle of the currents in the load referred to the input voltage may now be determined. This phase angle is the difference between the input impedance phase angle and the phase of the current in the input with respect to the current in the output. The current in the load and the current in the shunt portion of the inductor have a 90° phase difference and their vector sum is the input current. Then the phase angle between the input current and load current is

$$\beta = \tan^{-1} \frac{I_S}{I_L}.$$

where I_S is the inductor shunt current and I_L is the load current. The input impedance phase angle which also is the phase relationship between input voltage and current is

$$\phi = \tan^{-1} \frac{X_{in}}{R_{in}}.$$

The phase difference between these is the phase relationship between input voltage, which is our reference, and the output current.

$$\theta = -\tan^{-1} \frac{X_{in}}{R_{in}} + \tan^{-1} \frac{Ix}{I_L}.$$

The input impedances for the branches can be found in Fig. 8 by reading the x and y axis dimensions for the points labeled 1, 2, and 3. They are

Branch 1 (5000 watts)	$37.5 + j35$
Branch 2 (3200 watts)	$33.8 + j50.5$
Branch 3 (1800 watts)	$27.8 + j68.5$

The currents in the loads are determined by the relation

$$I_L = \sqrt{\frac{P}{R}}$$

and are for

$$\text{Branch 1, } I_{L1} = \sqrt{\frac{5000}{50}} = 10 \text{ amperes}$$

$$\text{Branch 2, } I_{L2} = \sqrt{\frac{3200}{50}} = 8 \text{ amperes}$$

$$\text{Branch 3, } I_{L3} = \sqrt{\frac{1800}{50}} = 6 \text{ amperes.}$$

The currents in the shunt portion of the inductors are determined by the relation

$$I_S = \frac{E}{X} \frac{\sqrt{PR}}{X}$$

where X is the reactance of the shunt portion.

The X can be determined from Fig. 8 by dropping our impedance points vertically to the 50-ohm parallel resistance circle and from this point following the parallel reactance circle to the y axis where the shunt reactance is read. This may be checked by measuring the distance from the impedance point to the 50-ohm circle and subtracting this value from 100.

The shunt reactance for Point 1 is found to be 87 ohms. This distance between Point 1 and the 50-ohm circle is measured and found to be 13 and confirms the value 87.

The shunt reactance for Point 2 is likewise found to be 73, and the distance from the point to the 50-ohm circle is measured and found to be 27 confirming the value 73.

In the same manner, the reactance for Point 3 is found to be 56. The distance here is 44, which confirms the value 56.

The shunt currents are then found to be

$$I_{s_1} = \frac{\sqrt{PR}}{X} = \frac{\sqrt{5000 \times 50}}{87} = 5.75 \text{ amperes}$$

$$I_{s_2} = \frac{\sqrt{PR}}{X} = \frac{\sqrt{3200 \times 50}}{73} = 5.48 \text{ amperes}$$

$$I_{s_3} = \frac{\sqrt{PR}}{X} = \frac{\sqrt{1800 \times 50}}{56} = 5.36 \text{ amperes.}$$

The phase angles of the load currents then related to the input voltage are

$$\theta_1 = -\tan^{-1}\frac{35}{37.5} + \tan^{-1}\frac{5.75}{10} = -13^\circ$$

$$\theta_2 = -\tan^{-1}\frac{50.5}{33.8} + \tan^{-1}\frac{5.48}{8} = -21.8^\circ$$

$$\theta_3 = -\tan^{-1}\frac{68.5}{27.8} + \tan^{-1}\frac{5.36}{6} = -26.2^\circ.$$

The phase difference between outputs using θ_1 as a reference are

$$\theta_1 = 0^\circ$$

$$\theta_2 = -8.8^\circ$$

$$\theta_3 = -13.2^\circ.$$

HYBRID (SHUNT-SERIES) POWER DIVIDER

The hybrid power divider, as shown in Fig. 2c, consists of a group of L networks each of which transforms the load (transmission line) impedance to a value of resistance that is determined by the power flowing into its load. Since the input impedance of each of these networks is greater than the output impedance, the shunt legs of the L networks are in parallel at their inputs and can all be combined as one reactance value equal to the reactance of all of the shunt legs in parallel. This reactance is generally capacitative and is not shown in Fig. 2c. The input impedance of each of the branches is determined by first selecting the desired input parallel resistance and determining the voltage developed across this resistance by the total power input. The input parallel resistance of each branch is then determined by the following relationship:

$$R = \frac{E^2}{P}$$

where E is the voltage across the input and P the power fed to each branch load.

Knowing both the input and output resistance, an L network for each branch may be designed or Fig. 8 may be used in the following manner. From the output load resistance value on the x axis, follow a straight line up to each of the input parallel resistances. The input impedances of each of the branches are found at the point where the vertical line crosses each input parallel resistance circle. Both series and parallel value of input resistance and reactance may be read at these points. The parallel reactance of all branches are combined in shunt to give the total parallel reactance of the input. If this is inductive, a capacitor having a reactance equal to this reactance is connected across the input, resulting in a resonant condition and an input resistance equal to that of the originally selected value.

Problem: Design a power divider, Fig. 10, for a three-tower directional antenna array where the total power of 1 kilowatt is divided and fed to the antennas in the following proportions: 200 watts, 350 watts, and 450 watts by means of transmission lines of 50-ohm impedance.

Assume that an input impedance of 62.5 ohms is specified. This may be transformed to any common point impedance desired by means of a T network.

The input voltage for our divider is found by the following relationship.

$$E = \sqrt{PR} + \sqrt{1000 \times 62.5} = 250 \text{ volts}$$

The input parallel resistances for each branch is then

$$R_1 = \frac{E^2}{P_1} = \frac{(250)^2}{200} = 312.5 \text{ ohms}$$

$$R_2 = \frac{E^2}{P_2} = \frac{(250)^2}{350} = 178.6 \text{ ohms}$$

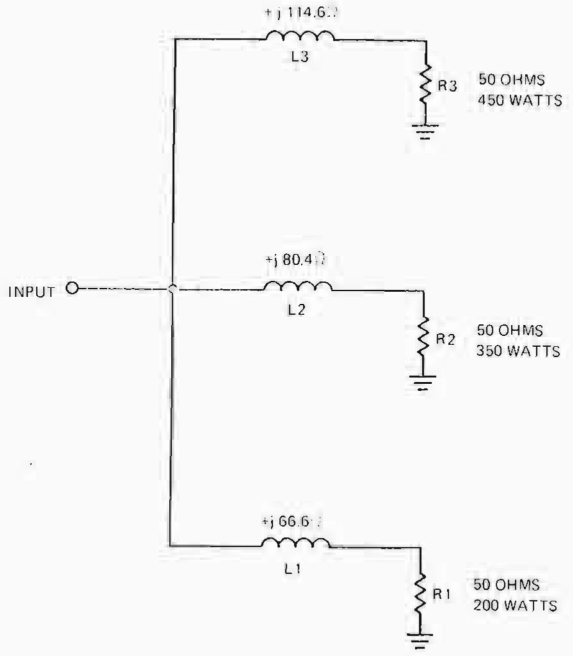

Fig. 10.

$$R_3 = \frac{E^2}{P_3} = \frac{(250)^2}{450} = 138.9 \text{ ohms.}$$

Moving in a vertical line up from the 50-ohm point on the x axis to a Point A on a 312.5-ohm resistance circle, we find a point whose rectangular coordinates are 50-ohm resistance and 114.6-ohm reactance. These are the series components of the input impedance, and the reactance value 114.6 ohms is the value of the Series Inductor $L1$. The parallel components of this impedance are found by following the circles to their indexes. The parallel resistance is the value we previously determined 312.5 ohms and the parallel reactance is found to be 136.2 ohms by following the reactance circle to the y axis. The series and parallel components are then:

$$R_{1s} = 50 \text{ ohms.}$$

$$X_{1s} = +j\,114.6 \text{ ohms}$$

$$R_{1p} = 312.5 \text{ ohms}$$

$$X_{1p} = +j\,136.2 \text{ ohms.}$$

In the same manner, the series and parallel components for the input impedance of Branch 2 are found to be at Point B.

$$R_{2s} = 50 \text{ ohms}$$

$$X_{2s} = +j\,80.4 \text{ ohms}$$

$$X_{2p} = 178.6 \text{ ohms}$$

$$X_{2p} = +j\,111 \text{ ohms.}$$

And for Branch 3, the values are found at Point C.

$$R_{3s} = 50 \text{ ohms}$$

$$X_{3s} = +j\,66.6 \text{ ohms}$$

$$R_{3p} = 138.9 \text{ ohms}$$

$$X_{3p} = +j\,104 \text{ ohms.}$$

The parallel resistances are then combined to give us the input parallel resistance.

$$\frac{1}{\frac{1}{R_{1p}} + \frac{1}{R_{2p}} + \frac{1}{R_{3p}}} = \frac{1}{\frac{1}{312.5} + \frac{1}{178.6} + \frac{1}{138.9}} = 62.5.$$

The parallel reactances are then combined to give us the input parallel reactance.

$$\frac{1}{\frac{1}{X_{1p}} + \frac{1}{X_{2p}} + \frac{1}{X_{3p}}} = \frac{1}{\frac{1}{+j136.2} + \frac{1}{+j111} + \frac{1}{+j104}} = +j38.6.$$

A capacitor of 38.6-ohm reactance is then connected across the input to resonate the circuit and to provide a resistive input impedance of 62.5 ohms. As mentioned before, this impedance may be transformed to any value by means of a T network.

The phase shifts encountered in the branches are given by this relationship

$$\theta = \tan^{-1} \frac{X_s}{R_s}$$

and

$$\theta_1 = \tan^{-1} \frac{114.6}{50} = 66.5°$$

$$\theta_2 = \tan^{-1} \frac{80.4}{50} = 58.1°$$

$$\theta_3 = \tan^{-1} \frac{66.6}{50} = 53.1°$$

An interesting special case of this power divider is called the quadrature power divider. Two outputs are required to have a phase difference of 90° with any power division ratio. Two L networks are used with one being a lagging network with an inductor in the series arm and a capacitor in the shunt arm and the other a leading network with a capacitor in the series arm and an inductor in the shunt arm. Then, if the input parallel resistance has the same value as the loads, the shunt arms will have equal values of reactance of opposite sign and can be omitted and the power divider is a branched network with a capacitor in one series arm and an inductor in the other. The solution of this divider is accomplished in the same manner as the hybrid divider with the only special requirements being that the input parallel resistance is the same as the load resistances, the phase difference is 90° and only two outputs are used.

CONCLUSION

The generally accepted types of power dividers have been described and design examples have been shown. Many combinations of these types are possible and possibly desirable depending upon the particular application involved.

These combinations are left to the ingenuity of the reader.

REFERENCES

1. E. A. Laport. *Radio Antenna Engineering.* New York: McGraw-Hill Book, 1952.
2. G. H. Brown. "Directional Antennas," *Proceeding I.R.E.*, 1937, **25**, 78-145.
3. A. P. Walker. *NAB Handbook.* New York: McGraw-Hill, 1960.
4. W. L. Everett and G. E. Anner. *Communications Engineering.* New York: McGraw-Hill, Chapter II.

11

Maintenance of Directional Antenna

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Except for the development of precise frequency control, it is probable that no other technical development has contributed so much to the efficient utilization of the standard broadcast band as the directional antenna. As of May 1974, there were authorized in the United States some 4,408 standard broadcast stations. Of these, about 1,800, or roughly 42 percent, use directional antennas in either daytime or nighttime or both. Because some stations use more than one pattern, a total of over 2,100 different directional-antenna patterns are involved.

Before authorization is granted for construction of a directional antenna in the United States, the Federal Communications Commission requires that a complete engineering showing be made. Before a license is granted for the regular operation of a directional antenna, a complete and thorough proof of performance must be made and submitted by the permittee and approved by the FCC.

We can thus assume that each directional antenna is operating properly at the time that it commences regular operation. But what of the problems of maintenance of the antenna in day-to-day operation of the system? Let us examine the factors affecting the maintenance of directional-antenna systems.

Factors Affecting the Maintenance of Directional Antenna Systems

To begin with, the design of the antenna system will affect the maintenance problems. In his design, the engineer must determine whether the array will operate with reasonable stability and efficiency. Generally speaking, the design must be such as to avoid low values of base operating resistance, either negative or positive. Such a condition could lead to excessive losses in the system and possibly to a "flip-flop" operating condition where a small change in tuning results in a drastic change in operating parameters.

In so far as the design engineer can do so, he must avoid deep minima in the pattern, since this results in a condition where a relatively small change in phase or current can cause a relatively large change in field intensity radiated in the directions of the minima.

Further factors affecting the stability of a directional antenna and the problem of its maintenance arise in the design of the phasing and coupling equipment. A design which incorporates a minimum of resonant circuits will, in general, exhibit greater stability than one which has a number of such circuits.

In the physical location of phasing and coupling equipment, one method frequently used is to have the power-division and phasing equipment distributed through the system and placed in tuning houses at the antenna bases. While this has the advantage of requiring a minimum length of transmission line and furnishes some protection against unauthorized tinkering by operating personnel, it has the disadvantage of making the initial tune-up and any necessary subsequent readjustment more difficult and lengthy than would be the case with a more convenient arrangement. The alternative and a better arrangement is to concentrate the phasing and power-dividing equipment in the transmitter building. Here the effect of adjustments can be observed at once with the monitoring system, and the tuning of the array can be completed more easily and quickly. Under this concentrated arrangement, the equipment is usually better housed, thus making for better and easier maintenance.

The development of the operating impedance bridge and the common-point impedance bridge makes it possible to incorporate a device in each phasor which permits determination at any time of the impedance of the common point of input. The common-point impedance bridge is designed to be permanently installed. In cases where a station desires to use an operating-impedance bridge at several points in the antenna system, a system of meter jacks and shorting bars can be incorporated at the common point of input and at other measuring points. If the design of the phasor is such that the common-point input network is a T network, the input coil can be made continuously adjustable, with a front-of-panel control labeled "INPUT REACTANCE." Likewise, the coil in series with the shunt capacitor of such network can be made continuously adjustable, with a front-of-panel control labeled INPUT IMPEDANCE." Thus, the common-point input impedance can be measured and adjusted if necessary during regular operation of the station.

Transmission Lines

Still more factors affecting maintenance of the directional-antenna system arise in the course of construction of the system. The choice of transmission and sampling lines, for instance, is important. Open-wire lines are unsuited for use with directional-antenna systems. The characteristics of such lines change with the accumulation of water, ice, or snow on the wires and insulators, and this alters the operating parameters of the array.

The solid-dielectric transmission lines having an outer conductor of copper braid, such as RG17U and RG19U, are also unsuitable for a directional-antenna system unless special precautions are taken. The somewhat lower efficiency of these lines must be taken into account in the design of the system. Because the outer conductor of such lines "leaks" RF energy and because of the difficulty of adequately grounding the lines along each run, the most satisfactory way in which to handle this type of line is to install it in well-grounded metal conduit. The expense of doing this, however, increases the cost of the installation so greatly as to nullify the advantage of the lower first cost of the line itself.

An article on "Phase Stability of Coaxial Cable," by Fred Mysliwiec, in the August 1967, issue of *Broadcast Engineering,* graphically pointed out the relatively large phase shifts that can occur with temperature changes in the RG-17U type of line. Such characteristics, and similar characteristics exhibited by smaller solid-dielectric lines used for sampling lines, serve to emphasize the unsuitability of such lines for use in directional installations.

No more satisfactory transmission line or sampline line can be found than air-dielectric line having either a smooth or a corrugated outer conductor of solid copper and grounded adequately along each run. The inne conductor of such lines is supported by beads of ceramic or other suitable insulation or by spirally wrapped strips or tubes of polyethylene. In any case, the major portion of the dielectric is air or nitrogen. Lines having a solid outer conductor, but using a foamed polyethylene dielectric, are also suitable, and although such lines exhibit a greater phase/temperature change than lines with essentially air dielectric, the performance is usually acceptable for all but critical installations.

Transmission lines and sampling lines should be adequately grounded along each run, and when the proper type of line is correctly installed and maintained, such lines provide many, many years of satisfactory service.

In any installation of pressurized lines, particular attention must be given to the arrangement for pressurizing the lines. Maintenance of pressure in the lines is an important part of the overall maintenance of the system; therefore, the arrangement for pressurizing must be convenient and readily accessible.

It goes without saying that the tuning equipment must be adequately housed, that all ground connections must be well made, and that good workmanship must be used in all details of the installation if maintenance problems are to be kept to a minimum.

Antenna Monitor

One of the most important aids in maintaining a directional-antenna system, if not the most important, is an adequate sampling system and a reliable antenna monitor. A sampling loop mounted on the tower is to be preferred to a resonant pickup circuit coupled to the antenna lead. If the resonant circuit is used, it will be found that the relative phase and current indications of the antenna monitor will change as the circuit drifts or is jarred out of resonance. If such a sampling pickup is used, the maintenance procedure at the station should provide for frequent checking of resonance of each such circuit.

The antenna monitor at the station should be maintained according to the directions of the manufacturer.

GENERAL MAINTENANCE PROCEDURES

Mention was made earlier of the desirability of avoiding deep minima in the design of the directional-antenna pattern. It follows that in the adjustment of the antenna, the field radiated in the direction of each minimum must not be reduced substantially below the theoretical value, since, if carried too far, such a reduction will result in a low value of field strength difficult to maintain in regular operation.

After an array has been properly adjusted in the initial operation, useful and valuable information can and should be obtained by measuring the reactance of the component branches of all tuning networks. Then if it should be necessary to replace a defective component at a later date, the value of reactance originally established can be quickly achieved. Also, the data obtained from such measurements can be used in later checking the condition of a suspected component.

After a directional antenna has been properly adjusted, a record should be made of all dial settings of variable tuning elements and the position of any clips on tapped inductors should be marked. Such marking can be done quickly and effectively by painting a strip of fingernail polish across the clip and the turn of the coil on which it is located. Where a coil has two or more clips, a different color should be used for each clip. Then, if a clip should accidentally be dislodged, it is a simple matter to replace it in the proper location.

In the maintenance of a directional-antenna system, as in the maintenance of other equipment, one rule is important: Keep it clean! Components should be wiped and blown clean each week. The tuning houses should be kept rodent and reptileproof. It adds nothing to the operation of the system to have a scorched mouse, a dead snake, or a large dirt-dauber's nest scattered among the tuning components.

Vegetation should be kept down in the vicinity of each tower base. Cut vegetation should be raked away from the tower base and burned under supervision to minimize reseeding and to prevent a fire hazard. Chemicals can be used to inhibit growth of vegetation.

Pressure in the transmission and sampling lines should be maintained at 6 to 10 pounds per square inch, using dry air or dry oil-pumped nitrogen, to prevent the entry of moisture. If a leak develops, it should be located and repaired promptly. Periodic checks should be made of the pressure gauges so as to be certain that no gauge has become stuck and is giving false indications.

It is helpful to apply a very light coating of silicone compound to exposed insulators and end seals to prevent formation of a moisture film during wet weather. It goes without saying that all insulators should be kept free of paint.

Inspection of Components

An important part of the maintenance procedure is to make a weekly visual inspection of all elements of the antenna system. Broken insulators or other damaged elements should be replaced at once. Where necessary, lightning gaps should be respaced, using a piece of flat insulation of the proper thickness as a feeler gauge.

The tightness of all connections in the antenna tuning equipment should be checked at quarterly intervals. At yearly intervals and also after every violent windstorm, a transit should be used to determine whether each tower remains plumb. It is advisable at the same time to check all tower bolts and nuts for tightness and to check for bent members. During these checks, a visual inspection should be made of the guy wires and insulators for any signs of damage or deterioration. If a tower is found to be out of plumb or other difficulties are found, a competent tower erector should be employed to correct the situation.

A prosaic, but necessary, procedure is to check each monitoring point at monthly intervals (or weekly, if required by the license) not only for the measured field intensity, but also to observe whether the directions for reaching the monitoring point are still correct, whether the marking of the monitoring point is still legible, and whether the point is free of new construction which could affect the field intensity.

Meter Readings

Meter readings having to do with the antenna system should be made carefully and logged accurately so that if difficulty arises, a complete and accurate record of what has transpired is available for reference. If an electrical storm occurs in the vicinity of the antenna, that fact should be entered in the log. Readings of the antenna base meters and the sampling loop meters must be made under conditions of no modulation. Usually, the cooperation of studio operating personnel can be obtained and a pause allowed between announcements or musical selections so that each reading can be obtained accurately. In the alternative, it is possible to rig up an "audio kill" circuit with a relay to short the audio input to the limiter, said relay being actuated by a push button located at each RF ammeter position. Needless to say, care must be used not to interrupt important announcements with this circuit. Experience will show what length of interruption of the broadcast material is necessary to permit the RF meters to "cool down" for an accurate reading, but it will usually be not over 3 or 4 seconds. When reading antenna base meters, the operator should carry with him a monitor permitting him to discern when no modulation is present. A crystal diode rectifier wired across a telephone jack and equipped with a probe or pickup coil can be used with a pair of headphones to provide such a monitor.

A device which has proved useful in antenna work is shown in Fig. 1. With the switch open, this device is a useful monitor. Adequate pickup is obtained by holding the sleeve of the plug in one's hand while touching the tip to a metal panel, messenger cable, or the like. With the switch closed, the device becomes an effective noise limiter for use with a receiver in RF bridge work.

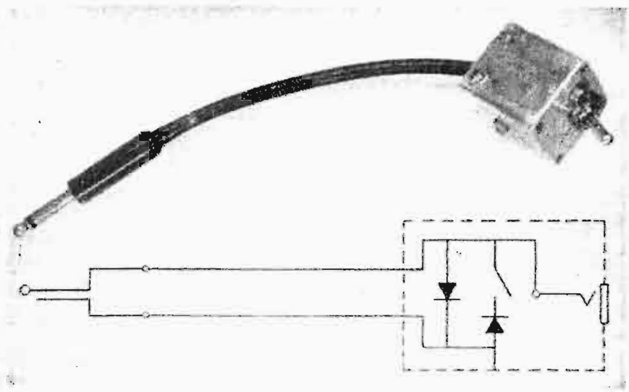

Fig. 1. Detector-noise limiter for use in antenna work.

Maintenance Report

Components

A report or maintenance book can be set up as follows. The first section shown in Fig. 2 will consist essentially of a complete description of the individual component parts arranged in four subdivisions consisting of inductance coils, capacitors, resistors, and relays. The listing in each of the subdivisions should carry a description of the unit, its location or function in the circuit, its type number, replacement-ordering information, and circuit designation. The listing should also cover the number of turns in use of each inductance coil, the value of each of the capacitors, and the dial settings of the capacitors if variable.

Meters

The second subdivision (Fig. 3) should furnish complete information concerning all meters used in the operation of the array and should consist of a listing of these units showing the circuit designations, the location and function of the unit, its range, type and serial number, and the current reading for the required output. The required antenna-monitor reading for normal operation should be listed in this subdivision.

Monitoring Points

The third subdivision (Fig. 4) should contain a listing of the monitoring points as designated by the Federal Communications Commission's license and should show the number of the monitoring points, a complete description for reaching these points, the bearing and distance, the specified unattenuated field value of one mile, the obtained unattenuated field value at one mile, together with the actual received field.

Diagrams and Measurements

The fourth and last subdivision (Fig. 5) should contain a schematic diagram and, if available, a wiring diagram of the complete antenna array equipment together with the series of curves from the Proof of Performance Report showing the dividing network or driving-point impedance of the array (Fig. 6) equipment and operating tower impedance (Fig. 7) if a single tower is used for nondirectional daytime operation. Additional pertinent information that would be of assistance to the maintenance engineer, such as transmission-line and capacitor gas pressures, should be included. While it may appear that some of this information will be a duplicate of the Proof of Performance Report, it is believed that by rearranging the data in this form and making them part of the maintenance routine, the constant reference to this information by the station engineering personnel will acquaint them with the equipment and its functions far better than a casual reference to the Proof of Performance Report.

Daily Work Schedules

The second section of the maintenance report book should contain a complete list and schedules of the daily work to be done and, where necessary, complete instruction covering the methods and equipment to be used. A suggested list is shown in Table 1. In the case of the example used, the antenna maintenance work is divided into two main classifications. The first classification is designed to cover the daily routine inspection and work that is to be handled by the "late trick" station engineer after sign-off. This work has been arranged in such a manner that all parts and circuits will be cleaned and inspected at least once each week. The second classification already mentioned has been designed to cover a series of

CIRCUIT INFORMATION

Circuit Designation	Circuit Function	Adjustment Information	Replacement Information
L1	Shunt input coil	20½ turns	Continuously variable coil—type 4224 MS4—26 μh
L2	Series input coil	9½ turns	Variable tap coil—type 322-4N4—26 μh
L3	No. 1 tank coil	8 turns	Variable tap coil—type 3208NT10—38 μh
L4	No. 2 tank coil	7 turns	Variable tap coil—type 3208NT10—38 μh
L5	No. 1 line feed coil	½ turn	Continuously variable coil—type 4103—HMS5—7 μh
L6	No. 2 line feed coil	7¾ turns	Continuously variable coil—type 4103—HMS5—7 μh
L7	No. 3 line feed coil	7 turns	Continuously variable coil—type 4103—HMS5—7 μh
L8	No. 4 line feed coil	5½ turns	Continuously variable coil—type 4103—HMS5—7 μh
L9	No. 1 line series phase coil	13¼ turns	Continuously variable coil—type 4224 MS4—26 μh
L12) L13)	No. 2 line series phase coil	8¼ turns	Continuously variable coil—type 4224 MS4—26 μh
L14	No. 2 line shunt phase coil	8½ turns	Variable tap coil—type 4164-N5—16 μh
L15) L16)	No. 3 line series phase coil	11⅓ turns	Continuously variable coil—type 4224 MS4—26 μh
L17	No. 3 line shunt phase coil	5¾ turns	Variable tap coil—type 4164-N5—16 μh
L18) L19)	No. 4 line series phase coil	8¼ turns	Continuously variable coil—type 4224 MS4—26 μh
L20	No. 4 line shunt phase coil	6 turns	Variable tap coil—type 4164-N5—16 μh
L21	No. 1 tower series input coil	11 turns	Variable tap coil—type 3164-N5—16 μh
L22	No. 1 tower series output coil (D)	7 turns	Variable tap coil—type 4165-N5—22 μh
L23	No. 1 tower shunt coil	D10 turns ND 3½ turns	Variable tap coil—type 3106-NT12—10 μh
L25	No. 2 tower series input coil	9 turns	Variable tap coil—type 4165-N5—22 μh
L26	No. 2 tower series output coil	4½ turns	Variable tap coil—type 4105-N5—12 μh
L27	No. 2 tower shunt coil	10 turns	Variable tap coil—type 4164-N5—16 μh
L29	No. 3 tower series input coil	1 turn	Variable tap coil—type 4143-N5—8 μh
L30	No. 3 tower series output coil	4 turns	Variable tap coil—type 4165-N5—22 μh
L31	No. 3 tower shunt coil	11 turns	Variable tap coil—type 4164-N5—16 μh
L33	No. 1 tower series output coil (ND)	10¾ turns	Variable tap coil—type 4165-N5—22 μh
L34	No. 4 tower series input coil	11¼ turns	Variable tap coil—type 3164-N5—16 μh
L35	No. 4 tower series output coil	5½ turns	Variable tap coil—type 3165-N5—22 μh
L36	No. 4 tower shunt coil	12 turns	Variable tap coil—type 3164-N5—16 μh
L24	No. 1 TC choke coil		RF choke
L28	No. 2 TC choke coil		RF choke
L32	No. 3 TC choke coil		RF choke
L37	No. 4 TC choke coil		RF choke
L38	No. 1 tower static drain		
L39	No. 2 tower static drain		
L40	No. 3 tower static drain		
L41	No. 4 tower static drain		
	Condensers	*Setting*	
C1	Shunt input capacity		Type 750FBA90—750 μμf
CA	Series input capacity		Type 1000 FBA90—1,000 μμf
C2	No. 1 tank tuning capacity	45	Type 750FVSP250—750 μμf
C3	No. 2 tank tuning capacity	85	Type 750FVSP250—750 μμf
C4	No. 1 line series phase capacity		Type 1500 FBA90—1,500 μμf
C5	No. 2 line shunt phase capacity		Type 1000 FBA90—1,000 μμf
C6	No. 3 line shunt phase capacity		Type 1000 FBA90—1,000 μμf
C7	No. 4 line shunt phase capacity		Type 1000 FBA90—1,000 μμf
C8	No. 1 tower series output capacity		Type 1000 FBA90—1,000 μμf
C9	No. 1 tower shunt capacity		Type 1250FD150—1,200 μμf
C11	No. 2 tower series output capacity		Type 1000 FBA90—1,000 μμf
C12	No. 2 tower shunt capacity		Type 1000 FBA90—1,000 μμf
C14	No. 3 tower shunt output capacity		Type 1000 FBA90—1,000 μμf
C16	No. 4 tower shunt capacity		Type 1000 FBA90—1,000 μμf
C17	No. 3 tower series output capacity		Type 1000 FBA90—1,000 μμf
C19	No. 4 tower series output capacity		Type 1000 FBA90—1,000 μμf
C20	No. 1 tower series output capacity (D)		Type 1000 FBA90—1,000 μμf
C10	No. 1 TC shunt capacity		Type CD 2-MFD
C13	No. 2 TC shunt capacity		Type CD 2-MFD
C15	No. 3 TC shunt capacity		Type CD 2-MFD
C17	No. 4 TC shunt capacity		Type CD 2-MFD
	Relays		
S1	Antenna array transfer relay		RF contactor
S4	No. 1 tower antenna ammeter switch		MBB switch
S5	No. 1 tower antenna transfer relay		RF contactor
S6	No. 2 tower antenna ammeter switch		MBB switch
S7	No. 2 tower antenna transfer relay		RF contactor
S8	No. 3 tower antenna ammeter switch		MBB switch
S9	No. 3 tower antenna transfer relay		RF contactor
S12	No. 4 tower antenna ammeter switch		MBB switch
S13	No. 4 tower antenna transfer relay		RF contactor

Fig. 2. Maintenance book showing complete description of the individual component parts.

Meter Information

Current

Meter	*Range*	*Model*	*No.*	D	ND	*Unit*
M1	0-8	640	2845	4.58	—	Transmitter input to divider network
M2	0-15	640	2843	1.0	9.9	Transmission-line current—tower 1
M3	0-8	640	2835	3.9	—	Transmission-line current—tower 2
M4	0-8	640	2820	3.8	—	Transmission-line current—tower 3
M5	0-8	640	2830	2.5	—	Transmission-line current—tower 4
M6	0-15	640	2810	1.0	9.45	Transmission-line coupling unit—tower 1
M9	0-8	640	2815	2.6	—	Transmission-line coupling unit—tower 2
M12	0-8	640	2816	3.85	—	Transmission-line coupling unit—tower 3
M15	0-5	640	2819	2.5	—	Transmission-line coupling unit—tower 4
M8	0-15	640	2821	3.0	10.39	Antenna current—tower 1
M11	0-8	640	2822	5.4	—	Antenna current—tower 2
M14	0-8	640	2823	5.35	—	Antenna current—tower 3
M17	0-5	640	2924	3.11	—	Antenna current—tower 4
*M7	0-15	425	3130	3.0	10.39	Remote antenna current—tower 1
*M10	0-8	425	3131	5.4	—	Remote antenna current—tower 2
*M13	0-8	425	3133	5.35	—	Remote antenna current—tower 3
*M16	0-8	425	3134	3.11	—	Remote antenna current—tower 4
MP1	0-150%	743	3638	100%	100%	Antenna monitor--tower 1
MP2	0-150%	743	3624	100%		Antenna monitor–tower 2
MP3	0-150%	743	3636	100%		Antenna monitor–tower 3
MP4	0-150%	743	3621	100%		Antenna monitor–tower 4

Note: All meters Weston Electric Company.
* External heater type—see Fig. 4-5 for location in circuits.

Antenna Monitor Readings for Directional Operation

Tower 1 Leads tower 2 by 230°
Tower 1 Leads tower 3 by 84°
Tower 1 Leads tower 4 by 302°

Fig. 3. Maintenance book showing complete information concerning all meters.

Monitor Points and Field-strength Information

Point 4

Azimuth angle	Distance, miles	Mv/m 1 mile Specified	Mv/m 1 mile Obtained	Mv/m Measured
12°	1.89	30	20	3.95

Insert location of measuring point as described in proof of performance

Point 14

Azimuth angle	Distance, miles	Mv/m 1 mile Specified	Mv/m 1 mile Obtained	Mv/m Measured
40°	2.75	90	76	6.5

Insert location of measuring point as described in proof of performance

Point 25

Azimuth angle	Distance, miles	Mv/m mile Specified	Mv/m mile Obtained	Mv/m Measured
63°	1.33	70	25	8.55

Insert location of measuring point as described in proof of performance

Fig. 4 *(Continued)*

Point 62

Azimuth angle	Distance, miles	Mv/m 1 mile Specified	Mv/m 1 mile Obtained	Mv/m Measured
181°	1.36	72	40	10.75

Insert location of measuring point as described in proof of performance

Point 82

Azimuth angle	Distance, miles	Mv/m 1 mile Specified	Mv/m 1 mile Obtained	Mv/m Measured
219°	2.18	52	40	5.6

Insert location of measuring point as described in proof of performance

Point 104

Azimuth angle	Distance, miles	Mv/m 1 mile Specified	Mv/m 1 mile Obtained	Mv/m Measured
302°	0.86	40	17	7.6

Insert location of measuring point as described in proof of performance

Point 118

Azimuth angle	Distance, miles	Mv/m 1 mile Specified	Mv/m 1 mile Obtained	Mv/m Measured
337°	1.15	61	40	13.4

Insert location of measuring point as described in proof of performance

Fig. 4. Maintenance book showing a listing of the monitoring points as designated by the FCC's license.

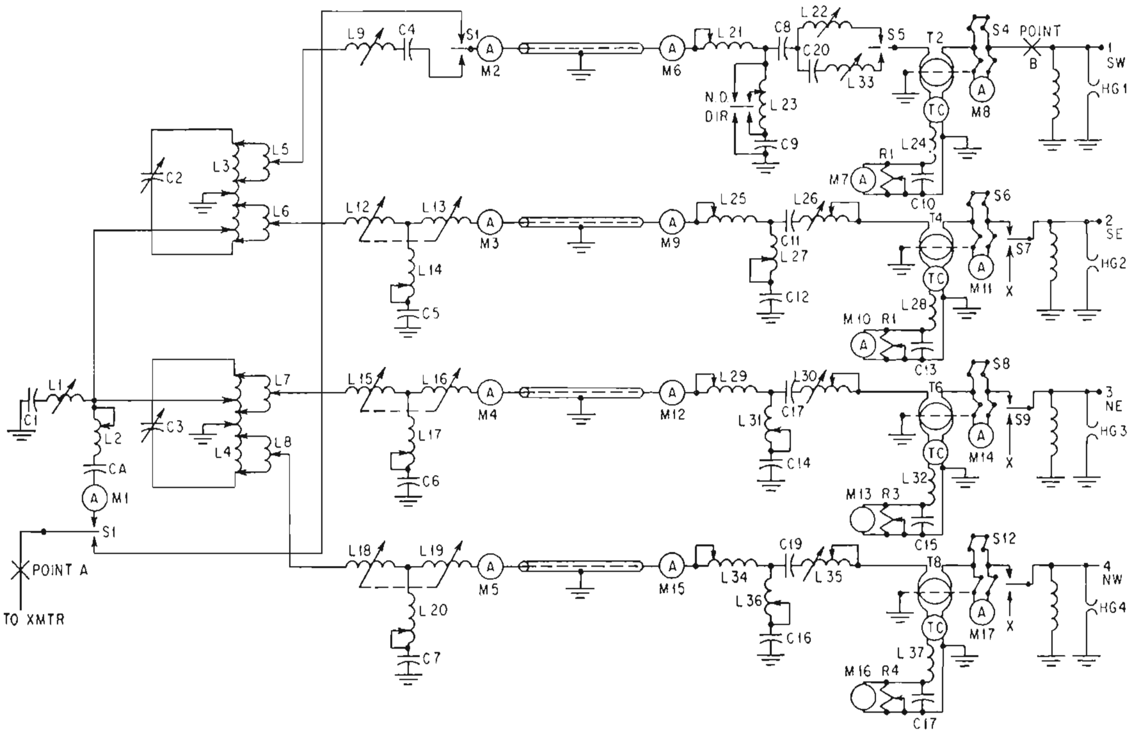

Fig. 5. Schematic diagram showing coupling and phasing networks.

FREQ (kHz)	R (OHMS)	X (OHMS)
1350	47	8.7
1355	58	4
1360	65	0
1365	68.5	-2.5
1370	68	-3
1375	62	-2
1380	51.5	0
1385	48	8.5
1390	54	25.4
1395	64	28
1400	80	23.2
1405	108	14
1410	153	0

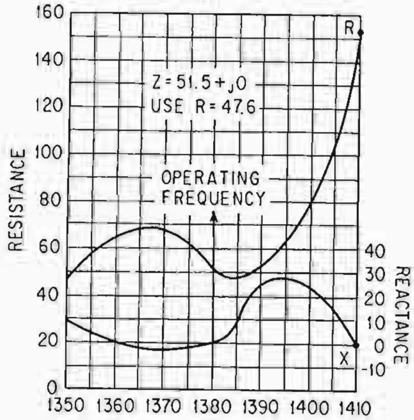

Fig. 6. Dividing network impedance.

FREQ (kHz)	R (OHMS)	X (OHMS)
1350	41.5	36
1355	42	37.5
1360	43	39.2
1365	44	41.3
1370	45	43.5
1375	45.5	44.5
1380	46.5	46.4
1385	47.5	47.5
1390	48.25	47.8
1395	49	50
1400	50	51.1
1405	51	52.7
1410	52.1	54.1

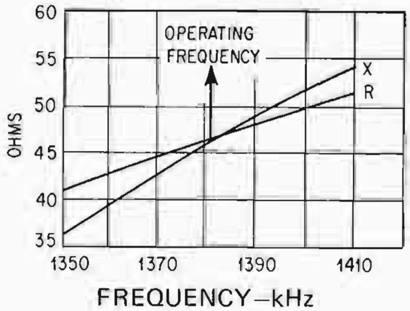

Fig. 7. Nondirectional Tower 1 impedance.

special maintenance routines for checking the array operation at regular specified intervals.

Weekly Log

The third section of the maintenance report book contains the weekly station maintenance log. This portion of the routine is of extreme importance, as it will provide the station supervisor or chief engineer with a method of checking the work done as well as the data necessary to determine the operating conditions of the array and its equipment at all times. The log shown in Fig. 8 as set up for the example station is arranged to cover one week's complete maintenance information divided into daily sections.

Each daily section provides space for recording the temperature, weather, array meter readings, antenna-monitor readings, transmission-line pressures, routine maintenance performed, routine tests results, other pertinent data, and the signature of the duty engineer.

The recorded data obtained from the daily and special maintenance tests after a period of six months can be plotted to show the actual operating conditions of the array. Variations from the normal conditions will undoubtedly appear in the graphs. By a careful analysis of the records, it will be possible to identify any variations due to seasonal or weather conditions. This accumulated information properly evaluated should provide the station engineer with a complete and thorough understanding of his directional-antenna-array operating and maintenance problems.

It is, of course, realized that the suggestions and recommendations described above are not the total and complete answers to all directional antennas. However, it is believed that the need for establishing schedules similar to the suggested program is well demonstrated and can be fitted to the individual station requirements, and the results of this program will be of mutual benefit to both the engineering staff and management.

Usually, the station license requires that field-strength measurements be made periodically at each of the monitoring points. In the event that the license does not require such measurements, it is a good practice to make them at monthly intervals.[1] Such measurements should, of course, be made carefully, and an accurate record maintained, indicating the date and time of each measurement and the field strength observed at each monitoring point. If any unusual conditions are encountered, a record should be made of them. If a monitoring point becomes unusable, an informal application should be made to the FCC to change to a new monitoring point along that radial.

In dealing with tuning equipment for directional antennas, we must deal with the component

[1] This is particularly important if the station contemplates applying to the FCC for remote control authorization.

Month			Sun.		Mon.		Tues.		Wed.		Thur.		Fri.		Sat.		Remarks				Eng.			
Date																								
Weather																								
Temperature																								
M1-Dir.																								
M2-N on-Dir.																								
M7-Dir.																								
M7-Non-Dir.																								
M10																								
M13																								
M16																								
#1-#2 Phase																								
#1-#3 Phase																								
#1-#4 Phase																								
TX Line #1 Press.																								
TX Line #2 Press.																								
TX Line #3 Press.																								
TX Line #4 Press.																								
Phase Monitor																								
Prot. Circuits																								
EMC TX Lines																								
Main Phase Unit																								
Non-Dir. Imp.																								
Dir. Imp.																								
FS Mon. Pt. #4																								
FS Mon. Pt. #14																								
FS Mon. Pt. #25																								
FS Mon. Pt. #62																								
FS Mon. Pt. #82																								
FS Mon. Pt. #104																								
FS Mon. Pt. #118																								
Overall Dir. Test																								
#1 Coupling Unit																								
#2 Coupling Unit																								
#3 Coupling Unit																								
#4 Coupling Unit																								

Fig. 8. Weekly maintenance report.

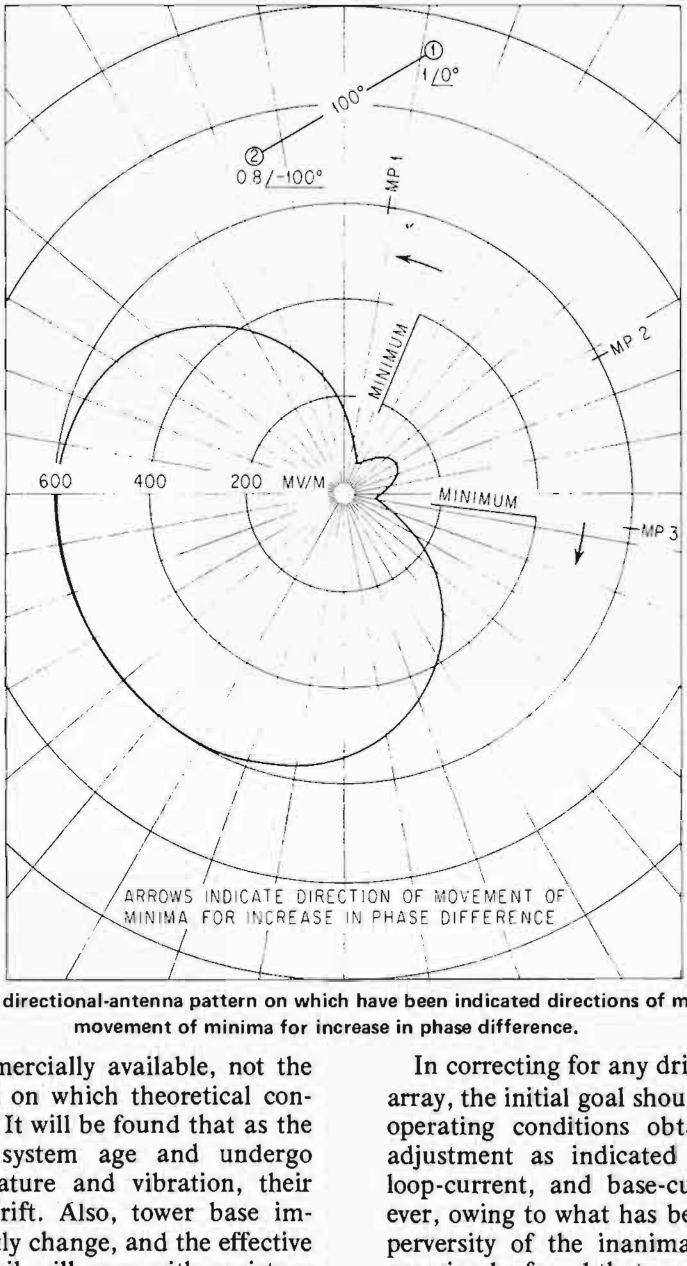

Fig. 9. Two-element directional-antenna pattern on which have been indicated directions of minima and directions of movement of minima for increase in phase difference.

parts which are commercially available, not the idealized components on which theoretical considerations are based. It will be found that as the components of the system age and undergo variations in temperature and vibration, their values will usually drift. Also, tower base impedances will frequently change, and the effective conductivity of the soil will vary with moisture content and temperature. In time, these changes may result in change of the operating parameters of the array to the extent that the field strengths at the monitoring points are no longer within the allowable values and it becomes necessary to readjust the array.

READJUSTMENT OF ARRAY

Any readjustment should be attempted only by personnel familiar with directional antenna theory. Since any adjustments of the tuning elements probably will alter the common-point impedance, it follows that the person making the adjustments must have either an operating impedance or common-point bridge or a usual RF bridge and associated equipment and must be familiar with their operation.

In correcting for any drift in adjustment of the array, the initial goal should be to reestablish the operating conditions obtained in the original adjustment as indicated by antenna monitor, loop-current, and base-current readings. However, owing to what has been politely termed the perversity of the inanimate objects, it will on occasion be found that reestablishing the original current ratios and phase indications does not result in producing the desired field strengths at the monitoring points. Assuming that the monitoring system is in good working order and that no reradiation is occurring from nearby metallic objects, it then becomes necessary to readjust the array.

Readjustment Aids

In undertaking readjustment of the array, certain aids may be found useful in guiding the adjustments to be made. For a two-element directional-antenna system, it is helpful to have a copy of the theoretical pattern on which the directions of the minima are indicated, as well as the direction of each monitoring point. Fig. 9

illustrates such a pattern. It is also helpful to indicate on this pattern the direction in which the minima will move for an increase in phase difference between the towers. It will be recognized, of course, that the depth of the minima will depend upon the current ratio. Theoretically the minima will become complete nulls if the fields radiated by the two towers are equal. This overlooks the effects of reradiation from nearby objects, but this concept does provide a point of departure for adjustment of the array.

A similar device may be found useful in readjusting an array with four towers arranged in the shape of a parallelogram. In this case, it is desirable to portray the basic patterns which go to make up the final pattern, preferably in contrasting colors. Fig. 10 shows a pattern produced by such a four-tower array. In Fig. 11, one of the basic patterns is shown as a solid line and the other as a dashed line. Here, too, arrows have been placed on the basic patterns to indicate the direction of movement of each minimum for an increase in phase difference between the sets of towers making up each basic pattern. The direction to each monitoring point is also given. Since the final pattern is the result of multiplying together the values of the basic patterns in any given direction, the effect of a change of parameters of a basic pattern on the final pattern can be readily visualized.

Vector Calculator

Of possible use for a two-tower system is a calculator in the form of a circular slide rule, based on an article appearing in the December 1944, issue of *Proceedings of the IRE.* Fig. 12 illustrates such a calculator, which was quickly constructed from two sheets of graph paper and a piece of cardboard. In the operation of this calculator, the towers are numbered 1 and 2, and the phase of Tower 2, read on the scale on the periphery of the rotary element, is set to the vertical zero degree line. The outer fixed-scalė on the base represents the bearing from the line of towers, measured from the Tower 2 end. A

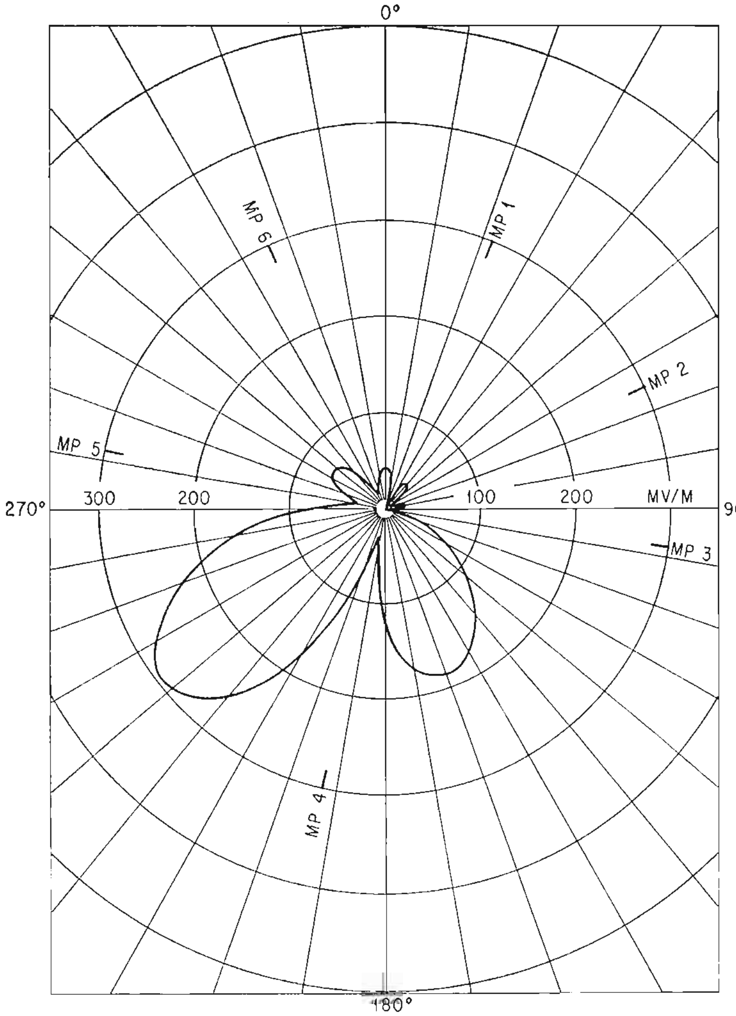

Fig. 10. Pattern produced by a directional antenna consisting of four elements arranged in a parallelogram.

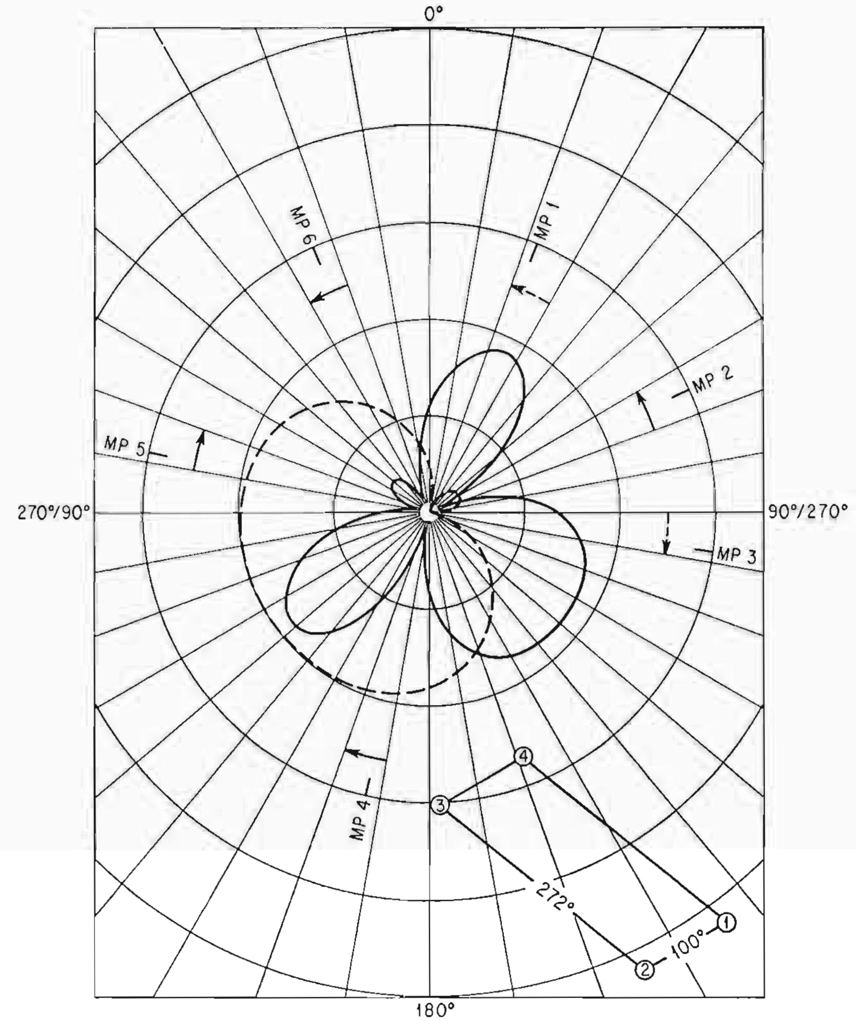

Fig. 11. Basic vector patterns which make up the pattern of Fig. 10. Arrows indicate the directions of movement of minima for increase in phase difference between pairs of elements.

separate outer scale is needed for each tower spacing. The group of figures on the runner represents field ratios. The resultant vector field is read from the inner scale opposite the figure for the field ratio. It can be seen that the effect of a change in phase or field ratio on the field radiated in any given direction can be quickly determined.

A modified form of the calculator can be used with a three-element in-line array. The vector representation of the resultant field of such an array in a given direction is as shown in Fig. 13, where vector 2 represents the field from the center tower and vectors 1 and 3 represent the fields from the end towers. Considering the position of vector 2 as fixed, vectors 1 and 3 revolve in opposite directions as one's vantage point is moved around the array.

When redrawn, the vector relationship is as shown in the lower half of Fig. 13. Here *R* is the resultant vector, drawn from the origin of vector 1 to the terminal point of vector 3. If we construct a mechanical device having scales depicting the position of vectors 1 and 3 for various bearings from the line of towers, we can then determine the effect of changes in operating parameters on the resultant field in any desired direction.

Such a device is illustrated in Fig. 14. Here the distance between pivot points for the rotary elements has been scaled to represent the magnitude of vector 2. The radius of each of the rotary elements has been chosen to represent the magnitude of vectors 1 and 3. If desired, a scale could be marked on each of the rotary elements along the line from the center to the 0° mark on the periphery.

When this device is used, a pencil mark or a small tab of drafting tape is placed on the periphery of each rotary element at a point corresponding to the phase of the tower there represented.

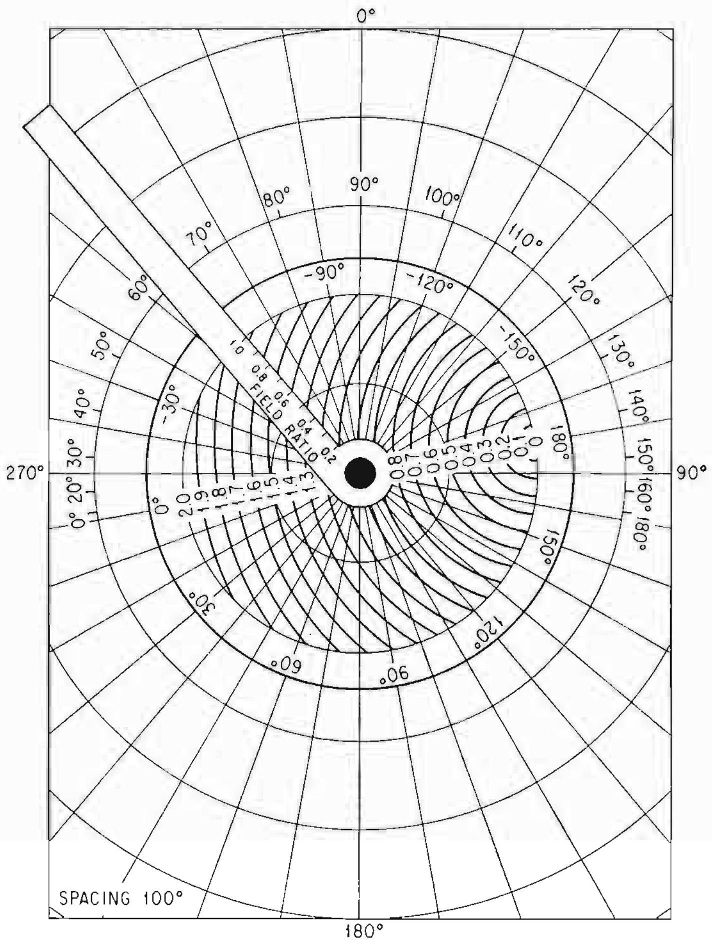

Fig. 12. Calculators for two-element directional antenna having spacing of 100° between elements.

To determine the relative field radiated in a given direction, the rotary elements are rotated so that the tab or mark lies at the desired bearing shown on each fixed scale. The distance between the 0° marks on the periphery of the rotary elements then corresponds to the resultant vector field. The effect of a change in phase of any of the towers or a change in field ratios can be readily visualized.

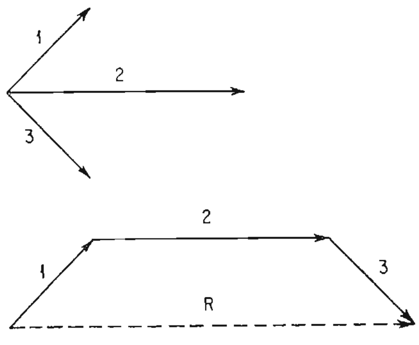

Fig. 13. Typical relationship of field vectors for three-element directional-antenna systems.

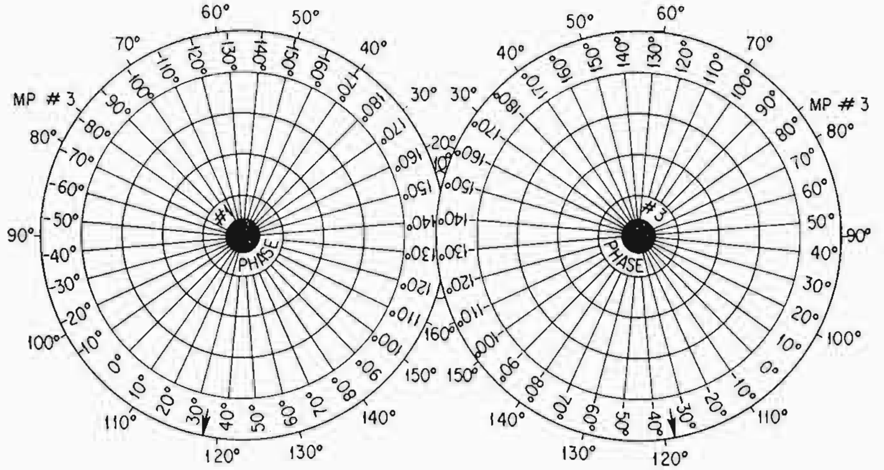

Fig. 14. Calculator for three-element in-line directional antenna.

Unfortunately, these relatively simple procedures cannot be so easily applied to arrays with more elements; however, if the basic patterns that go to make up the over-all pattern are known, these procedures can be applied to the basic patterns.

TABLE 1

Maintenance Schedules

Sunday

1. Transfer all towers and antenna phasing units to emergency transmission lines and operate at full power for 5 min.
2. Restore all equipment to regular transmission lines. Check operation under full power.
3. Clean and check all connections, remote meter, antenna monitor, and meter panels.
4. Check all antenna monitor tubes with tube checker. Check all transmission-line protective circuits.
5. Check and record all transmission-line gas pressures.

Monday

1. Check all condensers and other equipment in antenna phasing unit immediately after sign-off for overheating.
2. Clean and check all transmission-line end seals.
3. Clean interior of all sections of antenna phasing units.
4. Clean contacts and check alignment of antenna transfer relay.
5. Check and tighten all connections in antenna phasing unit.
6. Check gas-filled condensed pressures.

Tuesday

1. With array set for directional operation check drive-point impedance at X with radio-frequency bridge at operating frequency (first and third Tuesdays).
2. With array set for nondirectional operation check drive-point impedance at X with radio-frequency bridge at operating frequency (first and third Tuesdays).
3. Set up array for normal full-power directional operation. Compare readings of all antenna and remote antenna meters. Make any necessary adjustments.
4. Make complete set of field-strength readings at indicated monitor points (second and fourth Tuesdays).
5. Check and record all transmission-line gas pressures.

Wednesday

Antenna coupling unit 1:

1. Check all condensers and equipment in coupling house for overheating immediately after sign-off.
2. Check spacing and clean antenna and transmission-line horn gaps.
3. Check and clean all antenna lead-in insulators.
4. Check and clean all transmission-line end seals.
5. Clean contacts and check alignment of antenna relay.
6. Clean contacts and check alignment of antenna ammeter switch.
7. Check and tighten all connections of inductance coils and condensers.
8. Clean all meters.

Transmitter building:
Read and record all transmission-line gas pressures.

Thursday

Antenna coupling unit 2:

1. Check all condensers and equipment in coupling house for overheating immediately after sign-off.
2. Check spacing and clean antenna and transmission-line horn gaps.
3. Check and clean all antenna lead-in insulators.
4. Check and clean all transmission-line end seals.
5. Clean contacts and check alignment of antenna relay.
6. Clean contacts and check alignment of antenna ammeter switch.
7. Check and tighten all connections of inductance coils and condensers.
8. Clean all meters.

Transmitter building:
Read and record all transmission-line gas pressures.

TABLE 1

Maintenance Schedules *(Continued)*

Friday
Antenna coupling unit 3: 1. Check all condensers and equipment in coupling house for overheating immediately after sign-off. 2. Check spacing and clean antenna and transmission-line horn gaps. 3. Check and clean all antenna lead-in insulators. 4. Check and clean all transmission-line end seals. 5. Clean contacts and check alignment of antenna relay. 6. Clean contacts and check alignment of antenna ammeter switch. 7. Check and tighten all connections of inductance coils and condensers. 8. Clean all meters. Transmitter building: Read and record all transmission-line gas pressures.

Saturday
Antenna coupling unit 4: 1. Check all condensers and equipment in coupling house for overheating immediately after sign-off. 2. Check spacing and clean antenna and transmission-line horn gaps. 3. Check and clean all antenna lead-in insulators. 4. Check and clean all transmission-line end seals. 5. Clean contacts and check alignment of antenna relay. 6. Clean contacts and check alignment of antenna ammeter switch. 7. Check and tighten all connections of inductance coils and condensers. 8. Clean all meters. Transmitter building: Read and record all transmission-line gas pressures.

12
Transmission Lines for Broadcast Use

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Since the early days of broadcasting, transmission lines have been one of the vital elements of the broadcasting plant—the connecting link between transmitter and antenna. The choice of the proper line for adequate planning, construction, and maintenance procedures is an all-important ingredient of a satisfactory system. Transmission-line technology has changed along with changes in broadcasting. Starting with open-wire lines in the early days of AM broadcasting, the art has progressed through a wide variety of coaxial-line types, both air and solid dielectric, rigid and semi-flexible.

It is not the intent here to describe basic transmission-line theory or design methods. A wide variety of transmission lines are available to the broadcaster of today. His chief concern is the selection of the best one for his application and an understanding of the proper methods of installation and maintenance. Factors to be considered in selecting a line for various broadcast services will be presented. A discussion of recommended installation procedures will allow the broadcaster to lay out and construct a system suited to his specific requirements.

A large number of different transmission lines have been used in the past, including lines of various characteristic impedances, sizes, and physical characteristics.

Most of the coaxial lines and waveguides in this presentation and their flanges and connectors are those that have been standardized by the EIA (Electronic Industries Association). Most manufacturers of electronic products adhere to these standards so that interchangeability and interconnection between products of different companies can be accomplished. Current EIA standards include transmission-line conductor diameters as well as line flanges and connectors. The standard lines described herein have a 50-ohm characteristic impedance. Other standard lines having a 75-ohm impedance, are also used, but mostly for special UHF-TV applications. It is, of course, true that there are in existence transmission lines that are not covered by standards; however, the selection and use of these lines are usually considerations of the equipment designer rather than the broadcaster. Such special lines will therefore not be included in this chapter.

DESCRIPTION AND APPLICATION

In general, a transmission line is selected on the basis of efficiency (degree of attenuation), power handling, and mechanical considerations. In AM, FM, and TV, power handling is one of the most important factors to be considered. After a transmission line has been selected which will satisfy the power-handling requirement, the attenuation of the line must then be examined. A long-transmission-line installation requires a lower per-unit attenuation. It is a question of economics, balancing line cost, installation cost, and maintenance, versus the alternatives of antenna gain, tower height, and transmitter power. These economics usually favor a larger diameter transmission line (having less attenuation) and a better antenna rather than a high power transmitter.

Flexible Solid-Dielectric Coaxial Cable

The simplest and cheapest type of RF energy transfer is through the use of solid-dielectric cables such as RG-213/U and RG-218/U, as shown in Fig. 1. Solid-dielectric cables are com-

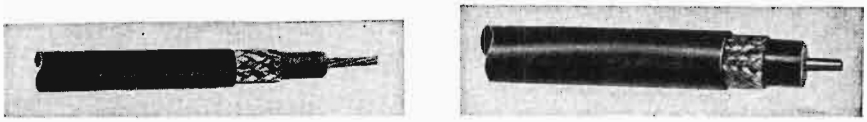


Fig. 1. RG-213/U and RG-218/U solid-dielectric cables.

prised of a solid or stranded inner conductor, plastic insulating material, braided copper sheath outer conductor and a protective plastic jacket. These highly flexible cables are used in applications where the length is short or the frequency is low enough that attenuation is not an important factor. Since attenuation in this type of cable is high, it is not recommended for long runs. Because of its aging characteristics, low isolation, and tendency to absorb moisture, it is not recommended for permanent outdoor use.

In the broadcast field, its use is generally limited to sampling lines, jumper connections, and occasionally as the main feeder line. In FM and TV installations, it is rarely used except for receiver monitor systems. For microwave, it is sometimes used for interconnections between components and in jumper connections at the bottom and top of the semi-flexible coaxial cable run. Solid-dielectric cable is frequently used in translator service because of short-length requirements.

Semiflexible Foam Dielectric Coaxial Cables

Semiflexible foam dielectric cables consist of a copper inner conductor, a foam polyolefin dielectric, and a flexible solid metallic outer conductor of copper or aluminum. Inner conductors are either copper wire or tubing, depending on cable size. These cables are available in continuous lengths either jacketed or unjacketed. Pressurization is not required with this type of cable. Sizes are available from 1/4 in. to 3-1/8 in. in diameter. A typical cable of this type, employing a corrugated copper outer conductor, is shown in Fig. 2.

Foam dielectric cables have become very popular in many services due to their moderate cost. In the broadcast field, they have found application in low-power AM directional arrays, AM sampling lines and FM main feeders. Foam dielectric cables have much better phase versus temperature characteristics than solid dielectric cables, as illustrated in Fig. 3.

The attenuation, size for size, is considerably lower than for solid dielectric cables. The foam dielectric is only about 50% solid, the remaining volume being a homogenous dispersion of fine closed cell bubbles, thus reducing dielectric losses. In addition, the dielectric constant is lower, allowing a larger inner conductor, thus reducing loss further.

The solid sheath also yields lower attenuation than braided sheaths and eliminates the RF leakage inherent in braided constructions.

Generally, this cable type offers of the low-attenuation advantages of semiflexible air dielec-

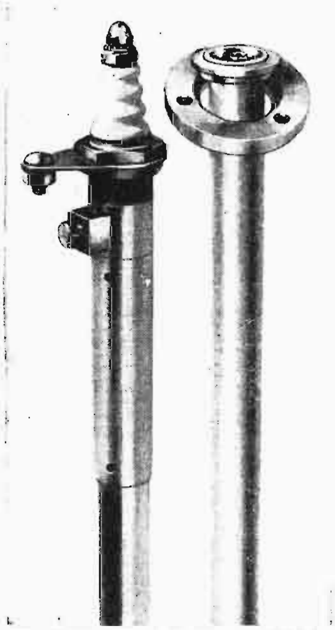


Fig. 2. Semiflexible foam dielectric coaxial cable.

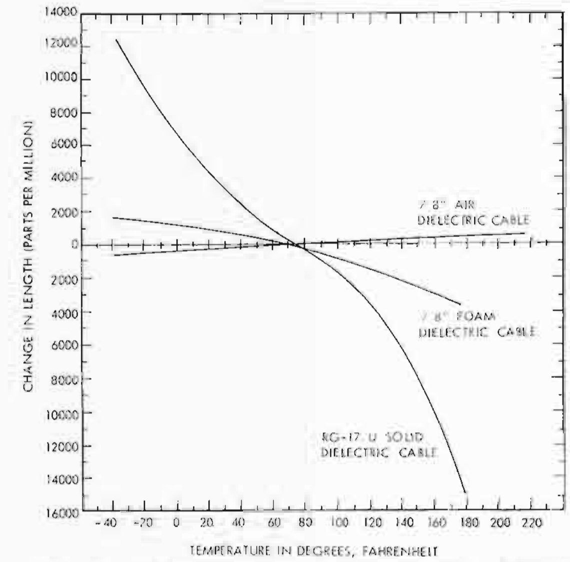


Fig. 3. Phase-temperature characteristics of coaxial cables.

Fig. 4. Semiflexible air dielectric coaxial cable.

tric cables, yet retains the advantage of no pressurization. A variety of end fittings are available and finished assemblies may be obtained from most manufacturers.

Semiflexible Air-Dielectric Coaxial Cable

Continuous semiflexible air-dielectric cable is the most popular cable for many installations, since it combines high efficiency and high power handling with ease of installation and a very low VSWR. It is used for all applications including microwave. There are several types on the market today. Electrical and mechanical data can be obtained from the various manufacturers. A typical continuous air-dielectric cable is shown in Fig. 4. Cable of this type is comprised of a continuous inner and outer conductor. The inner insulation is continuous throughout the entire length of the cable and comprises a very small percentage of the total volume. Since the cable is produced by a continuous manufacturing process, no joints are required even for very long lengths of several thousand feet. The continuous process eliminates many electrical discontinuities, and a low VSWR is achieved.

These cables are now available in sizes from 1/4 in. to 8 in. in diameter. The larger sizes (3 in., 5 in., and 8 in.) are particularly well suited to the high power levels used in broadcasting today; in AM, HF, FM, and TV. Installed cost and performance are better than in rigid line. Another advantage is that the entire performance may be measured on the reel before shipment.

Weatherproofing for most continuous cables is accomplished by a tough jacket covering the outer conductor. This enables the cable to be used in almost any environment such as salt air, direct ground burial, or under water.

Some continuous air-dielectric cables can withstand repeated bending, while others are limited to a few bending cycles. The manufacturer's flexing recommendations should be followed. Most continuous cables are shipped on reels and are uncoiled without difficulty. They can also be attached directly to a tower, thus eliminating the need for spring or sliding hangers. Pressurization is normally necessary for this type of cable to prevent accumulation of moisture.

Rigid Coaxial Transmission Line

Rigid air-dielectric transmission line has low attenuation and VSWR. It is manufactured from hard-temper copper tubing in standard 20-ft. flanged lengths. The rigid inner conductor is generally supported by Teflon pegs or discs. The inner connector used with rigid lines has a Teflon insulator which anchors the inner conductor and supports it in vertical runs. Fig. 5 shows 1-5/8 and 9-in.-diameter rigid lines.

Rigid transmission line is used mainly for high power levels. Its use in AM is generally limited to the main feeder lines on omnidirectional or

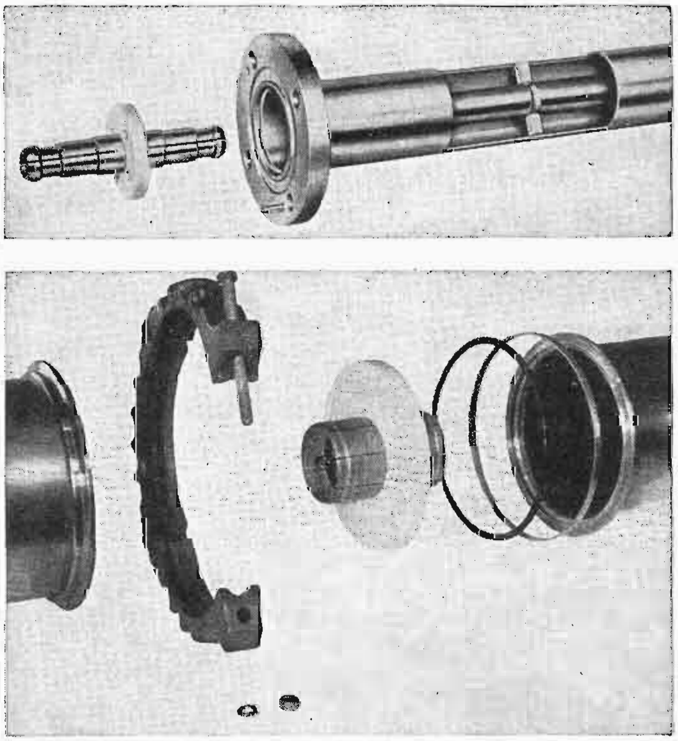


Fig. 5. 1-5/8- and 9-in. rigid coaxial lines.

directional AM arrays using 5 kw or more. In FM and TV, rigid line is often used for the transmitter-room interconnections, and sometimes as the main feeder to the tower. The 7/8- and 1-5/8-in.-diameter rigid lines are ideal for inside runs in low- or medium-power communications or TV broadcasting installations. These rigid transmission lines are especially recommended for connections between transmitters, diplexers, receivers, dummy loads, switching systems, and other components.

For FM and moderate power VHF TV installations, 1-5/8-in. and 3-1/8-in. lines are often chosen. For high-power applications in VHF TV and low-channel UHF TV, 6-1/8-in.-diameter transmission line is recommended. For the higher UHF TV frequencies up to 890 MHz (Channel 83) 75-ohm 6-1/8-in. line is used. Nine-inch-diameter rigid transmission line has been designed for very high-power systems. EIA standards RS-225 and RS-259 cover 50 ohm and 75 ohm rigid coaxial transmission line, respectively.

ELECTRICAL CHARACTERISTICS OF TRANSMISSION LINES

Attenuation

Attenuation in a transmission line is loss created by imperfect conductivity of the conductors and the imperfect insulating medium or dielectric. In open-wire lines, an additional loss is incurred in the form of radiation. In coaxial lines and waveguides, this loss is not incurred, since the RF field is totally enclosed within the cable. Attenuation for RF cables is generally expressed in decibels per 100 ft. In waveguides, the entire loss is conductor loss. In coaxial cable, the losses are conductor losses and the dielectric losses associated with material used as the inner-conductor support. In solid-dielectric cables, the dielectric loss is appreciable and at high frequencies may exceed the conductor losses in spite of high-quality dielectric materials. In air-dielectric coaxial cables, the insulating supports are limited to a very small portion of the total dielectric space, so that the dielectric is principally air; therefore, the total dielectric losses are generally negligible. At very high frequencies, they may become large enough to become a significant portion of the total loss.

Because of skin effect, the RF current penetrates less of the conductor as frequency increases. Attenuation due to conductor losses thus increases with frequency and is proportional to the square root of frequency. Attenuation due to dielectric loss is directly proportional to frequency. Measured attenuation curves for several line sizes are shown in Fig. 6.

Actual attenuation experienced in operation may be further influenced by VSWR occurring on the line owing to an imperfect load. This is generally not significant, since a considerable VSWR is necessary to produce any measurable loss increase. Loss is increased by VSWR by the factor $1 + (\text{VSWR})^2/2\text{VSWR}$. Fig. 7 illustrates this effect.

Efficiency of a transmission-line system can be easily calculated from the total attenuation.

$$\text{Efficiency in percent} = \frac{1}{\text{antilog}\,(a/10)} \times 100$$

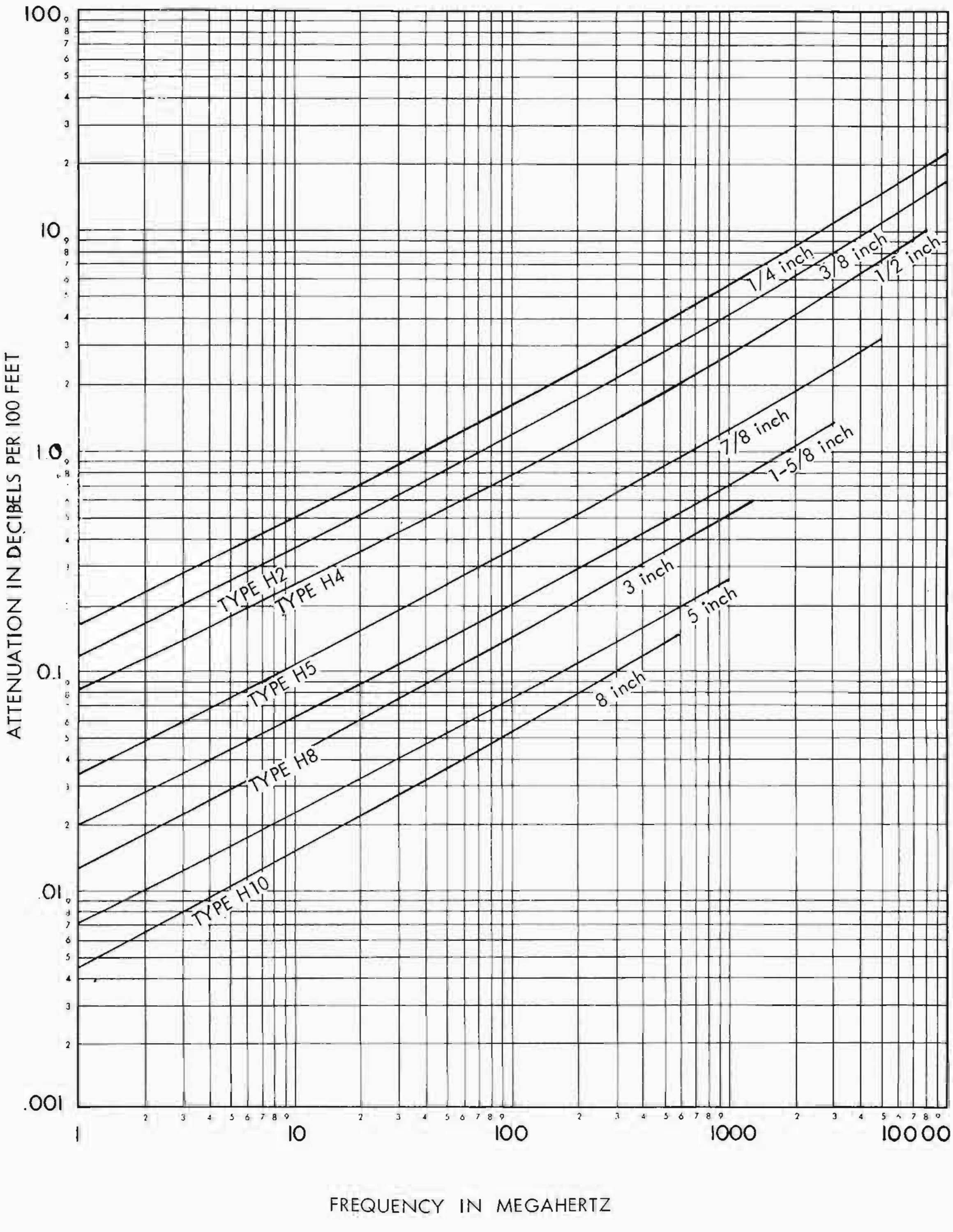
where a is the total attenuation in decibels. Often line sizes larger than necessary from the power-handling standpoint alone are used in order to obtain better line efficiencies.

Voltage Standing-Wave Ratio (VSWR)

When a transmission line is terminated in an impedance different from the characteristic impedance of the line, a portion of the energy traveling down the line is reflected. The amount of reflection depends on the degree of mismatch. The incident and reflected traveling waves combine to produce an uneven voltage distribution, or standing wave, along the line, and voltage and current maxima and minima occur. VSWR has been defined as the ratio of the maximum to minimum voltage; that is, $\text{VSWR} = E_{\text{max}}/E_{\text{min}}$. This effect is measurable with various types of instruments such as slotted lines, bridges, and reflectometers.

The effects of VSWR may or may not be a problem, depending on the type of service, power levels involved, etc. As VSWR increases, the maximum voltage points increase, and breakdown problems might occur if the power level and VSWR were high enough and the cable choice was small. Irregular heating along the cable due to current maxima may cause problems also, especially in solid-dielectric cables, where the plastic dielectric material may soften. These possibilities would require large VSWR values to cause problems. Other effects of VSWR, where the cable is not impaired but the service may be, are distortions in TV and, intermodulation in multiplex FM. As already described, VSWR also causes some increase in the actual attenuation of a transmission line.

In most services, a moderate VSWR is of no consequence as long as the line ratings are not exceeded. In AM broadcast applications, VSWR may be as much as 3 or more with perfectly satisfactory operation. In FM broadcasting, system VSWR is generally less than 1.75. In TV, a system VSWR of less than 1.1 is considered desirable. In general, discontinuities contributing



Attenuation curves based on:
VSWR 1.0
Ambient Temperature 24°C(75°C)
One atmosphere absolute dry air pressure (0 psig)

Conversion Data:
1 dB/100 feet=3.28 dB/100 meters
For 75 ohm cables, multiply values by .95
For ambient temperature 20°C(68°F) multiply value by .99

Fig. 6. Attenuation of semiflexible 50 ohm air dielectric coaxial cable with copper out conductor.

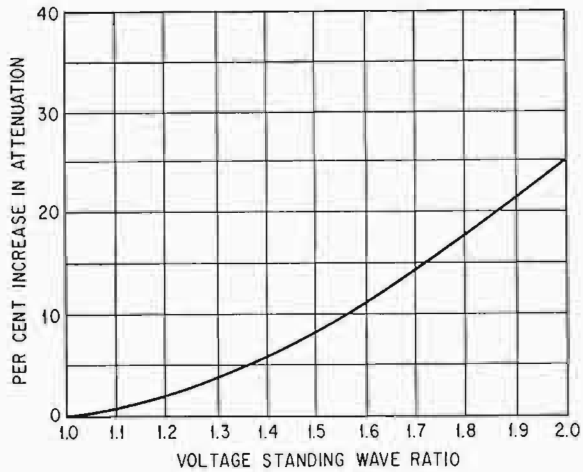


Fig. 7. Increase in attenuation in line due to VSWR on line.

to VSWR that are located close to the transmitter will have little or no effect on picture quality. The transmission line itself, the line fittings, or both may produce some VSWR. This is usually very small and is of little consequence for most services. For TV or certain microwave applications, it is sometimes large enough to influence performance.

In cases where the line has considerable attenuation, VSWR at the input end is lower than that of the antenna or load itself. The curves in Fig. 8 illustrate the extent of this effect.

Power Ratings

There are two power ratings for transmission lines. One is based on the maximum heating the cable construction might safely withstand. It is generally referred to as the "average power rating." The other is based on voltage-breakdown considerations and is generally described as the "peak-power rating." Consideration of both ratings is necessary for most services.

Average power is the power in the signal capable of creating heat. Peak power is that maximum rms power which can be reached in any interval (such as during a modulation cycle) and should not be misinterpreted as any relation between peak and rms voltages such as $\sqrt{2}$ in sine waves. In a continuous CW carrier (including FM), peak power equals average power. In 100 percent AM, the power rises to four times the carrier power, so in this case, the peak power is four times the carrier power. Since average-power rating is limited by heating which is created by line losses, this rating decreases with increasing frequency. Peak-power rating is dependent on voltage breakdown considerations which are not significantly frequency sensitive; thus this rating is constant with frequency. Transmission-line ratings can be arrived at by various experimental and calculated procedures. The overall picture is

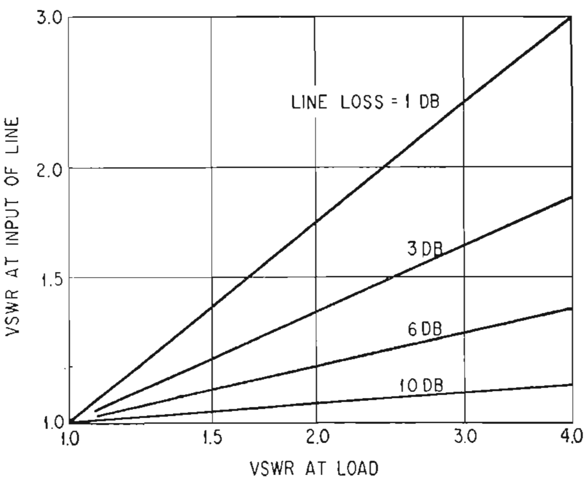


Fig. 8. VSWR improvement due to line attenuation.

complicated by the effects of environment, such as ambient temperature, cable pressure, and others. Whatever basis for rating is used, it must be stated with the rating. Once a rating is determined for the conditions stipulated, the rating can be adjusted for other conditions. As was mentioned, ratings can be arrived at by various means. The following procedure is one way which has been used for many years and has been found to be very satisfactory. Curves illustrating these ratings for several popular line sizes are shown in Fig. 9.

Rigid Air-Dielectric Coaxial Line

Peak-power rating. The procedure here is to establish a peak voltage the line will withstand every time if it is manufactured properly. The maximum voltage gradient occurs at the inner-conductor surface in a coaxial line.

A theoretical breakdown gradient cannot be used, since breakdown is a highly variable phenomenon occurring at widely different values depending on small effects such as scratches, dust particles, and insulator condition. Derating theoretical breakdown to 35 percent of theoretical has been found to be a practical value for a dc test voltage (or 60-cycle peak test voltage). The equation below is derived from the maximum voltage gradient in a coaxial line and includes factors considering pressure, temperature, and inner conductor curvature. It also includes the derating of 35 percent described above and results in a very reliable production test voltage. This test voltage is then further derated and used for power rating purposes.

$$E_p = 3.17(10)^4 a\delta \left(\log_{10}\frac{b}{a}\right)\left(1 + \frac{0.273}{\sqrt{a\delta}}\right)$$

where E_p = production test voltage, volts
a = inner-conductor OD, in.
b = outer-conductor ID, in.
δ = air-density factor = $3.92B/T$
where B = absolute pressure, cm of mercury
T = temperature, °K

($\delta = 1$ for $B = 76$ cm and $T = 23°\text{C} = 296°\text{K}$)

The values are generally rounded off as follows for the common 50-ohm line sizes:

Nominal Line OD, In.	*Production Test Voltage, dc Volts*
3/8	2,200
7/8	6,000
1-5/8	11,000
3-1/8	19,000
6-1/8	35,000
9	50,000

The next step is to derate this production test voltage to a realistic RF rms operating voltage. The voltage is derated to 0.7 of its above value to go to RF conditions, by $1/\sqrt{2}$ to go to rms value, and by a suitable safety factor which is usually 2.

$$E_{rf} = \frac{0.7E_p}{\sqrt{2}\,(\text{SF})} = 0.247E_p \quad \text{volts}$$

where E_{rf} = maximum RF rms operating voltage with no allowance for VSWR or modulation, but including safety factor
SF = safety factor on voltage of 2

This voltage, E_{rf} determines peak power rating.

$$P_{pk} = \frac{(E_{rf})^2}{z_0} \quad \text{watts}$$

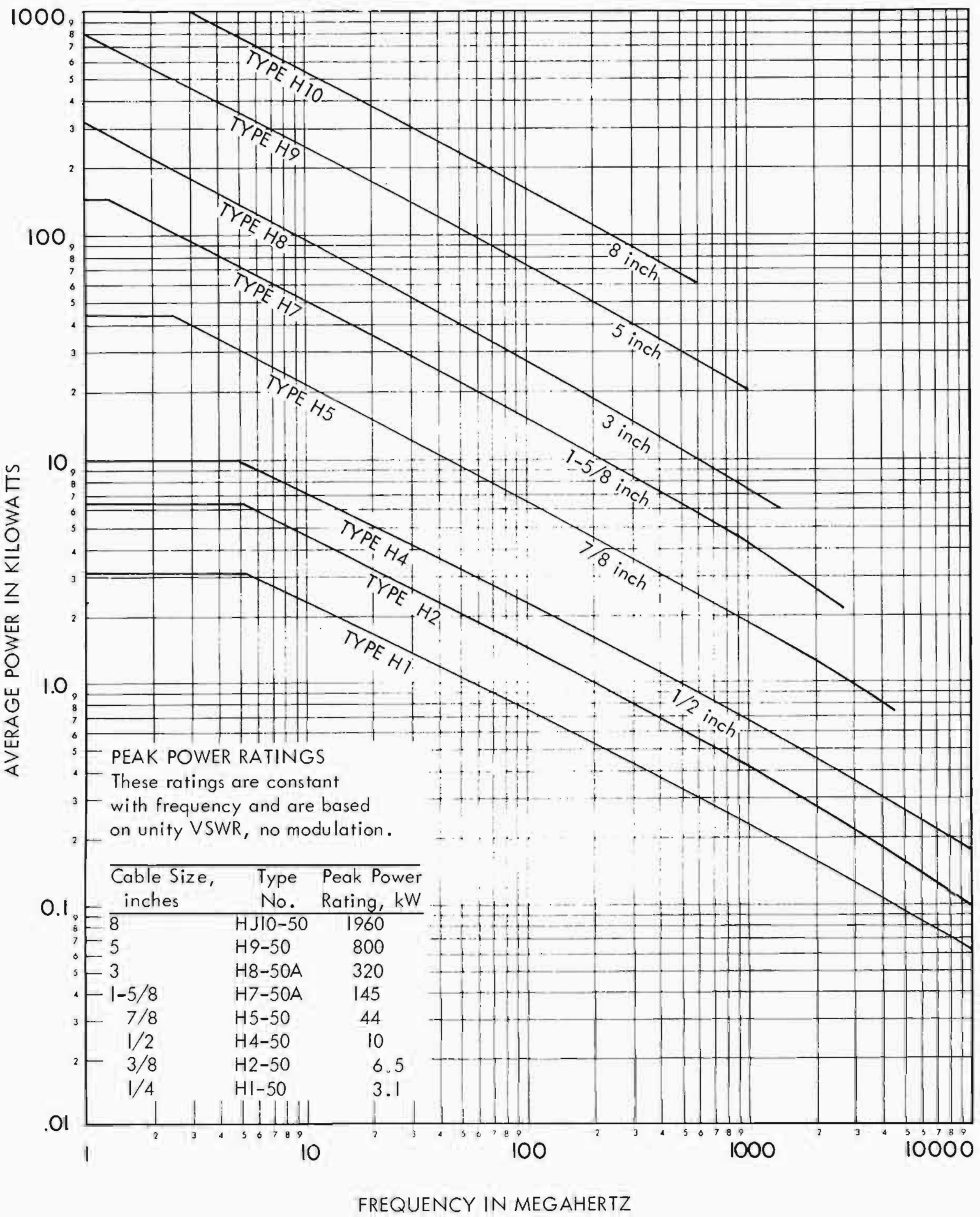
This rating must be derated further for VSWR and amplitude modulation, although these vary with the application and are not a part of the basic rating. This would be done as follows:

$$P_{\max} = \frac{P_{pk}}{(1+M)^2\,\text{VSWR}} \quad \text{watts}$$

where M is the modulation index and 1 is for 100 percent. This would derate P_{pk} by 4 for 100 percent AM due to modulation to obtain the rating in terms of carrier power or transmitter nameplate rating. Notice that peak-power rating must be reduced directly by VSWR.

A very significant point should be noticed in the equation for E_p, in that the breakdown voltage, in the range of pressures normally used, is approximately proportional to absolute pressure; thus, the peak-power rating is roughly proportional to the absolute pressure squared. This is often a valuable tool in achieving high-peak-power operation. Certain high-dielectric-strength gasses other than air, such as sulfur hexafluoride, have also been used to increase peak-power rating. This gas, as compared with air at equivalent pressures, will effect approximately a 2-to-1 voltage- or 4-to-1 peak-power-rating improvement. Combining the effects of using special gaseous dielectrics and pressurizing to several atmospheres pressure are also possible, compounding the improvement.

Average-power rating of coaxial line. Average-power rating is limited by heating due to line losses. Owing to the character of coaxial-line construction, the loss and temperature rise of the inner conductor are greater than those of the outer conductor. The ultimate temperature that the inner conductor might be safely allowed to reach determines the rating. This temperature is determined by such considerations as inner-



PEAK POWER RATINGS
These ratings are constant with frequency and are based on unity VSWR, no modulation.

Cable Size, inches	Type No.	Peak Power Rating, kW
8	HJ10-50	1960
5	H9-50	800
3	H8-50A	320
1-5/8	H7-50A	145
7/8	H5-50	44
1/2	H4-50	10
3/8	H2-50	6.5
1/4	H1-50	3.1

Average Power ratings based on:
VSWR 1.0
Ambient Temperature 40°C (104°F)
Inner conductor temperature 100°C (212°F)
One atmosphere absolute dry air pressure (0 psig)

Conversion Data:
For 75 ohm cables, multiply values by .70
For ambient temperature 35°C (95°F), multiply values by 1.11
For 5 psig dry air pressure, multiply values by 1.07
For 15 psig dry air pressure, multiply values by 1.2

Fig. 9. Average power rating for semiflexible 50 ohm air dielectric coaxial cable with copper outer conductor.

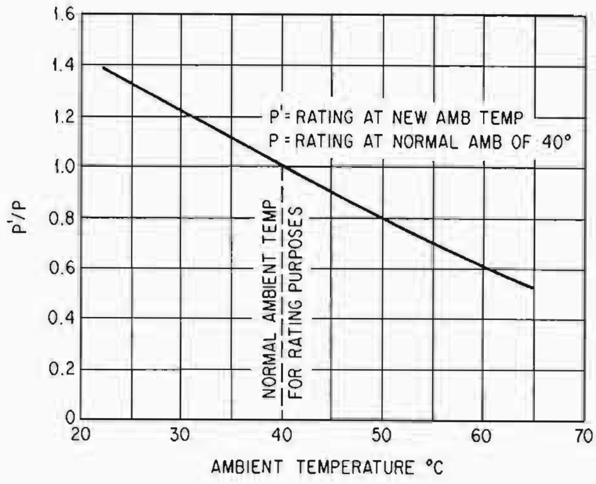


Fig. 10. Average-power-rating variation in transmission line for variation in ambient temperatures for a maximum center conductor temperature of 100°C.

conductor expansion and oxidation and dielectric life at an elevated temperature.

Most manufacturers base their average power ratings on an ambient temperature of 40°C (104°F). The temperature rise of the inner conductor, and therefore the average power rating, will vary with cable type and design details. A study of the ratings will usually reveal the conditions used to determine them. To be meaningful, these conditions should be stated on the ratings. See Fig. 10 for example. The sloping line is the average power ratings.

Average power ratings may be changed if the ambient temperature is changed. This is because the maximum temperature of the center conductor is the determining factor and the ambient temperature influences this. A graph is shown in Fig. 10 for a cable where the maximum inner conductor temperature is to be limited to 100°C.

Average power ratings may also be increased by special techniques such as pressurization with special gasses, coated conductors, etc. It is best to obtain information such as this from the manufacturer, since recommendations will vary with cable types.

Power Ratings for Various Services

Power ratings often published are already derated for various types of service depending on expected VSWR, modulation, and peculiarities in transmitter ratings (such as in TV).

In derating for VSWR, it is common to consider system VSWR as follows: broadcast and HF: AM, 3.0; FM, 1.75; TV, 1.1.

In derating for AM services, the peak-power rating is often derated by 4.5 to allow for modulation with some overmodulation, resulting in a rating for AM in terms of carrier power or transmitter nameplate rating.

For TV, transmitter nameplate ratings are usually the peak video power output value. The actual average power output for a black level picture (assuming the aural power equal to 20 percent of peak video power) is approximately 83 percent of the peak video power level. Thus, the actual average power output is less than the transmitter rating (for the 20 percent level aural example). Thus, for TV, some increase in average power ratings for the transmission line is possible.

Some of these deratings may seem of minor effect but are given to provide consistent ratings for the initial conditions of temperature rise or voltage governing the ratings. If the VSWR is known, it would be better to derate accordingly.

INSTALLATION

Mechanical considerations of a radio or TV station should involve not only the installation of the transmission line but also its maintenance. A carefully planned and executed original installation will assure long and trouble free operation.

The transmission line system (in the case of FM and TV consists of a vertical and horizontal run which connects to the antenna which connects to the transmitter or diplexer. A variety of hangers is required for supporting and anchoring transmission lines. Connections between various units of transmitter equipment inside the building are made by unpressurized line, which may incorporate a switching system for switching between units.

The use of continuous semiflexible coaxial cable simplifies installation planning and reduces the total cost of the installed line. When using semiflexible coaxial cable, expansion and contraction are negligible. The cable is attached to fixed hangers on the tower or directly to tower members.

The rigid transmission line requires the use of spring hangers on the tower and swinging hangers for the horizontal run to accommodate the expansion and contraction of the lines due to internal heating and changes in ambient temperature. The rigid line is anchored at the antenna by a rigid hanger and at the transmitter building by a wall anchor, so that movement of the line is away from the equipment. Over a temperature range of —25 to +125°F, expansion of the copper rigid line is about 1-1/2 in. per 100 ft. Provision must be made to allow for this movement. A steel tower expands or contracts with temperature change a rate of about 1 in. per 100 ft., and copper conductors of a transmission line will change length relative to the tower, approximately 1/2 in. per 100 ft., over the above temperature range. The spring and swinging hangers support the weight of the line but permit free axial movement during changes in temperature. This expansion contraction accumulates at the base of the tower; therefore, 15 or 20 ft. of line on each side of the elbow at the base of the tower must be free to flex and accommodate the change in length.

The importance of the effects of expansion and contraction of the rigid transmission line cannot be overemphasized. The force in the rigid transmission lines due to temperature changes is sufficient (when causing contraction) to tear hangers from the structure and pull the line from the transmitter building bulkhead fitting. When the line expands, severe buckling can occur and cause tower strain which could end in failure of the transmission line or tower.

Semiflexible Coaxial Cable Installation

Coaxial cable is often used in new installations. The following presents a step-by-step approach to the planning and installing of a TV or FM system on a typical 500-foot tower.

Precaution must be taken when planning an installation to consider the correct connectors to make the antenna and transmitter connections. The antenna and equipment flanges may be of a different size than the transmission line; the antenna may or may not require pressurization and dry air inlet and purge ports may not be provided.

The connector on coaxial cable can usually perform all functions with the same fitting. A gas barrier and gas port will help eliminate unnecessary transmission line connections in the system. See Fig. 11.

BILL OF MATERIALS

Items	*Quantity*	*Use*
1. End connector	1	For antenna end (as required to mate with antenna)
2. 600 feet continuous length/flexible coaxial cable.	1	For main run
3. End connector	1	For transmitter end (as required)
4. Wraplock, 100 ft./package	3	For attaching transmission line to tower and catwalk
5. Insulated hanger*	As Required	Prevent AM energy from being grounded
6. Grounding kit	3	For lightning protection
7. Wall/Roof feed-through	1	For weatherproof wall joint
8. Automatic dehydrator	1	To maintain line pressure
9. Hoisting kit	3	For hoisting coaxial cable

*If required for use on AM tower.

If an antenna with an air dielectric harness is not to be pressurized, a gas barrier antenna connector on the transmission line must be used. In this case, the unpressurized line above the gas barrier connector may collect moisture, so drain holes should be drilled immediately above the gas barrier.

The flexible coaxial cable is pressurized with dry air prior to shipment, to prevent contamination. The cable is shipped on a wood reel with the antenna end connector factory attached. The line should be kept pressurized during the installation.

Coaxial cable is generally hoisted directly from the reel up the tower. A pulley is placed high enough on the tower to allow the transmission line to be elevated sufficiently to make the connection to the antenna. A means of hoisting, such as a truck or a power winch, is required with a suitable steel hoisting line or rope. An axle is inserted through the hub of the cable reel and supported so that the reel turns easily, as the cable is being hoisted. The hoisting line is passed through the pulley at the top of the tower and sent back down the tower through the openings where the cable

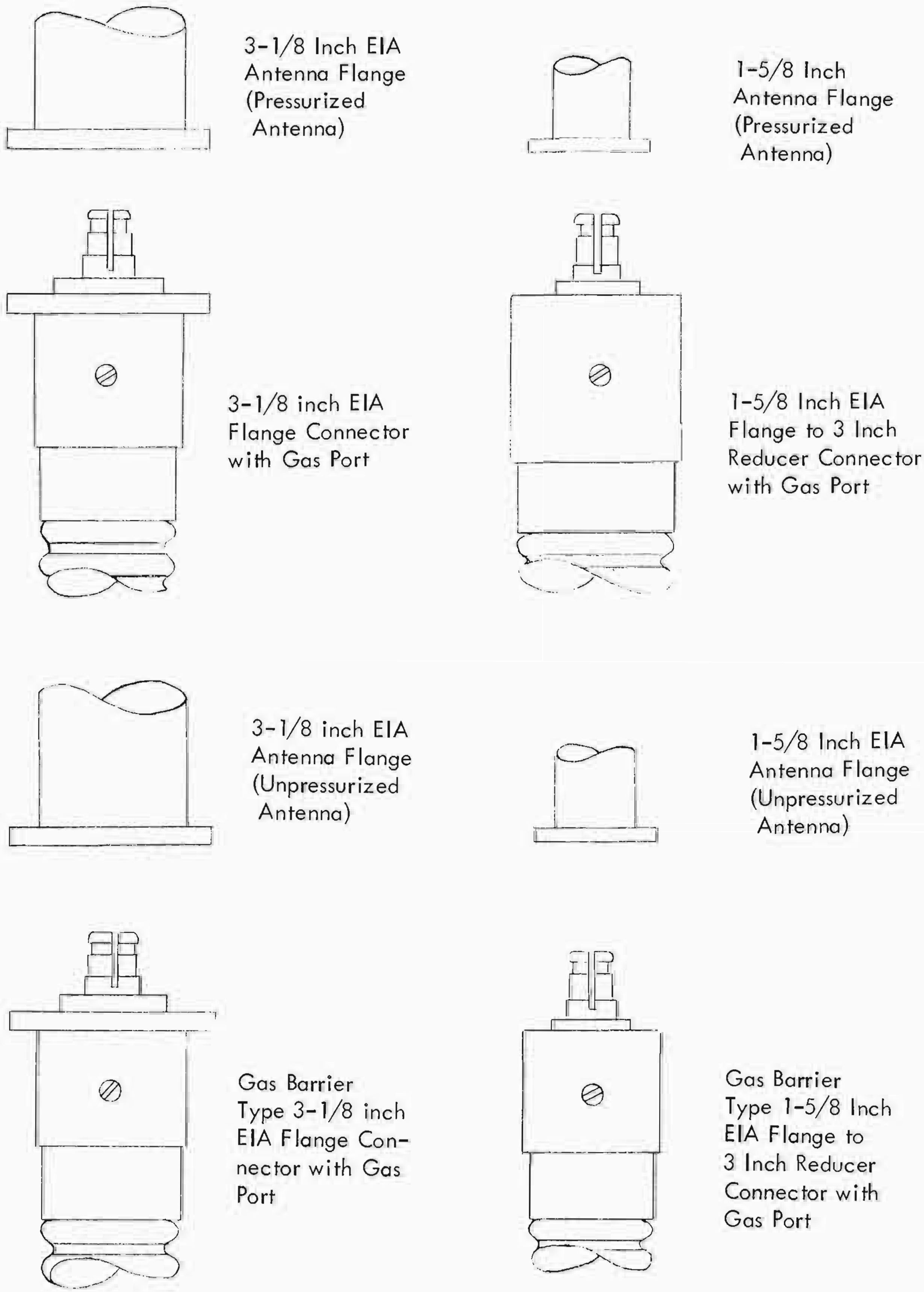


Fig. 11. Coaxial cable connector options.

will be attached. It may be brought down the outside of the tower if the cable is to be attached to the tower leg or on the outside lattice. Flexible coaxial cable is attached to the hoisting line with a "basket" hoisting grip. To prevent kinking, rotation of the reel must be controlled to regulate payout of the cable. The cable should be tied to the hoisting line with strong tape at 50-ft. intervals. Additional "basket" hoisting grips are applied at 200-ft. intervals. See Fig. 12.

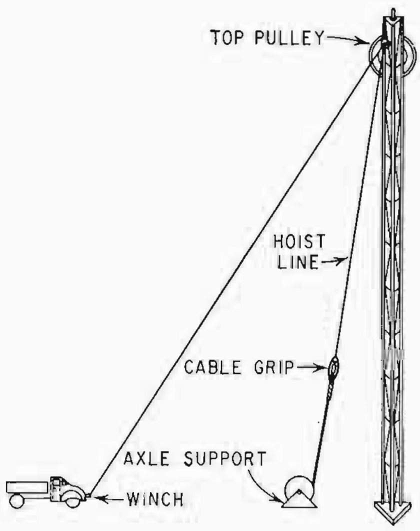


Fig. 12. Installation of cable.

When the cable is in position, antenna connection is made. The cable run is then attached to the tower with wraplock or rigid hangers. The weight of the cable is supported by the hoisting line while the attachment to the tower is made; at 3-ft. intervals for small diameter cables and 5-ft. intervals for cable over 1-5/8 in. in diameter. Fig. 13 shows standard attachment methods.

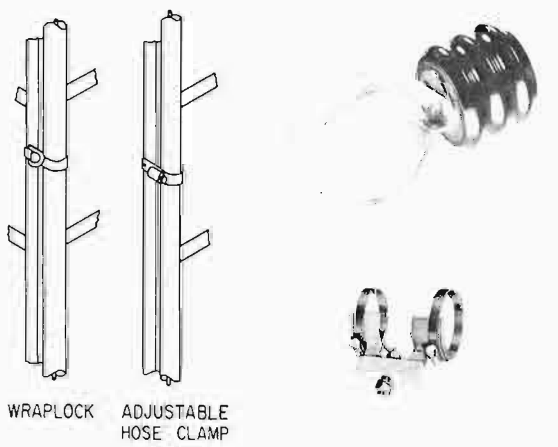


Fig. 13. Cable attachment.

If the supporting tower is also used as an AM broadcast radiator, some method must be used to prevent the AM energy from being grounded by the transmission line that feeds the TV or FM antenna. One method is to isolate the line up the tower for a distance of a quarter wavelength (at the AM broadcast frequency) from the base, using insulated cable hangers. Because of the quarter wave isolation at the base of the tower, a very high impedance between the tower and the line is presented to the AM energy. Common practice is to make the isolated section approximately .22 wavelength long and to use a variable capacitor at the base of the tower to tune to quarter wave resonance. Fig. 14 shows an installation on an AM tower.

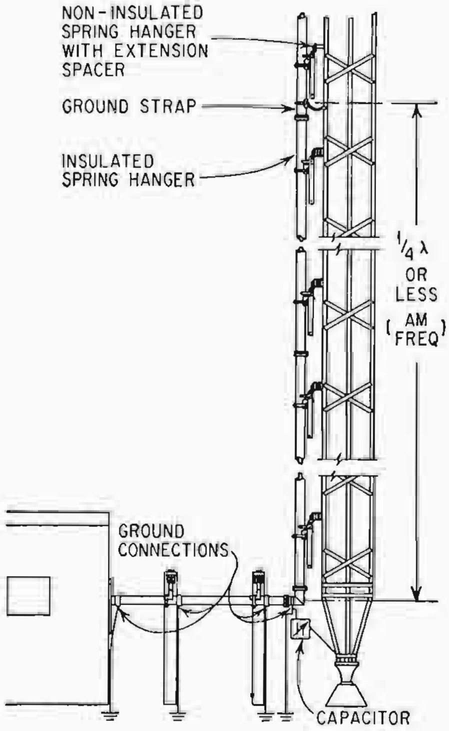


Fig. 14. Installation of AM tower.

Caution. Since a high RF potential exists between the line and the tower, the line should be mounted where it will not be accidentally touched by anyone on the tower ladder.

When coaxial cable is completely attached to the tower, the remaining cable is removed from the reel and laid out on the ground away from the tower. The transmitter end of the cable is either hung along a messenger cable, protected by an ice shield, Fig. 15, or buried in a trench, and routed through the wall of the transmitter building. The end of the cable is then trimmed to the required length, and the end fitting is applied. The cable

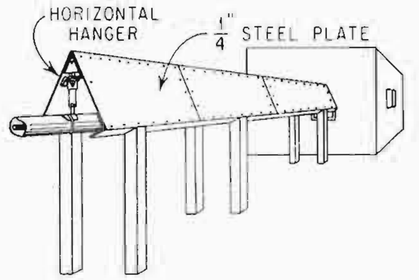


Fig. 15. Protected horizontal run.

fitting is then connected to the transmitter switch or diplexer.

Long horizontal cable runs may require that certain sections be placed underground. Vinyl or polyethylene jacketed lines are suitable for direct burial, or underwater use, with no effect of galvanic or corrosive action. A 6-in. layer of fine sand under and over the flexible coaxial cable should be provided to prevent damage from stones or other sharp objects. Buried cable should be below the area frost line and at least 3-ft. deep under roadways. It is good practice to install marders where cables are buried so that their presence is known.

Protection from lightning is obtained by grounding the cable outer conductor at the antenna end, at the tower base, and at the building entrance. In areas of known high incidence of lightning, grounding is done every 50 ft. along both the vertical and horizontal run. Grounding of the cable is done by removing the "jacket" and attaching copper strap or conductor from the cable to the tower.

After completing the installation, the coaxial cable should be purged. Purging and pressurizing can be done with an automatic dehydrator or with a nitrogen bottle and pressure regulator.

Purging with an automatic dehydrator in the system is done by allowing the dehydrator to operate continuously and loosening or removing the gas port plug or the antenna end of the cable run. The time for purging is dependent upon the length of the cable and the automatic dehydrator output capacity, usually one hour is sufficient. If purging is done with a nitrogen bottle, it can be done the same manner maintaining approximately 5 pounds pressure while purging. It is recommended that the line be pressurized three or four times to 5 pounds gauge pressure, releasing all pressure from the antenna end and between pressure cycles.

After purging, all outlets should be closed and the line should be kept pressurized as changes in temperature can cause moisture to condense and seriously impair performance and efficiency of the line.

Rigid Coaxial Transmission Line Installation

Rigid transmission line systems require care in planning an installation because of the accurate alignment required. Tower cross members, work platforms, ladders, and conduit boxes must be considered to assure that a straight path is available through the entire tower for the transmission line.

The following bill of material lists the typical components required for an FM or TV installation of 3-1/8 in. rigid transmission line on a 500-ft. tower.

BILL OF MATERIAL

Items	*Quantity*	*Use*
1. 90° mitered elbow, flanged	3	For changing line direction
2. Special lengths of line, unflanged	7	For custom applications
3. Soft-soldered flange kit	7	For field flanging lines and elbows
4. Rigid hanger	1	For anchoring top of line to tower
5. Mounting adaptor	50	For use if tower members do not have holes.
6. Combination spring and sliding hanger	49	For hanging transmission line
7. 20 ft. section of line	27	For main run
8. 15 ft. section of line	2	For main run
9. Lateral brace	1	For prevention of lateral line movement
10. Horizontal hanger	4	For free-swing support of horizontal line
11. Horizontal anchor	1	For anchoring line at building wall
12. Gas barrier	1	For pressure termination of line
13. Automatic dehydrator	1	For automatically pressurizing line
14. Straight coupling	7	For joining unflanged line
15. 90° elbow, unflanged one end	3	For changing line direction
16. 90° elbow, unflanged	2	For changing line direction
17. Grounding kit	3	For lightning protection

Transmission line assembly normally starts at the antenna end. A variety of conditions can exist at the antenna connection, so proper fittings must be selected. Where the antenna flange is of a smaller diameter than the transmission line, a reducer must be used. When the antenna harness is of air dielectric, air from the transmission line should be permitted to enter the antenna and an air inlet fitting should be inserted at the point of connection for use in purging the line. The air inlet fitting is not required if the antenna harness has an air inlet. When the antenna is not to be pressurized, a gas barrier must be used. Various antenna connections and fittings are shown in Fig. 16.

Since the connection at the top of the tower depends on the type of tower, type of antenna, and the position of the antenna, a custom fitted transmission line connection must be made at the antenna with two mitered elbows and two special lengths of line. The special lengths are field-cut to the exact dimension required and are flanged with soft-soldered flange kits. A rigid hanger is used at the top of the transmission line run so that thermal expansion and contraction of the line does not affect the antenna. A typical installation at the top of the tower is shown in Fig. 17.

For new installations using towers having angle-type members, the tower manufacturer, in most cases, will punch the members with holes for mounting the hangers. For towers that are already erected and for new towers with round members, mounting adaptors that attach the hangers to the towers without drilling are used. Tower members should not be drilled without approval of the manufacturer because of possible weakening of the structure.

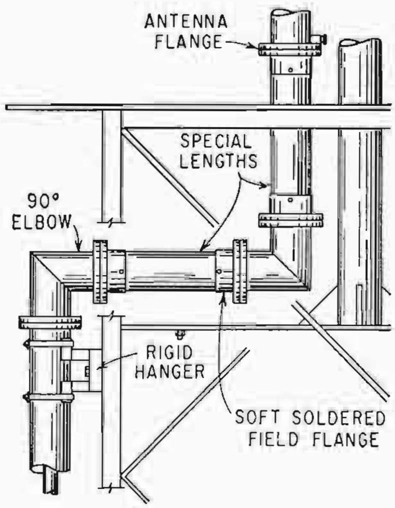


Fig. 17. Installation at top of tower.

The second step of the installation is attachment of the vertical run to the tower where the spring hangers and sliding hangers are used. The sliding hangers are merely guides placed at 10-ft. intervals along the vertical run to prevent any lateral motion of the transmission. Spring hangers are used to support the weight of the line and to accommodate differential expansion between line and tower. Sliding and spring hangers

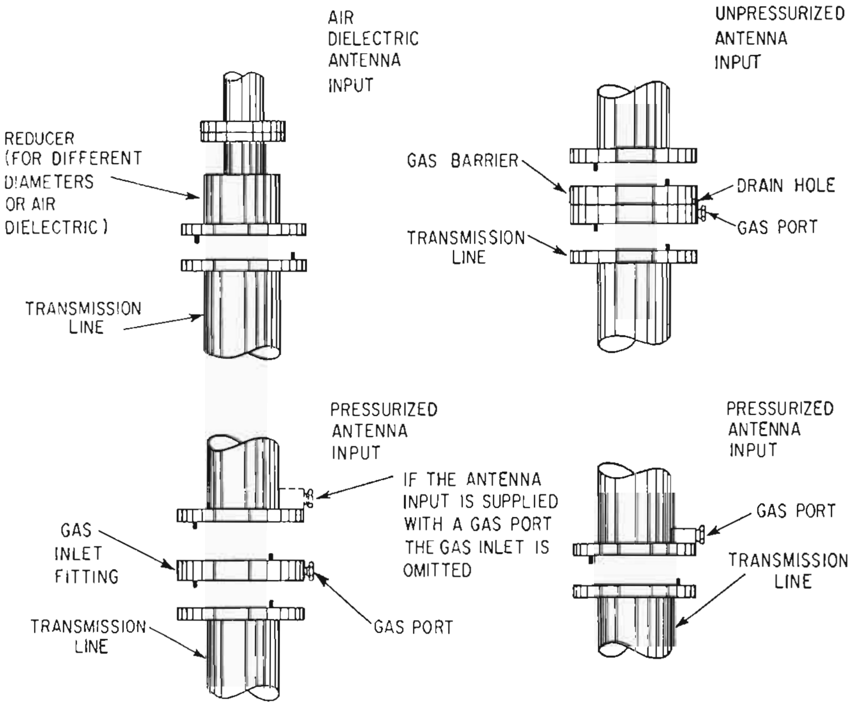


Fig. 16. Various antenna connections and fittings.

are made with and without insulators by some manufacturers as a combination hanger, as shown in Fig. 18. As the assembly proceeds, make

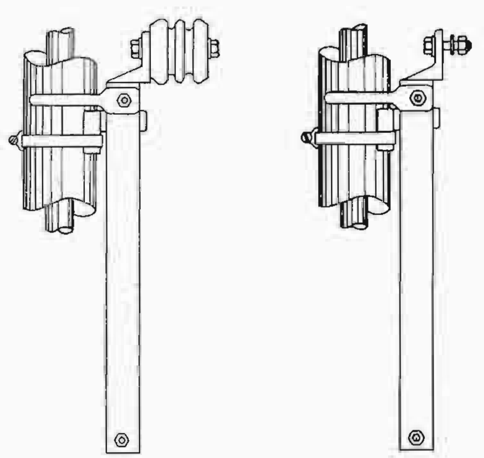


Fig. 18. Spring and sliding hangers (with and without insulators).

certain to use a combination spring and sliding hanger at 10-ft. intervals, placing a hanger 5 ft. from each end of the standard 20-ft. section, Fig. 19. The most convenient location to hang the transmission line is near the tower ladder, where it is easily accessible for periodic inspection.

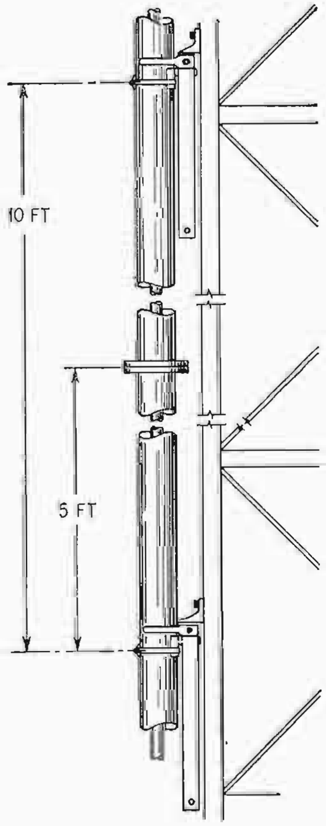


Fig. 19. Installation on tower.

Flexible line sections are used to correct transmission line misalignment for providing a slight change in direction as may be necessary. The flexible section for 3-1/8 in. transmission line is only 18 in. long; yet it can take up to 1/2 in. offset in the transmission line path, and can accommodate up to 30° bend. Flexible sections are used to accommodate vibration in transmission lines between equipment components, but are not intended to compensate for expansion or contraction due to temperature change. A flexible transmission line section is shown in Fig. 20.

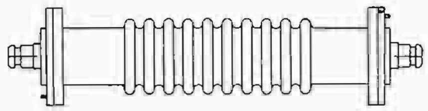


Fig. 20. Flexible section.

It is good practice in long transmission line runs to use breakaway sections (see Fig. 21) so that the line can be opened to measure antenna characteristics or to troubleshoot the line. With the use of a breakaway section, it is a simple matter to service antenna or transmission line. If a means of servicing the line is not provided, it is necessary to disassemble the run. Do not support more than one section of line on a flange joint without using hangers. As a precaution, leave the hoist line tied to the transmission line section until after the hangers are attached. Tapered towers involve changes in the line direction that are different from the 45° and 90° permitted by the standard elbows. In such cases, it is possible to bend a section of transmission line to make a change of up to 5° for 3-1/8 in. line or smaller, and up to 1° for 6-1/8 in. line. For greater changes, special angle elbows are required or two 90° mitered elbows can be connected in tandem as shown in Fig. 22 to produce the desired angle.

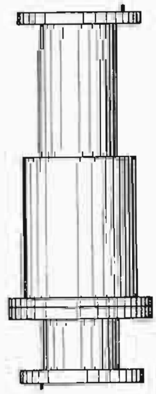


Fig. 21. Breakaway section.

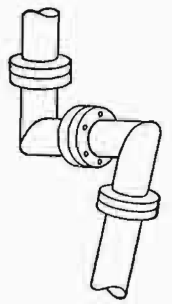


Fig. 22. Two 90° elbows in tandem.

The third step of the installation is at the base of the tower. The 15-ft. sections of line are installed here; one length vertically and one starting the horizontal run. These lengths are not supported by hangers but are left free to flex and accommodate the changes in length caused by line expansion and contraction, Fig. 23. If the bend from the vertical run to the horizontal run is 90°, a mitered elbow is used; however, if the bend is of some other angle as in the case of a tapered tower, two 90° elbows can be used in tandem to produce any angle from 0° to 180°. The bottom of the line (near the elbow) is supported with a lateral brace. The brace prevents lateral motion of the line, but permits line expansion and contraction.

The horizontal run, like the vertical run, is also affected by thermal forces, so provisions must be made to provide horizontal support while permitting the line to change length. To accomplish this, the line is supported by horizontal swinging hangers which bolt to support post arms. A horizontal swinging hanger is shown in Fig. 24. On vertical runs, the hangers should be placed at 10-ft. intervals.

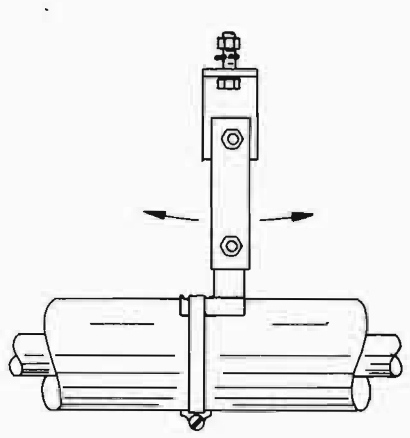


Fig. 24. Horizontal hanger.

The line is anchored at the building wall with a horizontal anchor which is similar to the rigid anchor used at the top of the vertical run. A horizontal anchor is shown in Fig. 25. Its purpose is to keep line movement away from the equipment, permitting expansion and contraction to build up at the tower end of the horizontal run.

Inside the building, the transmission line connects to the gas barrier immediately upon enter-

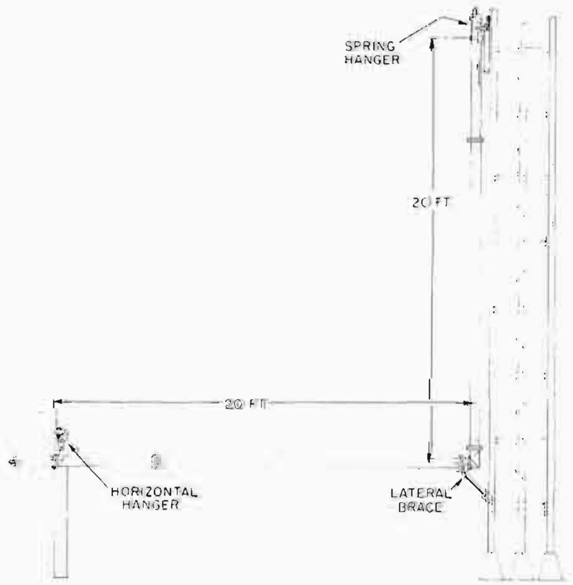


Fig. 23. Installation at base of tower.

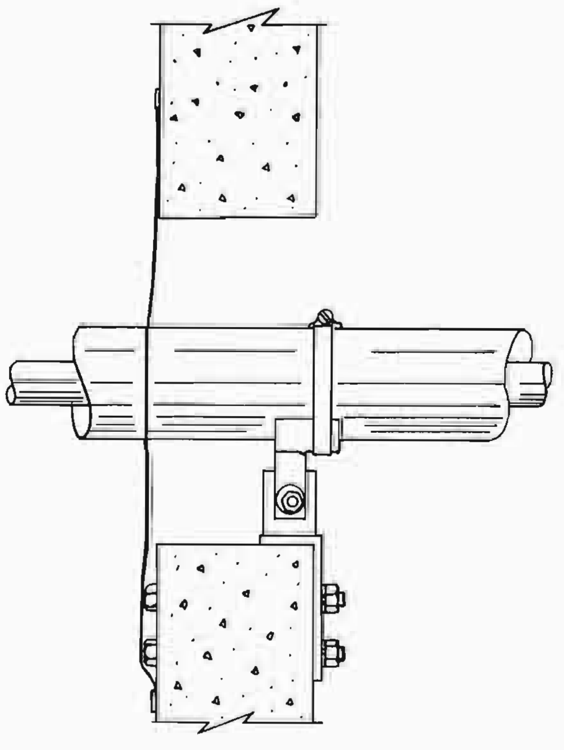


Fig. 25. Horizontal anchor.

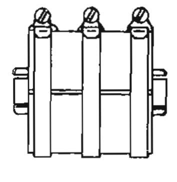


Fig. 26. Straight coupling.

ing the building. The barrier has a gas port to which the automatic dehydrator is attached. The automatic dehydrator keeps the entire length of line from the building to the antenna pressurized.

Connections between transmitters, diplexers, and switches inside the building are made with either flanged pressurized rigid line or with unpressurized coupling type connectors as illustrated in Fig. 26 and unflanged line.

Switching Systems

Coaxial switching systems such as patch panels or switches are recommended for all radio stations. These systems greatly reduce transmitter tune-up and testing time. "Off-the-air" time caused by equipment failure is also reduced, as standby equipment can be rapidly switched into use.

The type and configuration of the switching system required depends upon the needs of the station. The use of patch panels or remotely controlled switches is dependent upon local conditions. The systems described in this section are typical, having been used in many stations.

Patch panels are receptacles which are terminations of transmission line from equipment, strategically located on a panel so that desired connections between the terminations can be made by U links. These allow manual transfer or switching into dummy loads, alternate drivers, amplifiers and antennas. Usually, interlock circuits following the RF path are provided for safety. Figs. 27 and 28 show two typical patching systems, both using standard patch panels. Figs. 29 and 30 are photographs of the front and rear view of a standard five terminal 3-1/8 in. coaxial patch panel.

The power ratings of patch panels are usually the same as that for the equivalent size transmission line.

Coaxial switches are also used in switching systems. These have the advantage over patch panels in that they can be remotely controlled and are faster in operation. Remotely controlled switches make it possible to switch in auxiliary or standby equipment at remote, unmanned AM or FM stations. It is possible to control switches over telephone lines along with the other controls and metering circuits.

Coaxial switches are available for all sizes of transmission line up to and including 6-1/8 in. The power ratings of switches are usually equal to or slightly lower than the power rating of the equivalent size transmission line. They are available in many configurations, the most common being SPST, SPDT, and transfer types.

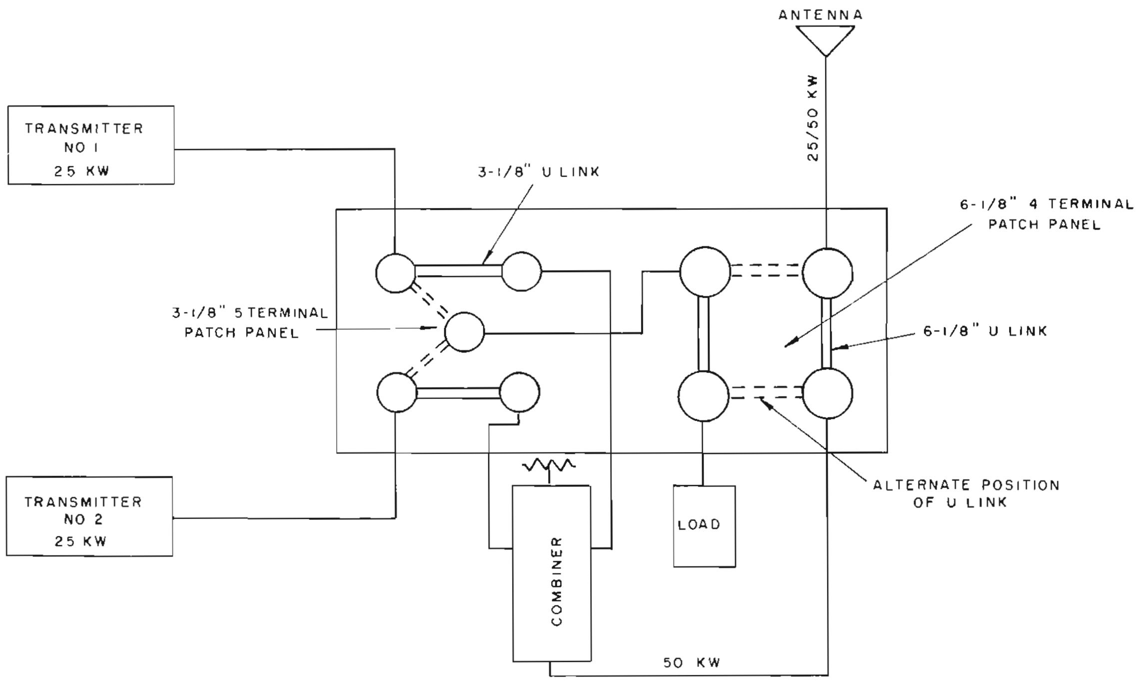


Fig. 27. 3-1/8 in. and 6-1/8 in. patch panels connecting two transmitters for greater power.

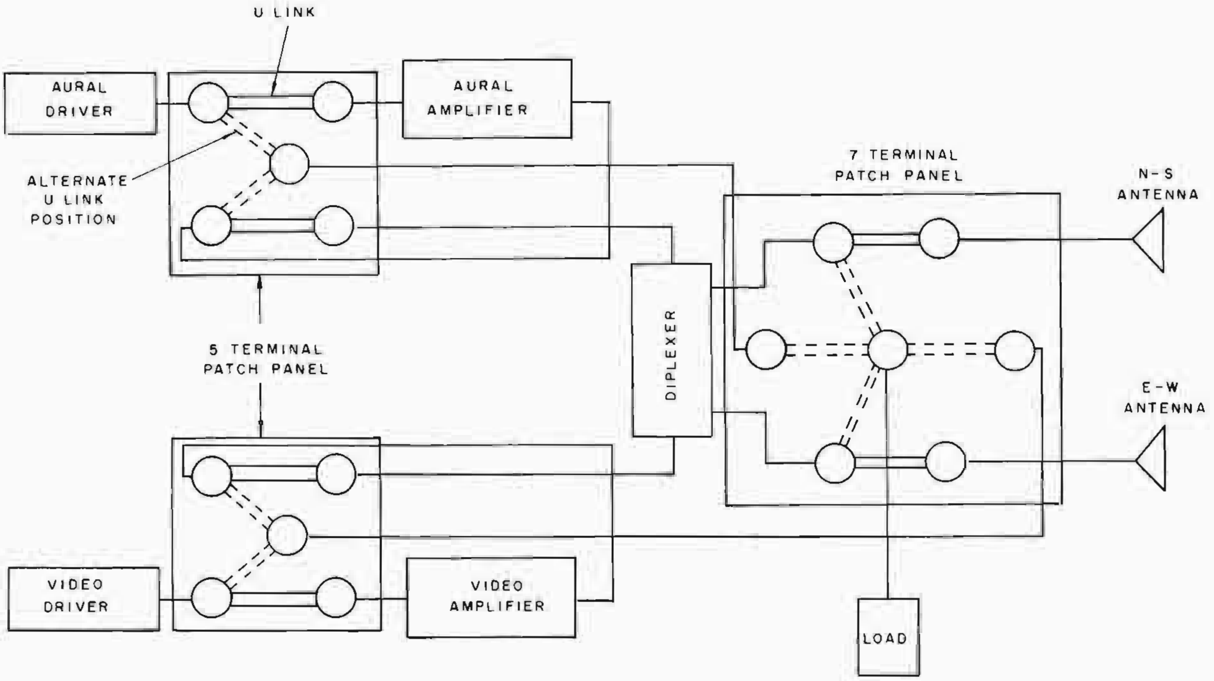


Fig. 28. Five terminal and seven terminal patch panel system.

Fig. 31 shows a commercially available transfer switch for 3-1/8 in. line. Figs. 32 through 35 show four typical switching systems varying from a rather simple system Fig. 32 to a complex system, Fig. 35.

The control circuits are also variable in design and depend upon the requirements of the station. Simple individual control switches or elaborate systems using relay logic, as shown in Fig. 36 can be used. Fig. 36 is a photograph of the control panel for the switching system shown in Fig. 35. This system automatically switches the proper switch to select the path desired. An illuminated RF path indicator is also included.

Fig. 37 is a photograph of the switching panel for the circuit shown in Fig. 35. This shows all the switches mounted on one panel or cabinet. It is not necessary to do this. It may be more desirable to mount the switches along the transmission line run, near the apparatus being switched. This will usually result in savings of transmission line and space. The control wires can be run to a central

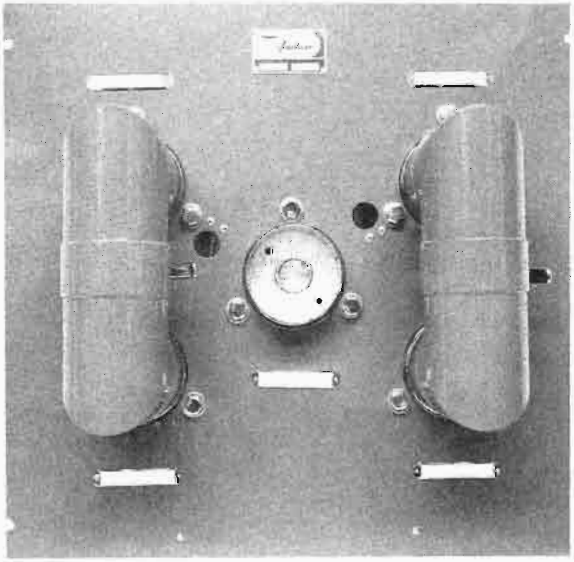


Fig. 29. Front view of standard five-terminal patch panel for 3-1/8 in. line.

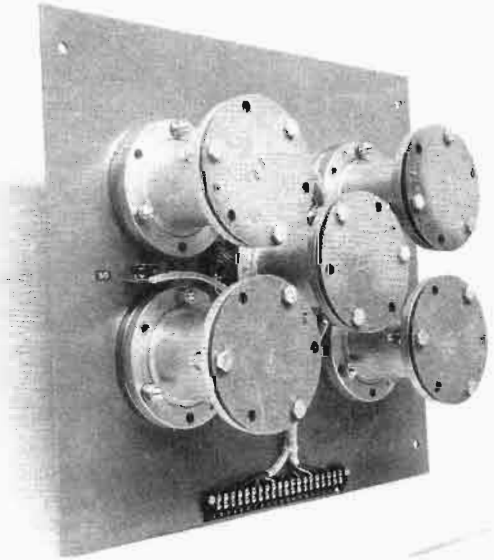


Fig. 30. Rear view of standard five-terminal patch panel for 3-1/8 in. line.

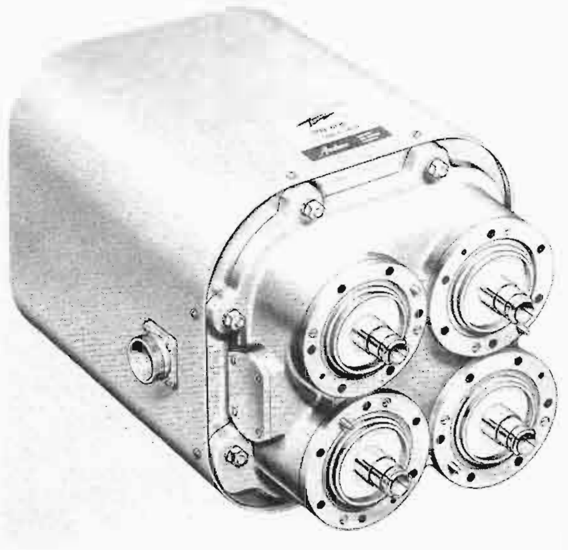


Fig. 31. 3-1/8 in. coaxial switch.

control panel located at the transmitter control panel.

Waveguide Installation

1. Installation of waveguide for broadcast use requires much more advance planning than a comparable installation of coaxial line. Each installation introduces special problems in mounting the waveguide on the supporting structure and in connecting it to the transmitter equipment. A great advantage of installing copper-clad steel waveguide is that there is no differential problem of expansion and contraction between the tower and the waveguide. This is true for two reasons: first, because the waveguide and tower are both made of steel and are identically affected by changes in temperature, and second, because of the very high efficiency and extremely low loss, no heat is created from the RF energy. Aluminum waveguide, because of its expansion and contraction, must be suspended by spring hangers in the same manner as rigid copper lines. The transitions at either end of the waveguide run are equipped with a gas barrier for pressure termination of the 3-1/8-in. coaxial line. Though the waveguide is unpressurized, the antenna and the 3-1/8-in. coaxial-line jumper connections outdoors usually are kept under pressure. A small copper tube is used to bring the gas supply up to the antenna.

The coaxial line between the transmitter building and the waveguide is also pressurized. Inside the building, however, the line is not pressurized.

The following Bill of Materials gives the approximate items and quantities needed for a

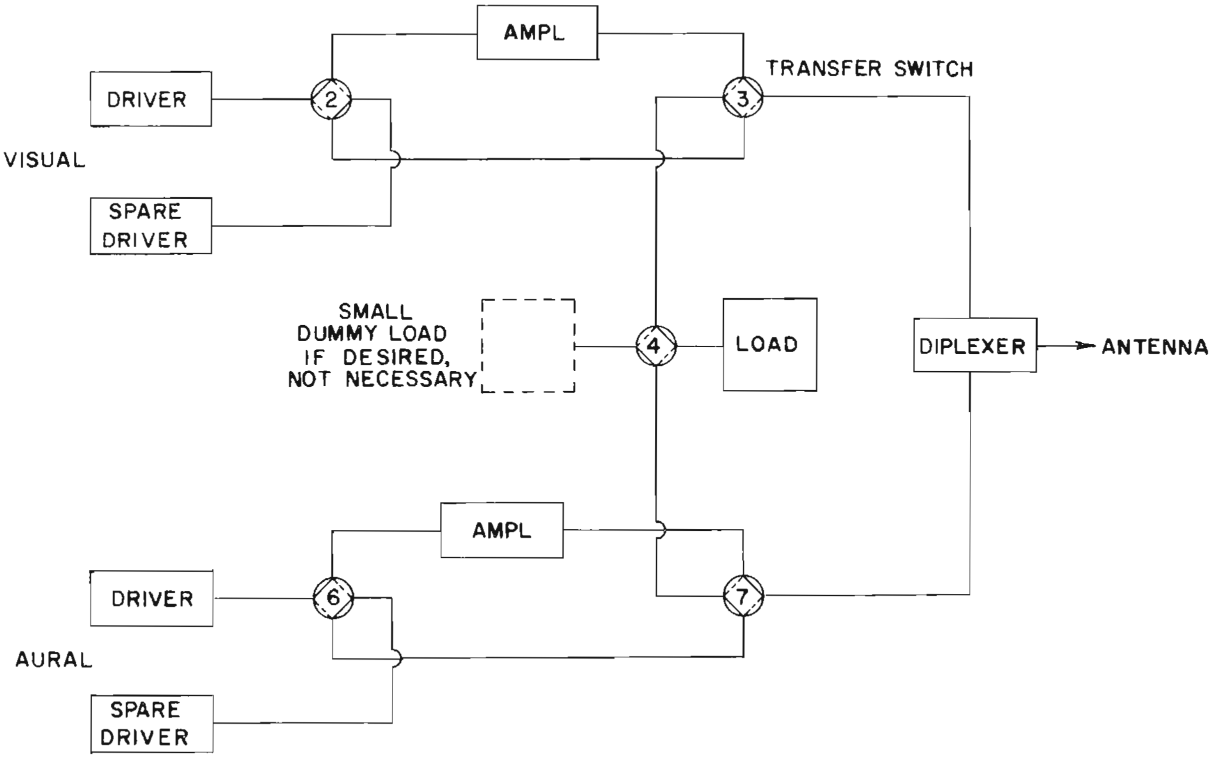


Fig. 32. Typical switching system for television station.

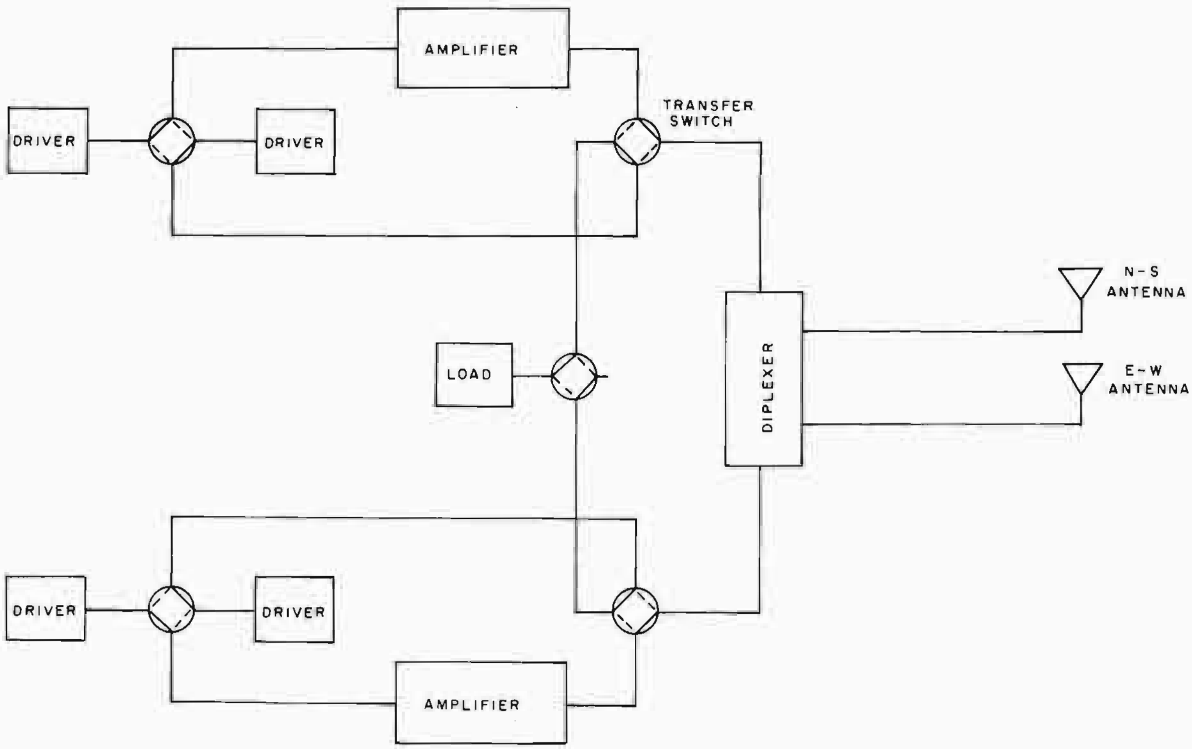


Fig. 33. Switching matrix for a quadrature feed antenna system.

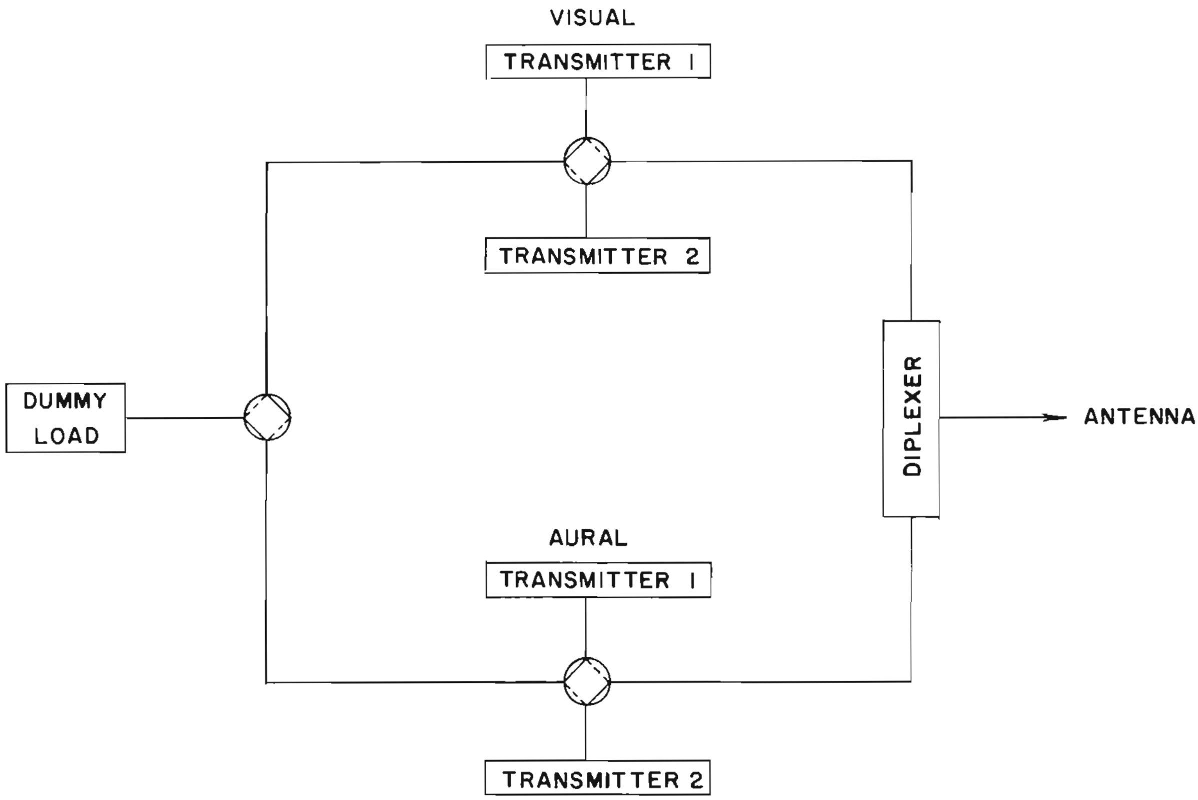


Fig. 34. Diagram of visual/aural system.

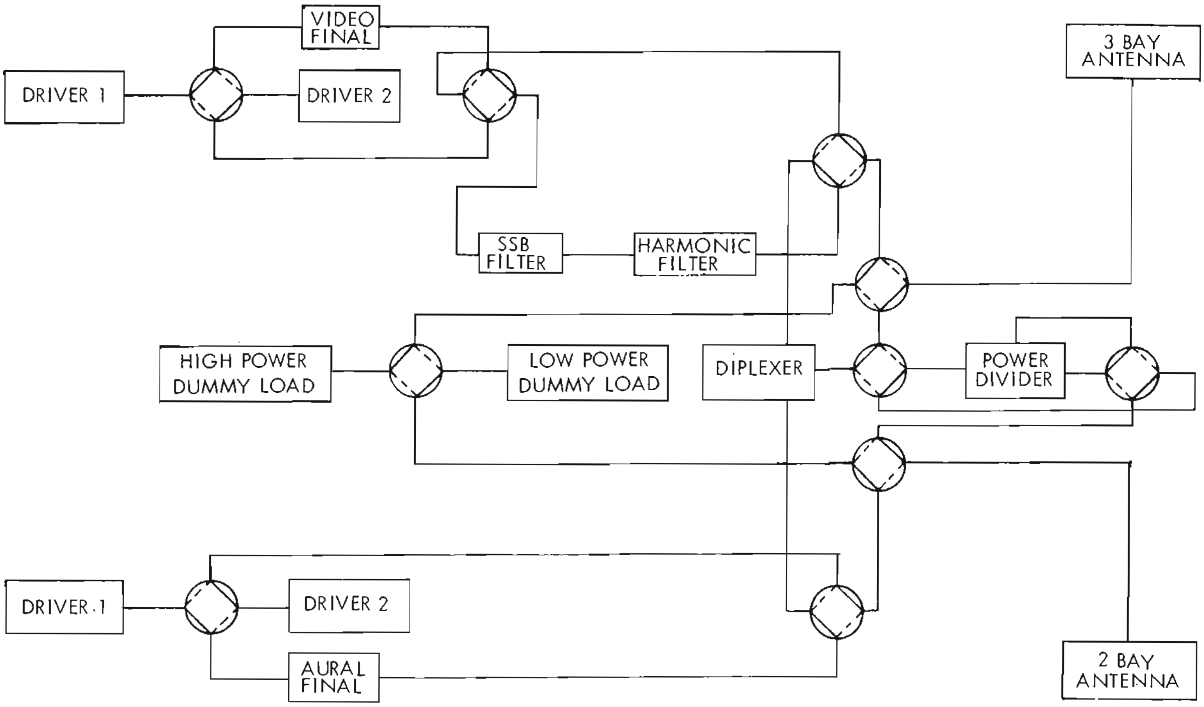


Fig. 35. Complex circuit diagram for switching matrix (see Fig. 37).

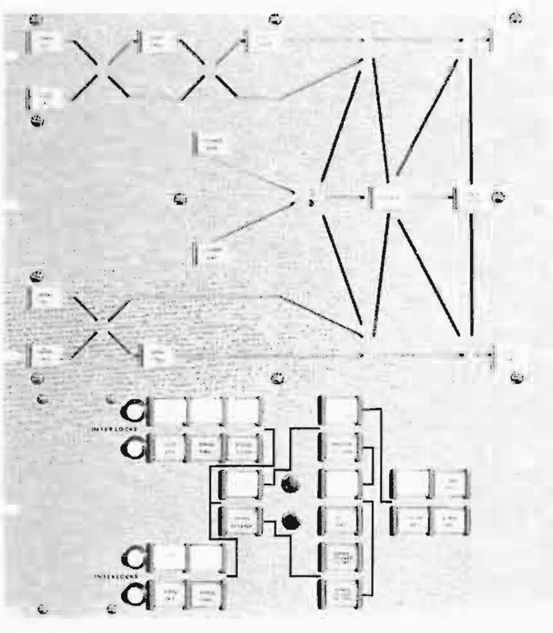


Fig. 36. Remote control panel.

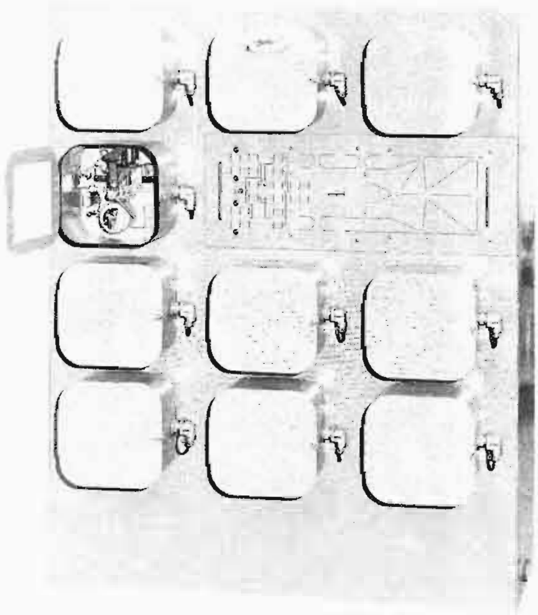


Fig. 37. Switching matrix.

typical copper-clad steel waveguide installation on a 600-ft. tower plus a 30-ft. horizontal run:

BILL OF MATERIALS

Items	*Quantity*	*Use*
1. 90° mitered elbow, flanged	3	For changing line direction
2. Special lengths of line, unflanged	8	For custom applications
3. Soft-soldered flange kit	9	For field flanging lines and elbows
4. Gas barrier	1	For pressure termination of line
5. Straight couplings	7	For joining unflanged line
6. 90° elbow, flanged one end	3	For changing line direction
7. 90° elbow, unflanged	2	For changing line direction
8. Automatic dehydrator	1	For automatically pressurizing line
9. Transition, waveguide to 3-1/8-in. line	2	For RF energy passage from waveguide to coaxial line
10. Tower hanger	59	For attaching waveguide to tower
11. Horizontal hanger	3	For horizontal support of waveguide
12. Waveguide, standard 10-ft. lengths	62	For main run
13. 90° waveguide elbow	1	For changing waveguide direction

2. At the top of the tower (as in the rigid coaxial transmission-line installation) a custom connection to the antenna is necessary. The coaxial connection from the antenna flange to the waveguide transition is made with two 90° mitered elbows, a special length of line cut as required, and two soft-soldered field flanges, as shown in Fig. 38.

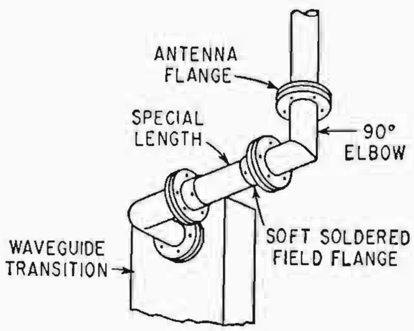


Fig. 38. Installation at top of the tower.

3. Along the tower, the waveguide hangers are used at 10-ft. intervals. They are placed at the middle of each standard 10-ft. waveguide section. Do not support more than one section of waveguide on a flange joint without using a hanger. It is much safer to leave the hoist line tied to the waveguide section until after the hanger attaches the section to the tower. The hangers used are the type that bolt directly to angle-type towers. Lateral-position adjustment is provided. Attachment to the waveguide is not difficult, as the hardware is captive and the clamping plates slide easily into place after the waveguide is positioned. A waveguide installation is shown in Fig. 39.

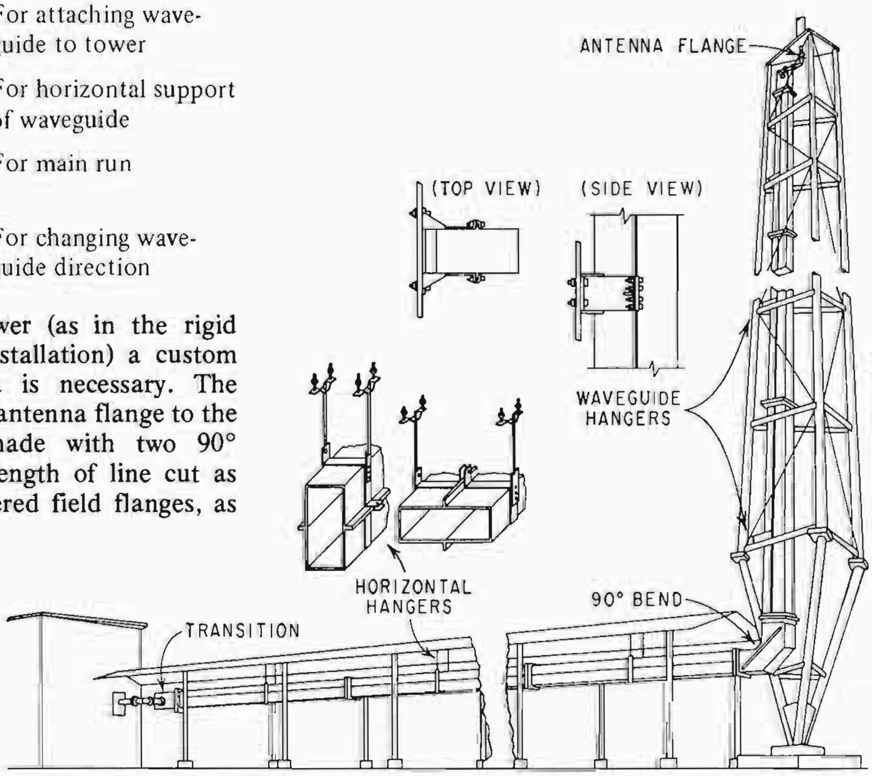


Fig. 39. Installation of Waveguide.

4. At the bottom of the waveguide run, a 90° waveguide bend is used. The one shown in Fig. 39 is an *H*-plane bend. Bends are usually supplied for 45° or 90°, but most suppliers fabricate special bends to customer specifications. A hanger is not required for the bend.

5. The horizontal run is supported with hangers that can be adapted to support the waveguide in either plane, as shown in Fig. 39. These are equipped with threaded adjustments so that perfect alignment of the waveguide sections can be made.

6. A transition is added to the end of the horizontal waveguide run for connection to the 3-1/8-in. coaxial line. (In some installations, the transmitter building is very close to the base of the tower. In such cases the transition can be installed at the bottom of the vertical run of waveguide and coaxial line used for the horizontal run.) From the transition, a 90° mitered elbow and two special lengths of line are used to bring the horizontal run inside the transmitter building. A gas barrier is then attached to the line, and the automatic dehydrator is connected to the gas barrier. For short lengths of line, a dry-air hand pump can be used for pressurization.

7. Once inside the building, all installations, procedures, accessories, etc., are the same for stations using waveguide as they are for those using rigid coaxial transmission line for the main RF feeder.

13

Antennas for FM Broadcasting

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This chapter is directed to the broadcasting engineer who must make technical decisions regarding frequency modulated transmitting antennas. The practical aspects of several types of FM antennas are discussed, together with their installation, operation, and propagation characteristics.

We are concerned here with transmitting antennas which provide a means of radiating FM power from a broadcast transmitter. These antennas are designed for operation in the FM band from 88 to 108 MHz in the western hemisphere. In the remainder of the world, the allocated frequency under CCIR recommendations for Band II vary but are generally confined between 87.5 and 100 MHz.

FM broadcast service has some distinct advantages over AM (medium wave) amplitude modulated broadcast service. These advantages stem from propagation characteristics of FM frequencies, as well as the modulation system. There is essentially no difference between day and night propagation conditions. FM stations have relatively uniform day and night service areas.

FM broadcasting was first authorized in the United States in 1940 by the Federal Communications Commission. The first FM station began operation in 1941. In 1945, the FM service was assigned to the 88 to 108 MHz band and divided into 100 channels, each 200 kHz wide.

There were 3,575 FM broadcasting stations operating in the United States at the beginning of 1976. About 99 percent of their antennas are nonsymmetrical, being mounted on one side of a steel structure. FM antennas outside the western hemisphere are usually symmetrical, installed on the four sides of a square steel support mast, or around a concrete cylinder. Both schemes are capable of providing excellent omnidirectional azimuth patterns.

Antennas for FM sound broadcasting use linear horizontal, vertical or circular polarization. In some countries horizontal and vertical polarization (Hpol and Vpol) are used as a means to prevent cochannel and adjacent channel interference. Circular polarization (Cpol) together with its special form, elliptical polarization (Epol) was introduced in the mid-sixties as a means of providing greater signal penetration into the many forms of FM receiving antennas, found in the broadcasters service area.

Receiving antenna types have proliferated as have the receivers. In the ten-year period between 1966 and 1976, there were 172 million FM radios sold in the United States, of which 18 million were automobile FM radios![1]

The FM antennas presently manufactured in the United States consist of a number of radiators, which are omnidirectional in the horizontal plane, when measured in free space. By stacking these in the vertical axis, the elevation pattern is compressed, and additional gain is obtained over a single radiating element.

Antennas for FM broadcasting must be chosen carefully, in order to cover the service areas properly. The maximum effective radiated power (ERP) should be achieved with proper balance between antenna gain and transmitter power. The height of the antenna over the service area, distances to areas of population, the ERP, and the economics are items that must be considered.

Antennas currently available in the United States differ considerably from those to be found in Europe. The various American types are discussed briefly so that the engineer will be informed on the subject. Considerable advances have been made in recent years in the design and fabrication of FM antennas. These improvements provide greater penetration of signal into automobile FM radios as well as popular small FM transistor radios, of all kinds. The newer FM broadcasting antennas must meet the more stringent requirements for FM stereo and quadraphonic broadcasting.[2]

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[1] 1975 EIA *Consumers Electronics Annual Review.*

[2] Vol. 1, National Quadraphonic Radio Committee, Report to the Federal Communications Commission, Nov. 1975, EIA, 2001 Eye Street, N.W., Washington, D.C. 20006.

Circular polarization for FM broadcasting has come of age. Most established broadcasting stations in the western hemisphere have converted their antennas to Cpol. For this reason, the discussion of antenna types will be on this class of antennas, following propagation and other matters.

PROPAGATION

FM propagation includes everything that can happen to the energy radiated from the transmitting antenna during its journey to the receiving antennas. It includes the free space path attenuation of the wave with distance, and encompasses such factors as refraction, reflection, interference, diffraction, absorption, scattering, Fresnel zone clearances, grazing, and Brewster angle problems.

Propagation is therefore dependent upon all these properties out to approximately 40 miles (65 km). Some additional factors enter the picture with longer service ranges. Radio wave propagation is further complicated because some of these propagation factors are functions of frequency or polarization, or both, and may have location and time variations.

The technical intent of the broadcaster is to put a signal into FM receivers of sufficient strength to overcome noise and to provide adequate limiting for at least a 20 dB signal-to-noise ratio. This RF signal level varies from about 2 μv per meter for high sensitivity FM stereo tuners, to about 50 μ v for less sensitive transistorized portables, as well as most automobile receivers.

FM antenna manufacturers do not guarantee coverage. They provide antennas which radiate a signal meeting certain levels depending on the antenna power gain and the transmitter power put into it. This is indicated as a free space value for 1 kw of input power, assuming a circular azimuth radiation pattern. These free space values are shown in the catalogs for reference purposes, and are achieved in practice only, when measured on a good antenna test range.

Some manufacturers in the United States provide azimuth pattern adjustment service, to insure a circularity of ±4 dB, when mounted on the side of a specific tower or pole.[3] It must be pointed out that this radiation pattern and gain is for free space conditions, one that is completely free from any obstructions to propagation. This is rarely found in actual installations. The radiation pattern and propagation are two distinctly separate parameters. They should not be confused as one and the same. They are not.

[3]As of January 1, 1976, firms such as Collins Radio Company, Harris Corporation and Jampro Antenna Company.

The radiation pattern is that which is transmitted by a given antenna, without any propagation limitations, on a good antenna test range. The propagation problems are conditions existing between the transmitting antenna and the receivers, and indicated in the first paragraph, under *Propagation.*

The actual service area signal strengths are based upon two probability factors. Contours are not solid signal areas. For example, the FCC FM signal coverage charts are based upon a probability of 50 percent of the locations, 50 percent of the time. This means that at any one given location the signal has a 50 percent chance to measure up to the predicted contour level. Furthermore, half the time at that location it may reach the level predicted while at other times at the same location, it may be lower or higher in strength.

These FCC charts are also based upon the assumption that excellent propagation conditions exist. One or more of the conditions mentioned in the first paragraph under this heading may reduce the measured signal strength from those predicted values.

PROPAGATION SPACE LOSS

Prediction charts, in addition to utilizing roughness factors, use space loss with distance as the limiting value. The power radiated from a FM transmitting station is ordinarily spread over a relatively large area. The power reaching the receiving antenna is a very small percentage of the total radiated power. Furthermore, the radio transmission loss may vary from 97 dB for 10 miles (16 km) to 112 dB for 50 miles (80 km). For various other distances, see Fig. 1. Notice that the path loss is a function of frequency.

At 100 MHz, and a distance of 30 miles (48 km), the figures indicate the path loss to be 106 dB. Doubling the distance increases the space loss by exactly 6 dB. The path loss does not attenuate the signal with distance as much as some other factors. Path loss between an earth station and a satellite is a classic book example of a 6 dB loss every time the distance is doubled. But a typical FM station signal travels over a perfect dielectric (air) and the imperfect earth's surface (ground). Herein lies the FM radio propagation problem.

With one wavelength spacing between the transmitting and receiving dipole antennas, the path loss is 19.85 dB. This loss increases in free space removed from the effect of the earth's surface by a 6 dB factor as the spacing is doubled, as indicated in the no mogram.

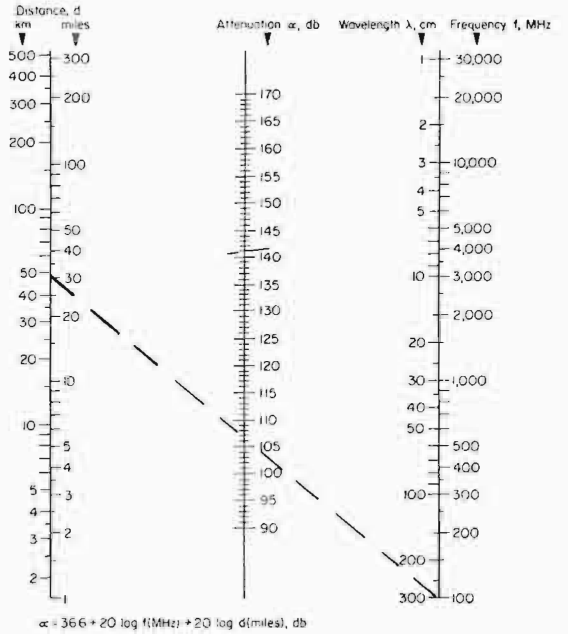

Fig. 1. Space loss as a function of frequency and distance. Dashed line shows space attenuation at 100 MHz.

PROPAGATION—LOSS THROUGH VEGETATION

Signal loss due to foliage has been well known to UHF broadcasters for many years.[4] This same condition exists for FM broadcasting, but with much less effect. Trees, shrubs, and other foliage on hills, or smooth terrain affect the reflected as well as the lateral signal loss with distance. With average values of permitivity and conductivity in both foliage and ground, a loss of about 2.5 dB was found to exist, at the FM frequencies.[5] The height gain factor is increased with heights above the foliage. Considerable depolarization takes place because the transmission through or reflections from ground foliage is a diffracted field contribution.

MULTIPATH PROBLEMS

The ideal reception condition is a strong direct single source signal. When signals from two or more paths due to reflections reach the receiver, a condition called multipath reception occurs. Poor reception takes place when there is insufficient strength difference between the direct and the reflected signals.

Nothing is more important in the way of broadcasting facilities than the location of the transmitting antenna. Great care should be exercised to find a suitable site. Poor reflection can result in very unfavorable signal propagation, and negate the entire project.

For example the transmitter should not be located so that strong reflections take place from nearby mountains. This can happen when the transmitter is placed on one side of a large city and the other side of the city has a high mountain range. Radiation into the city directly from the transmitting antenna, as well as reflections from the nearby hills and mountains will create two or more signal paths. These reflections can be as strong as −6 dB below the direct signal, and cause severe multipath reflections.

A TV station in this same location would experience unusable signals due to extremely heavy ghosting, even with directional receiving antennas, which exhibit strong pickup from their back sides. This is illustrated in Fig. 2.

The multipath example shown in the sketch was an actual case. The site was chosen by the FM broadcaster without proper engineering guidance because the hill was developed with power and road facilities. In fact, it had a UHF TV station once located there. Further examination revealed that the TV station failed due to extremely heavy ghosting in the principal city. The high mountain range caused severe multipath signals for the FM station.

A much better FM transmitting site could be located on the hills between the high mountains and the city using a directional transmitting antenna with very little radiation towards the mountains, thus greatly reducing reflections.

Multipath reflections are very easy to spot. On an automobile radio, the signal will appear and disappear with distance, which is quite rhythmic. It is sometimes called picketing, as it reacts like a picket fence stopping and letting the signal pass. A field strength meter will usually reveal great variations of signal when moving say 100 ft. (30 m) in a line with the transmitter. Cyclic variations over quite uniformly spaced intervals on the ground as great as 40 dB have been observed by the author.

Fig. 2. Example of poor station location causing severe multipath propagation.

[4]The Influence of Trees on TV Field Strengths at UHF, Howard T. Head, *Proceedings of the IRE,* Vol. 48, Page 1016-1020, June, 1960.

[5]Radio Wave Propagation in Forest Environments, Theodor Tamir, *IEEE Transactions on Antennas and Propagation,* Vol. Ap-15, No. 6, Nov. 1967.

The large variation in signal levels is caused by the reflections adding and subtracting from direct path signal. This is indeed caused by propagation problems existing in the path between transmitter and receiver. It really has nothing to do with the transmitting antenna.

A minor form of what appears to be multipath can be traced to high injection levels of the stereo subcarrier. The problem may be easily detected by simply switching the exciter from stereo to mono, and observing the field strength in the same suspected areas. If the mono operation reduces the multipath effects, then the stereo subcarrier injection level is too high and the modulation monitor should be checked for accuracy. Injection levels of 28 percent have been known to cause multipath signal variations as great as 23 dB, and disappeared when the level was reduced to 8 percent. This problem is caused by the differences in frequencies of the main and stereo subcarrier, which cause addition and cancellation in the signal field entering the front end of the receiver.

Propagation requirements dictate that the site must be free from reflections caused by hills and mountains, which can cause multipath conditions. The location and tower must also provide sufficient height over and to the service area for first Fresnel zone clearance, which is much more demanding than simple line of sight conditions.

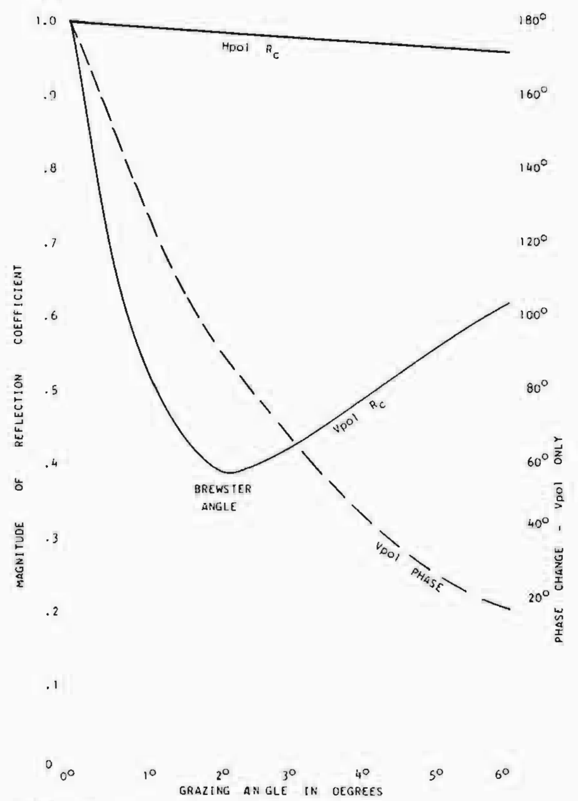

Fig. 3. Magnitude of reflection coefficient and phase change, as a function of grazing angle for Hpol and Vpol, at 100 MHz with a soil conductivity of 10 millimhos per meter.

GROUND REFLECTIONS

In the elevation plane between transmitter and receiver nearly all FM signal coverage lies within 10° below the horizontal plane. Generally the higher the transmitting antenna above the service area the greater will be this angle. Called the grazing angle, it lies between the horizontal plane and the earth's surface. The angle's of incidence and reflection are nearly the same. The depression angle and the grazing angle are not equal as would be the case for a flat earth. Reflections from these angles play an important part in the strength and quality of the received signal in FM broadcasting with Cpol.

The ground which causes reflections at these grazing angles does not treat Hpol and Vpol in the same manner. The Vpol is attenuated considerably more than the Hpol and the phase of the Vpol changes substantially with angle, while Hpol remains nearly the same. See Fig. 3. At these useful low propagation angles, there is considerably less Vpol signal than Hpol signal when grazing reflections take place. Field measurements confirm this fact.[6]

When ground reflections take place the polarization and axial ratios are considerably different from those which left the transmitting FM antenna. In service areas with larger reflection angles, the ratios also are different than at smaller angles.

It is quite difficult to predict accurately the reflection coefficient of the soil. The ground reflection coefficient can vary considerably as a function of polarization, frequency, grazing angle, surface roughness, soil type, moisture content, vegetation growth, weather and season. These are complex formulas for predicting the ground and the soil conductivity at the frequency of interest. For 100 MHz a value of 10 millimhos per meter ground conductivity was used, with a permittivity of 25, as being about average for the continental United States. When the soil conditions vary, the Brewster angle varies.

The chart in Fig. 3 shows how much the earth's surface affects the Vpol while there is little reflection loss or phase change for Hpol. At low reflection angles the phase of Vpol changes

[6] Study of Electromagnetic Wave Propagation at 112 MHz, A. Armstrong and H. Ziesing. April 1969, *Proceedings of IREE*, Australia, pages 105 to 110.

The Effect of Ground Reflections on Antenna Test Range Measurements. A. Moeller, March 1966, *Microwave Journal*, pages 47 to 54.

drastically, causing further reduction in the received Vpol signal in Cpol.

It should be pointed out that the reflection coefficient is a function of the electromagnetic qualities of the soil where reflection at low angles takes place. There are of course reflections taking place from nonsoil surfaces. Objects such as buildings, billboards, metal fences, also cause changes in the received axial ratios. Therefore it is quite common to find variations in polarization and axial ratios in different parts of the service area of an FM station due solely to the electromagnetic properties of the soil and objects on it.

Ground reflections caused by grazing angles also cause multipath signal problems, discussed under another heading. These problems can be greatly reduced by proper site selection together with adequate tower heights.

Referring to Fig. 3 again, notice that the minimum reflection coefficient occurs at a grazing angle of about 2°. Below this angle, the reflection coefficient rapidly increases to unity. The angle at which the minimum reflection coefficient occurs is called the Brewster or polarizing angle. The greatest attenuation for Vpol from ground reflection occurs at this angle.

Field measurements of Vpol signals will usually show a greater ratio of Hpol to Vpol due to this Brewster angle. It must be borne in mind that the Brewster angle is a function of soil conductivity and may change from place to place in the service area as well as during various seasons of the year.[7]

It is important then that for Vpol the transmitter site and antenna height above the service area provide grazing angles which are less than the Brewster angle. Otherwise the Vpol will be degraded and the radiation will be much more elliptically polarized.

SOIL CONDUCTIVITY

The conductivity and permitivity of the ground plays a part in the attenuation of FM signals, as they pass over it. Average soil has a dielectric constant of about 15 and a conductivity of about 10 mmhos per meter at 100 Mhz.[8] By removing the receiving antenna above the effects of the soil, the signal level is increased. It has been found by actual measurements that a received signal on 93.7 MHz increased 9 dB, when the test dipole was raised from 3.3 ft. (1 meter) to 30 ft. (10 meters).[9]

BREWSTER ANGLE

For polarization with electric field normal to the plane of incidence, there is no angle that will yield an equality of impedances for earth materials with different dielectric constants but like permeabilities. A wave incident at angle Øp with both polarizations present has some of the second polarization component but little of the first reflected. The reflected wave at this angle is thus plane polarized with the electric field normal to the plane of incidence and the angle Øp is the polarizing angle. It is also known as the Brewster angle, after the Englishman who first discovered this phenomenon in optics.[10]

For ground reflections occurring near the Brewster angle, the reflection coefficient is much smaller for Vpol than for Hpol. Therefore, the Vpol signal components of Cpol are attenuated considerably. This Brewster angle occurs about 2° below the grazing angle. See Fig. 3. The soil above the earth's surface, while varying greatly, has a dielectric constant between 2 and 15 mmhos at 100 MHz. It will also change from dry to moist conditions which further affect this constant, which in turn changes the Brewster angle. The Vpol component in Cpol transmissions is therefore attenuated considerably more than the Hpol.[11]

FRESNEL ZONE REQUIREMENTS

The presence of the earth's surface changes the propagation of radiation at FM frequencies and the field intensity is nearly always considerably less than the calculated free space value. A signal propagating over a flat earth consists of the direct wave plus the surface wave, the reflected waves and the induction fields and secondary effects of the ground. The surface wave is somewhat affected by the type of polarization, and the ground constants. When the wave is traveling at grazing angles (as is the typical case for FM), there is further loss, unless the receiving antenna is more than 5 wavelengths (about 50 ft., 15m) above ground.

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[7] *Ultra High Frequency Propagation,* Reed, Russell, 2nd Edition, Boston Technical Publishers, 1964, pages 223 to 238.

[8] Characteristics of Signal Strength and Dipole Antenna at VHF Near the Ground, A.H. LaGrone and D.M. Schwartz, *IEEE Transactions on Broadcasting,* December 1964.

[9] S. Ramo and J. Whinnery, *Fields and Waves in Modern Radio,* John Wiley and Sons, Inc., New York, New York, pages 312, 1960 and 301.

[10] Fields, and Waves in Communication Electronics, by Ramo, Whinnery, and Van Duzer, published by John Wiley & Sons, New York, 1967, page 364 and 365.

[11] VHF Field Strengths for Line of Sight Reception, R. Aitchison, *Proceedings of IREE,* Australia, July 1975, pages 225 to 231.

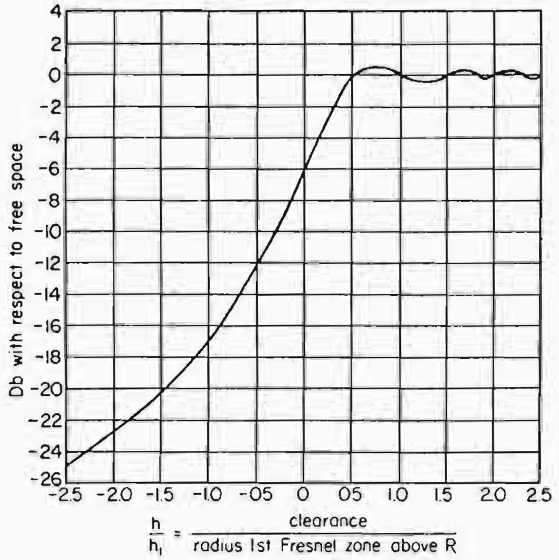


Fig. 4. Attenuation of FM propagation when the path between transmitter and receiver lacks Fresnel zone clearance in the ratios shown.

For instance, if the line of sight exists between receiver and transmitter in overland paths, there is no assurance that a strong signal will be present unless one-half or more Fresnel zone clearances are also present between the line of sight path and any obstacle. That is, there must be no large obstruction inserted into the volume occupied by the signal. There is considerable loss, typically 12 dB, when the Fresnel zone clearance is only one half of what it should be.[12] If the clearance is less than twice, the loss is nearly 22 dB. This requirement is not commonly understood. Fig. 4 shows the attenuation versus the ratio of the Fresnel zone clearance. The zone clearance may be achieved by increasing the height of the receiver, but this is not practical, so the transmitting antenna height must be increased.

The amount of clearance above ground or the path obstacle is described as the Fresnel Zone after the French scientist who discovered this phenomenon in optics. Fresnel zones are circular areas surrounding the direct line of sight path of a radius such that the path length from the zone perimeter is a multiple of one-half wavelength longer than the direct path. This is shown in Fig. 5. The zone diameter varies with frequency and path length.

Referring to Fig. 5 if TAR is the line of sight path, then TBR represents a path which is half a wavelength longer than TAR. The circle radius AB is called the first Fresnel zone. Signals with paths through this zone will tend to reinforce the direct signal.

The path TCR is one wavelength longer than the direct path. The area outside the first Fresnel zone but within the circle radius AC is called the second Fresnel Zone. We can similarly draw third, fourth, fifth Fresnel zones and so on, if the radius permits. The areas become progressively smaller so that only the first two zones need be considered in FM broadcasting.

The total energy contributed by all Fresnel zones is equal to half the energy contained in the first zone.

The Fresnel zone is frequency and distance dependent since the signal in the boundary must be multiples of one-half wavelength. The expression for determining the first Fresnel zone radius at the midpath point is given by:

$$R = 1{,}140\,(d/F)^{1/2}$$

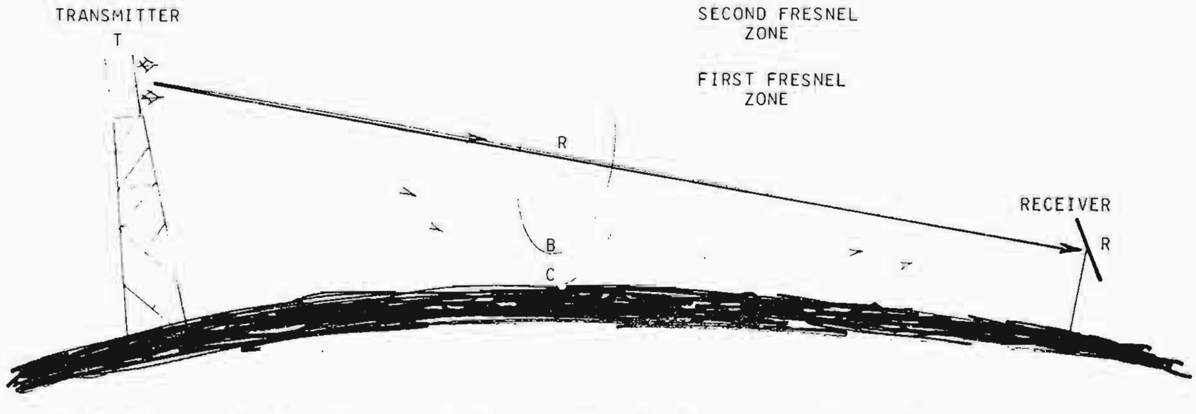


Fig. 5. Sketch showing Fresnel zones. Note that mid-path had complete firth and second zone clearance.

Where: R is the Fresnel zone radius in ft.
d is the half path distance in miles
F is the frequency in megacycles.

[12] Study of Electromagnetic Wave Propagation at 122 MHz, B. Armstrong and H. Ziesing, *Proceedings of IREE*, Australia, April 1969.

For example, a 30 mile (48 km) path will require a first Fresnel zone radius clearance over the ground at the mid-path of 171 ft. (52 m), at 100 MHz. It is important to note that this is the maximum radius. As the point of observation is moved towards the receiver, or towards the transmitter, the radius becomes smaller, as illustrated in Fig. 5.

The height of the receiving antenna is beyond the control of the broadcaster. Therefore, in order to furnish adequate signal strength, the broadcaster must use sufficient tower height over average terrain, so as to permit first Fresnel zone clearance at the mid-path point, to his outer service area, from the antenna center of radiation.

The tower heights shown in Table 1 are strongly recommended. These minimum heights are based on relatively smooth terrain paths, using 4/3 earth curvature. Use of these tower heights will generally provide the signal levels predicted by the FCC 50/50 FM propagation charts, or the recommended CCIR tables.

TABLE 1

Recommended Tower Heights for First Fresnel Zone Requirements

Tower height recommended		Distance to service area		Midpath Fresnel zone clearance	
Ft.	Meters	Miles	Kilometers	Ft.	Meters
152	46.3	10	16.2	57	17.4
228	69.5	15	24.2	86	26.2
304	92.6	20	32.2	114	34.7
380	115.8	25	40.3	143	43.5
456	140.0	30	48.4	171	52.1
532	162.1	35	56.5	200	60.9
608	185.3	40	64.5	228	69.5
684	208.5	45	72.6	257	78.3
760	231.6	50	80.6	285	86.9

If it is not possible to provide these tower heights, then the signal will suffer due to attenuation caused by lack of Fresnel clearance. This loss can be considerable. Fig. 4 shows the attenuation to be expected with adequate clearance as well as marginal values. The loss increases rapidly as the clearance is reduced.

The important consideration for proper signal coverage is to provide sufficient tower height so as to insure first Fresnel zone clearance to all service areas.

Tower heights of 150 ft. or less should be avoided unless the location is a mountain top or other prominent point providing the necessary clearance. Mere line of sight conditions between the receiver and transmitter are not sufficient. Adequate Fresnel zone clearance must be used if anticipated signal levels are to be achieved.

The importance of Fresnel zone clearance has been stressed because it is very important in FM installations. It is not clearly understood by many engineers who pick out transmitter sites, yet is vitally important, in assuring good signal strength, within the service area.

Signal Strength Variations with Time

It has been found that there is as much as 4.78 dB change in the ratios between vertical and horizontal polarization, over a one month continuous measurement period, in the FM band. Eighteen FM stations signals were measured on a daily basis for a month's time,[13] in Washington, D.C. The FM stations ranged from 0.8 km to 62.8 km distant (1.29 miles to 101 miles). ERP was 2.3 to 50 kw, and antenna height above average terrain from 85 to 194 meters (278 ft. to 635 ft.). The further away the station, the more the polarization ratio varied with time. It may be concluded from this that depolarization does indeed take place, and with a given path, will vary from day to day over a month period.

STRENGTH VARIATIONS DUE TO TERRAIN ROUGHNESS

Normally, the field strength in large samples, over relatively smooth terrain, may vary as much as 6 dB from the predicted values for 50 percent of the locations, 50 percent of the time (FCC 50/50 prediction curves). However, the rougher the terrain, the greater the variation becomes. Measurements made at 30 ft. (10m) on 87.75 MHz in the Denver, Colorado, area had the following variations, 50 percent of the locations where measurements were made.[14]

Field Strength Variation at 50 Percent of Measured Locations Versus Type of Terrain

Relatively smooth earth	6 dB
Hilly, small mountains	12 dB
Mountainous areas	23 dB

The above measurements were made in two radii of 25 (40 km) and 36 miles (58 km) from a 50 kw transmitter. These variations of signal are primarily due to ground reflections, which cause the received signal to go into quiet limiting, where cancellations take place, into the

[13]Signal Polarizations in the VHF and UHF Broadcast Spectrum, Richard A. Tell, *IEEE Transactions on Broadcasting,* December 1974, Volume BC-20, Number 4.

[14]Measurement of Service Area for Television Broadcasting, Robert S. Kirby, National Bureau of Standards, Boulder, Colorado, *IRE Transactions on Broadcast Transmission Systems,* February 1957, pages 23 to 30.

noise. It is apparent that the rougher the terrain, the more the variations. A 23 dB signal variation is a voltage ratio of 14.1 times on the increase and 7 percent on the decrease ratio.

Radio propagation over irregular terrain at FM frequencies like TV, is subject to many variations, the fine details being essentially unpredictable. Within approximately 31 miles (50 km), depending on the height of the antenna, these signal variations are almost entirely due to terrain conditions between the transmitting antenna and the FM receiver. Terrain factors include roughness, actual blockage by hills, reflections from nearby hills, or mountains, and lack of Fresnel zone clearance of the direct path.

The FCC has for many years used signal strength prediction charts which were based upon smooth earth techniques. In Docket 16004 in mid-1975, the FCC ordered that the signal strength predictions for FM as well as TV be based upon more accurate methods, utilizing a terrain roughness factor. This roughness was that encountered between 6 miles (10 km) and 31 miles (50 km). For FM a roughness factor of 410 ft. (125 m) indicates a correction of the predicted signal by a 3 dB reduction.

Due to several complaints by consulting engineers as well as broadcasters, the FCC has reset the implementation of these new curves starting from May 1976. Since there is some doubt as to exactly when and in what form they will be used, they have been omitted from this chapter. It is very noteworthy that the FCC has at long last taken a step forward in improving the accuracy of these curves. The CCIR, however, does recommend a terrain roughness factor for predicting service ranges for FM broadcasting. The CCIR also recommends the use of soil conductivity in computing contours since the soil does play an important part in the reflections present at low grazing and reflection angles.

The ideal approach to radio propagation contour predictions would be to have complete data. This would include all the necessary geodetic information, plus the electrical soil data, and a mathematical model which would permit a highly accurate path loss calculation.[15] Realistically, radio propagation is not that well defined.

CALCULATING SERVICE CONTOURS

From the FCC coverage prediction charts, it is possible to draw contours of the various grades of service for a given ERP from its height above average terrain. These are best guess predictions, at 50 percent of the locations at 50 percent of the time. The FCC has tried to make these charts more accurate, by introducing a terrain roughness factor in late 1975. This was suspended by the FCC until mid-1976. It is not known what curves will be finally used. To avoid confusion, they have been omitted from this chapter at this time.

If contour predictions are desired, it is suggested that the old curves from the Commission's Technical Rules be used, until new ones are finally instituted.

It must be pointed out that Cpol radiation does not increase the distances of the FCC service contours. Interference and allocation contours are not changed. The service contours are predictions, based upon the Hpol energy, with reference to a Hpol dipole in the field. The Cpol radiation is disregarded in these measurements, as well as predictions. The ERP of the station is only based upon the Hpol radiation, even when using a Cpol transmitting antenna.

UNITED STATES TECHNICAL STANDARDS

The FCC permits certain combinations of maximum ERP from maximum heights above average terrain from 2 to 10 miles (3.22 km to 16.1 km). The Technical Standards specify an ERP of 100 kw at 2,000 ft. (609 m) in Zone II. The FCC has divided the United States into three zones for the purpose of determining maximum power depending on height above average terrain, for co-channel and adjacent channel interference allocation purposes. Zone I is generally the eastern United States, east of the Mississippi River. Zone II covers the remainder of the United States, except the Gulf Coast area which is Zone IIA, and has abnormal propagation due to refractive indexes. Table 2 indicates the maximum ERP values at maximum heights for the different zones and classes of stations. Class D is for educational institutions, such as college and university campuses. Classes A, B, and C are for both educational, noncommercial and commercial FM broadcasting stations.

Some stations are using much more ERP than those shown in the table. This is due to the grandfathering privilege granted by the FCC, before these rules went into effect. There are several dozen stations with ERPS in excess of 100 kw operating in the United States.

Fig. 6 shows the FCC maximum ERP power allowed, versus the average height over the 2 to 10 miles terrain radials. (3.22 to 16.1 km). This is the FCC's Fig. 3, Section 73.333 revised in February 1970.

[15] Practical Approach to Radio Propagation Measurements, Robert Forrest, *IEEE Transaction on Vehicular Technology*, Vol. VT-24, No. 4, November 1975.

TABLE 2
Maximum FM ERP and Height above Average Terrain

Class of station	Zone I		Zone IA[a]		Zone II	
	Max. ERP	Maximum height	Max. ERP	Maximum height	Max. ERP	Maximum height
A	3 kw	300 ft. 91 m	3 kw	300 ft. 91 m	3 kw	300 ft. 91 m
B	50 kw	500 ft. 153 m	50 kw	500 ft. 153 m	—	None —
C	—	—	—	—	100 kw	200 ft. 619 m
D	10w[a]		10w[b]		10w[b]	

[a]Excluding Puerto Rico and the U.S. Virgin Islands.
[b]Maximum transmitter output power. No antenna restriction.

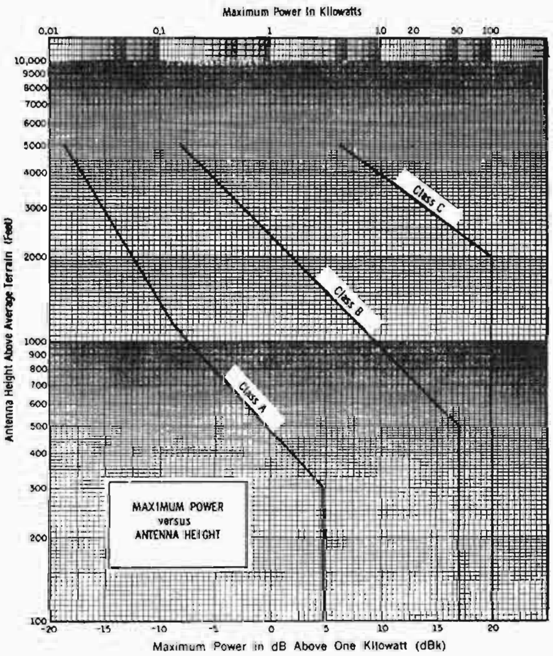


Fig. 6. Maximum power versus antenna height.

MEASUREMENT HEIGHTS

The signal received in an automobile whip antenna at 5 ft. (1.5 m) above ground is unfortunately much lower than one that may be received at 30 ft. (9.14 m). Of course, it is impossible to have receiving mobile antennas at the higher height. But in very smooth terrain there is nearly a direct relationship with height, and in the example, the signal at the standard dipole measurement height will be nearly 6 times stronger (7.78 dB). However, in areas where there is terrain roughness or in mountainous areas, there is even greater increases with the same height increase.[16]

It is highly recommended that field strength measurements be made by sampling field strength at 30 ft. (9.14 m or 10 m), instead of low heights, and multiplying by a ratio.

ANTENNA POLARIZATION MEASUREMENT

An antenna's polarization property is defined by the nature of the wave it radiates. However, it may be more convenient to measure the required component amplitudes by testing the receiving response under illumination by waves of various polarizations. In practice the vertically and horizontally linear amplitudes are measured separately and together with the phase difference. The linear incident fields must be set up parallel in space, with the appropriate coordinate system defined with respect to the antenna under test.[17]

FM BROADCASTING FROM SATELLITES

Much has been written about direct FM broadcasting from satellites to homes. Present technology presents several limitations.[18] There is a technical limit of about 2 kw at 100 MHz for RF breakdown. An ERP of about 420 Mw is required from the satellite to provide a 1 mv signal into a dipole on earth! This is due to the 165 dB of space loss in the 22,300 miles (36,000 km) between the earth and the geostationary satellite.

However, a large receiving antenna with the necessary amplifiers could produce a useable signal from an ERP of 2 kw, for community FM distribution or for network operation.

[16]Measurement of Service Area for Television Broadcasting, Robert S. Kirby, National Bureau of Standards, Boulder, Colorado, *IRE Transaction on Broadcast Transmission Systems*, February 1957, pages 23 to 30.

[17]Antenna Polarization Analysis by Amplitude Measurement of Multiple Components, Dr. L. Clayton and S. Hollis, The ESSAY, published by Scientific-Atlanta, Inc., Georgia, January 1975.

[18]Report of U.S.A. USSG/BC-837 CCIR Study Group Report, Questions 34-1/10 and 23-1/11, December 18, 1975. Broadcasting Satellite Service, Sound and Television.

It is possible to have a clean line of sight path without any propagation problems from the earth to the satellite. But with 100 kw ERP, the signal on earth would be about 16μ v, due to propagation space loss, not quite strong enough to provide a useful signal in ordinary FM receivers.

ANTENNA POLARIZATION

Three primary types of polarization are found in FM broadcasting. Cpol is rapidly becoming the most popular in the western hemisphere. This is followed by Hpol in Europe, Asia, and Africa, then Vpol. A mixture of vertical and horizontal is used in some countries for allocation purposes to increase the signal interference protection by receiving antenna discrimination.

The reader may wish to supplement his reading of the following paragraphs on polarization with in-depth articles about various types of polarization. Several excellent chapters may be found in some antenna books. Please refer to Footnote 19 for additional well written information.

Linear Polarization

In order to properly understand Cpol, linear polarized antenna radiation should be discussed first. If the electric field vector of the radiated wave lies in a given plane parallel to the direction of propagation, the wave is said to be linearly polarized. In Fig. 8, Vpol radiation is depicted. All the waves propagate in the same direction and with the same frequency. The magnitude of all the E and H vectors (electric and magnetic fields) can change with time but they cannot change direction. It is customary to describe the polarization of a wave according to the direction of the total electric field vector.

Between two satellites, two dipoles have linear polarization. The earth reference is missing so they cannot be described as either Hpol or Vpol. They are therefore linear polarized antennas because they respond to each other most when in the same plane.

For convenience linear waves are referenced to the earth plane. Hpol waves have the electric field horizontal with the earth's surface, while Vpol waves have electric fields which are vertical to the earth's surface. A dipole placed parallel with the ground is an example of a Hpol antenna, as in Fig. 7. Rotating it 90° places the E vector vertical, and it thus becomes a Vpol antenna as shown in Fig. 8.

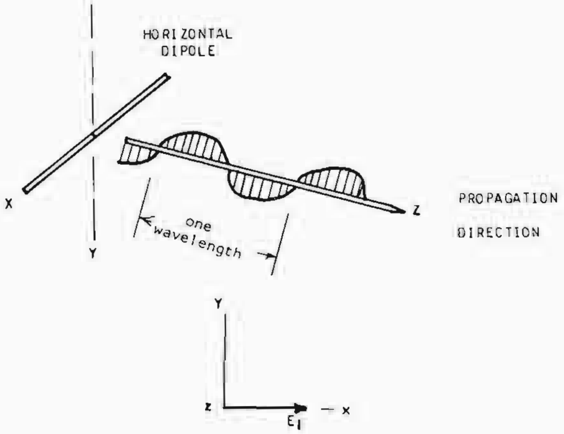


Fig. 7. Horizontal polarization. The field vector Ex is horizontal and there is no vector in the Y axis. The propagation towards Z is horizontally polarized and is linear.

Circular Polarization

Circular polarization (Cpol) is quite different. If there are two plane waves of the same frequency but of different phases, amplitudes and orientations of the field vectors, the superposition of these waves is called an elliptically polarized wave.

If these two plane waves combine so that the magnitudes of Vpol and Hpol of the electric fields are equal, and one (either Hpol or Vpol)

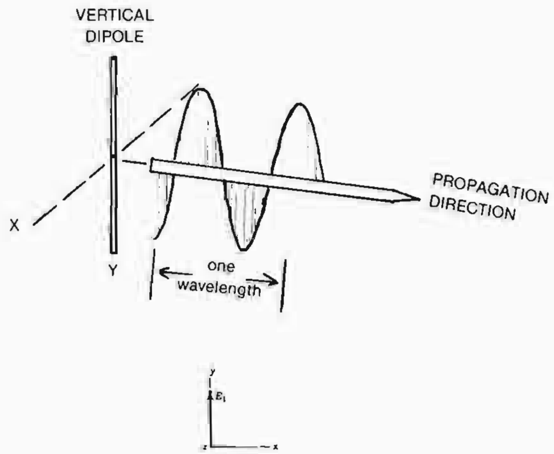


Fig. 8. Vertical polarization. The field vector Ey is vertical and there is no vector in the X axis. The propagation towards Z is vertically polarized and is linear.

[19]References for Circularly Polarized articles:

Ultra High Frequency Propagation, Reed, Russell, Boston Technical Publishers, 1964, Chapter 8, pages 313-335.

Antenna Engineering Handbook, Jasik, McGraw-Hill, 1961, Chapter 17, pages 17-1 thru 17-26.

Electromagnetics, John Kraus, McGraw-Hill, 1953, Chapter 9, pages 344-390.

Reference Data for Radio Engineers, Sixth Edition, Howard Sams, ITT, 1975, Chapter 27, pages 27-1 to 27-5.

Fields and Waves in Communication Electronics, Ramo, Whinnery, and Van Duzer, John Wiley & Sons, 1967, pages 322-327.

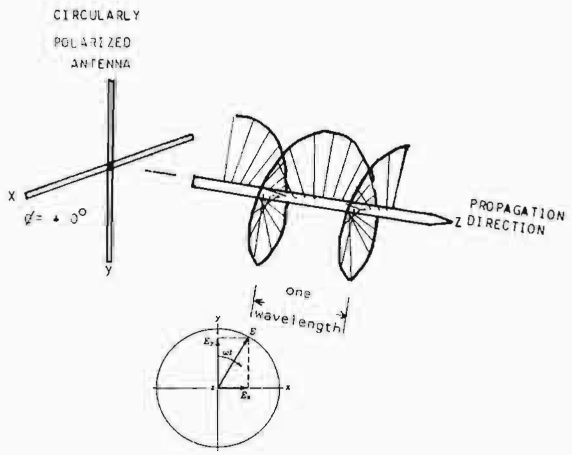


Fig. 9A. Circular polarization. The field vector Ex leads the field vector Ey by 90°, so the polarization is right hand circular.

leads or lags the other by 90 electrical degrees, the wave is Cpol. The vector addition of the two fields at 90° is somewhat larger than either field considered alone, (Fig. 9) even if both had the same amplitude. It is this vector enlarged field that rotates at the carrier frequency, as depicted in Fig. 9A, traveling one wavelength.

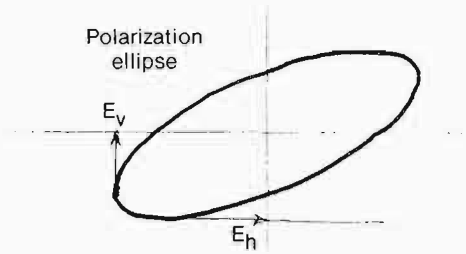
The angular rotation of the resultant E vector in the plane of the propagation is the circularly polarized (Cpol) field. If it were possible to stop the propagation for an instant, the polarization of the wave could be anything between horizontal and vertical, depending on when it stopped. As time progresses, the plane of polarization changes through a circle, for each RF cycle of the carrier frequency, hence, the name circular. The Cpol E vector rotates unlike Vpol or Hpol which remain constant.

It is this rotation which changes the sense of polarization that gives Cpol its signal penetrating qualities, so useful in FM broadcasting.

Fig. 9 shows how the electric field rotates in a clockwise direction, as shown in the vector diagram. The Ex vector is shorter than the Ey vector because it is lagging by 90° at the instant shown.

Polarization and Axial Ratios

The polarization ellipse is oftentimes used to illustrate the variation in amplitude found in Vpol. Fig. 10 shows how the quality of Cpol is demonstrated after measurements or in theory. The *polarization ratio* is the voltage ratio of the vertical and horizontal components. It is measured on the antenna range with a reference dipole rotated from vertical to horizontal earth references. The *axial ratio* is that ratio between maximum and minimum voltage components at *any* orientation of the reference dipole perpendicular to the direction of propagation. Both terms are needed to adequately define the Cpol performance. The axial ratio is shown in Fig. 11.



Axial Ratio $= \frac{E_h}{E_v}$

Fig. 10. Polarization ratio. The larger voltage E_v of the vertically polarized component divided by the smaller voltage E_h, expressed in dB, with the plus or minus sign omitted.

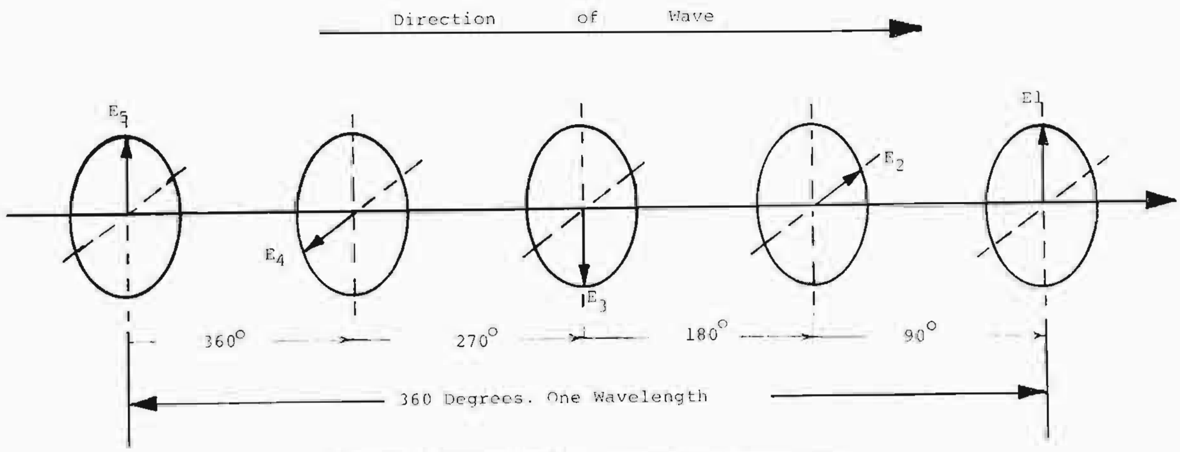


Fig. 9B. Propagation of a circularly polarized wave.

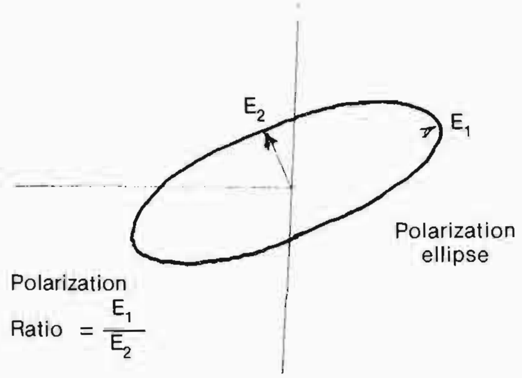


Fig. 11. Axial ratio. The larger voltage E divided by the smaller voltage E equals the axial ratio, usually expressed in dB.

For a perfect Cpol radiator, the axial and polarization ratios would be unity or ODB. In practice the ratios may vary as much as 1.75 to 1 or 4.9 dB. This is still quite good for FM broadcasting.

It should be pointed out that these ratio measurements should only be made on the antenna test range under ideal conditions. Once the transmitting antenna is installed, the propagation conditions may change both ratios drastically.

Another factor is ellipticity. When the magnitude and the pointing of the voltage vector varies during each cycle, the wave is elliptically polarized. When this ellipticity and thus the axial ratio become infinite or nearly infinite, the wave is linearly polarized. If the ellipticity or axial ratio is 1, then the wave is Cpol.

When attempting to produce Cpol, elliptical polarization resulting from poor axial ratios of 1.75 or greater, are thought of as imperfect Cpol.[20]

In the beginning of FM many homes had Hpol outdoor receiving antennas. Then home receivers with built-in antennas came along, as FM broadcasters increased their ERPs. The auto radio with its whip antenna requires Vpol signals. There were 33 million FM automobile radios in the United States as of January 1, 1976.[21] With these developments, the need for Cpol became evident and is now a requirement for successful FM broadcasting.

CHOOSING A FM ANTENNA

There are several different makes and types of FM antennas offered to the broadcaster. In deciding which one to specify or purchase, the engineer should consider the power gain, azimuth and elevation patterns, beam tilt and null fill requirements. Deicing requirements, if any, as well as the choice between heaters and radomes should be decided. Fig. 12 shows an antenna specification sheet, which may be used to gather firm quotations from sellers, all bidding on the same specifications.

Gain

The question of using a high power transmitter with a low gain antenna, or a high gain antenna with a low power transmitter, to achieve the same ERP is an old one. It is usually decided without solid engineering information. If the presence of the ground is disregarded, there would be no electrical difference what combination of transmitter power and antenna gain is used for a given ERP. Therefore, the nature of the terrain determines the final choice from an engineering viewpoint.

Many believe that the highest transmitter power should be used with the lowest antenna gain. Half the ERP power produced is wasted, since it occurs above the useful elevation pattern and goes into outer space! The other half strikes the ground where it is reflected by the terrain, which reflects some of the signal, causing multipath conditions.

If the Cpol antenna gain is low (1 or 2), considerable energy will strike the ground to be reflected from the terrain near the transmitting site. Hill and mountain top locations should therefore use antennas with moderate gains whose elevation pattern concentrates the signal into the service area. Fig. 13 shows the effect of wide elevation patterns in Fig. 13A, and with a narrower pattern in Fig. 13B. Notice that in Fig. 13B there are less reflections into the service area because there is little radiation near the tower. While the sketch shows an elevation view, there are also reflections from nearby hills which would be seen in a plot view of Fig. 13B.

Many nontechnical people believe that the higher the transmitter output power, the stronger the signal into the service area, for the same ERP. This is simply not true! The ERP is the sum of the transmitter power times the antenna gain, less the transmission line loss. Any number of combinations will achieve the same ERP. See Table 3, for Cpol antenna-transmitter combinations.

What will change with higher transmitter powers is the width of the elevation pattern as shown in Fig. 13A. Wide antenna widths from low gain antennas may in fact be undesirable,

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[20]Opinion Research Corp., Study Commissioned by ABC-FM Spot Sales Report, distributed by NRBA, January 8, 1976.

[21]*Antenna Engineering Handbook*, Henry Jasik, Editor, McGraw-Hill, 1961, page 17-3.

FM ANTENNA SPECIFICATIONS

PROPOSAL ______________ REV. _____ DATE ______________________ FREQ. ______________

ANTENNA ______________________ TYPE NO. ______________________ NUMBER OF BAYS _____

CUSTOMER ______________________________________ LOCATION ______________________

REPRESENTATIVE ______________________________ CONSULTANT ______________________

SKETCH __________________ V-PATTERN ____________________ H-PATTERN ______________

ELECTRICAL SPECIFICATIONS

1. Required Maximum ERP for Station ______________________
2. Minimum ERP (if Directional) and Azimuth ______________________
3. Antenna Peak Power Gain Ratio (Vg X Hg) ______________________
4. Antenna RMS Power Gain Ratio (Vg) ______________________
5. Horizontal Peak Power Gain Ratio (Hg) ______________________
6. Horizontal Plane Pattern Circularity ______________________
7. Antenna Electrical Beam Tilt ______________________
8. Antenna Null Fill, Angle and Percentage ______________________
9. Required Antenna Input Power for ERP ______________________
10. Antenna Safe Input Power Rating ______________________
11. Antenna VSWR, Across ± 200 KHz. No Ice ______________________
12. Transmission Line Type and Length in Feet ______________________
13. Line Efficiency at Operating Frequency ______________________
14. Transmitter Output Power for Required ERP ______________________

MECHANICAL SPECIFICATIONS

1. Antenna Net Weight, Estimated ______________________
2. Wind Load at 85 Mph thrust ______________________
3. Antenna Input Connector Size, EIA, 50 Ohms ______________________
4. Radomes or Deicers ______________________
5. Height, Top to Bottom Input Connector ______________________

Fig. 12. FM antenna specifications.

TABLE 3
Transmitter Powers with Various Antennas for Same ERP

Transmitter power	Antenna input	Number of bays	Antenna gain	ERP	Elevation beamwidth
10 kw	9.09 kw	10	5.5	50 kw	6.1°
20 kw	18.52 kw	5	2.7	50 kw	12.2°
40 kw	33.3 kw	3	1.5	50 kw	20.0°

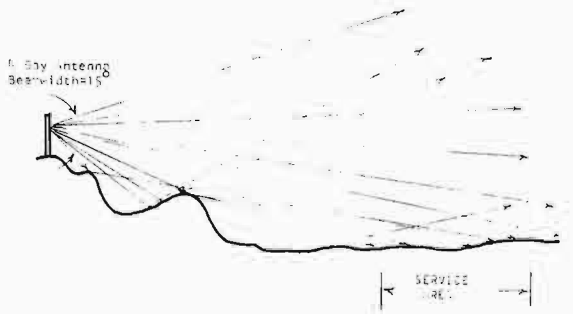

Fig. 13A.

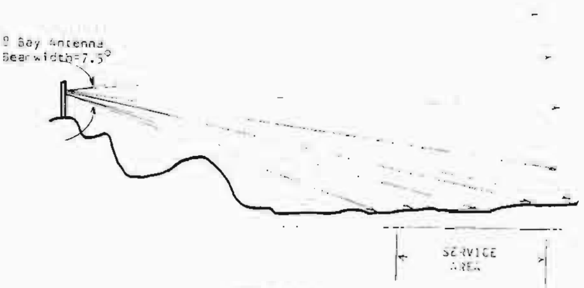

Fig. 13B.

causing multipath reflections and associated problems.

This problem of antenna gain, site location, and site height has been thoroughly investigated in Europe both for FM and TV broadcasting by several governments. The European Broadcasting Union strongly recommends the highest height be used with sufficient antenna gain to put a proper signal into the nearest part of the service area.[22] High power transmitter low gain antenna combinations are not recommended.

Exceptionally high transmitter locations on the periphery of the service area are exceptions to this rule. The elevation angles, for example, required from Mt. Wilson antenna farms for Los Angeles illustrate this point. From a height of nearly 5,800 ft. (1,767 m), the service area is from −2 to −14° of elevation.

[22]Site Selection, by K.H. Kaltbeitzer (I.R.T.), Technical Monograph 3104, European Broadcasting Union, Technical Center, 32 Avenue Albert Lancaster, Brussels, 18, Belgium.

To conclude this discussion, the antenna should be chosen whose gain and thus its elevation envelope covers *only* the desired service area. Antennas with wide elevation angles (lower gain) may cause multipath problems depending on terrain conditions. High power transmitters with low gain antennas, also have a continuing expense through operating power consumption costs.

Site

Another factor which is related to the choice of antennas is the transmitting site location. In general, the higher the height over the service area, the stronger the signal at a given distance. The FCC has equalized the signal strengths, by reducing the allowable ERP values, as the transmitting height is increased. This is shown in Fig. 6. The choice of height then dictates the desirable antenna elevation pattern, to prevent avoidable terrain reflections. From the antenna gain, the transmitter output power can be determined, allowing for the transmission line efficiency.

It must be pointed out the Cpol radiation does not increase the distance to a given FCC signal service contour. Interferences and allocation contours are not changed. The service area contours are established by prediction methods or measurements of the Hpol radiation of a given amount of power and height.

DIRECTIONAL ANTENNAS

In the United States the FCC permits directional antennas for use by certain stations for cochannel and adjacent channel protection, to existing stations. This type of directional antenna is not permitted for TV and they are unique to FM broadcasting.

Several manufacturers make suitable FM antennas for this purpose. The FCC authorization requires that a completely measured azimuth Hpol pattern be submitted, so that the amount of ERP towards the protected station will meet the specifications of the construction permit. The elevation pattern need not be measured, but may be calculated.

In Fig. 14 the directionalized azimuth pattern of an Hpol antenna is shown. Dashed lines ex-

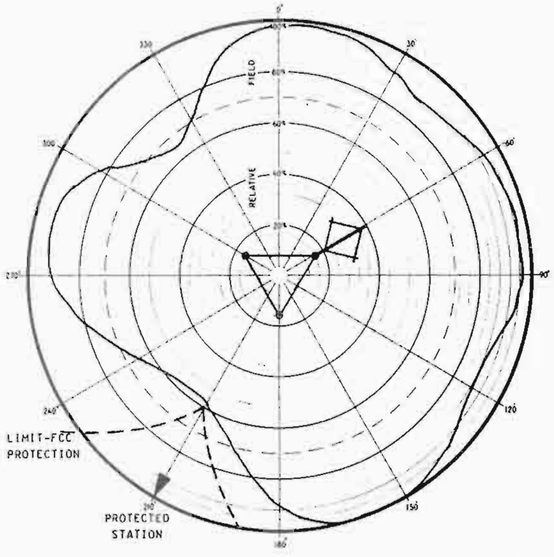

Fig. 14 Directionalized FM antenna, Hpol azimuth pattern. Azimuth power gain = 1.346. Peak power gain = 2.02 null gain † 0.68.

tending from 210° indicate the maximum allowable rate of field increase from the protection null as 2dB per 10° of azimuth. Another FCC requirement is that the ERP in any azimuth in a directional antenna not exceed the maximum authorized ERP. This nearly always occurs in nondirectional antennas because the antenna is rated on an RMS basis of the azimuth pattern.

Prior engineering by the station's consultant indicated that the maximum allowable ERP toward the protected station was 1,000 watts. The Class A station had a maximum ERP of 3,000 watts. The antenna was designed and adjusted so that the radiation towards the protected direction, 210°, would be 1,000 watts or less. The maximum ERP occurred between 150 and 165°. The antenna and operating parameters are shown below:

SAMPLE DIRECTIONAL ANTENNA PARAMETERS

Maximum ERP, Hpol	3,000 watts
Maximum ERP, Hpol, towards protected azimuth	1,000 watts
Peak antenna power gain, Hpol . . . (1.50 × 1.346)	2.02 (3.05dB)
Antenna input power for 3,000 watts peak ERP	1,485 watts
Coaxial transmission line efficiency	66%
Required transmitter power output	2,250 watts

This is a typical directional FM antenna, although the values may change with the requirements. Notice that the Hpol values are used for ERP as well as protection. The Commission has informally adopted a rule that the measured Vpol azimuth pattern in a directional FM antenna may not exceed the Hpol values by more than 1 dB. This requires additional work but is easily accomplished.

Directional FM broadcasting antennas have worked out quite well over the years. They provide an excellent means of maximum allowable ERP for the directional stations coverage area, while good site location permits reduction to co-channel or adjacent channel stations to operate without interference. The day and night time signals do not change in FM. Only one pattern is required and stability is excellent.

The directionalizing is usually accomplished by the use of parasitic elements for both the Hpol and Vpol, when a Cpol antenna is used. When the antenna maker does the directionalizing, they will submit a certificate by a registered professional engineer (PE) that the measured pattern is as shown in the polar plot, and taken from antenna test range measurements.

Since the antenna is directionalized, the peak power gain must be used, and not the RMS gain, when computing the ERP. In omni antennas, the RMS power gain ratio is used for ERP calculations.

Azimuth Patterns

Nonsymmetrical side-mounted FM antennas are much more economical then screen dipole antennas. Side-mounted antennas suffer from poor azimuth patterns. This is due to reflections and other effects of the supporting steel tower.

It is very difficult to predict, without measurements, the azimuth pattern of such an antenna. Simply leg mounting it does not insure good azimuth patterns away from that leg. Circularities as poor as ±24 dB have been measured on five ft. (1.52 meter) wide towers. Small towers tend in general to provide somewhat more uniform patterns, but they all produce strong lobes and deep nulls as great as ±12 dB.

The answer to this problem is to get pattern adjustment or optimization service from the manufacturer. This is fully described under *antenna pattern service.* To simply install an antenna on a particular face or leg of a tower, hoping to get at least the RMS value of ERP towards the main service areas is very risky.

Beam Tilt

The elevation pattern in some installations may be tilted so that the peak value strikes the farthest part of the service area. A standard FM antenna without any beam tilt normally radiates

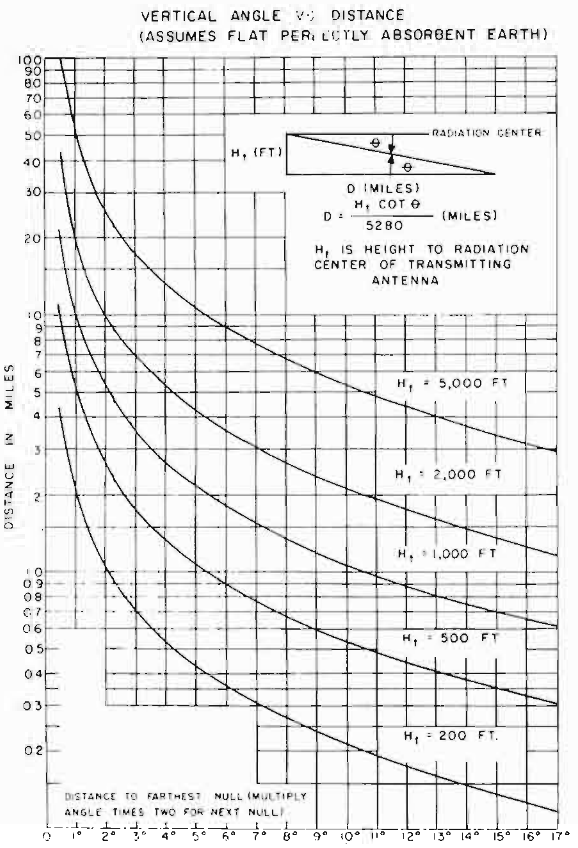

Fig. 15. Elevation angles to terrain from various heights assuming flat earth conditions.

more than half of its power above the horizon. All this power is lost.

The higher the antenna above its average terrain, the further it can serve. It also follows that the higher the antenna above terrain, the greater is the elevation angle down to the earth's horizon. This is shown in sketch form in Fig. 15. In order to hit the service target near the horizon, the elevation pattern may be tilted downward in all azimuths, by using electrical beam tilt. This is done by delaying the current to the lower elements in the antenna array, in such amounts and sequence as to produce the correct amount of tilt. The farthest service areas require the greatest amount of power. Beam tilt is the antenna designer's tool to accomplish this goal.

Consulting engineers who are familiar with this problem can easily work out the required amount of beam tilt, if it is necessary. Practical values are one-half and three-quarters of one degree, depending on height and antenna elevation pattern. Beam tilt is usually not required for antennas with 8 or less bays, since the half power beam width is approximately 7.6° or 3.8° below the horizontal plane value for 8 bays. It is wider as the number of bays is decreased.

Null Fill

The power gain of the antenna determines the shape of the elevation pattern, as a result of the phase and amplitude of each bay. This determines the elevation angles, in which little or no radiation occurs, due to the antenna arraying factor. The elevation patterns for all antennas are available from the manufacturers. If these patterns indicate nulls, which strike the present or future population areas, they should be filled in. The amount of fill-in depends on the distance to the population, and therefore, the required ERP for a satisfactory signal level. In problem areas, the first null below the peak is filled from 5 to 15 percent field, 10 percent being quite common. In some rare cases of extremely high transmitter locations above service areas, the second null may require fill-in of about 5 percent. Null fill reduces the peak power gain of the antenna by putting some of the power into the nulls. This reduction is usually less than 5 percent, however. Since the service areas at the null angles fall quite close to the transmitter, very little ERP is required for satisfactory signals.

The reader is referred to the next chapter for a discussion on television antennas, whose horizontal (azimuth) and elevation (vertical) pattern requirements are identical for FM broadcasting.

ANTENNA PATTERN SERVICE

Simply mounting the FM antenna on the face or leg nearest the principal city does not insure radiating the strongest signal in that direction. In many cases the opposite may be true. Some towers will exhibit a null in the least expected azimuth. Patterns are moderately frequency sensitive. They are affected by the cross-sectional shape and size of the tower, as well as the type of bracing. Generally, the vertical tower members including conduits, elevator rails, or other coaxial lines affect the Vpol azimuth pattern. The tower cross sectional shape, size, type of bracing whether X or zig zag or horizontal girts, ladders and self-supporting tower tapers, all affect the Hpol azimuth pattern. Tower reflections from Cpol antennas present special problems since the reflection is the opposite sense of rotation. The radiator must be treated with parasitic elements which are responsive to linear polarization. A screen reflector cannot be used, with Cpol radiators, to shape azimuth patterns.

Some American antenna manufacturers have for several years offered pattern adjustment service.[23] This service consists of duplicating

[23]For example, Jampro Antenna Company, since 1966.

about 20 ft. (6 m) of the tower with all of its accessory items, from information supplied by the customer. This duplication must be exact. Then one or two bays of the antenna are mounted on one side of the tower or pole. The azimuth pattern is measured in both planes of polarization for a Cpol antenna, on the antenna test range on frequency. The mounting of the radiators is changed by distance or orientation, face or leg, plus the installation of parasitic elements, in order to achieve a useful azimuth pattern. This work may take several days or several weeks, depending on the frequency, type of tower or pole and desired pattern. Every attempt is made to make the azimuth pattern as circular as possible or to put the radiation in the most desirable azimuth directions. By using Vpol parasitics, the Vpol azimuth pattern is shaped to conform as well as possible with the Hpol azimuth pattern.

Fig. 16A shows typical 5 ft. (1.5 m) triangular tower patterns. Notice that the original measured pattern has a Hpol azimuth circularity of ±13 dB, with a Vpol of 12.2 dB. After pattern treatment there is considerable improvement. The deep nulls were removed, as shown in Fig. 16B with a Hpol circularity of ±3.47 dB and a Vpol circularity of ±3.87 dB. The strongest radiation is towards the desired directions, indicated by the shaded lines.

When buying a new FM antenna, pattern measurement service should also be ordered to insure a useful azimuth pattern. Otherwise it will be quite unpredictable.

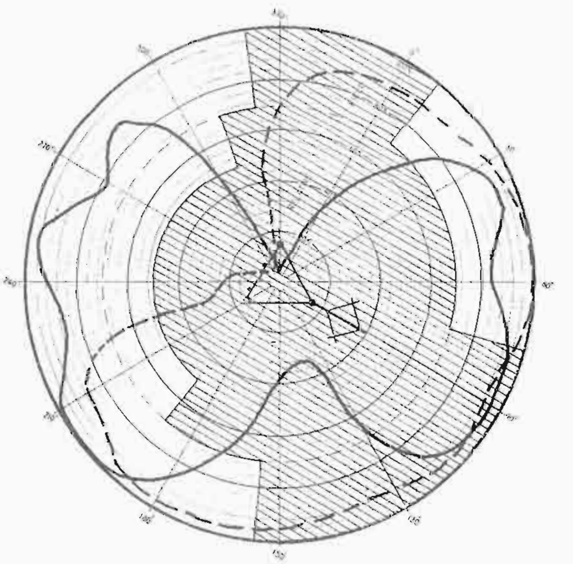

Fig. 16A. Measured azimuth pattern of Cpol antenna *before* pattern optimization. Solid curve indicates Hpol, with circularity of ±13.0 dB. Dash curve indicates Vpol, with circularity of ±12.2 dB. Shaded area shows broadcasters desired coverate 5 ft. (1.52M) tower width. Frequency, 97.5 MHz.

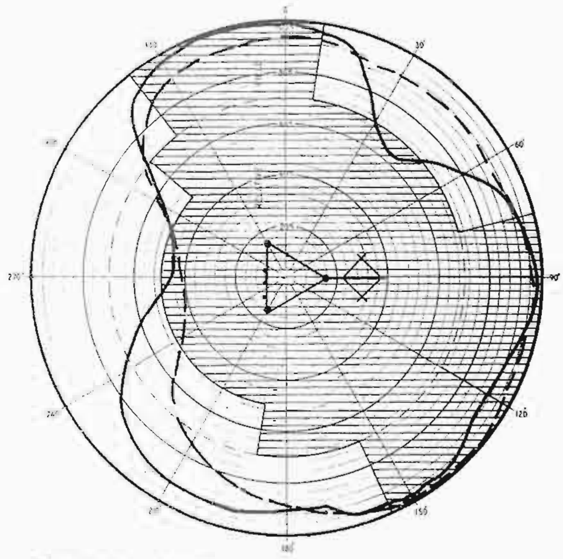

Fig. 16B. Measured azimuth pattern of Cpol antenna *after* pattern optimization. Solid curve indicates Hpol, with circularity of ±3.47 dB. Dash curve indicates Vpol, with circularity of ±3.87 dB. Shaded area shows broadcasters desired coverage 5 ft. (1.52M) tower width. Frequency, 97.5 MHz.

Screen dipole panel antennas mounted around the sides of the support exhibit excellent azimuth patterns. However, their cost is considerably higher than a typical nonsymmetrical antenna with pattern service.

ANTENNA FEED SYSTEMS

In the United States, nonsymmetrical FM antennas use the transmission line shunt method of feeding. The radiating elements are simply shunted every one wavelength across a rigid section of line. The radiating elements, however, are either high impedance or low impedance, and require different methods of compensation at the feed point.

High Impedance Method

This permits the shunting of several radiating elements directly across one large coaxial transmission line. Moderate power capacity and simplicity are easily achieved.

When a transmission line is not well matched, the voltages integral wavelengths apart, on that line, will be in phase. If loads are shunted across a transmission line, at spots which are integral numbers of wavelengths apart, they will appear to be electrically in parallel. This is the load that appears from the sending end of the transmission line.

By shunting the radiating elements exactly one wavelength apart across the line, all the elements are fed in phase. However, the im-

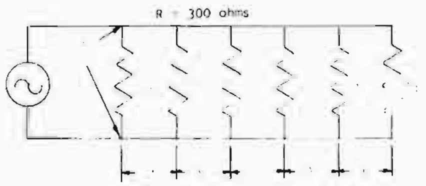

Fig. 17. Shunt feed system, using high impedance elements.

pedances of each load must be equal so that they all receive the same amount of current. This is accomplished by finding an impedance match on the radiating element.

Let us assume that a six-bay antenna is to be constructed, and shunt fed by a 50-ohm transmission line. Each element is tuned to six times the line impedance, (6 × 50 = 300-ohms), and connected one wavelength from the next. The transmission line will thus be automatically matched at the botton element point to 50 ohms, (six 300-ohms loads in parallel equalling 50-ohms). Each element will also receive 1/6th of the total power, if the loads are all equal to 300-ohms (See Fig. 17.)

The above method works well, if the individual elements can be matched to rather high impedances of up to 400-ohms each, for an eight-bay antenna. Over this number, the antenna is split and fed in the center, making possible 16-bays using this same method. The high-feed impedance is susceptible to degradation in VSWR, from heavy fog and rain, and most certainly by ice or snow unless radomes or deicers are used.

This method of shunt feeding reduces the VSWR bandwidth since each radiating element must be exactly one wavelength apart. With deviation of the FM carrier, this factor becomes an important consideration. The radiating elements must have rather high Q values in order to present the high impedance necessary for matching across the main coaxial line.

Low Impedance Method

A better way to shunt feed the elements and overcome the adverse effects of high-impedance elements is through the use of one or more step transformers. This method is shown in Fig. 18. The radiating elements are all 50-ohms. They are shunted across the main coax feeder as in the case of the high-impedance shunt fed system. The spacing is also one wavelength so that the phasing, on the operating frequency, is the same for all elements.

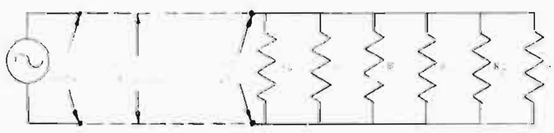

Fig. 18. Step transformer method, used to feed 50 ohm radiating elements.

The impedances among the several elements are the same, and therefore, the current is the same. The impedances are reflected across each shunt point. The example shows six 50-ohm elements, leaving 50/6 or 8.33-ohms across the lowest element.

A simple one step quarter wave transformer of 20.4-ohms is placed below the lowest shunted element. This transforms the 50-ohms transmission line down to the 8.33-ohms of the load, thus matching it.

This low impedance method has several advantages. The radiating elements are matched to the low value of 50-ohms and have low Q. Because of this, they are not troubled with the moisture environment, which may change the dielectric constant, and thus, the resonant frequency with rain or fog to change.

The 50-ohm loads presented by each radiator are easy to match out during fabrication. All the radiators are electrically the same, although they may vary a bit at their feed points due to the mutually coupling adjustments. To achieve wider bandwidth, step transformers may be used after the fourth bay, as one manufacturer does (Jampro). While this increases the cost, the VSWR bandwidth of ±200kHz is easily achieved.

To insure proper gain, and elevation pattern, some firms measure the phase and amplitude of the rigid coaxial section on the operating frequency, before the radiating elements are attached, at the factory.

Other Feed Systems

Screen dipole panel antennas are usually fed through a corporate feed system, with branching feeds and semiflexible cables. By using phase impedance compensation in the feed system, it is possible to achieve excellent VSWR over the entire 20 MHz FM band. The individual screen dipole VSWR values need not be more than one megacycle wide. This method originated with the Europeans, who use it for wideband screen dipole television antennas.

CIRCULARLY POLARIZED FM ANTENNA TYPES

There are several types of Cpol antennas available to the industry. Some are more suitable to

FM broadcasting than others. For example, an end fire helical antenna would produce Cpol radiation but would not be suitable because it has high gain and directivity. On the other hand, a side fire spiral antenna[24] will produce excellent axial and polarization ratios, has good azimuth and elevation patterns, and does not use dipoles to produce the Cpol type of radiation. It should be quite clear that Cpol radiation does not necessarily come from two crossed dipoles, or ring stub antennas.

If one recalls that the field voltage vector is rotating at all times with respect to the earth plane, then it can be visualized that Cpol radiation is not limited to linear dipoles or ring stubs. It was easy to develop antennas from existing linear horizontal and Vpol towards Cpol. Crossed dipoles backed by a screen was such an early embodiment. Another was to use an existing horizontal ring and simply add vertical stubs. Other construction included a short side fire helix and the patented[25] two half wave crossed dipoles fed in phase quadrature. This last Cpol radiator is perhaps unique, and is described in detail under Cpol antennas.

COMMERCIALLY AVAILABLE CIRCULARLY POLARIZED FM ANTENNAS

In 1976 there were about six different types of FM broadcasting antennas made in the United States. These antennas have many things in common. For example all the nonsymmetrical antennas are designed for side mounting to a steel tower or pole. The radiating elements are shunted across a common main rigid coax line. This has eliminated the problems associated with the older corporate feed system with its semiflexible lines.

By using the technique described earlier, shunting elements every one wavelength across a transmission line makes matching easy. Bandwidth is limited by the VSWR bandwidth of the individual element, and the use of internal transformers.

With more than about eight-bays the matching problem becomes difficult and there is some beam squint. That is, the elevation pattern begins to change slightly with the deviating frequency. Therefore, antennas with more than about 8-bays are fed from or near the center, dividing the phase change in half and eliminating the beam squint. Center feeding also simplifies the VSWR matching problem.

There are three basic types of Cpol radiating elements. The most common is the ring with stubs. The two half wave crossed dipole and the short side fire helix are the other two. The latter are more symmetrical physically and electrically than the ring stub types and have better axial and polarization ratios when measured in free space.

Other common factors include mounting brackets, which are made special in some cases, or universal to accept a wide assortment of tower legs or faces.

Electrical deicing equipment is supplied as an additional item. They are usually factory installed. Kits are furnished for interbay connections, but the broadcaster must supply power from the building to the center of large arrays, or the bottom element on smaller antennas. Local electrical codes should be followed.

A thermostat is used with small deicer wattages. With larger power, thermostatically operated power relays are used. Then there are more sophisticated deicer control systems which operate only when temperature and humidity conditions produce sleet or icing.

Most deicers use a resistance heating element which is inserted into the antenna radiator arms. One supplier uses a different method dropping 115/230 volts to a few volts with a transformer located at each bay. The low voltage is passed thru the ice sensitive arms of the radiator and connected to the far ends, by a teflon insulated wire. The current return is by the stainless steel antenna element, whose ohmic resistance is sufficient to produce enough power loss to supply the required heat.

In addition to deicers, all antennas are available with plastic radomes, for sleet and ice protection.

Wideband FM antennas are not very popular in the United States, but some are in use, in the larger cities, where a high location is available. These include New York City, Salt Lake City, Utah, and Houston, Texas, where high buildings or a favorable mountain site provide excellent common antenna locations. Several makes of screen backed dipoles are available, which may be used for this purpose. Using phase impedance compensation similar to the European scheme, the entire 88 to 108 MHz band may be covered with one antenna with a VSWR of 1.1 to 1 or better. Power ratings are sufficient to accept several 25 or 40 kw transmitters. These antennas may also be installed on the faces of a triangular tower, or around a cylinder. One manufacturer uses a number of continuous spiral arms supported around a cylinder as a Cpol antenna. (See Fig. 19.) This antenna may also be used for community stations, with high power transmitters operating at several different frequencies in the band.

A means for tuning out reactances after the antenna has been installed on the side of a steel support is also common. They are located at the input to the antenna and consist of adjustable location dielectric slugs, or fixed position variable capacitors.

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[24]US Patent No. 3,906,509, to Jampro Antenna Company.

[25]US Patent No. 2,637,533, Jampro Antenna Company.

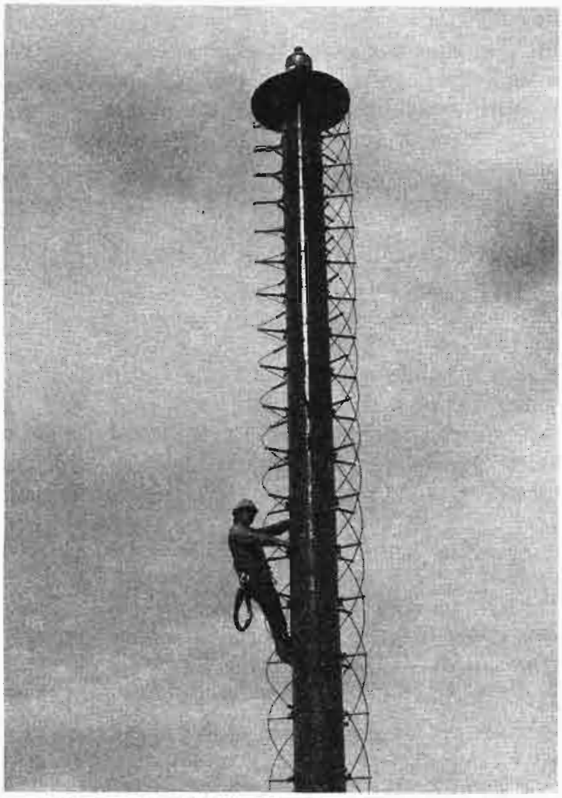

Fig. 19. Cpol omnidirectional antenna for wide band FM use, 88 to 108 MHz.

In the following pages some of the more popular American antenna types are described in some detail. It should be clear that each seller has other types and models which vary in electrical and mechanical characteristics. Table 4 gives electrical and mechanical information about several makes of six-bay Cpol antennas, of the side-mounted nonsymmetrical type.

COLLINS FM ANTENNAS

This firm offers a Cpol antenna, made by ERI, under US patent 3,474,452. The antennas are designed for use in monaural, stereo, and multiplex FM broadcasting. They have a 1.1 to 1 VSWR bandwidth for ±100 KHz.

The basic radiating element is a ring, with two stubs, one pointing downwards, and the other upwards. The ring is fed thru a short balun, to equalize the power to each half of the radiator. The balun is protected from the weather thru the use of plastic cover plates. Fig. 20 shows the typical mounting of this high power Cpol antenna, to a pole. Notice the universal type of mounting bracket.

The Collins[26] G4CPH antenna radiates a Cpol wave. The element is designed to withstand wind

[26]Collins Radio Group, Dallas, Texas 75207.

TABLE 4

Electrical and Mechanical Specifications for Some Cpol FM Antennas (Six-Bay Models)

Brand Name	Collins		Harris		Jampro		RCA		Phelps Dodge	
Type No.	37CP-6		FMS-6		JSCP-6		BFG-6		CFM HP-6	
SPECIFICATION										
Electrical:										
Frequency Range, factory tuned any one FM channel	88-108 MHz		88-108 MHz		88-108 MHz		88-108 MHz		88-108 MHz	
Free Space Azimuth Circularity	±2 dB		±2 dB		±1 dB		±1 dB		±1 dB	
Safe Input Power rating	40 kw		40 kw		40 kw		36 kw		30 kw	
VSWR Bandwidth after field trimming for 1.1/1	±100 KHz		±100 kHz		±400 kHz		±100 kHz		N/A	
Mechanical:	Pounds	kgs	Pounds	kgs	Pounds	kgs	Pounds	kgs	Pounds	kgs
Net weight, without radomes or de-icers but with standard mounting brackets	544	247	520	236	498	226	381	173	404	184
Wind Loading at 112 mph (180 km/hr)										
a. without radomes & deicers	1,014	460	945	430	730	332	920	418	780	355
b. complete with deicers	N/A	N/A	N/A	N/A	851	387	1,040	473	930	423
c. complete with radomes	1,740	791	1,699	772	1,210	550	Radomes not recommended		1,170	532

Notes: All above antennas are circularly polarized right hand—clockwise. They are supplied with normal tower mounting brackets. All have 3-1/8 in. EIA input connectors, 50 ohms. Information taken from sales literature and other sources, in early 1976. N/A = Not available from printed information.

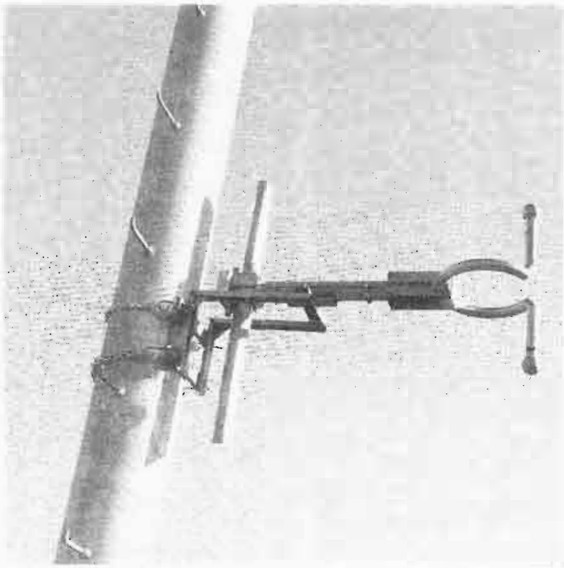

Fig. 20. Single ring stub type Cpol Collins Radio FM antenna, with typical pole mounting.

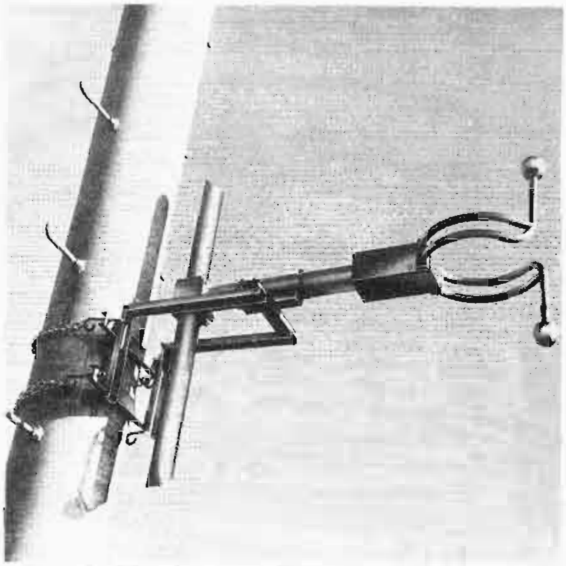

Fig. 21. Double ring stub type Cpol Harris FM antenna showing typical pole mounting.

velocities of over 100 mph (161 km/h). Antennas with up to 16 bays are available. Antennas of 8 bays or less are normally fed from the bottom. A six foot (2 m) matching transformer is connected to the bottom bay, and the input is 3-1/8 in. 50 ohms EIA flange. Antennas with 9 bays or more are center fed if an even number of bays, or at a point one-half bay below the antenna center if an odd number of bays. A 10 ft. (3 m) matching transformer is connected to an elbow attached to the center-feed tee.

Factory installed deicers are available using either 300 or 500 watts per bay. Complete interbay heater-cable junction boxes and other items are included. The element to tower mounting brackets are of stainless steel.

Other FM products by Collins include a lower power version, educational FM antennas, and FM/AM antenna isolators. See Table 4 for more electrical and mechanical specifications of a six-bay antenna.

HARRIS FM ANTENNAS

The high power Cpol antenna marketed by Harris Corporation (formerly Gates Radio Company)[27] is offered in one thru 16 bays. Antennas with null fill, beam tilt, and special ratios of Hpol to Vpol power (elliptical polarization) are available by special order.

The type FMS called the dual-cycloid consists of two basic parts: the radiating element and the interconnecting rigid transmission line sections. In Fig. 21 a single FMS element is shown with a section of rigid transmission line mounted to a pole. The radiating elements are all identical in any one antenna. The element uses a ring design as the basic unit. Two vertical elements have replaced the fixed end plates of the former ring Hpol element. The rear terminal block is now a matching balun, mating the antenna impedance to the interconnecting transmission line.

The vertical elements have adjustable caps for fine adjustment of the horizontal to vertical radiation ratio which is set at the factory. Corona suppression balls are included as a standard item. All antenna elements are fabricated from a weather resistant brass alloy. As is common with other antennas of this type using one coaxial feed line, the antenna elements are shunted one wavelength vertically. The main feed line has a standard 3-1/8 in. EIA female flange and the input impedance is 50 ohms.

The antenna is supplied with mounting brackets for standard types of uniform cross-section towers. Brackets for other types of tower or poles are also available.

Antennas with eight or less bays are usually fed from the bottom thru 6 ft. (1.8 m) long matching transformers. Antennas with nine or more bays are fed near the center. A 10 ft. (3 m) transformer is connected to an elbow attached to the center feed tee, and is part of the antenna.

The antenna is available for any one frequency in the 88 to 108 MHz FM band with clockwise Cpol. The power gains are with respect to a horizontal dipole. The VSWR at the input with side

[27]Harris Corporation, Broadcast Products Div., 123 Hampshire Street, Quincy, Illinois 62301.

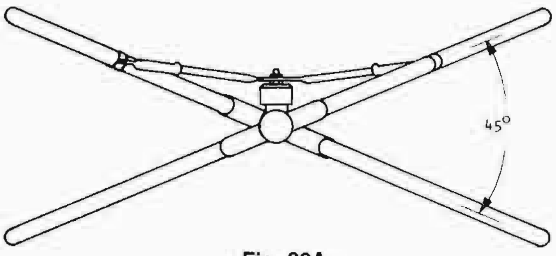

Fig. 22A.

mounting to a steel tower is 1.5 to 1 or better without field trimming, and 1.1 to 1 or better after field trimming for ±100 kHz bandwidth. These Harris antennas are manufactured by Electronic Research, Inc., under US Patent 3,474,452.

Electrical deicers are made for operation on either 115 or 230 volts as specified in the purchase order. The deicers are factory installed and include shielded interbay cable in the kit. Plastic radomes are also offered in the event that electrical heaters are not desired, in ice or sleet environments.

Notch filters, multiplexers and other filter components for use in FM systems are supplied by Harris. Pattern optimization and measurement service is also available. For more information of a typical six-bay antenna, see Table 4 for electrical and mechanical specifications.

JAMPRO FM ANTENNAS

The most popular FM antenna fabricated and sold by Jampro Antenna Company[28] is the Type

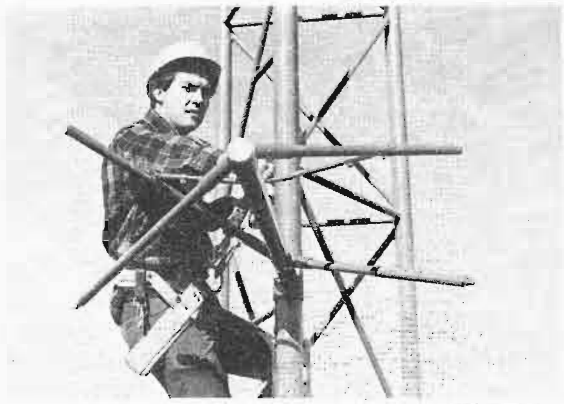

Fig. 23A. Rigger installing Cpol radiator to lower leg.

JSCP, called the Penetrator. This Cpol antenna consists of four quarter wave arms which form the four sides of a square. The square has two driven arms while the other two are parasitic. The feed system is such that the radiation is in 90° phase quadrature with equal amplitudes meeting all the requirements for a Cpol radiating antenna element.

The angle between the arms is 45°. Both arms shown in Fig. 22A are fed from one point. This element has two half wave dipoles, both driven. The aperture efficiency is high due to its large cross sectional electrical size being 0.38 wavelengths. See Fig. 23.

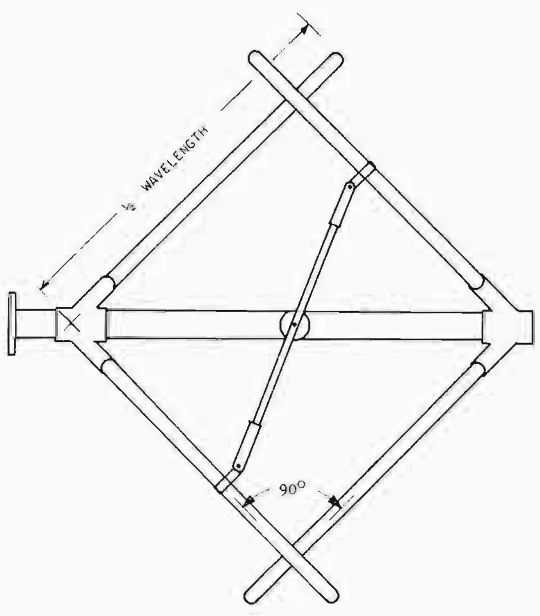

Fig. 22B.

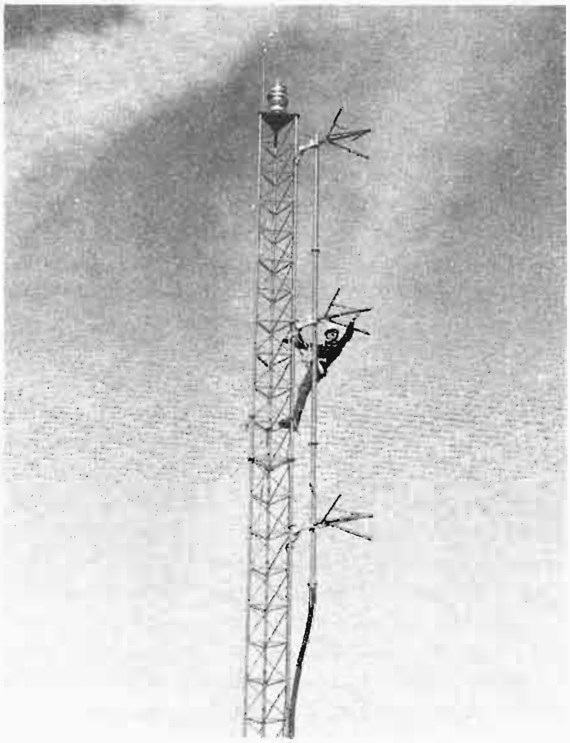

Fig. 23B. Typical nonsymmetrical Cpol antenna leg mounted to tower.

[28]Jampro Antenna Company, subsidiary of Cetec Corporation, 6939 Power Inn Road, Sacramento, California 95828.

The Cpol is a result of the 45° angle between the two dipole planes and is a patented feature, in the United States, Canada, and United Kingdom. If the four arms were in the same plane and parallel with the earth plane, the radiation would be Hpol. The key to Cpol comes from the 45° angle while Vpol would result if the arms were opened up to about 180° with each other.

The antenna is ruggedly constructed using heavy wall marine brass tubing. See Fig. 23A. The arm casting is also of brass. The feed system permits dry air pressurization to the center Teflon insulated feed bushing. Due to the low Q, the VSWR is not affected in any measurable way by heavy fog or rain. Small end tuning stubs permit the radiators to be field trimmed after installation. The wishbone feed arms can also be adjusted for further VSWR improvement or to move the resonant frequency up or down one channel, ±200 kHz. The element has a standard 1-5/8 in. EIA input connector.

This antenna is stacked vertically for increased elevation pattern gain. Cpol power gain ratios up to 7.8 (8.92 dB) are available, which require a 14-bay antenna. A three-bay JSCP-3 antenna is shown in Fig. 23B.

The aimuth pattern of a single penetrator antenna, supported in its center by a small diameter pipe, has been measured to be within ±0.5 dB. Using the same mounting, the single element produced an axial ratio of 1.20 to 1 together with a polarization ratio of 1.32 to 1.

During fabrication the entire antenna is mounted on a tower similar to that to be used by the broadcaster. The VSWR of the system is adjusted and a final VSWR plot made. This chart appears in each of the two instruction booklets sent out with the antenna.

Jampro also offers a high power version of the Penetrator, Type JHCP, called the Brute, which is also Cpol. It uses 2 in. (5 cm) radiating arms and has a 3-1/8 in. EIA Input connector. It is rated at 40 kw for 2-bays, and is shunted across a 6-1/8 in. main feed line.

The spiral FM antenna Type JSS is for wideband use and covers 87.5 to 108 MHz. Using several arms around a steel support cylinder, the power rating is 70 kw per bay. A two-bay version with a Cpol gain of 3.1 is rated at 140 kw and may be used by several stations at one time. Fig. 19 shows typical construction.

The screen dipole panel antenna Type JSD may be mounted on the sides of a triangular or square tower or the sides of a large cylinder. These too are wideband antennas and may be used simultaneously by several broadcasters anywhere in the 87.5 to 108 MHz band. It has a VSWR of 1.1 to 1 or better across the entire 20 MHz FM band (CCIR Band II). It is Cpol, but may be furnished either Hpol or Vpol as required.

A ring stub antenna Type JLCP rated at 2 kw per bay is available for low power educational use.

Deicers

Electrical heating elements are inserted at the factory into the four quarter wave arms and one is put into the support boom near the feed through insulator. Each heater is rated at 100 watts with 230 volts ac, 50/60 cycles for a total wattage of 500 watts per bay. For light heating, 115 volts may be applied with a total of 125 watts.

The resistance heaters are impervious to moisture, use welded glass insulation and meet US government MIL specs for enclosed heating devices.

A deicer kit, to be installed on the tower by the rigger, includes pigtails, conduit connection boxes as well as interbay power cable. The broadcaster has a choice of deicer switching equipment, varying from a simple thermostat for small antennas to temperature and humidity controlled relays.

Radomes

Glass reinforced plastic (GRP) radomes may be supplied. These two-piece radomes are supported by the special shape element support boom. The aerodynamically designed radome produces a very low drag coefficient. See Fig. 24.

As with all its antennas, Jampro installs the radomes on the antenna during the final phases of the VSWR tune out and adjustments at the plant, on the test towers. This procedure yields a measured VSWR plot for the instruction booklet, with the radomes in place. The radomes change the VSWR, and therefore must be compensated by the element tuning.

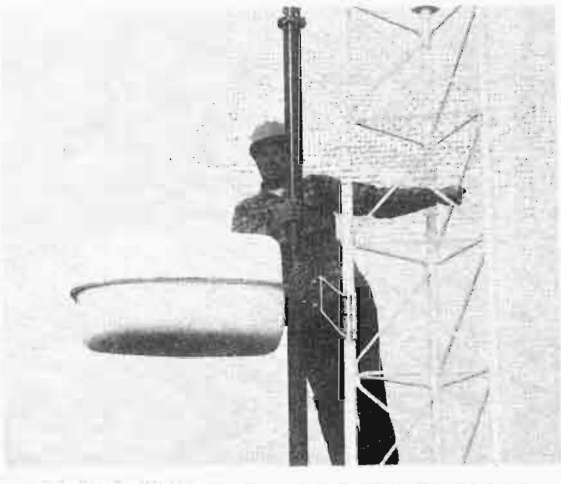

Fig. 24. Radome used on single bay FM antenna.

The broadcaster must verify the fact that the proposed supporting structure will indeed safely hold the antenna with deicers or radomes, by using a qualified structural engineer and checking the entire plan.

Antenna Test Range

Only by measuring on a test range can the azimuth pattern be verified.[29] After installation, the antenna pattern cannot be predicted from field measurements due to propagation factors. One cannot work back to the antenna radiation pattern from what is measured in the field. In addition to the azimuth pattern, this is also true of the axial and polarization ratios.

MCI FM ANTENNAS

Micro Communications Inc. of Manchester, New Hampshire[30] designs and manufactures, as well as sells a screen-backed crossed-dipole Cpol antenna. Designed to be installed on the faces of a triangular tower or other supporting structure, the antenna exhibits excellent azimuth patterns. Each bay uses three-panel antennas.

Fig. 25 shows a single bay, consisting of three of the arrow head dipole design, under the radomes, mounted on three sides of a triangular tower. For additional power gain, several bays are stacked vertically on the faces of the tower, approximately one wavelength. A corporate feed system, with semiflexible interbay cables, is used to feed the radiators.

Other products by MCI for FM broadcasting include high power diplexers for combining several stations into one of these antenna systems.

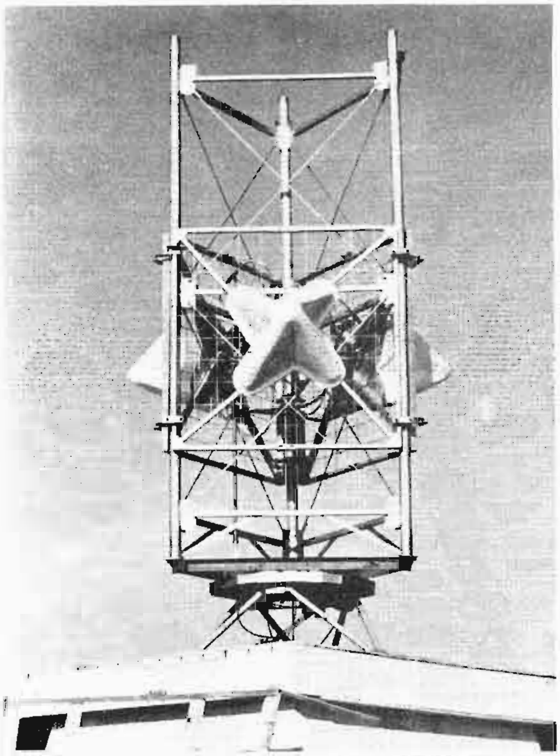

Fig. 25. Crossed dipole screen panel with bond FM antenna, single bay mounted on face of a triangular tower. (Courtesy MCI)

PHELPS DODGE FM ANTENNAS

This firm has a Cpol radiator which is basically 1½ turn helixes mounted on one wavelength shunt feed lines. Each Phelps Dodge[31] radiator is adjusted so as to be 50-ohms times the total number of elements. For example, an 8-bay antenna would have 400-ohm elements. This is accomplished by the ground loop feed system, used to excite each element, thru a coaxial arm, with porcelain insulation.

Each radiator is constructed of 1-5/8-in.-diameter copper tubing with spherical ends to eliminate corona problems. Each antenna array contains a matching transformer approximately 6 ft. (2 m) long, which is used to adjust the VSWR after installation.

Antennas with up to 8-bays are fed from the lowest bay, and larger antennas are center fed. If beam tilt or null fill is required, the multi-element array needed to provide the required pattern is center fed with appropriate power divider and phaser supplied at additional cost. See Table 4 for additional information.

Electrical deicers for operation on 230 volts with 500 watts of power consumption per bay, are available as options. The company also offers Hpol antennas, along with low-power, low-cost educational antennas.

RCA FM ANTENNAS

RCA[32] markets several types of Cpol antennas. These include panel as well as the non-

[29] *Test Procedure for Antennas,* IEEE Publications, No. 149, January 1965, IEEE, 345 East 47th Street, New York, New York 10017.

[30] Micro Communications Inc., Grenier Field, Manchester, New Hampshire 03103.

[31] Phelps Dodge Communications Co., Route 79, Marlboro, New Jersey 07746.

[32] RCA, Broadcast Systems, Camden, New Jersey 08102.

symmetrical side-mounted FM antennas. In addition it also sells multistation panel antennas and AM/FM tower isolation units.

Four versions of a side-fire short-helix type antenna element shunted across a rigid coaxial line are offered. The helix diameter, number of arms, and the size of the main coax line determine the safe power handling capacity. The power gain ratio remains the same according to published data regardless of the helix diameter, which varies from 17 in. (432 mm) for the educational BFI-C 500 watt unit to 25 in. (635 mm) for the higher power 6 kw unit, model BFG. The aperture cross sectional size at the center of the FM band is 0.2 wavelengths. All radiators are made of stainless steel.

The antenna may be mounted on one side of a triangular tower, either on the face or leg, or it may be pole-mounted. The antenna is bottom fed with up to 7 bays. With 8 or more bays, it is fed near the center. The input is a 3-1/8 in. EIA 50 ohm flange.

The high power BFG antenna is a three pole system. That is, the helix has three fed arms and three parasitic arms. See the photograph Fig. 26, which shows a similar model BFC-B, with four arms. These arms may be tilted to produce more Hpol than Vpol, where Epol is desired.

The electrical deicers when ordered are factory installed. The deicing system in the BFG, BFH, BFI, and BFC series, do not have an internal heating element. The heat is produced by the ohmic resistance of the stainless steel radiating element. Voltage step-down transformers are mounted near the element to shunt coax line mounting flange. These operate at 208/240 volts 50/60 cycles and produce a low voltage which is passed through the radiating element arms with heavy gauge wire with Teflon insulation. The ohmic resistances of the radiating stainless steel element produces the power loss, and thus the heat for deicing purposes.

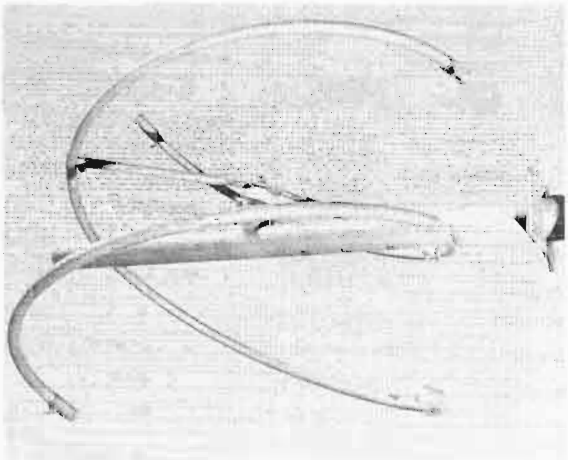

Fig. 26. Single stainless steel radiator, using four arms, (RCA Cpol type BFC-B.)

Radomes are not available for the high power BFG series, so deicers must be used if sleet or ice conditions prevail. The BFC series is available with radomes, which changes the safe power rating from 4 kw to 10 kw, for each bay of bays of four or less. These radomes increase the wind loading by 134 pounds (60 kg) per bay at 112 mph (180 km/hr).

The company's popular BFG series is power rated at 104 degrees F, (40 degrees C) ambient, for 6 kw for each radiator, and 40 kw maximum for any antenna. For higher temperatures there is a derating factor of 0.8 for temperatures of 122 degrees F (50 degrees C).

The free-space azimuth pattern circularity is ± 1 dB. However, the actual azimuth pattern, as will all side-mounted antennas, depends largely on the tower or pole environment. They recommend the antenna be mounted above the guys; or if guys go through the antenna, that these be broken up with insulators.

The VSWR of the antenna is adjustable after installation on the tower or pole to meet their published specifications of 1.1 to 1 for a ± 100 kHz bandwidth.

Beam tilt and/or null fill are optional extra items in the BFG series. They are usually desirable in the higher gain antennas with 8 or more bays. If beam tilt or null fill is required in seven or less bays, the antenna is near center fed at additional cost.

RCA also furnishes directional arrays which are custom built to the broadcaster's requirements.

SHIVELY FM ANTENNAS

The Shively[33] antenna Type 6810 has an input power rating of 10 kw, for each bay. It is of the ring stub variety, and uses a coupling loop, to match impedance as well as provide the proper amount of coupling to the vertical 3-1/8 in. main coaxial feed line.

The antenna consists of a single transmission line with individual bays separated approximately ten feet (3 m) from each other. Each element is constructed of copper and brass. Eight bays or less are end fed from the bottom, and the

[33]Shively Laboratories, Inc., Raymond, Maine 04071.

larger antennas from the center. The manufacturer states the ±150 kHz bandwidth to be 1.1 to 1, after trimming with adjustable transformer, which is supplied with the antenna. The Hpol azimuth pattern is ±1.5 dB in free space.

Cpol RECEIVING ANTENNAS

The benefits of Cpol transmitting antennas may be further improved through the use of Cpol receiving antennas. FM receiving antennas of the Cpol type were not available for sale in early 1976. Undoubtedly, as soon as Cpol is authorized for television, there will be an ample supply of Cpol for TV as well as FM reception.

A Cpol receiving antenna will yield a 3 dB increase in signal when receiving a Cpol signal if the sense of polarization is correct. This type of receiving antenna will also provide better signal to noise ratios since multipath is greatly reduced. They will make excellent receiving antennas for fringe areas because of their inherent gain and noise reduction qualities.

ANTENNA SYSTEM VSWR BANDWIDTH

The antenna system VSWR does not affect the coverage unless the VSWR is very high (2.0 to 1 or greater) and there is considerable transmission line loss, 3 dB or greater. In most modern day FM installations these conditions do not prevail. Therefore, we are concerned here only on the performance of the transmitted audio.

The necessary VSWR of the antenna system as presented to the FM transmitter has been established unofficially by common usage as 1.1 to 1. This is a reflection coefficient of 5 percent, which equals a reflection of −26.5 dB. This combines all the reflection presented by the antenna, transmission line, harmonic filter, directional coupler, and other coaxial items, as the FM transmitter load. There is no known FCC specification, or CCIR recommendation.

The FCC assignment channels are spaced 200 kHz, but this is not in any way a system bandwidth limit. With modulation indexes of greater than 15, RF energy extends beyond ±200 kHz. In Fig. 2C, Warrent Bruene in Chapter 18, (*FM Broadcast Transmitters*) indicates the RF power distribution for an audio frequency of 5 kHz.

With lower audio frequencies, the modulation index is even greater and power distribution is wider. The antenna system VSWR must respond to a greater bandwidth if the third significant side band is considered at the higher modulation indexes.

Transmitter Bandwidth

In FM modulation, the bandwidth is theorectically infinite. In practice the amplitudes of the side band frequencies beyond the maximum swing become small. (Please see Chapter 18, page 434-436 on FM Modulation theory.) Even for small swings (FM deviation) the bandwidth must be sufficient to fully include the first order sidebands or no intelligence will be transmitted.

During modulation of the FM carrier, the power in the side bands is greater than that at the FM center frequency. For example, at a given instant the maximum power may be in one of the upper sidebands, 165 kHz above the carrier frequency. The antenna system must perform properly at this frequency as well as 165 kHz below where the power also appears.[34]

The —30 dB bandwidth with 100 Hz of audio on a quadraphonic FM carrier, using the 95 kHz AM subcarrier, is ±200 kHz. The antenna bandwidth therefore for quad depends on what significant sideband power is to be considered. Nevertheless, the important levels are certainly at −30 dB or less, requiring an antenna bandwidth of at least ±200 kHz.

The basic problem due to high VSWR is reflected signals which cause the transmitter RF amplifiers to look into a reactive load, with nonlinear phase and impedance characteristics.

In stereo and quadraphonic broadcasting, the separation and noise between and in each channel is affected by the antenna system VSWR and the electrical time delay of the transmission line. The problem is somewhat like that of television ghosting. If the time delay is quite great, a very low reflection ghost may be clearly seen. If the delay is very short, a large amount of reflection may be tolerated.

In addition to this, synchron noise (a European CCIR term) may be present in narrow VSWR bandwidth systems. The carrier, when deviating with modulation, causes higher amplitudes of reflection, with wider frequency excursions. This causes amplitude modulation with FM modulation, due to the narrow VSWR bandwidth of the antenna system. Typical European specifications are 55 dB below 100 percent modulation, for AM noise produced with 400 Hz audio modulation of the FM carrier.

Tests have indicated that the transmitting antenna system VSWR at the carrier frequency produces cross talk, as a function of the VSWR value.[35] The tests were made with a FM station

[34] *Measuring Wide Bandwidth FM Deviation*, C.N. Charest, Philco-Ford, Electronic Design News Magazine, March 1, 1969.

[35] Transmitting Antenna VSWR Effects on FM Stereo, Peter Onnigian, *IEEE Transactions on Broadcasting*, August 1963, pages 1 through 6.

operating on 96.9 MHz with an ERP of 75 kw. The FM antenna was fed through 300 ft. (90 m) of 1-5/8-in. rigid coaxial transmission line. Receiving tests were made with a high performance FM receiver 15 miles (25 km) across the city.

In the measurements, good stereo separation (greater than 30 dB) was obtained with VSWR values of 1.1 to 1 across ±200 kHz, from 50 to 11,000 Hz. With an antenna system VSWR of 1.2 to 1 the 30 dB separation was reduced to 7,500 Hz. At 1.5 to 1 VSWR it was impossible to measure any audio tones whose stereo separation was better than 26 dB. See Fig. 27.

Unfortunately, the transmission line length could not be extended, to measure the effects with a given VSWR value. The cause of the crosstalk (reflection) would be delayed further and become more measureable, with longer transmission lines. These tests proved the desirability of low VSWR for the FM channel, and its significant deviation sidebands. Quadraphonic FM broadcasting is more demanding of VSWR bandwidth. The present FCC biphonic (stereo) 100 percent modulation represents 75 kHz deviation of the main carrier with a 38 kHz subcarrier for the stereo information.

Some music service firms have noticed a definite crispness in the music of their client's stations which have good antenna VSWR values. This characteristic is difficult to measure but is audibly observed. It is due to a lack of distortion and crosstalk as a result of reduced reflections from the antenna system.

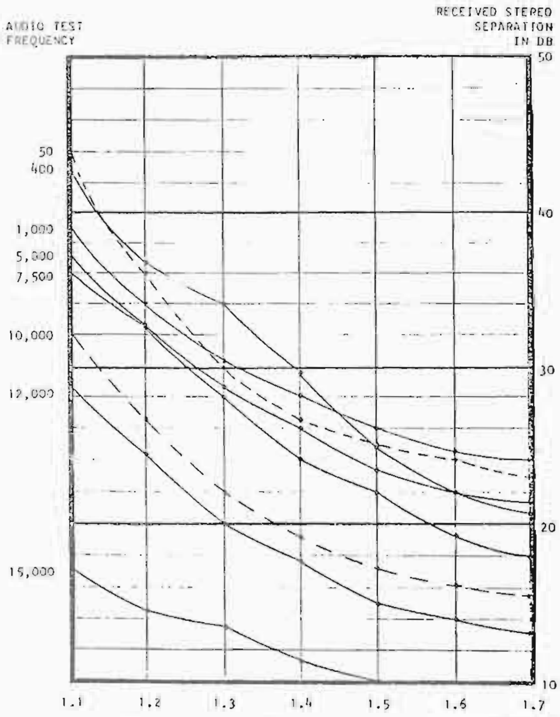

Fig. 27. Stereo separation versus antenna system VSWR.

At this writing, (early 1976) five basic proposals were made to the FCC for quadraphonic sound, producing four discrete sound channels through the FM receiver. All proposed systems have a baseband frequency spectrum of 95 kHz, which is 20 kHz more than the present 75 kHz FCC pilot carrier stereo system. Some of the proposals call for a subcarrier at 95 kHz to be frequency modulated.[36]

VSWR Recommendation

There are no industry or government standards for VSWR bandwidths for FM broadcasting antenna systems. It is therefore recommended that for stereo or quadraphonic sound, the industry adopt a maximum VSWR value of 1.1 to 1, for a minimum bandwidth of ±200 kHz. This would be measured at the coaxial line flange, normally connected to the transmitter. It would include the reflectometer coupling, harmonic filter, all coaxial transmission line components and the FM antenna.

This VSWR will prevent undue degradation due to crosstalk, reflections, phase delays, and synchron noise, with transmission lines of up to 328 ft. (100 m). Antennas with transmission lines up to 650 ft. (200 m) should have even lower VSWR values; 1.08 to 1 across ±200 kHz is recommended for these longer lengths.

These values are easily obtainable with some of the present state of the art narrow band non-symmetrical antennas. A measured VSWR plot of an installed six-bay Cpol antenna, together with 625 ft. (190 m) of 3-in. heliax line, is shown in Fig. 28. It has a VSWR bandwidth of ±375 kHz, under 1.1 to 1 and 1.08 to 1 for ±250 kHz.

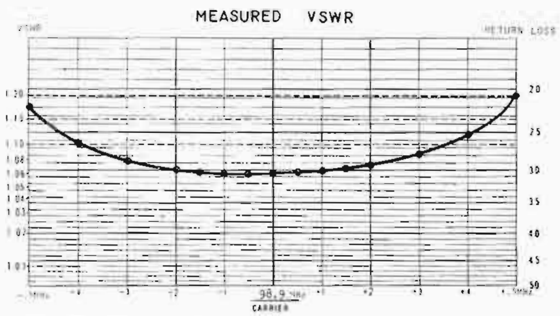

Fig. 28. Measured VSWR plot of six-bay FM antenna, together with 625 feet (190m) of 3 inch heliax coaxial line.

[36]Vol. 1, Report of National Quadraphonic Radio Committee, Nov. 1975, EIA, 2001 Eye Street, N.W., Washington, D.C. 20006.

DUAL ANTENNAS AND MISCELLANEOUS FEED SYSTEMS

In Europe, Asia, and Africa, it is quite common to find antennas which have an upper half and lower half, with two transmission lines of equal length to the transmitter room. These two lines are normally fed by a power splitter. The upper half and lower half work as a common antenna, through the power splitter located in the transmitter room instead of in the antenna, as is common in American systems. This dual feed system has the advantage of providing a spare antenna half, in the event that one transmission line or one-half of the antenna becomes defective or requires maintenance. With one-half of the antenna and full power fed to it, the ERP is reduced 3 dB.

Another method is to feed each half of the antenna with a separate amplifier and line. A common driver and exciter are used to feed, for example, two 20 kw amplifiers, for a total of 40 kw transmitter power. This has the additional advantage of providing a means for transmitting with one amplifier into the entire antenna system (through proper coaxial switching), while doing maintenance work on one amplifier. Here again the ERP is reduced only 3 dB. If each amplifier feeds one-half of the antenna, without switching, and one amplifier line or antenna half stops working, then the ERP drops 6 dB. This is an ideal situation for remote controlled stations in difficult to get to mountain sites.

The electrical phase of the carrier must be kept equal to each antenna half, in order that serious beam tilt does not occur. This may be accomplished with monitoring devices.[37] These systems are quite practical with 2 × 20 kw transmitters, and high power nonsymmetrical FM antennas, offered by American manufacturers. They also work very well with the multichannel wideband symmetrical panel antennas, popular in Europe, and also available from some American antenna makers.

ANTENNA VSWR TUNEUP

The immediate metallic environment of the side-mounted FM antenna affects its VSWR. All currently produced FM antennas in the United States have provisions for field trimming the VSWR. Some manufacturers completely assemble the antenna, install it on a tower similar to the one to be used, and tune the various elements for conformity to establish quality control VSWR values. Others do not. VSWR transformers (fine tuners) as well as means to tune the individual radiating elements are found on some antennas. All these antennas may be tuned for their best VSWR on the tower from which they are to operate.

To properly tune an FM antenna, after installation, requires test equipment not normally found in stations. A test package would consist of a signal generator, counter and a 35 dB or better directional coupler. If such equipment is available, it should be connected to the main transmission line at the point beyond the harmonic filter. The entire antenna and transmission line can then be tested. If the VSWR does not meet the specifications, then the transmission line should be terminated in its characteristic impedance (usually 50-ohms), and the line should be checked. This should indicate where the difficulty lies.

If proper test equipment is not available, then the reflectometer in the transmitter may be used as an indicator of second choice. Reflectometers are of various types, and some permit expansion of the reflected reading, without upsetting the calibrated value. After the entire system is working and power has been applied to the antenna, the reflectometer should be calibrated in accordance with the transmitter manufacturer's suggestions. The reflected value should be noted. If this value is above 1.1 to 1, the station engineer may want to fine tune the antenna. If the value is above 1.7 to 1, the rigger should inspect the installation.

If the antenna system is to be field tuned, it is recommended that the normal forward (incident) value be obtained on the transmitter reflectometer. The reflectometer should then be switched to reflected position and expanded if the meter circuitry permits this without upsetting the calibration of forward power. The rigger must be below the antenna by at least 5 ft. at all times during these adjustments.

The tuning steps are those recommended by the antenna fabricator, or the following method may be used. After noting the reflected initial reading, the fine tuner or matching transformer should be adjusted, until the lowest value is found. If this is not satisfactory, then the individual elements should be adjusted, if this is possible. In all cases, one or both of these adjustments should bring the VSWR down to 1.1 to 1 or better. If not, then the manufacturer should be consulted.

FM transmitter reflectometers used in the above manner suffer two problems. First, they must be placed *after* the harmonic filter in the transmission line, otherwise harmonics are picked up by the reflectometer. The single channel antennas also reject harmonics, making the reflectometer read high VSWR values, when the harmonic filter is not working properly.

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[37] Parallel FM Transmitters 3 Parts, Tom Polino, *Broadcasting Engineering*, July, August, September 1975.

Another cause of difficulty with transmitter reflectometers is their poor directivity. That is their ability to tell the difference between forward and reflected power. Most transmitter reflectometers have directivities of about 20 dB. For test purposes and to read 1.1 or 1.08 to 1 more accurately, a coupler with at least 40 dB of directivity is required.

If the FM transmitter emits spurious signals, these will be reflected by the single channel antenna, and show up as increased VSWR. A wideband screen antenna will absorb this power, as will the station dummy load. This confusion can be clarified by looking at the radiated power into the antenna with a spectrum analyzer, when in doubt.[38]

TRANSMISSION LINE SYSTEMS

For FM antenna systems, two basic methods have come into common use. One uses rigid coaxial line sections in 20 ft. (6.09 m) lengths, with elbows, flanges, spring hangers and other devices. The other has a semiflexible coaxial transmission line. Both systems work out quite well. These two methods of providing power to the antenna are shown in Fig. 29.

For more details about transmission lines, see Chapter 12.

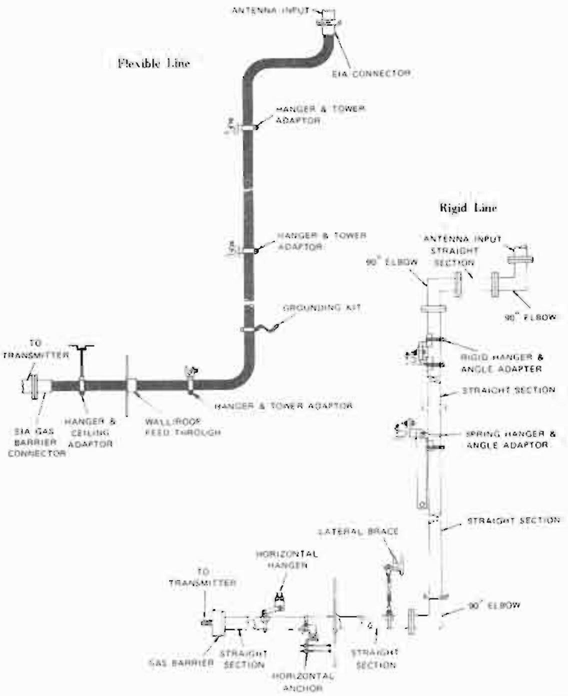

Fig. 29. Typical installations of flexible and rigid coaxial transmission lines to feed FM antennas.

[38]"Spurious Radiation From FM Broadcast Transmitters," Eldon Kanago, pages 77 through 81, *Proceedings of the 1967 NAB Engineering Conference,* National Association of Broadcasters, Washington, D.C.

FM ANTENNA INSTALLATION ON AM TOWERS

In many cases, it may be economical and convenient to install the FM antenna on a tower used for AM broadcasting. If the steel tower is insulated, the FM power may be transferred across the base insulator without upsetting the AM tower operation.

The easiest way is to use a device marketed by several firms called an AM/FM isolator or FM isolation transformer. It has two tightly coupled RF coils which are resonant at the FM operating frequency. An adequate air gap is provided for the medium wave AM power thru the resonant loops.

Fig 30 shows the internal construction of a typical isolation transformer. The insulation for AM for the top of the box is high density polyethelyne. This top provides a rain shield as well as protection from dust and mud. The spacing between loops is greater than the base arcovers due to static and high modulation peaks would take place across the loops.

A typical installation using an isolation transformer is shown in Fig. 31. The FM coax going to the box from the transmitter building is grounded. The top of the box, which is insulated from the remainder of the box, is connected to the tower. The isolation transformer is physically and electrically shunted across the tower base. The FM coaxial line runs from the top of the box to the antenna using metallic hangers. Care must be taken to allow for the copper line expansion, if rigid line is used, by letting the box move with the expansion. With semiflexible line, this is not a problem since the flexible line does not exert undue stress.

Insertion loss at the FM frequency is typically less than 0.15 dB, with a VSWR of 1.05 to 1 or

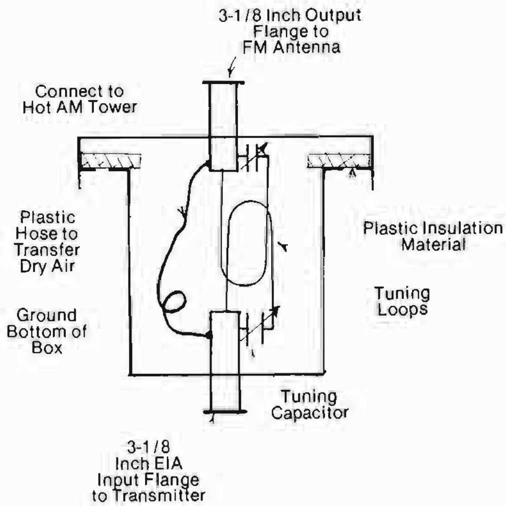

Fig. 30. Typical FM/AM isolation transformer.

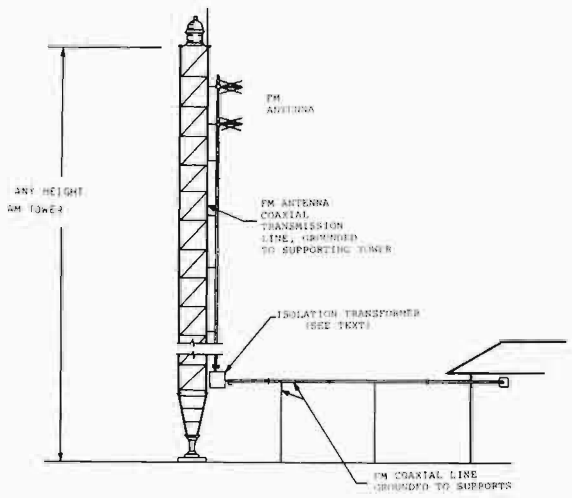

Fig. 31. FM antenna fed thru isolation transformer using conventionally installed FM coaxial transmission line.

better, when terminated in a 50-ohm load for a bandwidth of ±0.5 MHz. The shunt loss at the AM frequency is about 30 dB, while the shunt capacity will vary from about 40 to 200 mmfd depending on the make and model. Safe AM power ratings are 7.5 to 50 kw with FM ratings of 10 to 40 kw.

A less popular method is to use the technique of quarter wavelength transmission lines. Simply stated, the opposite end of a shorted quarter wavelength line has high impedance. This high impedance is placed across the AM tower base and may be successfully used to provide isolation.

In Fig. 32 there is a vertical run of rigid FM transmission line, which is a quarter wavelength long on the AM frequency. The grounding of the FM coax strap is adjusted during AM base impedance readjustment. The remainder of the coax is on insulated hangers. If the AM support tower at the FM coax ground is shorter than 75° then a capacitor is used to adjust the electrical length to 90°. In practice only about 75° of insulated line is required since the coax line hangers and distributed capacity of the line tend to increase the electrical length.

The isolation transformer method is more popular because it has two distinct advantages, and is not more expensive in the average installation than the insulated quarter waveline technique. The small capacitance of the isolation transformer does not upset the AM tower base impedance. It has the further advantage in directional arrays of not causing any undesired AM radiation which may change the protection nulls.

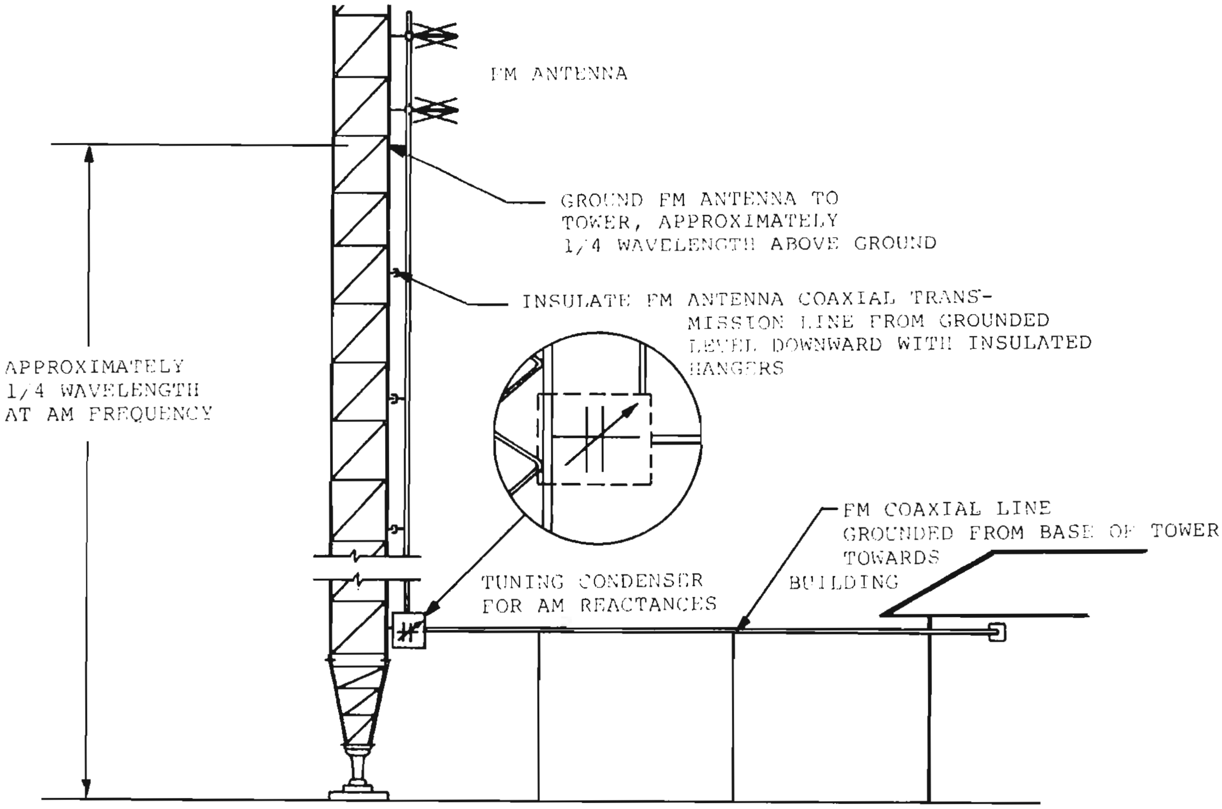

Fig. 32. Insulated FM coaxial line used to isolate FM antenna from AM tower.

An isolation transformer has been in use on a single 50 kw AM tower with a 40 kw FM transmitter for several years. What makes its use even more noteable is that the tower is located about one-half mile (0.8 km) away from a cement factory. The dusty environment has not caused any insulation problems.

After the FM antenna and line have been installed with either method, the AM tower operation must be checked and adjusted as necessary with proper test equipment. There is always some additional shunt capacity which must be tuned out of the AM antenna tuning units (ATU).

STRUCTURAL CONSIDERATIONS

Most FM antennas in the western hemisphere are installed on the sides of a steel supporting structure, between 18 and 60 in. (45 to 152 cm). The antenna and its transmission line as well as the mounting brackets introduce wind loading, in addition to their dead weight. The total load must be considered in the safety of the overall tower structure. The wind loading is a result of the amount of physical surface presented to the wind. It is sometimes called the wind catch area. It consists of either flat or round antenna members, coaxial lines and mounting brackets and hardware.

The dead weight of these antennas is significant, but not as important as the live load, which is the load as a result of winds. The dead weight is always present. The live load is added when the wind comes up, and is usually much greater than the dead load. See Table 4 for wind loads for a typical six-bay antenna.

A guyed triangular tower of 300 ft. (91 m) height may have a downward load on the tower legs of 40,000 pounds (18,180 kg). This will consist of the dead weight of the tower and all its attachments, plus the pull from the guy cables. It can be seen that adding several hundred pounds of FM antenna to the existing dead tower load is not overly important.

Tower wind loads are important and the resulting live wind loads should be considered. The wind acts not only on the FM antenna but on the supporting tower. For example, a 10-bay Cpol antenna has a net weight of 1,074 pounds (488 kg) with radomes. With a 112 mph (180 km/hr) wind, the resulting wind load of the antenna is 2,065 pounds (938 kgs), nearly twice that without the customary rated wind velocity.

One of the advantages of the single channel nonsymmetrical FM antenna is its simple tower requirements. A wideband 10-bay screen dipole FM antenna, with radomes, has a wind load of 7,527 pounds (3,421 kg), nearly 3.65 times that of a 10-bay nonsymmetrical side-mounted antenna.

When an existing or new tower is to be used to support an antenna, a structural engineer familiar with towers and mast should be retained to make the necessary calculations and determine if the tower is suitable. The tower supplier will usually work with the broadcaster when a new tower is furnished. In an event, structural engineering is strongly recommended to prevent damage to equipment and possible loss of life by using EIA Standard RS-222B or its latest amendments, in addition to local building code requirements. In Europe, the Middle East and Africa, British Standards Institute 4360/2642 may be used, and in Canada S-37, 1965.

GUY CABLES IN ANTENNA APERTURE

The presence of steel guy cables going thru the antenna aperture on a guyed steel structure was studied by Jampro Antenna Company during 1968. It was found that guy cables had less than ± 0.3 dB in either the azimuth or elevation pattern of a Hpol antenna. On Vpol antennas it is approximately ± 0.9 dB on the azimuth pattern. The strongest effect is on Cpol where azimuth and elevation pattern distortions as great as ± 1.7 dB were measured.

Guy cables are small in wavelength and do not cause blockage. They do pick up and reradiate energy if the polarization is correct, but the greatest cause is due to brute force excitation.

In addition to pattern anomolies the guy cables being RF excited reradiate near the ground. This may cause RF feedback problems in some high power installations with low level audio equipment located in a building near the tower base.

It is recommended that any guy cable going thru the antenna aperture be insulated, in the areas shown in Fig. 33. Plastic fiberglass (GRP) insulating rods as well as flexible plastic rope covered with a PVC jacket are available. The black jacket prevents deterioration due to ultra violet sunlight radiation. Tracking problems, which are sometimes found with AM (medium wave) broadcast tower use, have not been observed in FM use.

Strengths exceeding the steel cable with which the plastic is to be used should be specified. See Table 5 for strength details. Porcelain insulators may also be used every 30 in. (830 mm) but they are expensive, bulky, and increase the system wind load.

Both of the above types of insulated lines are available with suitable metal end fittings, for

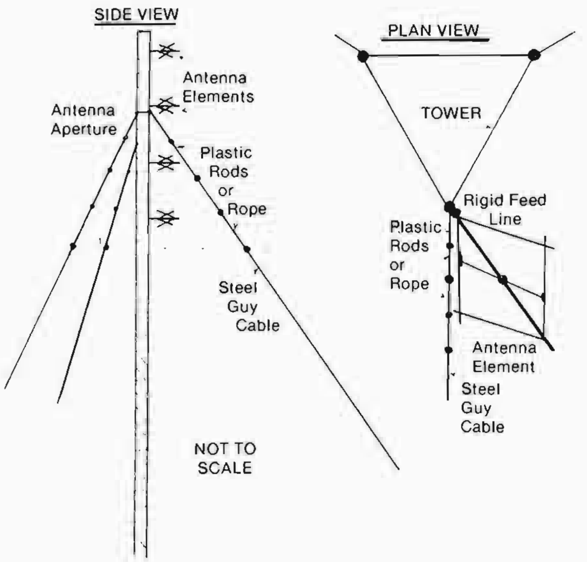

Fig. 33. Plastic Guy Rods or Rope Insulation to break up steel guys.

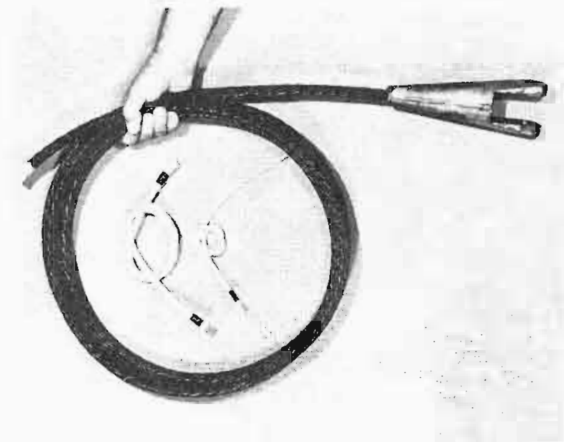

Fig. 34. Length of PHILLYSTRAN plastic guy cable rated at 55,000 pounds (25,000 Kgs) with PVC jacket and end jaw termination. Two unjacketed smaller cables are shown in center.

TABLE 5

Plastic Guy Cables and Rods

Maker and type no.	Working strength	Dielectric constant	Dielectric strength
Phillystran[a]			
PS29-6x19x	30,000 pounds (13,636 kg)	3.5	470 volts/mil
PS29-6x37x	55,000 pounds (25,000 kg)	3.5	470 volts/mil
Joslyn[b]			
900	60,000 pounds (27,270 kg)	4.8	350 volts/mil

[a]Philadelphia Resins Corporation, Commerce Drive, Montgomeryville, Pennsylvania, 18936.

[b]Joslyn Mfg. and Supply Company, 155 North Wacker Drive, Chicago, Illinois 60606.

use with a tower on one end, and a steel cable on the other end. Both eye and jaw type fittings are available. The plastic rods come in lengths from 3 ft. (1 m) to about 14 ft. (4.26 m). Several may be put in series to reach the required length. They are stiff and shipped in straight lengths.

The Phillystran is available in continuous lengths of up to 1,000 ft. (304 m) and kits are available for putting on end fittings in the field, if so desired. Otherwise they may be put on pre-cut ordered lengths from the factory. The Phillystran plastic cable has low stretch. A black plastic cover is used to protect it from the sun's rays as well as corrosive atmospheres. With low power dissipation factors they are transparent to RF energy. The plastic rope is very flexible. It may be shipped in a coil or reel and is quite lightweight, as shown in Fig. 34.

For safety the plastic break-up insulator working strength should be greater than the steel cable with which it is used. Ample strength in various sizes is available. The manufacturer should be consulted for their recommendations for proper use.

LIGHTNING

Lightning is a natural phenomenon that has always fascinated man. It performs the function of maintaining a balance in the global electrical system. But apart from this, lightning is an extremely destructive force—annually killing an estimated six thousand people and inflicting a billion dollars in property losses—including FM antennas.

Because FM towers are usually located on high ground, hilltops, or high buildings, they require lightning protection since they are likely recipients of lightning strikes. The type of damage that can be caused by lightning to a FM tower is varied. Smaller coaxial lines will usually melt; larger coax, (1-5/8, 3-1/8) will also melt in some cases, and others will conduct the heavy current into the transmitter building to do damage there. The FM antenna itself may heat, arc, melt, and otherwise be damaged. Holes in the other conductor, burns and melting at flanges, are common. Teflon insulation will burn, depositing a film of carbon, causing further damage if RF from the transmitter continues after the strike.

Protection of the FM antenna system may be provided to some degree, by taking several precautions. The top of the tower should have a lightning rod, about a ft. (0.3 m) higher than the uppermost obstruction light. The FM

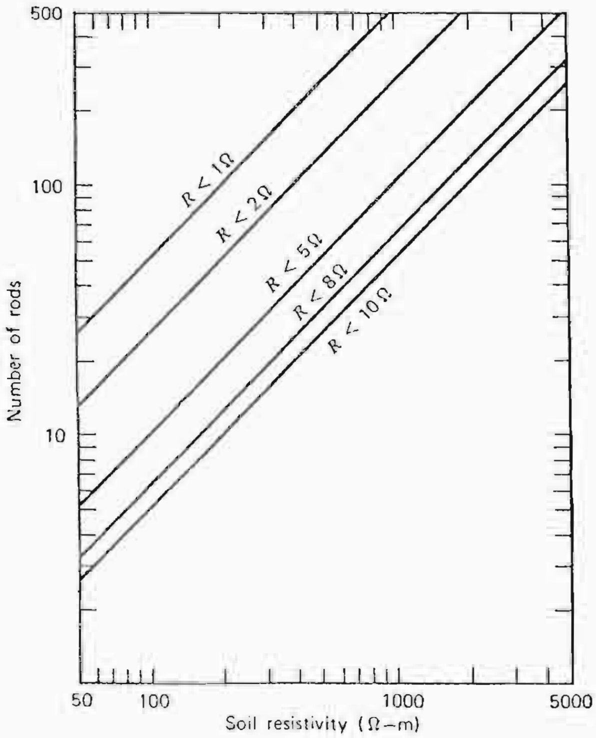

Fig. 35. Number of rods (10 ft. long, 0.75 in. diameter, spaced more than 20 ft. apart) needed to attain a required resistance value R for any value of soil resistivity.

antenna itself should be firmly grounded to the tower, or it should have excellent connections, so as to handle very high currents, for 1 or 2 seconds. If the coaxial cable is buried between the tower and the transmitter building, it must be at least six feet away from any tower base grounding system.[39]

A ground system should be located immediately around the base of the tower. This should have a direct current loss of 10-ohms or less. Low resistance may be obtained by using ground wires buried in the soil. Six radials, spaced 60°, buried as deep in the soil as possible and running out up to 150 (45.7 m) ft. each, should provide a ground system with less than 10-ohms, if the soil is shallow, or rocky. Fig. 35 shows the number of equally spaced ground rods, required for any known soil conductivity, for a 10-ohm ground connection. Guyed tower anchors should also be grounded. This is shown in Fig. 49, page 172, in Chapter 8, Design, Erection and Maintenance of Antennas Structures, by Walter Guzewicz, in this book. It is important to install the proper number of ground rods to obtain at least 10-ohms contact with the earth at the base of the tower plus at least one ground rod at each guy anchor if the tower is guyed.

If the FM antenna is located on an AM insulated base tower, then the spark gap should be set at the lowest point providing protection at the highest AM modulation peak. In these cases a FM coaxial transmission line isolator should be used to carry FM power across the tower base. These FM isolators may sometimes burn due to lightning charges or strokes. Since the internal spacing between input and output is so close for minimum RF insertion loss at the FM frequency, arcing may occur due to lightning strokes in these isolators. Therefore, it is highly desirable to set the AM tower base spark gap horn or balls, at 3/8 in. (1 cm) or less, if possible.

Another way to protect the FM transmission line isolator is to use an RF choke across the tower AM base. This tends to reduce the static build-up voltages due to passing thunderstorm clouds, snow, hail, or dust storms. Arc overs due to these sources usually do not cause damage, but may trip the FM transmitter reflectometer since they will create a current flow through the reflectometer circuitry.

ELECTRICAL DEICERS

A covering of ice over the active antenna radiating elements usually increases the VSWR. This is due to the fact that the electrical resonance of the antenna is lowered in frequency with the ice coating, which slows the velocity factor on the active elements, making them electrically longer. A means therefore should be provided to protect the transmitter from VSWR increases due to ice with persistent coatings over 1/16th of an inch (1.5 mm).

Two methods of deicing are in common usage. One uses electrical heaters inside the active parts of the antenna. This is economical in initial purchase and does not appreciably increase the wind catch area. It has a continuing cost when ice is present, as electrical power must be used to provide heating. The other method uses a plastic covering around the active parts of the antenna, and thus keeps the ice off. All American-made FM antennas are available with electrical deicers or plastic covers. The choice depends on cost factors.

Electrical deicers are furnished as a separate accessory item. They are designed for operation with 110/120 volts 50/60 Hz power sources. When heavy deicer loads are present, deicers may be ordered for use with 220/240 volts, single phase power circuits.

Single bay deicer power requirements vary from 300 watts up to 1,500 watts, depending on

[39] *Lightning Protection*, J.L. Marshall, John Wiley & Sons, New York, 1973, Chapter 7, pages 114 through 144.

Fig. 36. Typical electrical tie in box with interbay cable.

the ice loads and conditions. Power wattage should be chosen with care. Deicers are supplied with a complete interbay kit, consisting of power junction boxes, conduit, clamps, etc, to tie power lines between bays. Fig. 36 shows a typical installation.

Deicers must be ordered at the time the antenna is ordered since they are installed at the factory. Optional items include power relays, low/high temperature thermostats, and humidity sensors.

Deicers usually provide years of trouble free service if properly installed. Actual deicer heating element defects are quite rare.

Poorly dressed deicer wiring cables can cause RF burns in the power cable, as well as the wall of adjacent coax, causing air leaks, and associated problems. Interbay conduit should be thoroughly grounded to the supporting tower or pole, to prevent RF burns. Deicer installation is electrical work and must not be left to tower riggers who are not familiar with it. It should be supervised by a competent person, knowledgeable in electrical matters.

RADOMES

Plastic covers, commonly called radomes, protect antennas from environmental exposure, principally ice. A covering of ice over the active antenna radiating elements usually increases the VSWR. The electrical resonance of the antenna is lowered in frequency, since the ice coating slows the velocity factor on the elements, making them appear electrically longer than they are physically without ice. Radomes do not normally degrade the performance of the antenna.

The plastic material available for use in radomes is quite transparent at the relatively low FM frequencies. Therefore, transmission loss due to absorption is usually not measureable. Most manufacturers make certain that the shape, dimensions, and the type of material is such that very low reflections are present, which are tuned out during final adjustments, so as not to impair the VSWR of the antenna with radomes.

A radome is subject to thermal and structural loads. Ambient temperatures from below freezing to perhaps 110° F (45° C) must be safely survived, without physical distortion, and cracking. Glass-reinforced plastic (GRP) is the material of choice. Polyehtylene tends to soften and distort in high ambient temperatures, with operation of the antenna at high power levels.

Environmental problems caused by rain, ice, snow, hail, lightning, vibration, and winds are problems for radomes. Well-designed and manufactured radomes can survive these acts of nature.

By far, wind loads produce the most severe stresses both to the antenna and its supporting tower. FM antenna suppliers show wind loads to be expected in their literature with no ice conditions at 112 mph wind velocity (180 km/h) as a standard. If the maximum wind velocity is higher or lower than this value, the correction can be made by using a factor of 50 pounds per square foot, round surfaces at this velocity (244 kg per square meter). If the resulting windload is higher than rated in their specifications, the antenna manufacturer should be consulted to determine, if the radome can withstand the higher wind velocity.

The supporting structure should be evaluated by a structural engineer to determine if the radomed antenna can be safely supported. Not only is there greater windloading, but the additional torque load may be too much. This twisting of the tower leg or face is a very important structural consideration. A typical FM antenna radome is shown as Fig. 24. Made of glass-reinforced plastic (GRP), this Jampro radome has a white protective gel coat.

The radome is coated with an ice resistant paint. This paint usually has titanium dioxide to make it white and reflective to ultraviolet radiation, which deteriorates polyethylene radomes, unless thus protected. A white gel coat over the fibreglass radome not only inhibits ice coatings, but prevents ultraviolet radiation from deteriorating the plastic.[40]

It is interesting to note that water has a dielectric constant of 63 with a loss tangent of 0.55. When air is mixed with water and frozen as in snow, the dielectric constant goes down to 1.3, while the loss tangent is a low 0.0005. When

[40]*Radomes for Microwave Application*, A. Holtum and K. McKee, Bulletin 600, June 1964, Andrew Corporation, Orland Park, Illinois.

frozen in the form of water, the dielectric constant is 3.2 and the loss tangent is a low 0.008[41] This indicates that snow and ice do not present significant RF loss, when coating a radome, but do present some reflection because of the dielectric ratios of 1.3 and 3.2 times that of air.

Plastic radomes provide an effective way to overcome icing problems, without measureable RF loss or VSWR detuning effects for FM broadcasting antennas.

INSTALLATION PROCEDURES

The suppliers furnish detailed installation procedures with their antenna products. These instructions should be closely followed by the riggers. Many factors relating to the installation are taken for granted. The following items are specifically called to the attention of the broadcaster's engineer to insure proper installation and good performance for many years.

1. Follow manufacturer's instructions. See that the riggers also read these instructions.
2. Do not leave antenna parts where rain or moisture can enter. Store indoors or keep units capped as received.
3. Do not allow dirt or other foreign matter to enter any coaxial part.
4. Protect all antenna parts from physical damage and abuse.
5. Hoist antenna members carefully, with a tag line to prevent damage by striking against the tower.
6. Install on the tower as indicated by the manufacturer's instructions, remembering that bay number 1 is the uppermost top unit.
7. Riggers should lubricate "O" rings with a small amount of silicone grease before mating the flanges.
8. The full complement of flange bolts should be used and they should be as tight as possible.
9. Tuners or individual element devices, if used, should be adjusted only after the entire antenna and tower installation has been complete.
10. Rigid transmission lines should be properly installed with two hangers, per 20 ft. (6 m) length, and with the inner conductor retaining pin, if any, on the top of each section. One hanger should be approximately 1 ft. away from a flange. These lines must not be dented during installation. If dented, replace or straighten out with a round metal plug, several thousands of an inch smaller than the ID of the outer conductor.
11. If semiflexible cable such as heliax is used, it should be firmly tied down at least every 5 ft. (1.5 m) for 3-in. line and every 3 ft. (1 m) for 1-5/8-in. line. Also tie it down where it comes in contact with any sharp metallic member of the tower.
12. After physical installation has been completed, in accordance with the manufacturer's recommendations, the main transmission line should be pressurized with dry air through a dehydrator, air pump, or by using nitrogen gas.
13. Dry air (or gas) pressure should be maintained at all times. Some antenna warranties are not valid unless this is done. Dry air prevents the entrance of moisture. A sudden drop of air pressure indicates a leak, which should be located and remedied. Leaks come about from many sources. They include lightning damage, chafing through mechanical movement, cracks due to vibration, and copper fatigue. Even stray bullets from carelessly handled guns can cause problems.
14. While the recommended level of air pressure varies, its purpose is to keep moisture out and to signal the presence of more serious trouble. Moisture within a coaxial line may cause electrical breakdown by flashing across internal insulation. Moist air, over a long period of time, will cause the copper conductor to oxidize, causing considerable loss in electrical efficiency, as well as heating in high power installations.
15. When initially putting dry air (or gas) in the line, the coaxial transmission line system should be purged. This can be done through the use of valves provided for this purpose by some firms, or loosening one of the uppermost flanges so it leaks air. The extent of purging should be sufficient to let all the trapped moist air escape to be replaced by the dry air from the pressurizing system.
16. The antenna system should be checked by a qualified rigger everytime the obstruction lights are replaced, or if lights are not used, at least once a year. The rigger should look for vibration and storm damage such as loose or broken coaxial line hangers, loose tiedowns or semiflexible lines, and signs of arcing across any exposed insulator. These insulators should be wiped off with a dry rag to remove any dust or dirt which may have accumulated. In corrosive air environments, it may be desirable to clean these insulators with carbon tetrachloride liquid.

RADIATION HAZARDS

Exposure to high power VHF-UFH electromagnetic radiation can be harmful to people, due to the the effects of overheating upon the living tissue. Heating is a function of the

[41] *RADAR Handbook*, Merrill and Skolnik, pages 14-30, McGraw-Hill Book Co., New York, 1970, New York.

radiated field. It is generally expressed in terms of the average power flow per unit of the incident area, and indicated in milliwatts per square centimeter. In the United States, OSHA (Occupational Safety and Health Act of 1970, Department of Health, Education and Welfare) has set a maximum level for nonionizing radiation of 10 mw per square centimeter. For FM broadcasting, this is equal to 200 volts per meter, if measured by a suitable field strength meter. The US Bureau of Radiological Health[42] has suggested methods of measuring this radiation level with an accuracy of better than 0.69 dB.

There is considerable difference of opinion as to the safe *level* of radiation as a function of frequency. However, the duration of the level has been generally indicated as ten minutes, by the developed nations. Power at different frequencies is additive for heating hazards. The eyes are the most sensitive to damage, followed by the testes.

The most direct approach to providing protection from radiation exposure is to determine the minimum safe distance from the closest FM radiating element. The protection distance from an antenna depends on the peak radiation direction and distance. The peak ERP does not occur at the base of an FM tower, but at the horizontal in most cases. Fig. 37 shows the recommended distances for radiation of less than 10 mw per square centimeter. This was taken from the FCC guideline for VHF-UHF Radiation Hazards.[43]

A recent proposal for the installation of four different FM stations, using a common antenna with 100 kw ERP each (400 kw total ERP) mounted on a building roof, was disapproved by OSHA. It was determined by computer analysis that the radiation level on the roof would be in excess of 200 volts per meter, in some areas, due to reflections which would double the total field in some spots. The lowest element of the common antenna was raised to a height of 100 ft. (30 m) in order to meet the safe level.

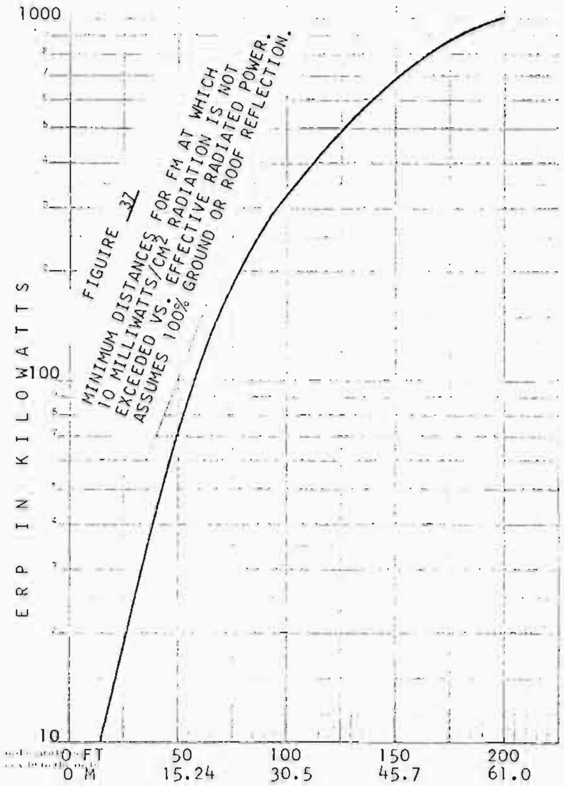

Fig. 37. Minimum distances for FM at which 10 milliwatts/CM^2 radiation is not exceeded versus effective radiated power, assumes 100 percent ground or roof reflection.

Roof-mounted or high mountain installations with relatively short towers may present similar radiation hazards, when a total of 300 kw or more is being transmitted from several broadcast stations. Medium to high gain antennas, on towers of 100 ft. (30 m) or higher will usually not present radiation hazards at the current United States safe level of 10 mw/cm^2 (ten milliwatts per centimeter squared).[44]

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[42] Precise Microwave Power Density Calibration Method Using the Power Equation Techniques, W. Herman and H. Bassen, U.S. Dept. of HEW, DHEW Publication FDB 75-8028, March 1975.

[43] Report 7104, VHF-UHF Radiation Hazards and Safety Guidelines, Federal Communications Commission, Washington, D.C. 20554.

[44] Computation of the Electromagnetic Fields and Induced Temperatures within the Human Eye, Taflove and Brodwin, *Microwave Theory and Techniques,* Vol. MTT-23, Number 11, *IEEE Transactions,* November 1975.

14

Antennas for Television Broadcast

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Television broadcast antennas presently operate at the following frequencies:

Channels 2 to 6, 54 to 88 MHz
Channels 7 to 13, 174 to 216 MHz
Channels 14 to 83, 470 to 890 MHz

Television antennas are unique with respect to several characteristics. Since each channel is 6 MHz in width, the antenna must have the proper performance characteristics over this band. Since higher gain antennas are used, especially at the higher frequencies, the vertical pattern must be suitable for the population distribution in the vicinity of the antenna so as to provide adequate field strength for television service.

Definition of Antennas

An antenna is defined as a structure associated with the transition between a guided wave such as may exist in a transmission line and a free-space wave. Such a structure usually consists of radiating elements and means for distributing the energy to these elements.

Antenna Terminals

The antenna terminal is defined as an accessible point where the entire antenna including the distribution system terminates into one[1] feed[2] line at the design characteristic impedance.

Broadcast-Antenna Requirements

Azimuthal Pattern

Definition. An azimuthal pattern is a plot of the free-space radiated field intensity versus azimuth at a specified vertical angle with respect to a horizontal plane (relative to smooth earth) passing through the center of the antenna.

A horizontal pattern is an azimuthal pattern when the specified vertical angle is zero.

For many higher gain antennas where beam tilt is employed, the azimuthal pattern at the specified beam tilt is significant. In general it has been customary to determine television broadcast-antenna radiation by an azimuthal pattern at the specified beam tilt and a sufficient number of vertical plane patterns all taken at various frequencies in the channel.

An omnidirectional antenna is defined as one that is designed to be omnidirectional. Antennas with variations up to ± 3 dB have rendered satisfactory service and are considered to be omnidirectional.

A directional antenna is one which is designed to be directional.

Present FCC Standards have limited the maximum to minimum radiation at 10 dB for Channels 2-13, and 15 dB for Channels 14-83.

Vertical Pattern

Definition. A vertical pattern is a plot of free space radiated field intensity measured in the Fraunhofer region versus vertical angle in any specified vertical plane which contains the center of the antenna and the center of the earth.

The Fraunhofer region,[3] or "far field," as usually defined extends beyond a point where the distance between the transmitting and receiving point is $2a^2/\lambda$, where a is the length of the radiating portion of the antenna and λ is the wavelength.

Requirement for broadcast service. A free-space radiated field should not be influenced by the proximity of the earth in such a way as to set up a nonuniform field over the antenna aperture, and proper precautions must be taken to accomplish this.

[1] Or two lines for a quadrature system.

[2] In accordance with Electronics Industries Association Standards.

[3] Kraus, "Antennas," Sec. 1-2.

Gain

Definition. Gain[4] is the ratio of the maximum[5] power flow per unit solid angle from the subject antenna to the maximum power flow from a thin, lossless, half-wave, horizontally polarized dipole[6] having the same power input when the measurements are made in the Fraunhofer region.

As can be seen from the above, gain depends on several factors.

1. The amount of power concentrated in the maximum direction
2. Losses in the antenna, which include ohmic and other losses such as energy radiated at polarizations other than the desired one

The amount of power concentrated in the maximum direction can be determined by a comparison with a reference antenna[7] or by integrating the total power flow through a sphere,[8] which is done by taking a sufficient number of vertical patterns and an azimuthal pattern.

Both methods are capable of giving accurate results when the proper precautions are taken.

Ohmic losses are taken into account in the comparison method or can be calculated when using the power integration method. Cross-polarized radiated energy can be measured.

The measurement of gain must be carefully done with a full knowledge of all the problems that are involved.

Gain Requirements. Gain requirements for a television broadcast antenna depend on transmitter power, economics, and field-strength requirements as determined by the terrain and population distribution.

Transmitter Power. The maximum effective radiated powers currently permitted by FCC are:

Channels 2 to 6, 100 kw
Channels 7 to 13, 316 kw
Channels 14 to 83, 5,000 kw

For the most popular transmitter sizes in each range, the following gains are needed allowing 75 percent transmission-line efficiency:

Channels 2 to 6, 4 to 6
Channels 7 to 13, 12 to 18
Channels 14 to 83, 25 to 60

[4] *Ibid.*, Sec. 2.

[5] "Maximum" refers to the maximum in the vertical plane. For an omnidirectional antenna these maxima must be averaged for a number of vertical patterns taken at various azimuths.

[6] The directivity of a ½ wavelength dipole antenna over an isotopic antenna is 1.64.

[7] "IRE Standards," Antennas, Methods of Testing. C.C. Cutler, A.P. King, and W.E. Kock, Microwave Antenna Measurements, *Proc. IRE*, vol. 35, pp. 1462–1471, December, 1947.

[8] E.H. Shively and L.D. Wetzel, Pattern Measurements of RCA UHF TV Antennas, *Broadcast News*, vol. 82, pp. 14–21, February, 1955.

Economics. Economics is a factor in antenna choice. As a general rule, combined costs of transmitters and antennas are less to achieve a given effective radiated power when a higher gain antenna is used. This is true until unsupported antenna heights are of the order of 200 ft., where structural considerations cause antenna costs to go up rapidly.

Input Impedance

Input impedance is the complex impedance looking into the antenna terminals throughout the television channel.

Most antennas are designed for the same input impedance as the standard transmission line at the antenna terminal. Impedance-matching requirements for television antennas are generally more severe than for other types to avoid reflected energy which would cause an echo or ghost in the picture when the antenna does not terminate the line properly.

ANTENNA SPECIFICATION CONSIDERATIONS

An antenna specification should assure the purchaser that all of the important parameters such as gain, pattern requirements, and impedance are in accordance with the best state of the art, but, at the same time, not so unduly restrictive that cost becomes excessive without any improvement in actual performance. Specifications are a basic requirement for governmental agencies which must buy on a bid basis but are not usually required for commercial stations where the selection is often made on the basis of other considerations. The specification can be summarized on a sheet such as shown on Fig. 1.

General Comments Relating to Specifications

Gain

In achieving the given effective radiated power required to serve the area under consideration, there is a choice between using a low power transmitter and a high gain antenna or vice-versa.

For VHF antennas, the transmitter power to antenna gain ratios are fairly well established. For Channels 2-6, antennas usually use gain values from about 4 to 6 depending upon the length of the transmission line run. Foı .he Channels 7-13 band gain values vary from 12 to 18 depending upon the transmitter power and the length of the transmission line run. For UHF antennas, it is economically not feasible to use low gain antennas such as are used for VHF, for several reasons:

ANTENNA SPECIFICATION SUMMARY

Specification No.__________ Purchaser __________ Date__________

Location of Transmitter: Latitude__________ Longitude__________

City __________ State__________

Altitude above mean sea level: At ground level__________; at tower top__________

ELECTRICAL SPECIFICATIONS	VALUE	DB	UNITS
Vertical Power Gain, Main Lobe (Same as RMS Gain)			Ratio Over Dipole
Horizontal Gain in Main Vertical Lobe			Area Ratio
Directional Gain			Ratio Over Dipole
Circularity			±From Avg. Circle
Peak TV Power Capability (20% Aural)			KW
Beam Tilt			Degrees
Vertical Pattern Dwg. No.			
Horizontal Pattern Dwg. No.			
Input Line Size			Inches
Input Characteristic Impedance			Ohms
Antenna System Specification	3		%
Wind Load			# Sq. Ft.

Fig. 1. Antenna specification summary for bid requests.

1. The ERP values permitted are higher in order to compete with VHF performance.

2. Transmitters must therefore generate higher powers and are therefore more costly.

3. However, the antenna gain must also be increased since otherwise the cost of the transmitter would be excessive. Hence, vertical gains of the order of 25 to 60 are used. It is feasible to do this since the mechanical structures are of a reasonable height because of the shorter wavelength.

However, the higher gain requires some special considerations since the higher gain results from narrowing the main beam. For a given transmitter input, the high gain antenna may sacrifice local coverage for more distant coverage, see Fig. 2.

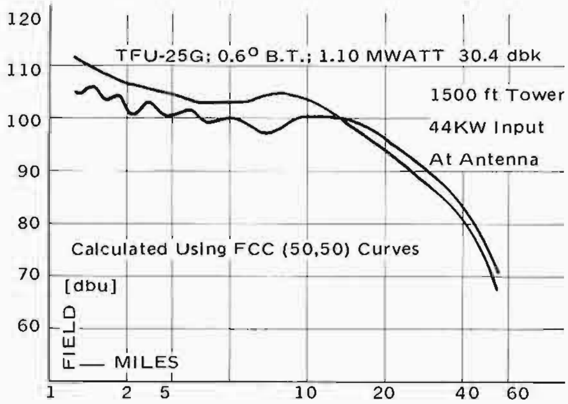

Fig. 2. Comparison of high and medium gain antenna performance with the same power input. Note the reduction in local coverage. For the same ERP raise the TFU 25G curve by 2.6 dB.

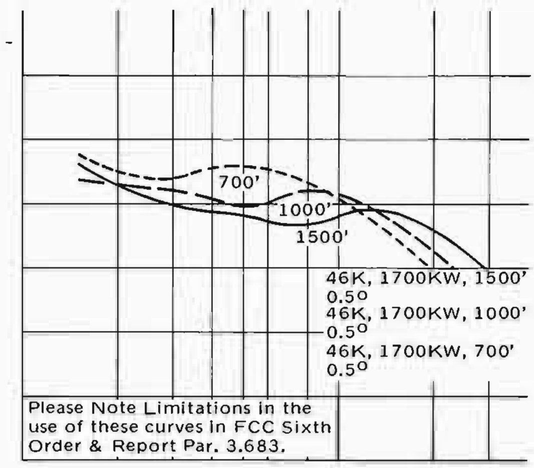

Fig. 3. Comparison of the same antenna, and the same ERP at a height of 700, 1000, and 1500 feet. Note the reduction of local coverage with an increase in height.

Hence, if a higher gain antenna is contemplated, local field strengths should be calculated, using the FCC (50,50) propagation curves. It is generally advisable to maintain a 100-dB level over the important local area to be covered. Most vertical patterns are designed to accomplish this with an effective radiated power of the order of 1 megawatt at a 1,000 ft. In hilly terrain it may be desirable to increase this figure by 10 dB or more and in heavy populated cities with large structures by 6 dB or more.

If fields of this order cannot be achieved with a high gain antenna, the transmitter power should be increased to achieve it, or a lower gain antenna used.

An increase in height over terrain has the same general effect as increasing the gain of an antenna. For distant areas within line of sight covered by the main beam of the antenna the field strength in millivolts per meter for a given ERP increases approximately as the height over smooth terrain. However, the nearby areas generally receive less field strength since the vertical angle looking up towards the antenna is steeper to a point where the vertical pattern usually radiates less energy. See Fig. 3 comparing a 46 gain antenna at three heights. Hence, an increase in height should be studied in the same manner as an increase in gain.

Beam Tilt

Beam tilt is necessary to bring the main vertical beam tangential to the earth, which is curving away from it. To accomplish this for a 1000 foot elevation a beam tilt of about 0.5° is required. The beam tilt for other heights can be calculated from the relationship:

$$\text{Beam tilt angle} = .0153\sqrt{\text{height over service area}}$$

It should be noted that height over the service area may not necessarily be the height over average terrain especially in a mountainous area. Also if a body of water limits the service area, as in the case of Los Angeles, with the transmitter on Mt. Wilson, it may be desirable to aim the main beam to a point somewhat short of the coast line.

In some cases, a little higher beam tilt may be desirable to improve local coverage. Beam tilt does reduce the vertical power gain in the horizontal direction especially for a higher gain antenna. However, the loss in local coverage is generally a more important consideration than vertical power gain in the horizontal direction.

Power Capability

Power in TV systems is usually in terms of "Peak TV Power," which is the instantaneous power developed in the peak of the synchronizing pulse of the visual transmitter. Since the black level signal is 0.75 of the total voltage value of the pulse, the black level power (for a totally black picture) is 0.75^2 or 0.5625. The duty cycle of the synchronizing pulses, both horizontal and vertical, adds about 4 percent to this power so that black level power is 0.6 of the peak TV power. Since the aural FM transmitter is usually 0.2 of the peak TV power, the total heating or CW power in a TV signal is 0.8 of the peak TV power.

Transmission line powers are usually quoted in terms of CW power for unity VSWR values, unless otherwise specified and would, hence, require a power capability of 0.8 of the peak TV power for the conditions stated.

Antenna power ratings are also in terms of peak TV power including the 0.2 aural power. The antenna power rating also makes an allowance for the VSWR which is likely to be encountered inside the antenna.

Hence, a 110-kw antenna power rating would mean that the antenna could take the full output of a 110-kw visual transmitter including the 0.2 aural power. Actually the long transmission lines usually encountered in TV service attenuate this power to a lower value so that for an 80 percent line efficiency, the antenna requirement would be only 88 kw for a 110-kw transmitter.

Vertical Patterns

The vertical pattern is usually shown as a plot on rectangular coordinate paper of relative voltage versus depression angle below the horizontal (see Fig. 4).

The angular width of the main beam of the antenna is directly related to the gain although this may vary somewhat with the method of pattern synthesis. For most null-filled antennas, the beam width at the half power or 0.707 voltage point is 58.3 divided by the gain for 0° beam tilt and no null fill. Thus for a vertical gain of 24, it would be about 2.4° and for a gain of 42, it would be about 1.4°.

Hence, the specified gain generally determines the shape of the main beam. The amount of fill at greater depression angles than the main beam can be varied within limits although this will also decrease the gain. The greater the fill, the lower the gain. These relationships can be seen from the patterns Fig. 4 and the table below where the same number of layers for a given beam tilt will have gains and values of fill as follows:

Fill Value for Null No. in Percentages

Gain	*1*	*2*	*3*
34.7	11	1	2
31.6	15	6	5
30.0	21	7.5	6
22.5	39	17	10

The amount of null fill and the number of nulls that need to be filled depends upon how close the populated area is to the transmitter site. Allowance should of course be made for population movement towards the site in the future. The depression angle below the horizontal, which requires null fill, can be calculated approximately by the following relationship:

$$\text{Depression angle in degrees} = \frac{.0109 \times \text{height of antenna in feet over service area}}{\text{miles to nearest population.}}$$

If the angle is less than 3°, regular curves or tables which appear in manufacturer catalogues should be used because they allow for the earth's curvature. If it is more than 15°, the tangent of the angle should be used. If the transmitter site is in the center of the population area or right on the edge of it, consideration should be given to a "shaped" pattern of the types shown in Fig. 5 which will provide fill to fairly steep angles which is not necessarily true for a null-filled pattern. The "shaped" pattern is somewhat higher in cost.

Horizontal Pattern

Most omnidirectional antennas have a circular pattern with a "circularity" of the order of ±1 to ±2 dB.

A directional antenna is advisable only for special terrain situations, such as the San Joaquin Valley in California, or where the antenna is located near a large body of water, or where the service areas are at certain separated locations. It must be recognized that the number of square miles over which a given field strength is obtained is always less with a directional antenna. The most optimum condition in this regard is an omnidirectional antenna located in the center of the area to be served. This can be seen from the following considerations:

Some relative approximate relationships can be deduced from propagation formulas which pertain within the radio horizon over plane earth as follows:

$$r \propto \sqrt[4]{p}$$

$$A \propto \sqrt{p}$$

$$P \propto \sqrt{h}^2$$

Where r is the distance to a given field contour; p is the "effective radiated power" in the main beam;[9] A is the area served within a given field contour; h is the height of the antenna above the service area.

In Fig. 6 the area enclosed by a given field intensity contour for a relative "effective radiated power" of "1" and a relative height of "1" is πr^2. The transmitting site can also be moved to the perimeter of the circle and a directional antenna employed which has a horizontal pattern in the shape of a quarter of a circle as shown in Fig. 6b. The horizontal gain of such an antenna is four, hence, $P = 4$.

From the relationship above $r \propto \sqrt[4]{p}$, r becomes the $\sqrt{2}$. The area to the same field intensity contour served is then:

$$A = \frac{\pi(\sqrt{2}r)^2}{4} = \frac{\pi r^2}{2}$$

[9]The value here used is not only the product of transmitter power and antenna gain, but also the increase in "effective radiated power" due to an increase in height.

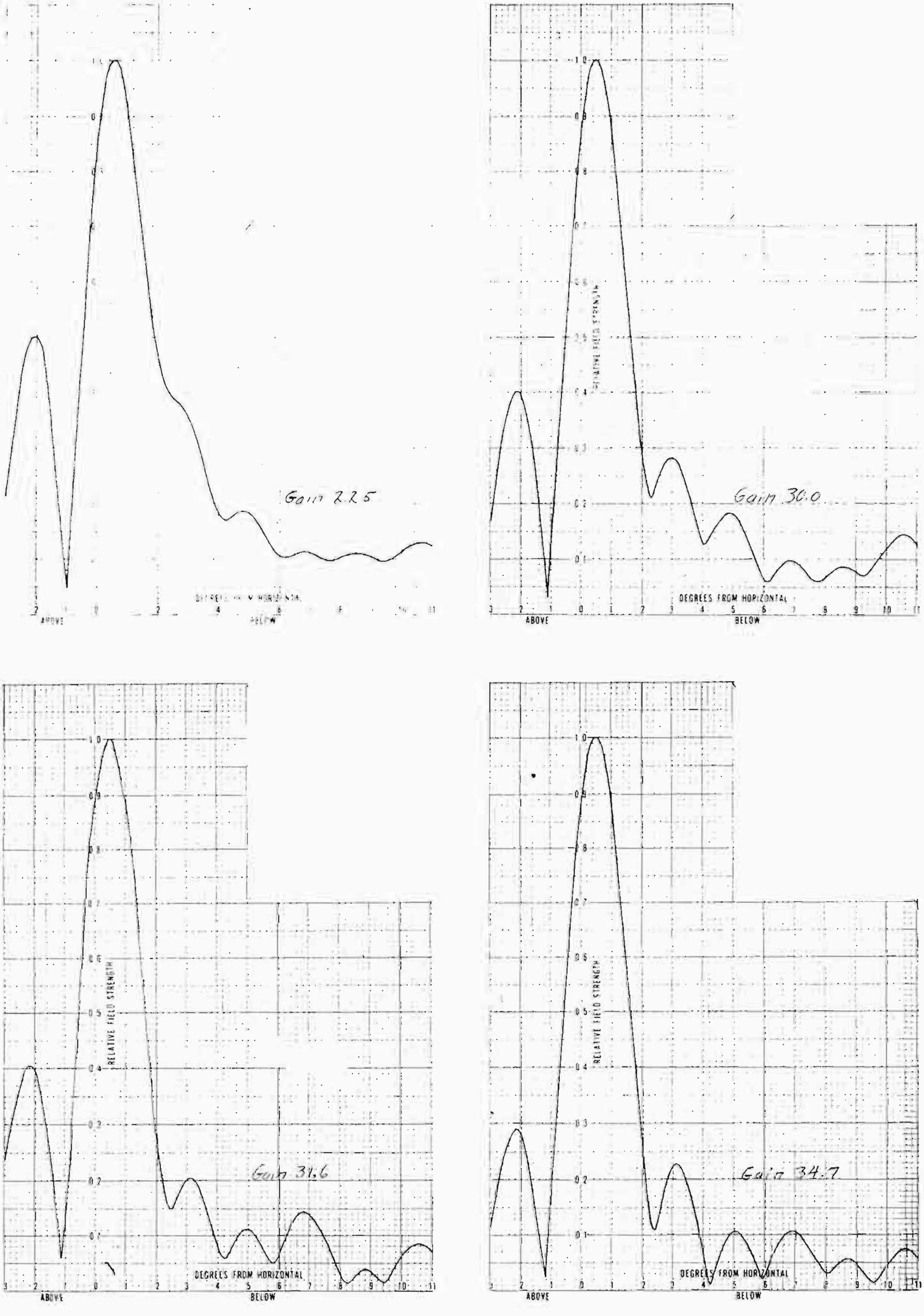

Fig. 4. Four vertical patterns of the same thirty-one layer antenna. Note the decrease in gain as the fill from 2.5° to 11° is increased.

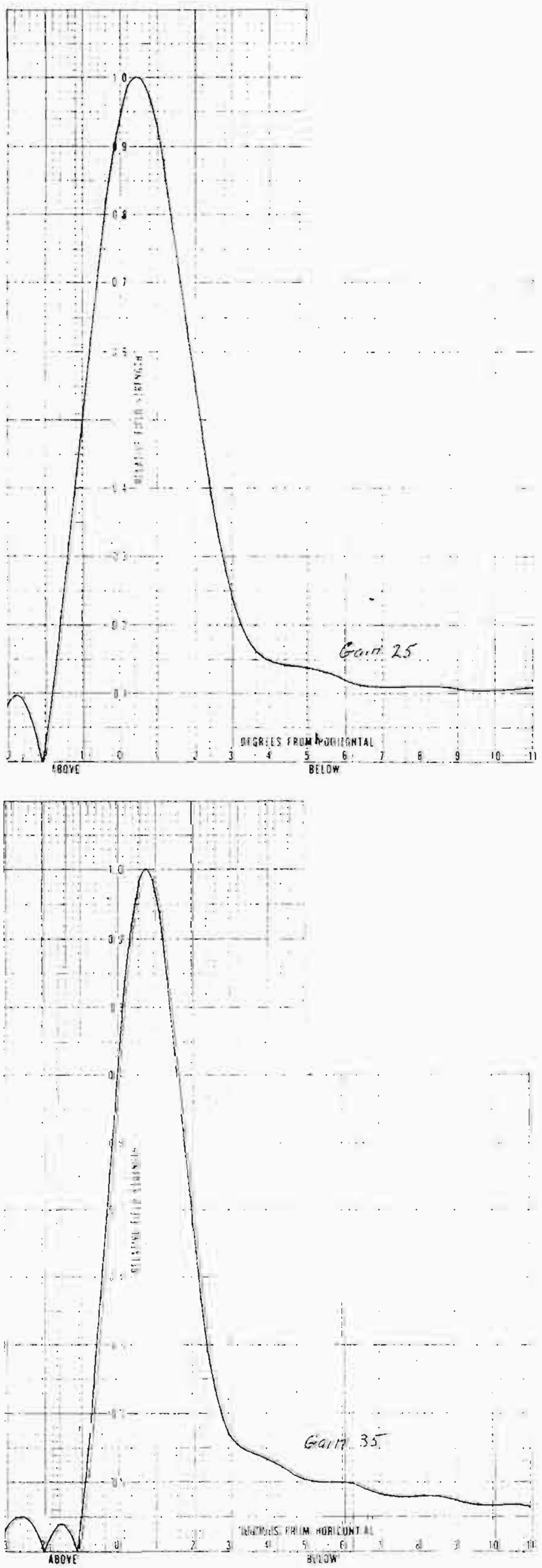

Fig. 5. The "shaped" pattern is achieved by methods described on pages 2-262 ff. They are generally used in large metropolitan centers where the service area starts very close to the antenna.

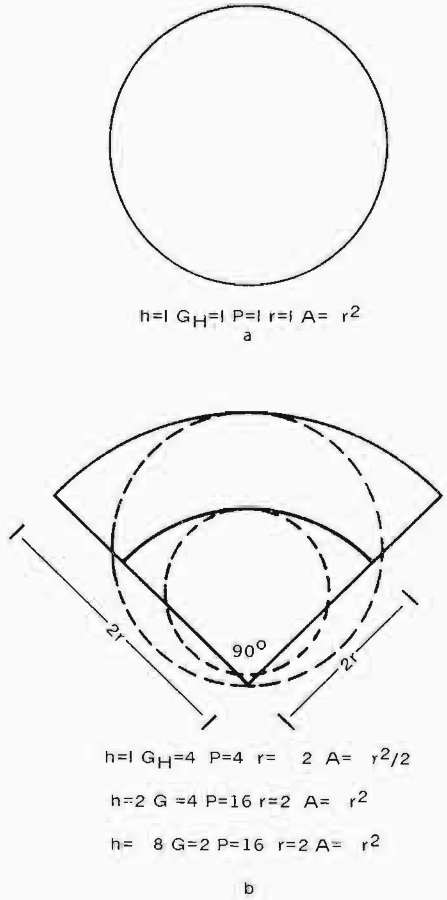

Fig. 6. The most efficient coverage is obtained when the antenna is located centrally in the service area. Only one half of the area is covered with the same input power at the same height from the perimeter using a directional antenna.

Hence, using the same transmitter power with an optimum directional antenna with a horizontal gain of 4, only one half of the area is covered as compared to Fig. 6a and, hence, the coverage efficiency is 50 percent.

It can be stated generally that because of the fourth root relationship between distance and radiated power that the center of the area to be covered is the best location for maximum coverage efficiency.

However, there is another factor: height. From the relationship above, it is noted that if the height is doubled, the "effective radiated power" increases four times. Hence, in Fig. 6b, doubling the height will provide "effective radiated power" "p" of 16 and "r" becomes 2. The area covered is then:

$$A = \frac{\pi(\sqrt{2}r)^2}{4} = \pi r^2$$

which is the same as for "a."

The antenna postulated in "b," however, is not permitted under the 15 dB rule. A practical antenna may have a horizontal gain of about 2. To obtain an "effective radiated power" of 16 will require a height increase of $\sqrt{8}$ or 2.8 times.

Another general rule is that where a sufficient natural height can be obtained a directional antenna can be an advantage. To obtain any advantage, however, heights beyond a relative value of 2.8 must be obtained under the conditions postulated above. Hence, it can be seen that the maximum area is covered with a given ERP from the center of the area to be served. If the antenna is located on the perimeter instead of in the center of the same area using a directional antenna, the area covered drops to approximately one-half or less. This results from the fact that the service radius varies approximately as the fourth root of the ERP. If a natural low cost height, such as a mountain site, is available at the perimeter which is approximately three times as high as that which would be used in the valley, the full area can be recovered. The economics of each situation should be studied. Because of the fourth root relationship between the service radius and the ERP, a voltage plot of a directional antenna can be misleading. The area to be covered should be calculated using propagation formulas to obtain a true evaluation. Often the benefits may be found to be marginal and possibly detrimental.

Antenna Input Impedance Specification:

The primary purpose of an input impedance specification is to obtain a good match to the transmission line which carries the power up to the antenna. If the mismatch is too great, the reflected power may be of such magnitude that it travels back to the transmitter where it is generally re-reflected back to the antenna and appears as a secondary image on the television picture. The image is delayed by twice the length of the transmission line.

Subjective experiments have established that the reflection should be no greater than 3 percent of the incident voltage. The method of measuring this is described under "System Specifications."

However, when the antenna is being designed and tested, a complete system is not available so that VSWR (voltage standing wave ratio) across the channel is used as a design guideline.

The relationship between the percentage of reflection and the VSWR of the antenna to achieve it can be related by a computer program.[10] Due to the concentration of energy at picture carrier and 3/4 mc above, the VSWR values should be kept fairly low in this region, say below a VSWR of 1.05 at visual carrier. The values below visual carrier are not as critical since

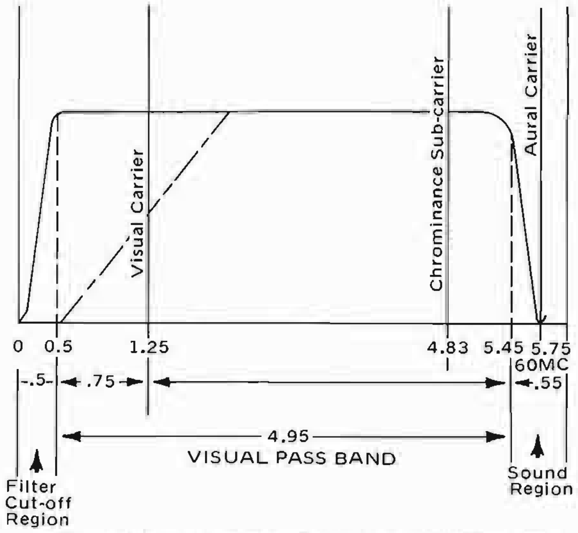

Fig. 7. Note that the visual band is located one half megacycle away from the edges of the channel. Due to the receiver characteristic the VSWR values below visual carrier have a relatively lesser effect on the RF pulse reflection value.

the slope in the receiver cuts off most of the energy in this region as shown in Fig. 7. Hence, the VSWR over the balance of the picture pass band can be as shown in Fig. 8.

However, these values are really only design guidelines and should not be used as a specification since the real criteria is the 3 percent pulse reflection value, which is the only specification that is really meaningful. It is a temptation to include as many specifications as possible in the hopes of arriving at a good system. However, specifications that are redundant and more stringent than necessary only serve to increase costs without any improvement in performance.

System Specification Performance After Erection

The primary purpose of testing the antenna system is threefold:

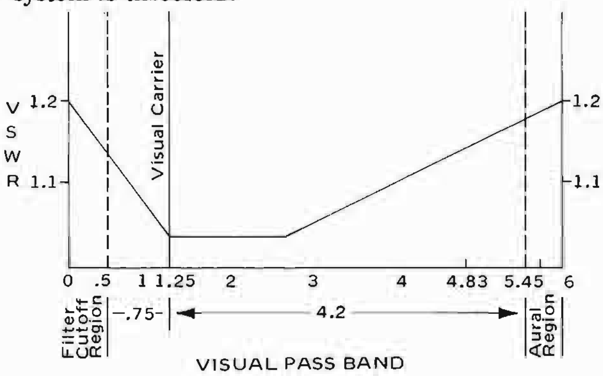

Fig. 8. Based on the visual energy distribution in the channel and the receiver response, the above VSWR versus frequency characteristic will achieve better than a 3 percent pulse reflection value.

[10] See *Pulse Techniques* by Dr. M.S. Siukola, published in the IEEE transactions on Antenna Propagation.

1. That the transmission line and components are properly assembled.
2. To determine that the reflection from the antenna and other components at or near the tower top are sufficiently well matched so that no visible ghost occurs.
3. That the impedance presented to the transmitter is within proper limits. Actually if Conditions 1 and 2 are met, Condition 3 will be met.

Transmission Line and Components

For an extremely broad band device like a transmission line which is usually designed to cover the entire, or at least, a large portion of the TV band, the dc pulse is a very effective test to determine if the line and components have been properly assembled. This is a short pulse of perhaps 20 nanoseconds at about a 15,000 cycle repetition rate. The wave front is steep enough so that each section of line can be discerned on an oscilloscope. Each joint will manifest itself as a separate vertical line. If one of the pulses is higher than the others, the joint should be investigated for an improper connection or other fault. It is sometimes good practice to assemble the line from the bottom up so that the reflection from each piece can be seen so it is inserted and an immediate correction made. It is also advisable to tap each joint with rubber mallet to locate incipient trouble due to single point contact or improper connection.

Since the pulse covers a wide frequency band, components optimized for a specific channel will manifest themselves as a discontinuity. However, since their location is known and since the distance to their location can be determined from the oscilloscope, this should not present a problem.

As a further check on the frequency sensitive components, the RF pulse test described below can be used since it displays the transmission line run and the antenna on a time base on the oscilloscope. See Fig. 11 which shows a typical RF pulse response. Any value over 1 percent in the transmission line run should be investigated.

The combination of a dc pulse test and RF pulse test will give a thorough evaluation of the transmission line system. These tests will then assure meeting requirements of "1" above.

Proper Match of Far-end Components

A number of methods are possible to determine this match after installation. Industry practice has generally settled on two methods one for VHF and the other UHF, each of which are best adapted to the particular requirements.

For VHF the RF sweep measurement method is generally used. This method has a distinct advantage over a straight VSWR measurement taken in the station in that the close-in components and the far-end components have a different periodicity on the oscilloscope trace. This enables each to be determined separately, and the match at the far end can be determined. This method has been used successfully at VHF for many years. It is, however, not as well adapted to UHF since a suitable delay line which is sufficiently smooth and has a low attenuation is not readily available. Hence, the RF pulse method is used at UHF when a system performance specification is required.

The RF pulse test was designed to simulate actual picture transmission, which is a series of

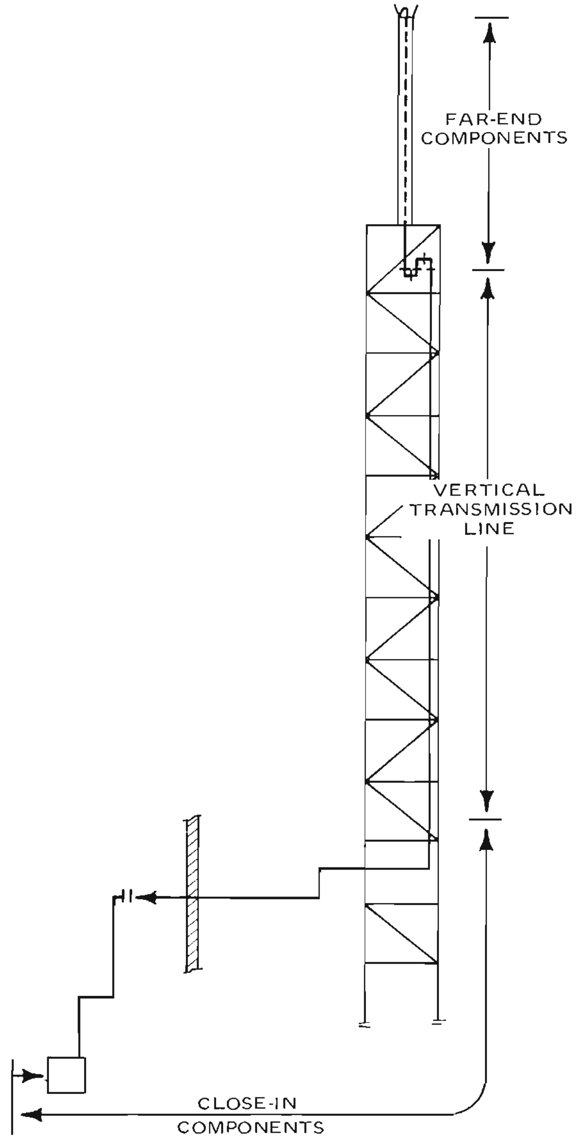

Fig. 9. The three elements of an antenna system can be treated as two discontinuities separated by a long transmission line. As the electrical length of the line changes with frequency the impedances alternately add and subtract.

pulses. It is, of course, possible to transmit a regular picture to see if any "ghosts" exist. However, the antenna system may be completed before the transmitter is operative and the picture test is only qualitative rather than quantitative.

To simulate the most pessimistic condition, a 0.25 microsecond pulse is used which has a band width of ±4 megahertz, and which covers the picture band plus about 3-1/4 megahertz of the lower sideband region where the antenna is not matched. Hence, a vestigial system must be used to receive the return pulse just as in normal home reception.

The 0.25 microsecond pulse simulates the smallest picture element that is transmitted. With this pulse width all of the tower top components would appear as a single reflection. With the proper instrumentation, the percentage of reflection can be measured. The criterion used in the industry is 3 percent which was determined by subjective tests of an ideal system by a number of experienced viewers and has been found to be completely adequate.[11] (See Fig. 10.)

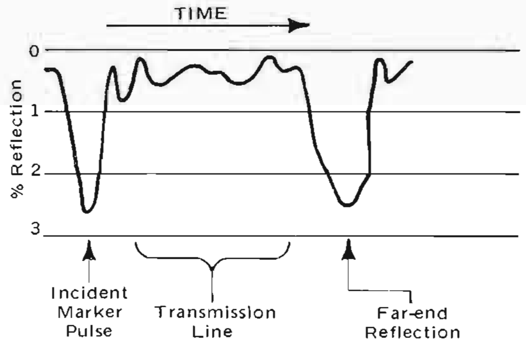

Fig. 10. A typical VSWR versus frequency characteristic of an antenna system based on the alternate addition and subtraction of the close-in and far-end discontinuities.

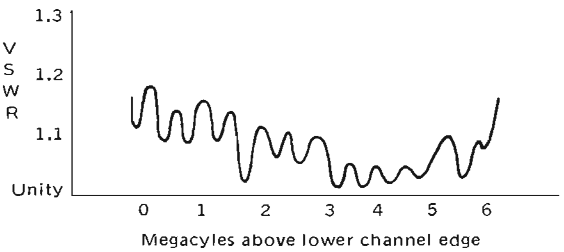

Fig. 11. Typical oscilloscope trace of an antenna system using the RF pulse method. The evaluation is based on the transient response of the system which is directly related to picture quality rather than the less meaningful steady state values such as VSWR which can be misleading.

[11]For a fuller discussion of RF pulse techniques see *Pulse Techniques* by Dr. M.S. Siukola published in the IEEE Transactions on Antennas and Propagation.

The Third requirement is Presenting a Proper Impedance to the Transmitter

A typical antenna system is shown in Fig. 9. This system consists of the "far-end components," the transmission line run, and the close-in components in the station. At a given frequency in the channel the electrical length of the transmission line becomes a multiple number of half-wave lengths in which case the far-end and close-in impedances add. At a slightly higher or lower frequency, the electrical length becomes an odd multiple of quarter wavelengths in which case the far-end and close-in impedances subtract. The number of complete cycles in the 6 megacycle channel is L in feet/82. For a 984-foot line there would be 12 cycles in the channel. Fig. 10 shows a typical VSWR plot versus frequency.

Because some of the components are at the end of a long transmission line and others are adjacent to the transmitter, there are two effects with regard to the transmitter. The close-in discontinuities which are usually within less than 100 feet from the transmitter will reflect back towards the transmitter in 0.1 to 0.2 microseconds and become a part of the initial pulse. This has a first order effect of a constant alteration of the load which the transmitter sees. This can be resolved by changing the output coupling for that load condition. Usually the change is of the order of 10 to 20 percent and has no effect on the picture quality.

If the close-in components have a VSWR value of 1.1 and the far-end components also have a value of 1.1 the total variation will be from 1.0 to 1.2 or 0.2 which for the worst generator impedance has the effect of a 20 percent change in impedance and, hence, in power which amounts to only an 0.8 dB variation and is not detrimental.

Even this high VSWR variation to our knowlledge has never caused any problems.

However, the VSWR variation is automatically limited by the 3 percent pulse requirement which in the higher energy content portion of the channel limits the value to a 12 percent or a 0.5 dB variation.

Hence if the 3 percent pulse specification is met it automatically takes care of the transmitter impedance considerations.

VSWR System Measurement

This measurement has been used in the past as the only system requirement. Since it adds up the close-in and far-end components, it leaves much to be desired as a meaningful specification since it is often difficult to resolve which is which. The close-in values are of little significance to picture quality and the far-end components are quite important. Hence, it lumps together the important and the unimportant with a rather indeterminate means of separating the two.

In an attempt to make it meaningful, the VSWR values have been limited to absurdly low values in specifications which have added considerably to the cost without adding anything in the way of performance.

This constitutes an improper use of specifications since economically there is no justification for the stringent values.

The measurement, however, does have one value in that it affords a quick check of the system since VSWR measuring equipment is more readily available than pulse equipment. A record measurement without reference to values taken after the installation can be filed and used as a periodic check on the system or to determine if changes have occurred or if problems are suspected.

Summary

The antenna specifications cover gain, beam tilt, power capability, vertical pattern, horizontal pattern for directional antennas and antenna impedance requirements to meet the 3 percent system pulse specifications.

The antenna system specification includes a dc and RF pulse test of the transmission line and the antenna, and for record purposes only, the system VSWR.

Electrical Performance Changes Due to Mechanically Imposed Conditions

Deflection of Antenna and Tower Due to Wind

Guy tension in guyed towers is usually adjusted so that the tower deflects as a straight member.

Towers for broadcast service when so specified are designed for a maximum deflection of 0.5°, which means that the top plate will deflect this amount for the maximum wind velocity. For instance, a 40-lb tower will thus deflect 0.5° for a 100-mph wind. Since tower deflection varies as the square of the wind velocity, the deflection will be 0.125° for a 50-mph wind.

Structurally a free-standing antenna can be considered as a cantilever beam in which the deflection increases toward the end. Antenna deflection is stated as the angle from the vertical of the chord that connects the base to the top of the antenna.

In order to evaluate the effects of deflection, an example for a high-gain UHF antenna will be given.

Figs. 12 and 13 show the pattern variations of a UHF antenna of the slotted cylinder type with a gain of 46 when the antenna is 102.8 feet in height. The entire antenna is constructed of 18-in. steel tube with a 1.218 wall using six peripheral slots in each layer.

The phase and amplitude of each layer of the antenna were synthesized to obtain a vertical pattern for the curved condition where the antenna was bent toward the service area and away from it.

Two conditions are shown for a wind velocity of 50 and 100 mph as summarized in Table 1.

The 50-mph wind condition is one that may occur[12] twenty-five times a year at a 1,000-ft elevation above terrain and about four times a year at a 500-ft elevation.

[12]Report of TASO Committee 1.3 on Television Antennas. Final Report of TASO Sub-Committee 1.3.2. on Towers, Sec. 3.6.

TABLE 1

Wind Velocity mph	50.		100.	
Wind load psf	10.		40.	
Deflection of antenna at top, in.	4.9		0.914	
Deflection, degrees, of chord from bottom to top	.227		0.914	
Tower deflection degrees	.125		0.5	
Antenna and tower deflection degrees	.352		1.414	
Signal Variation for Deflection Extremes, dB	**Toward Service Area**	**Away from Service Area**	**Toward Service Area**	**Away from Service Area**
At horizon (main beam) antenna only	−0.5	−0.3[a]	−7.8	−5.8
At horizon for antenna and tower	−0.7	−0.4	−18.8	−13.4
At a location with respect to the vertical pattern where the greatest signal variation occurs for antenna only	+3.6	−2.7	+6	−10.8
At a location with respect to the vertical pattern where the greatest signal variation occurs for antenna and tower	+4.2	−5.3	+12.7	−5.2

[a]Values are not the same, since in this antenna, radiation above the horizon has been suppressed and the pattern is not symmetrical.

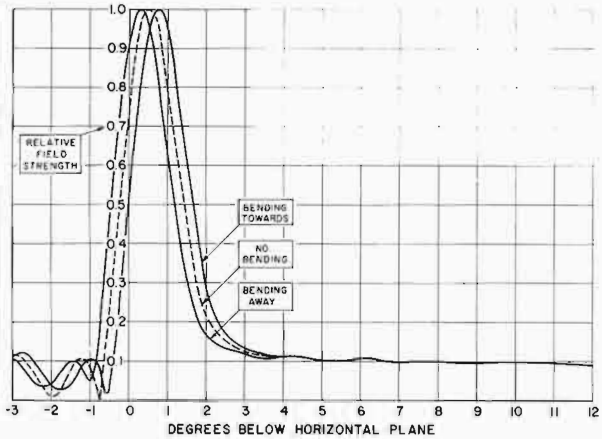

Fig. 12. Calculated vertical patterns of the TFU-46C antenna affected by static load: flat-surface wind load 10-psf, wind velocity 50 mph.

The 100-mph wind is a design-limit figure which rarely occurs and is one during which there would probably be little television viewing. Most outdoor receiving antennas would probably be severely damaged in such a wind, and power service seriously curtailed.

Hence the 50-mph figure is one that is generally considered applicable for an evaluation of this type.

Most television receivers are designed to have a flat AGC response down to 100 microvolts across the receiver terminals. Hence no effects due to wind acting on the transmitting antenna will be noticeable except in fringe areas where the signal drops below this value.

In the case cited above, the signal variation in the fringe area would be less than 1 dB and could be considered negligible.

The maximum variation in the case cited above occurs at 1.75° below the horizon or at 6.3 miles for a 1,000-ft difference in elevation between the transmitting and receiving antenna. At this distance the field strength is usually at a sufficiently high level so that a 2-to-1 variation will not go below the 100 microvolt level at the receiver terminals.

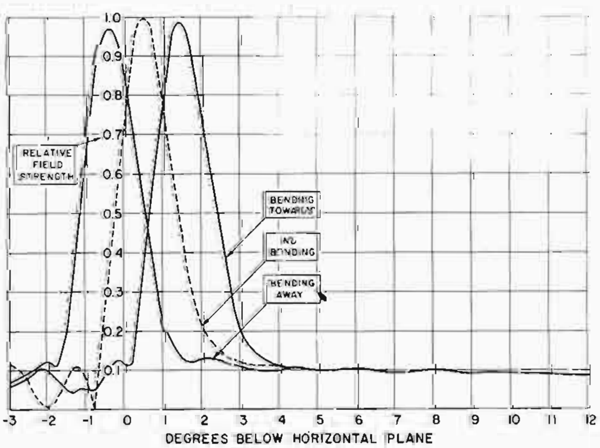

Fig. 13. Calculated vertical patterns of the TFU-46C antenna affected by static wind load: flat surface wind load 40psf, wind velocity 100 mph.

Analyzed on this basis even the 100-mph wind condition is not too serious except in the fringe area. It should be noted that the variations are limited by the fact that the antenna is designed not to have nulls near the main beam.

For lower gain antennas with a wider beam the variation would be even less than those shown.

DESIGN AND THEORY

Elemental Radiators

Television antennas in common use are developments of one or another of a few basic types of radiator. These are the half-wave dipole, the loop (magnetic doublet), the slot, and the helical. Some of the antennas combine characteristics of more than one of these types.

For purposes of mathematical representation or as a reference for comparison of charactertics of antennas, the concepts of "point source"—a fictitious emitter so small as to have no dimensions—and "isotropic radiator"—which radiates energy uniformly in all directions—are sometimes used.

Antennas of the horn, lens, and long horizontal (Beveridge) or vertical wire types do not currently find application at television frequencies and are not considered herein.

Half-wave Dipole

If the ends of an open-wire transmission line are turned outward, as shown in Fig. 14a, they form what is known as a dipole. The electric (*E*) fields, at right angles to and connecting the two sides of the transmission line, extend outward, forming circles in all planes passing through the axis of the dipole, as shown in Fig. 14b. The magnetic (*H*) fields which, in the transmission line encircled the separate wires and tended to cancel each other owing to the opposing directions of the flow of current in the two wires, now appear as circles about the dipole.

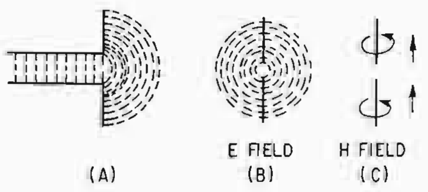

Fig. 14. Electric (E) field, and magnetic (H) field of a dipole.

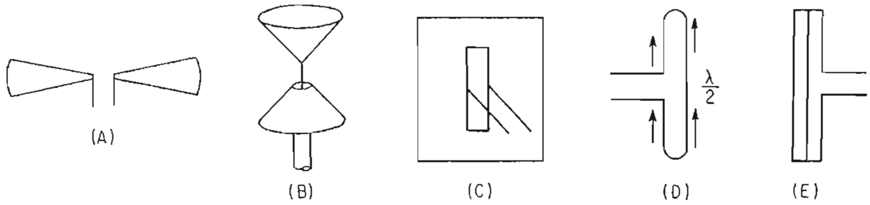

Fig. 15. Examples of radiators having dipole-like characteristics: (A) and (B) biconical antennas, (C) slot-fed sheet, (D) folded dipole, (E) folded dipole with additional element.

If the length of the dipole is made a half wavelength long at the frequency of an imposed signal, it becomes, in a sense, a resonator, with energy reflected from the ends of the radiator setting up standing waves. The energy is alternately stored in the electric and magnetic fields.

At high frequencies, the fields so formed do not have time to collapse completely before other fields, of opposite polarity, are set up. The result is that outer portions of the field never return but are pushed out of the area close to the antenna known as the "induction-field" region and move away, forming the "radiation field."

Since the power in the field is dissipated power (I^2R) in the same sense that power appearing as heat due to ohmic resistance in the dipole is dissipated power, it is convenient to relate this power to the current which produces it by a fictitious "radiation resistance." This is in addition to the ohmic resistance in the radiator circuit.

The ratio of stored energy to dissipated energy is called the Q of the antenna circuit. As any circuit contains L, C, and R, this is a function of the relationship between the inductive reactance of the circuit and the resistance. In the case of the dipole the inductance decreases with increasing diameter of the dipole arms. Also the amount of energy reflected from the ends, resulting in greater stored energy, is reduced by increasing the size of the arms. This results in greater bandwidth. Application of this fact leads to the biconical radiators in Fig. 15a and 15b and to the slot-fed sheet radiator, Fig. 15c.

Another form of the dipole is the half-wave folded type shown in Fig. 15d. Here, the ends of a simple dipole have been joined by another closely spaced element. Since the voltage distribution is the same in both, the currents are in the same phase and direction. The result is an input impedance of 300 ohms as compared with 73 ohms for a simple half-wave dipole. Addition of rectangles as in Fig. 15e increases the input impedance by a still greater factor.

Because the folded ends act like stubs, they become capacitive at higher frequencies. This is opposite to the tendency of the series *LCR* circuit by which a dipole can be represented. The result is a cancellation to some degree of the reactances and a tendency for the impedance to remain constant, making the antenna more broadband than the half-wave dipole.

The distant radiated field of the folded dipole is the same as that of the simple dipole.

Loop

The folded dipole discussed above may be considered as a special case of a loop antenna as well as a type of dipole. In fact, any closed loop of conductor which does not carry equal and opposite currents very close together, that is, within the "near," or "induction," zone, will fall into this category and will radiate at least some of the power supplied to it.

The loop or ring radiator may be rectangular or circular, as seen in Fig. 16a and b.

Variation in the size of the loop yields radiation patterns of various shapes, in planes at right angles to that of the loop, as could be expected by comparison with the horizontal fields of two AM radiators with various spacing and phase relationship. That is, if sides 1 and 2 of the square loop in Fig. 16a are considered to be the two AM radiators, the combined radiation pattern in a plane at right angles to them will vary with the spacing between them. For loops with diameters less than 0.585 the maximum field will be in the plane of the loop, and loops much smaller than a wavelength are therefore most commonly used as elements of television antennas. Radiation in a direction normal to the loop is always zero, regardless of the size of the loop.

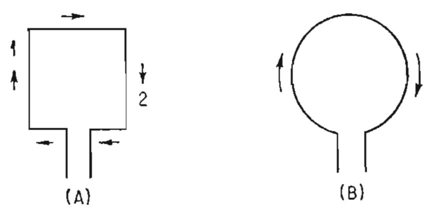

Fig. 16. (A) Square loop and (B) ring radiator.

Slot Antenna

As has been mentioned under Half-wave Dipole, the slot antenna has a great similarity to a dipole.

Figs. 17a and 17b show the two types, oriented so that the (*E*) fields of both are horizontal. Currents in the slot type spread out over the entire sheet, and radiation takes place from both sides of the sheet.

The resemblance between the two becomes even more pronounced when it is recognized that the field patterns of the two will be equivalent if the physical dimensions of the slot and the cross section of the dipole are the same. For example, the fields of the two radiators in Fig. 17c and 17d are the same. A very similar situation occurs in optics, where the phenomenon is known as Babinets principle. Using a term from optics, the antennas are said to be complementary where this situation exists.

Furthermore, the impedance of the slot is proportional to the admittance of the dipole of the same dimensions by the relationship

$$Z \text{ slot} = \frac{35{,}476}{Z \text{ dipole}}$$

and the bandwidth characteristics of one are the same as those of the other.

Actually, the above discussion is rigorously accurate only if the sheet is of infinite extent, but it is substantially correct if the edge of the slot is half a wavelength from the slot.

The input resistance to a slotted sheet is of the order of 500 ohms. This can be modified by shifting the position of feed along the slot. A value of 50 ohms can, for example, be obtained with the feed about 0.1 of the slot length from one end.

Radiation can be limited to one side of a very large sheet by boxing in the slot on the other side. If the depth of the box is such as to present zero susceptance at the feed point, the input impedance will be appropriately double that of the same antenna without the box (see Fig. 18).

Bending the sheet into a cylinder results in another form of slot antenna which also takes on characteristics of a stack of coaxial rings (Fig. 19).

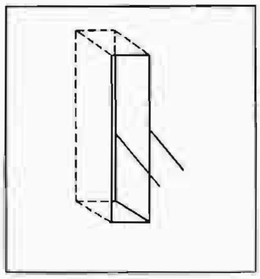

Fig. 18. Slot-fed sheet radiator with slot boxed to limit radiation to one side of sheet.

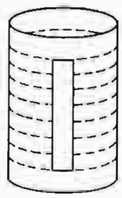

Fig. 19. Slot-fed sheet radiator bent to form a cylinder, showing resemblance to stack of ring radiators.

Helical Element

A conductor wound in the form of a helix can be made to have maximum radiation either in the axial direction or in a direction normal to the axis, depending on the circumference of the helix and on its pitch. For radiation in the "normal" (or sidefire) mode, the helix dimensions must be small compared with a wavelength (see Figs. 20a and 20b).

The limitation on the size of a helix for normal operation imposes restrictions on bandwidth. This can be offset to some extent by phase-shifting devices along the helix which compensate for variations in impedance with frequency.

Since the helical element is used in almost a pure form in a commercial antenna to be described under Helical Antennas, further discussion will be left till that section.

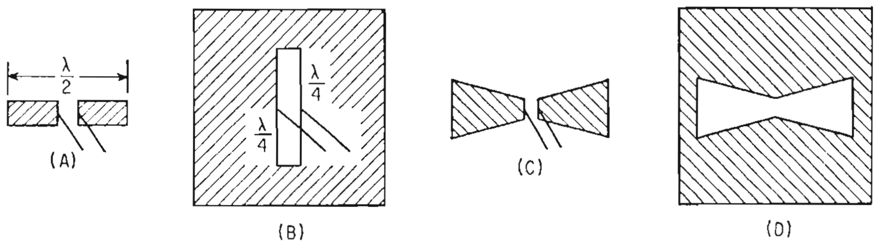

Fig. 17. Dipoles (A) and (C), with complementary slot-fed sheet radiators (B) and (D).

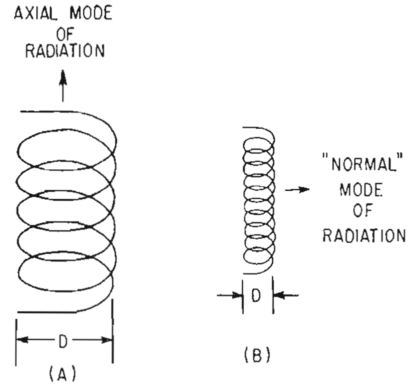

Fig. 20. Helical antennas, showing effect of pitch and diameter on direction of maximum radiation.

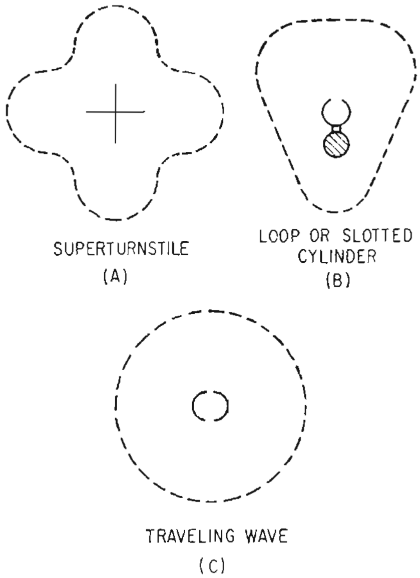

Fig. 21. Typical azimuthal patterns of well-known types of TV broadcast antennas.

Antenna Patterns

Azimuthal Patterns

In television, with the inherent limitations on coverage due to high-frequency propagation effects and the limitation on the number of stations with any area as set up in the existing allocation plan of the Federal Communications Commission, the large majority of requirements have been for omnidirectional antennas.

As is pointed out in the discussion of omnidirectional patterns, the primary criterion of a truly circular or omnidirectional pattern is the intent to make it omnidirectional. In the past, variations of 3 dB on each side of a true circle have been accepted as within the meaning of the word omnidirectional.

Since energy flows equally in all directions from a theoretical "point source," its horizontal pattern is a true circle. A thin dipole, vertical to the earth's surface (i.e., with vertical polarization), most nearly approaches this and has a similar azimuthal pattern. Except for these two cases, however, the finite physical size of television transmission antennas and the physical irregularities of their surfaces, due to the requirements of mechanical construction, result in the sum of the energies from various portions of the antenna as received in one direction varying from that received in another. Typical azimuthal patterns of some well-known antennas are shown in Fig. 21.

Except for the effects of supporting structures upon which they are mounted, rings or cylindrical antennas inherently have better circularity than other shapes. Ingenious methods have been used, however, to combine noncircular patterns of several radiators to obtain circularity. An illustration of this is the so-called turnstiling principle applied to dipoles. Fig. 22a shows the typical "figure-eight" horizontal pattern of a very small dipole. If a second dipole is placed at right angles

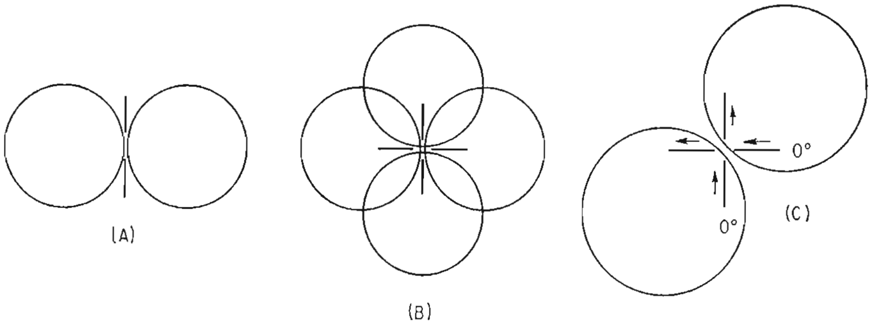

Fig. 22. Addition of fields of crossed dipoles. (A) Figure-eight patter of a single dipole, (B) superposition of a second dipole at right angles, (C) pattern obtained when both dipoles are fed in phase.

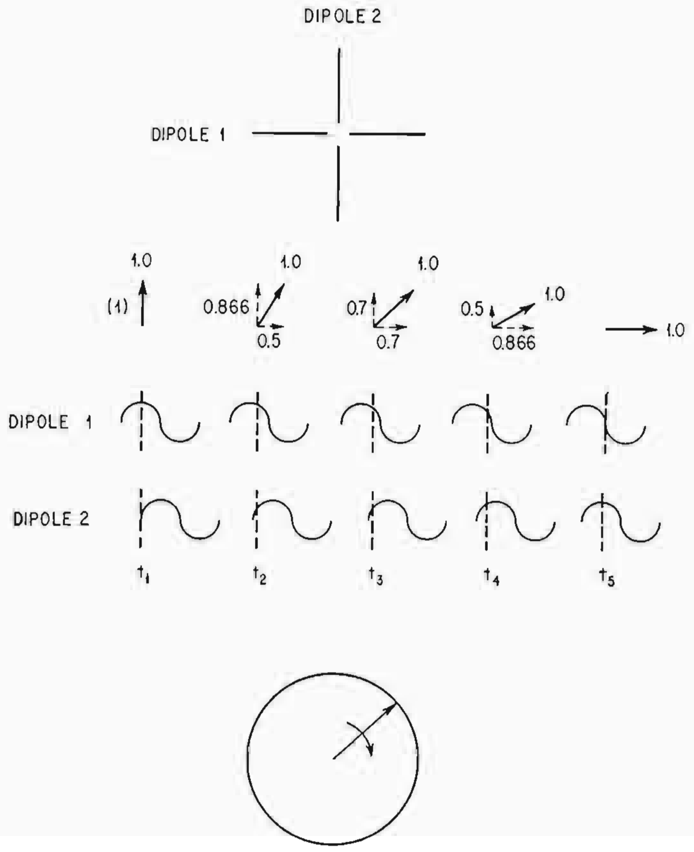

Fig. 23. Addition of field of crossed dipoles using "turnstiling" principle to produce circular pattern.

to the first, the two patterns will overlap, as shown in Fig. 22b. If both are fed in phase, addition of the radiated energies will result in a pattern such as is shown in Fig. 22c.

If the dipoles are fed 90° out of phase, the separate fields will add as shown in Fig. 23. Here we have two dipoles 1 and 2 placed in space quadrature, with current conditions in the radiators as shown at various times. At time t_1 the current dipole 1 and the resultant field of that dipole will be at a maximum, represented by a vector of unity length pointing upward. For dipole 2 they will be zero. The combined field will be unity. At time t_2, 30° in phase later, the field of dipole 1 will have reduced to 0.866 of its value and that of dipole 2 will be 0.5 of its maximum value. Addition of these two vectors at 90° in space phase will produce a resultant which again has a value of unity.

Analysis of the conditions at t_3, t_4, and t_5 indicates that the same total field will be obtained in each case. Ideally, then, we see that turnstiling produces a constant field rotating in the horizontal plane at the rate of the signal frequency.

In actual practice the dipoles are not infinitesimally small, and a supporting pole and feed lines tend to distort the fields of the dipoles from the ideal. The vectors do not then add in such a way as to result in the same total in all directions. The normal pattern is then scalloped, as shown in Fig. 21a, with the amount of variation from circular increasing with size of the supporting pole at a given frequency and with increase in frequency for a given-size pole.

Other methods of obtaining omnidirectional patterns which have been used are the "clover leaf" of small loops (Fig. 24b), the triangle of folded dipoles (Fig. 24c), the small loop (Fig. 24d), the "supergain" with the dipoles backed by screens and fed in quadrature (as are the turnstiled dipoles) (Fig. 24e), and the helix wound around a tower structure with phase compensators to maintain correct phase relationship between successive turns of the helix (Fig. 24f).

Although omnidirectional antennas predominate in television broadcasting, there are locations where their use is impractical and even insufficient, and it becomes obviously desirable to direct the main portion of the radiated energy in both the horizontal and vertical planes to serve specific areas best. Examples in the United States are the Denver, Colo., area, where the presence of mountains to the rear of logical transmitting sites would set up undesirable reflections if the signal

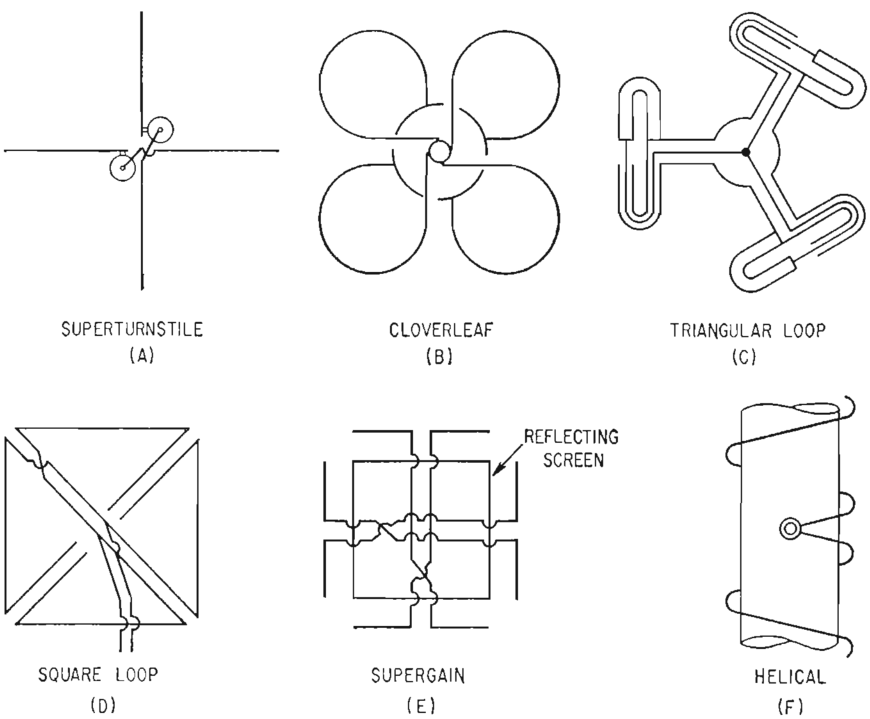

Fig. 24. Configuration of elements used to obtain omnidirectional patterns.

were allowed to radiate toward them, and the southeast coast of Florida, where the populated area borders the coast for great distances with only swamp immediately to the west.

Here the irregularities of the so-called omnidirectional patterns can be exploited to some extent, but truly "directional" patterns are more desirable. In order to obtain directional patterns, in either the vertical or the horizontal planes, correct relation in amplitude and phase of the signal coming from different portions of the antenna is necessary. This can be accomplished to some extent by physically spacing the radiating elements properly. For a given spacing, the pattern can be further modified by varying the phase and amplitude of the respective radiated signals. An example of this is shown in Fig. 25a where two point sources are fed in phase with each other but are spaced 180° apart. By the time the signal from *A* reaches *B*, the phase of the signal being radiated from *B* will have changed 180°. If the signals are equal in magnitude, they will cancel in the direction to the right. The same line of reasoning shows that no signal will be radiated to the left. Toward the top and bottom of the page, the signals will always be in phase,

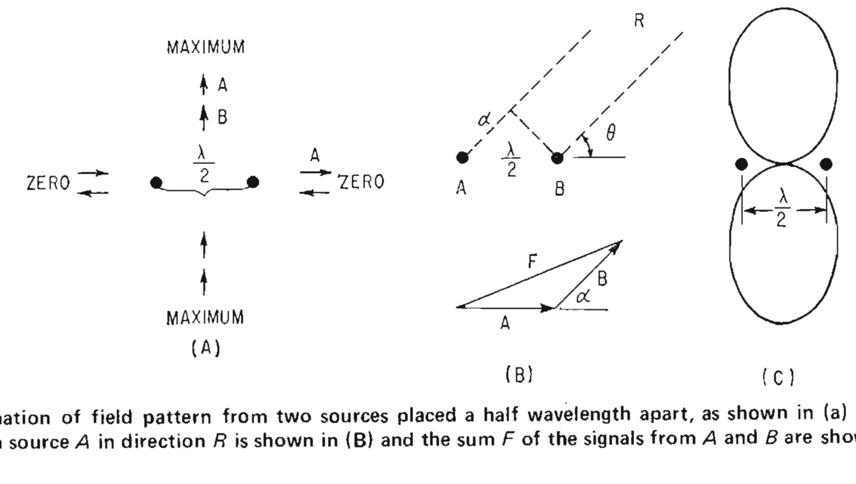

Fig. 25. Formation of field pattern from two sources placed a half wavelength apart, as shown in (a) and fed in phase. Leg of signal from source *A* in direction *R* is shown in (B) and the sum *F* of the signals from *A* and *B* are shown in (C).

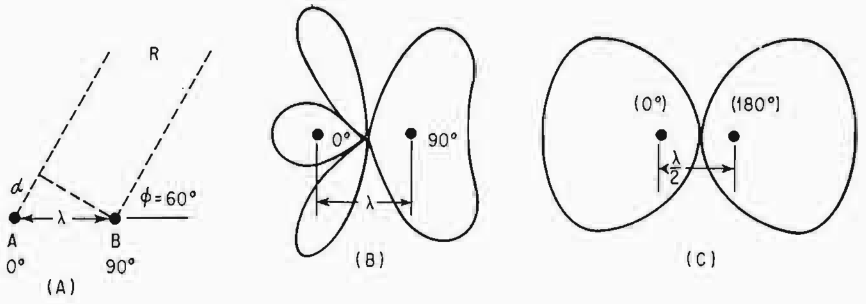

Fig. 26. Field pattern resulting from sources (C) a half-wavelength apart fed 180° out of phase and (B) a wavelength apart fed 90° out of phase. (A) Formation of null at $\phi = 60°$ for condition (B).

giving a total radiation equal to the sum of the two individual ones. Factors showing amplitude and relative phase are given in all four cases.

At some other angle in the plane of the paper, conditions shown in Fig. 25b will pertain. At some great distance R, the signal from A will lag that from B by an amount ϕ. The sum of the two will have a value F, somewhat less than the sum of A and B, as shown. If this process of analysis is continued for all angles of ϕ and the values plotted as relative magnitudes, a radiation pattern like the one shown in Fig. 25c (commonly called a figure-eight pattern) will be obtained.

If A and B are radiating 180° out of phase with the same spacing, signals to the right and left will reinforce each other, and they will be the same reasoning cancel at right angles to this, as shown in Fig. 26c.

For a spacing of one wavelength and a phase difference of 90° the signal from A will lag that of B by 90° toward the right, giving a resultant of 0.707 of the value of one signal. At an angle of $\phi = 60°$ toward R, the two will become equal but opposite in phase and the signals will cancel (Fig. 26a). Continuing this analysis yields a pattern shown in Fig. 26b.

It can be seen that varying the third parameter, amplitude of signal, from either or both sources will increase the number of patterns which can be obtained, since the vectors now being added vary in length as well as in angle to each other.

The same method of analysis can be applied to more than two sources, with a corresponding increase in the number of vectors. In fact, the effect so analyzed actually takes place with any type of antenna which is not a point source, since each small portion of the antenna acts as a point source with particular phase, amplitude, and position relationship to each other such position.

Where individual radiators of finite size, having by themselves patterns which are directional in character (as, for example, a dipole), are grouped to form an "array," it is customary to consider each as a point or isotropic radiator in determining the phase at which their signals must be added to those of the other individual radiators, or "elements." For arrays of reasonable complexity, this relationship can usually be expressed as an equation, and the pattern which it represents is known as the "array pattern."

If the pattern of the individual element is itself expressed as an equation, the total field pattern (i.e., pattern of relative magnitudes of field intensity) of the array can be obtained as the *product* of the "element pattern" and the array pattern.

To find the phase of the resultant signal in any direction, it is necessary to *add* the phase of the element pattern to that of the array pattern in that direction.

As pointed out above, an "element" may be considered in turn as a group of smaller elements. We have thus a tool for handling the calculation for quite complex arrays as illustrated in Fig. 27a. Assume that elements 1 and 2 are fed in phase and 3 and 4 are fed in phase but 1 and 3 are fed 90° out of phase. One and 2 give a pattern shown in Fig. 27b.

Now if 1 and 2 are considered as one single element with effective center of radiation halfway between the two and 3 and 4 are considered another element, the array pattern of the two new elements is a cardioid (Fig. 27c). Multiplying the patterns of Fig. 27b and c together in all directions yields the pattern shown in Fig. 27d.

If all elements of an array do not have the same element pattern, or if the array is quite complex in phase, amplitude, and geometry of elements, it is necessary to combine the element patterns on an angle-by-angle basis taking into account the array factor. An illustration of the method is shown in Fig. 28, where two point sources are fed with unequal currents in the ratio of 2 to 1 and with the upper one lagging the lower by 30°. In the direction $\phi = 60$, A lags B by $\lambda/2$ owing to its relative position. It lags an additional 30° due to the imposed phase. The unequal vectors are therefore combined at an angle of $90° + 30° = 120°$, giving a total amplitude of 1.732. Increasing the number of elements simply requires the

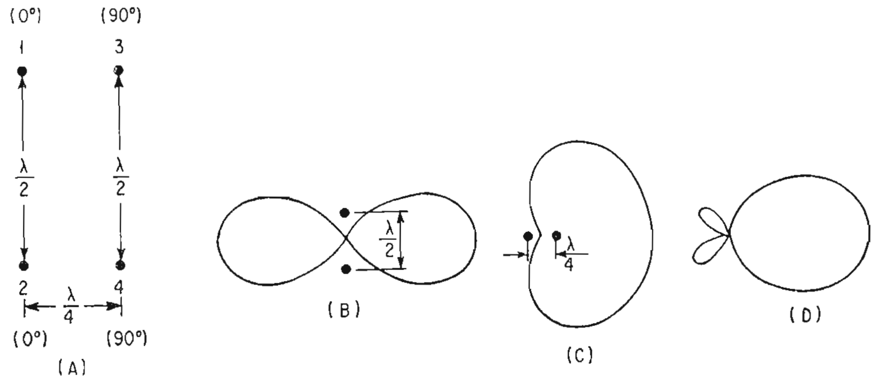

Fig. 27. Evolution of a pattern (D) by multiplication of an element pattern (B) by an array pattern (C). [Sources located and phased as shown in (A).]

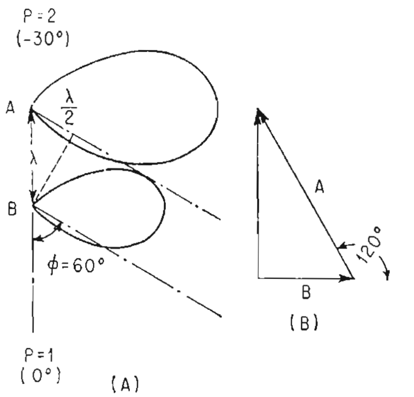

Fig. 28. Combination of signals from two sources having unequal currents and phase and positioned a wavelength apart.

addition of more vectors with correct relative signal strength and phase.

Examples of directional patterns of antennas in current use are shown in Fig. 29.

A reversal of the above procedure makes it possible to start with a desired pattern and to determine what relative phases and amplitudes are required to obtain it. A particular type of element and form of array must be presumed, of course, to make such a computation possible. This procedure is known as pattern sythesis. The speed of electronic computing devices renders this approach highly practical and effective.

The above discussion of the calculation of patterns has ignored the effects on element patterns of the presence of other radiators in close proximity. Mutual effects among elements alter current and phase conditions within the element and must be taken into account if the effect is appreciable.

A word should be said about the limitation on the use of directional antennas for commercial television in the United States. Where there is clear indication that directionalizing will not be against the best interests of the market area being served, the Federal Communications Commission will approve its use. The broadcaster may desire this to conserve power by limiting radiation over nonpopulated areas or to avoid multipath echoes from nearby mountain ranges. There is currently in effect a rule which provides that the difference in field strength between the maximum signal and the minimum signal in the horizontal plane shall not exceed 10 dB.

Vertical Patterns

The need for higher gain (see under Gain) than can be obtained with a single radiating element requires "stacking" the elements one above another. This, on the undesirable side, increases

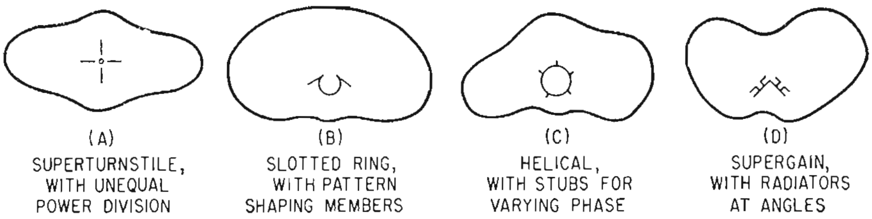

Fig. 29. Examples of directionalized horizontal patterns in current use.

the condition of "lobing," or wide variations in the amplitude of the resultant radiation pattern in the vertical planes. On the desirable side, however, it provides more separate elements by control of which the patterns can be made nearly ideal for television broadcasting.

Reference is made to the discussion of Azimuthal Patterns for an outline of the theory of pattern formation. The same principles apply in the vertical plane. Fig. 30a shows the vertical pattern of a point source or of a horizontal dipole. Fig. 30b and 30c show the effect of stacking two- and six-point sources one above another, a half wave apart, with currents of equal amplitude and phase. Fig. 30d shows the same information as Fig. 30c for the portion of the pattern between $\phi = 0°$ (horizontal) and $\phi = 270°$, on rectangular coordinates, with field intensities plotted against angle below the horizontal. This is the customary method of pattern representation, enabling one to see in convenient manner the relative field strength at any angle into the area served by a broadcast station down to the base of the antenna tower.

The presence of nulls in the pattern of a television broadcast antenna is undesirable, because receiving areas at the angles where nulls are indicated received either less than the required signal or one which is the sum of reflections from objects which lie outside the null area. This latter condition often results in multiple "echoes" in the received picture.

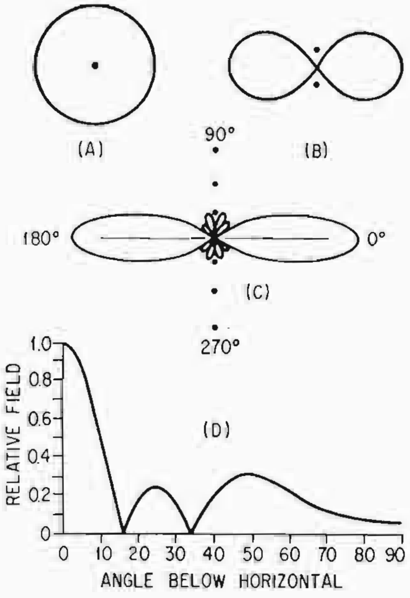

Fig. 30. Effect of stacking several point sources having equal currents and phase. (A) Vertical pattern of single source, (B) two sources, (C) six sources. Information given in (C) is shown in rectangular coordinate form in (D) for angles between horizontal (0°) and directly below the array (270°).

The angles at which nulls appear for the case of a vertical array of equally spaced radiators fed by signals of equal amplitude and phase can be approximately found by the relation

$$\phi = \arctan \frac{\pm K}{nd}$$

where K is the null in question (the one nearest the main beam having a K value of 1, the next one 2, and so on). The number of elements is given by n, and the spacing of elements in wavelengths by d.

A quick rule-of-thumb method to obtain the distance of a null is to multiply the antenna height by the antenna gain and divide by K, thus

$$d = \frac{hg}{K}$$

Various methods are used in the design of antennas to "fill in" the null axis. Simple power division, whereby the upper or lower half of the elements are fed with a greater amount of power than the other half, results in the elimination of all odd-numbered nulls (see Fig. 31a).

A more complex power distribution was proposed by J. S. Stone, wherein successive elements are fed with amplitudes proportional to the coefficients of a binomial series. Thus for three elements the distribution would be in the relation 1, 2, 1, and for five 1, 4, 6, 4, 1. The result is an elimination of all minor lobes and all nulls except the ones directly at the base of the tower and directly above the antenna.

A similar result is obtained if the amplitude is exponentially tapered from one end of the an-

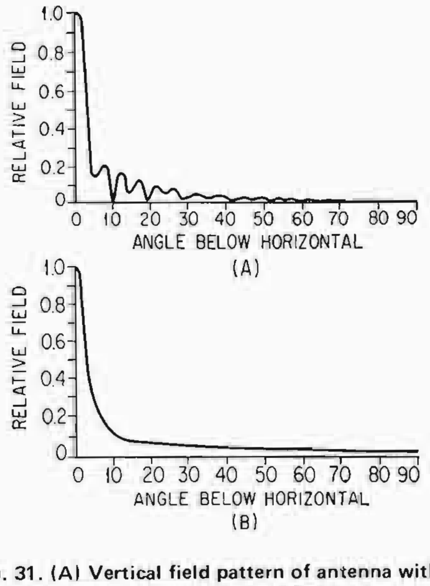

Fig. 31. (A) Vertical field pattern of antenna with a gain of 12 having twice as much power in the upper half as in the lower half. (B) Vertical field pattern of an antenna with many separate radiating elements with ideal phase and power distribution to obtain smooth pattern.

tenna to the other, as in the traveling-wave antenna.

Still more elaborate is a combination of power division and phasing to obtain specific desired pattern shaping (see under UHF Antennas).

With the number of elements available in antennas having gains of 30 and upward, patterns have been obtained by these methods which are almost without a visible ripple (see Fig. 31b).

The filling of nulls, while highly desirable in cases where the area served would be otherwise affected, must be done at the expense of gain to some extent, since power is usually drawn from the main beam to furnish the filling signals. Proper pattern synthesis can, however, reduce this effect to a minimum, taking power instead from the portion of the pattern above the horizon, where it would otherwise serve no useful purpose.

Directionalizing the vertical pattern so as to direct the main lobe of energy at other than the horizontal direction is permitted by the Federal Communications Commission where it can be shown that the public can be more adequately served. Certain restrictions limit the type and amount of such directionalizing, however, namely:

1. The power radiated in the main lobe may not exceed that authorized for nondirectional operation for the particular area.
2. Power radiated in any direction above the horizontal may not exceed the power radiated in the horizontal after directionalizing.
3. Requirements for Class A and Class B coverage must still be met.

Directionalizing in the vertical planes is normally accomplished by variation in phasing among elements in the array. This may be a lumped effect, as when the lower half of an antenna is fed in such a way as to lag the upper half in phase, or it may be a smooth transition of progressive phasing throughout the length of the antenna. In either case, the net result is to tilt the main beam downward, so that it points to the horizon or below. Antennas on Mt. Wilson in California, serving the Los Angeles area, offer examples of this type of directionalizing to obtain maximum coverage of the area with the least loss of power over the ocean beyond.

Combinations of electrical and mechanical "tilt" are used when the antenna is on top of a plateau overlooking a city in which a strong signal is desired. When the electrical and mechanical tilt are made equal, the total tilt toward the city is double the electrical tilt alone, with no tilt in the opposite direction along the plateau.

In considering the formation of total patterns a word should perhaps be said on the effect of distance on this formation. With antennas having a length (or "aperture") of several wavelengths, there is a distance within which the shape of the pattern is found to vary. This occurs because the distance is so small that radiation from the separate elements comes to the receiving point at different angles from the source rather than along parallel paths. Movement changes the angles and the distances from the separate elements at an unequal rate, resulting in variations in the sums of the individual signals. The field within this region has not "stabilized," and calculations which assume parallel paths of the rays do not yield an accurate result. The region from the outer border of the near or "induction-field" zone to the point at which the rays become essentially parallel and the pattern stable is known as the Fresnel zone. Beyond this region the formed pattern takes the form investigated by Fraunhofer, and the region is known as the Fraunhofer zone. For practical purposes the distance of the boundary between the zones is

$$d = \frac{2a^2}{\lambda}$$

where a is the total aperture in wavelengths.

Gain

Directionalizing horizontal and vertical patterns has been discussed in previous sections. The object is to force the energy to radiate in directions in which it can be usefully employed. In television broadcasting, these directions involve all the region below a plane tangent to the earth's surface and passing through the antenna. The area with which we are concerned is from the base of the antenna out to points somewhat beyond the horizon. Power radiated above this region serves little useful purpose, and it is desirable to reduce it as much as possible.

To indicate the effectiveness of this directional process, the increase of signal intensity obtained thereby is related to the signal intensity which would be received from some standard reference antenna such as a half-wave dipole or an isotropic source having the same input power. The value of the ratio so obtained is called the "gain" of the antenna. A more specific definition of gain is given on page 330.

It should be noted that because of the fixed relationship between the shapes of the patterns of the two antennas commonly used for reference, a gain value as compared with a half-wave dipole can be converted to a corresponding value using an isotropic source as a base of comparison by use of a multiplying factor of 1.64.

As has been seen, the effect of adding more and more basic elements in a linear array with equal spacing between them and energized by equal currents in the same phase is to force the formation of a major lobe of energy. The result is greater gain in the direction of that (main) lobe. Gain can just as well be stated for any other direction, and at times this is done, but usually statements of gain are limited to the main-lobe direction.

Ideally, the determination of the value of gain of an antenna would be made by measurement of the received signal in the direction being considered followed by the same measurement with the reference antenna inserted in place of the antenna being evaluated. This is one of the methods in use. Various precautions must be taken to ensure accuracy, such as the construction of a theoretically exact reference antenna and recognition of the change in propagation conditions during the substitution process and of the difference caused by the electrical effect of the environmental condition (the supporting structure, for instance).

For all practical purposes, it has been found to be just as accurate to measure the radiated pattern of the antenna being considered in as much detail as is necessary to be able effectively to reproduce a solid, the distance to each point of which from the antenna position within it is representative of the relative value of field strength in that direction.

To determine the gain, it should be remembered that with the same input power to the two antennas being compared and omitting ohmic losses, the total radiated power will be the same in both cases. If, then, we imagine the solid referred to above as being remolded into a sphere (in the case of comparison with an isotropic source) of the same volume, this volume will be the same as that of the pattern of the reference antenna with the same power input. With this condition and holding the volume constant, if the pattern of the measured antenna is allowed to re-form to its proper shape, the main lobe will project beyond the surface of the sphere. The radius of the sphere and the distance to the tip of the main lobe will be in terms of volts. Corresponding powers will be proportional to the squares of these values. Comparison of these powers will give the power gain desired as compared with an isotropic source in this instance.

An illustration of this in one plane only is given in Fig. 32. The circle contains the same area as the pattern being considered and represents the field pattern of an isotropic course with the same power input. The gain in the main lobe, ignoring losses, will be

$$G = \frac{E_A}{E_i}$$

For an antenna having the same vertical pattern in all directions of azimuth, comparison using the pattern in only one plane is sufficient, since such an ideal case never exists. However,

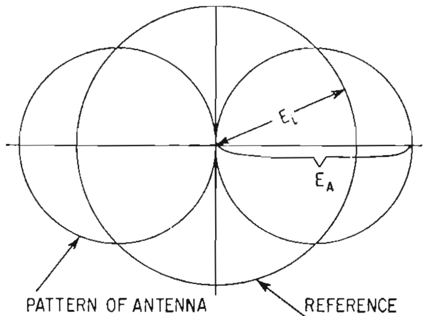

Fig. 32. Comparison of pattern of a measured antenna with circle of equal area to determine gain.

integration of the entire pattern is required to take account of directivity of the horizontal pattern and variations in the shape of the vertical patterns.

As an example, gain determination of a superturnstile antenna is found to be quite accurate if one horizontal pattern is taken along with vertical patterns every 30° about the antenna. These patterns can, of course, be computed for a given antenna if enough information of the characteristics is available to justify confidence in the accuracy of computations. Determination of the gain in this case follows the same method as with measured patterns.

The method of obtaining measured field patterns of broadcast television antennas is to support the antenna in a horizontal position at a sufficient distance from ground and nearby objects to minimize the effects of reflection. By the principle of reciprocity a signal radiated from a distant source and picked up by the antenna under test will appear at the input to the antenna with the same value as if the input and output conditions of the antenna and the distant source were reversed. This simplifies the measurement, since in this way work on the antenna and measurement of the pattern can take place at the same location with the distant source fixed and the signal simply radiated.

With these conditions, rotating the antenna about a vertical axis will provide a vertical field pattern in one plane. Revolving the antenna 30° about its own (normally vertical) axis will place it in a position where a new vertical pattern can be taken.

With the antenna at right angles to a line to the "source," revolution about its own axis will yield a horizontal pattern.

For any other position than that normal to the line to the source, an azimuthal pattern can be obtained for the angle being considered (for instance, the pattern of the variation of the maximum value of a main lobe tilted below the horizontal).

Since it is customary to measure the gain of an antenna in terms of the amount of signal radiated with the desired polarization considered effective, all energy with other polarizations being considered lost for effective use, measurement of this lost energy is also necessary, the amount being accounted for as a decrease in gain. This is usually done by rotating the polarity of the transmitting source and determining the amount of energy received for this condition by the antenna under test.

In the statement of gain for commercial purposes, losses in the feed system and radiating elements must also be accounted for.

Gain is proportioned to aperture, which, for the types of antennas used in telecasting, is the active height of the antenna. Length represents both antenna cost and an overturn load for which the tower must be adequately designed. The efficiency with which the aperture is used becomes an important criterion of antenna design. Gain per wavelength is a yardstick by which this efficiency is indicated. This yardstick must, of course, be used judiciously, since desired characteristics such as null fill and directionalizing must, in turn, be paid for in terms of gain. In general, omnidirectional broadcast antennas currently being built and used have gains per wavelength which vary between 1.05 and 0.80, depending on the amount of null fill.

It is interesting to note that for a uniform current sheet, with all elements of the sheet having equal phase and amplitude, the theoretically maximum gain per wavelength which can be achieved for antennas over two wavelengths is 1.22. With such a value, full nulls would exist throughout the pattern. No commercial antennas now in use attain this ideal value.

Impedance

Transmission-line theory tells us that maximum transfer of power takes place when a load terminating a line has the same impedance as the characteristic impedance of the line. Since the final load in a radiating system is space, it is desirable that the antenna match the impedance of space, or approximately 377 ohms, at the point of radiation.

The ease with which a signal is radiated determines the effective impedance of the antenna at the boundary with space. Thus, a logarithmic horn of the type shown in Fig. 33 flaring outward to a considerable diameter at the mouth expands the wavefront and launches it practically without interference. If the characteristic impedance of the horn (determined by the ratio of D to d) is maintained down to the entrance to the taper, that entrance (input to the antenna) will have an impedance of 377 ohms. Because the impedance throughout the elements is constant and resistive in nature, the antenna is not sensitive to frequency, signals of all frequencies being transferred equally well. This insensitivity to frequency is called "bandwidth," and the horn has nearly the ultimate in bandwidth.

A biconical dipole antenna (Fig. 15a and 15b) with flaring arms, has a similar action and an input impedance of around 300 ohms. This, too, has a large bandwidth. On the other hand a dipole with thin areas is very critical to frequency and so transfers the energy to the radiated field at a maximum rate only at the frequency where the over-all length is $\lambda/2$. At other frequencies considerable reflection occurs and the input impedance changes rapidly. At the resonant frequency the input impedance is about 73 ohms.

The input impedance of a superturnstile antenna (see under Superturnstiles) is about 150 ohms (both batwings together), of a helical antenna 100 ohms and of a resonant fullwave slotted cylinder about 40 ohms.

In each of these cases it will be seen that the antenna has, because of its construction and electrical response, effectively transformed the impedance as seen at the space boundary to some other value. If, in the process, compensation has been made so that the impedance seen by the signal is relatively constant at all frequencies involved, the antenna will have adequate bandwidth. If compensation is not made, the bandwidth will be narrow. The superturnstile, with its broad radiators and compensation afforded by the slot between radiator and pole, is very broadband. A ring or a thin-dipole antenna, on the other hand, is extremely narrow.

If the load terminating a line does not have an impedance equal to the characteristic impedance of the line, some of the power is not transferred but is reflected back down the line. Combination of this energy with that coming up the line sets up "standing waves" similar to those found at sound frequencies in musical instruments or on a vibrating string. The ratio of the maximum to the minimum voltage of such a wave is called the voltage standing-wave ratio (VSWR) and is denoted by the symbol ρ. It is used as a figure of merit to indicate the efficiency of transferal of power.

Another such figure of merit is the ratio of reflected to incident component of voltage at the load or at an impedance discontinuity. This is denoted by the symbol Γ and is called the reflection coefficient.

The values of ρ and Γ are related by the formula

$$\rho = \frac{1 + |\Gamma|}{1 + |\Gamma|}$$

A third effect of an impedance discontinuity and the resulting reflection of power is the possibility of creating an "echo," or repeated picture as viewed by a receiver. If the portion of the signal reflected from a mismatch in the line or antenna is not totally absorbed in the output circuit of the transmitter, it is rereflected toward the antenna. The part of this which reaches the antenna and is radiated appears as a second picture, to the right of the primary one, which may be of such intensity as to be very objectionable.

Where an echo causing mismatch occurs, it is possible to locate approximately the section of line in which the reflection occurs by measuring the distance between the initial picture and the echo on a receiver screen. Since the width of a picture represents 53 μ sec of time, and since a signal can travel 26,150 ft. through a transmission line and return to the starting point in this length of time, the proportion of the picture width (in inches) which the delay (in inches) of the echo represents is the same proportion of 26,150 ft. which the signal traveled before striking the reflecting mismatch. That is,

$$D = 26{,}150 \times \frac{\text{delay of echo beyond initial picture, in.}}{\text{width of receiver screen, in.}}$$

where D is the distance from transmitter to discontinuity.

It has been pointed out that antennas may transform the impedance seen at the space boundary to some other impedance at the input. If, for instance, the D/d ratio of the horn shown in Fig. 33 was changed gradually along its length, there would be a smooth transition to some new impedance looking into the input of the value

$$Z_C = 138 \log \frac{D \text{ (input)}}{d \text{ (input)}}$$

Because the horn is difficult and costly to manufacture, it is customary to use simpler and more abrupt transformations in order to match two unequal impedances. A simple and effective transformer for a narrow band of frequencies is obtained by inserting between the impedances to be matched a quarter-wave section of line having a characteristic impedance equal to the geometric mean of the two impedances. That is,

$$Z_C \text{ (of transformer)} = \sqrt{Z_1 Z_2}$$

Since the length of the transformer is $\lambda/4$ for only one frequency, the bandwidth of the transformation is small. Matches over wider bandwidths can be obtained, however, by using several such transformers end to end (thus approximating the tapered horn). Choice of proper characteristic impedances for the various sections can be made by following standard techniques or by cut and try.

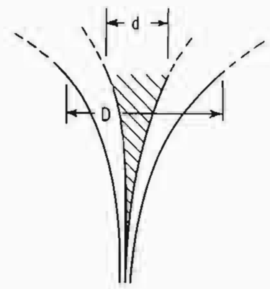

Fig. 33. Logarithmic horn used as ideal broadband radiator.

Another method of impedance matching is to choose a point in the line where the input admittance appears as pure susceptance. Insertion of a lumped susceptance of opposite sign (for instance, a disc of Teflon as capacitive susceptance) will balance that in the line and yield a matched condition. This method is good only for a single frequency.

Impedance matching of an antenna to a line can be accomplished by choosing a point to feed the antenna where the impedance of the antenna appears as the desired value. Off-center feed of a slot, for example, offers a considerable choice of input impedance.

The placement of input to a $\lambda/2$ dipole along a quarter-wave shorted stub offers again a large range of input impedance (see Fig. 34).

Bandwidth

As discussed under Impedance, the range of frequencies over which a circuit maintains a more or less constant impedance is called its impedance bandwidth. Limits of the bandwidth occur when the impedance exceeds some value agreed upon for defining the bandwidth.

Methods of obtaining this bandwidth have been touched upon. Basically they consist of so designing the antenna or intermediate transforming elements that they are not sensitive to frequency change. The horn, through its shape, presents only resistance at the input. The superturnstile

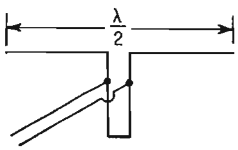

Fig. 34. Impedance matching by selection of point of feed of dipole with shunt stub.

(see under Superturnstiles), by paralleling a parallel-resonant circuit (which becomes capacitive with increase in frequency) with the series-resonant circuit of its radiator (which becomes inductive with increase in frequency), obtains a virtual cancellation of reactance over a considerable frequency range, rendering this antenna one of the most broadband television antennas in general use.

The same principle is applied in the traveling-wave antenna, which, instead of using quarter-wave stubs in parallel with the feed point as in the superturnstile, utilizes a slot whose shape provides the response of a parallel-resonant circuit.

On other antennas, broadbanding stubs and, at times, a series of half-wavelength transformers, spaced at proper intervals apart, are used to obtain impedance bandwidth.

Another interesting method, quite different from the above, is the use of a "power equalizer" to broadband otherwise narrow-band radiators.[13] A bridge diplexer (see Aural and Visual Transmissions) can be effectively used to absorb most of the power reflected from the antenna. Fig. 35 shows east and west radiators being fed 90° out of phase with north and south radiators.

The incoming signal fed from a notch diplexer on filterplexer through a single-line feed enters the visual input of the bridge diplexer and leaves it as two signals 180° out of phase (or + —). After passing through the additional 90° length on the left line, the signal in this line reaches *A* 270° out of phase with that reaching *B*. With equal reflection from *A* and *B*, the reflected signals return to the diplexer.

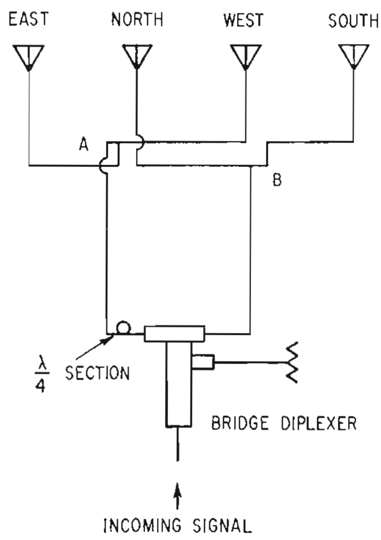

Fig. 35. Use of bridge diplexer as "power equalizer" in broadbanding of quadrature fed antennas.

[13] R.W. Masters, A Power-equalizing Network for Antennas, *Proc.* IRE, July 1949, p. 735.

The 90° section again shifts the phase in line *A*, and the two signals reach the diplexer *in phase.* The diplexer action is such that both reflected signals are now passed out through the aural input to a load which absorbs all the power. Since none return to the transmitter by way of the visual input, there is no standing wave, and the transmitter therefore appears to see an impedance match over the whole channel.

An antenna may have impedance bandwidth, but its radiation pattern may vary with frequency. That is, it may not have pattern bandwidth. This normally occurs because radiating portions of the antenna, being fixed in position mechanically relative to other elements, in effect change this relative spacing as the frequency changes (i.e., in terms of wavelength). The higher the frequencies of operation, the less sensitive antennas are to this as a general rule, because, for a given spread of frequencies (6 MHz for television), the present bandwidth (ratio of operating range, MHz/center frequency of range, MHz) becomes less at high frequencies. Thus, a change of 6 MHz at 600 MHz is only 1 percent, while at 60 MHz is 10 percent.

The traveling-wave antenna, operating normally in the vicinity of 200 MHz, takes care of the problem by incorporating circuit elements which effectively retard the phase of the signal with increase in frequency and advance it with decrease in frequency (see Traveling-wave Antenna). The result is to maintain the wavelength constant at all frequencies of a channel and so in turn to maintain the radiating elements at constant virtual spacing from each other.

Pattern bandwidth is important to the maintenance of video response. Correct relationship of amplitude and phase of signal is important at all frequencies within the channel, within the limits of good engineering practice, particularly in color transmission.

Gain bandwidth is the range of frequencies over which the gain remains constant. This is, of course, closely related to pattern bandwidth. It is particularly important in television, where it is desirable to use a given physical size of antenna over a broad number of channels to obtain approximately the same characteristics at each channel.

Feed Systems

The feed system of a television broadcast antenna is commonly considered that portion of the transmission system having its input at the antenna terminal which is at the top of the vertical run of coaxial transmission line in the tower and its output at the radiating elements.

Most antenna gains in the manufacturers' literature take the losses of the feed system into account, which are considered as reduced antenna gain. Therefore, when system losses are calculated, the feed-system loss should be excluded, having already been accounted for.

Types

In the television broadcasting field, three types of feed systems are in wide use. They are the branching, standing-wave, and traveling-wave feed systems. Each meets a need peculiar to its own application. Where frequencies vary from 54 to 890 MHz, where power-handling-capacity requirements vary from 500 to 120,000 watts, where gains vary from 0.5 to 60, and where pattern shapes vary between extreme limits, it is logical that good economics dictates various types of feed systems.

Branching. The branching-type feed system is used in the superturnstile antenna. It is characterized by the progressive subdivision of input signal in a more or less uniform manner, from the input of the antenna to the end seals. A large majority of the antennas using this feed system accomplish the subdivision of power by means of a junction-box assembly into which is plugged the individual radiator feed lines.

Standing Wave. The standing-wave-type feed system is used in slotted-cylinder UHF antennas. For details refer to *Slot Types* on page 349.

Traveling Wave. The traveling-wave feed system operates on the principle of a gradual attenuation of the input signal through radiation resistance as it progresses from the input along the aperture of the antenna. An application of this principle is the helical antenna. Page 362 gives more details. A more recent development is the application of this feed system to a cylindrical-slot antenna known as the traveling-wave antenna described on page 363.

Fig. 36a shows the principle of this feed system using short rod radiators to illustrate the theory. A number of radiators per wavelength uniformly spaced are loosely coupled to a coaxial line. Because of the number of radiators and the relatively slight reflection due to each, the effect is essentially that of a uniform loading. The result is a uniformly attenuated traveling wave in the line. Since a traveling wave has a linear-phrase characteristic, the excitation of each successive radiator will be lagging from the previous one by an amount which depends on the spacing between the radiators and the velocity of propagation in the line. If the radiators are alike, their currents will have the same phase relationship as the excitation. Thus the radiating currents will be successively lagging, and repetition of phase occurs after every guide wavelength.

To obtain an omnidirectional pattern the radiators, instead of being in line, can be moved

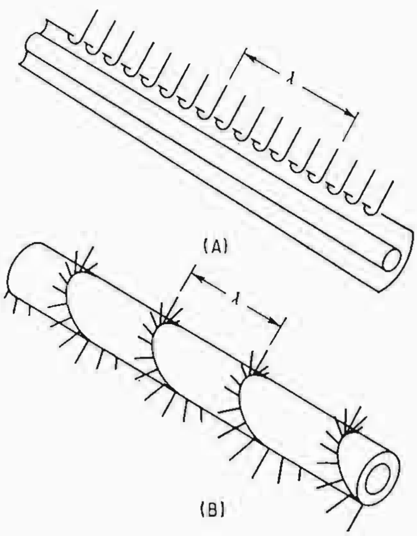

Fig. 36. Basic principles employed in the traveling-wave antenna feed system.

around the periphery to form a "spiral" as shown in Fig. 36b. For a horizontal main beam the pitch of the spiral has to be equal to the guide wavelength in the transmission line. In this arrangement all the radiators in any one vertical plane on one side are in phase and the phase difference between radiators in different planes equals the azimuth angle difference between the planes; that is, the phase rotates around the periphery. The rotating phase produces a rotating field which, because of the relatively small amount by which the magnitude of current changes from layer to layer, produces an omnidirectional pattern.

Aural and Visual Transmissions

For the broadcasting of standard television signals, the video-signal amplitude modulates a separate visual transmitter and the audio-signal frequency modulates a separate aural transmitter, the output of which is generally one-half the peak visual power output of the visual transmitter. To radiate these two separate signals, various techniques can be employed.

Separate antennas. Separate antennas can be used, one to radiate the visual signal, the other to radiate the aural signal. When this procedure is used, a separate transmission line connects the output of the particular transmitter to the input of the respective antenna. Two precautions should be observed: (1) The isolation of the individual antennas must be sufficient to prevent interaction and cross modulation within the systems. (2) The patterns of the individual antennas must be sufficiently alike so that the ratio of the visual signal to the aural signal is neither too large nor

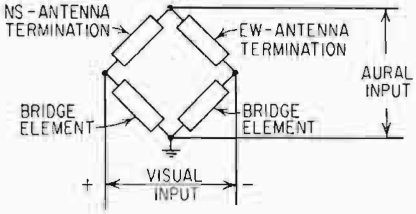

Fig. 37. Bridge diplexer represented as a Wheatstone bridge.

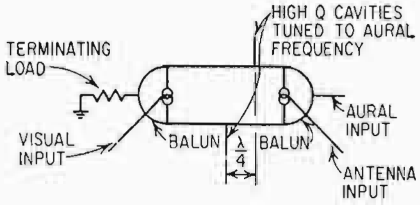

Fig. 39. Notching diplexer schematic.

too small. An example of this kind of installation is the use of the upper half of a superturnstile antenna for visual and the lower half for aural transmission.

Bridge systems. The bridge diplexed system of antenna feed is used in the superturnstile antenna. The complete antenna is fed through a bridge network where the two inputs are in quadrature. The radiating systems are also arranged in a quadrature relationship so that the azimuthal pattern is substantially circular as described under Azimuthal Patterns. The north-south system, which radiates a figure-eight horizontal pattern is constructed in a vertical plane at right angles to the plane of the east-west system, which also radiates a figure-eight pattern with 30 dB or more isolation between the two systems. Each of these radiating systems forms a termination for the two legs of the "Wheatstone-bridge-type diplexer" as shown in Fig. 37. The visual signal is fed into the bridge balanced to ground, and the aural signal is fed in unbalanced to ground.

The superturnstile antenna can be fed with a "ring-T" type of diplexer, which also requires a two-line feed as illustrated in Fig. 38.

Notch diplexer. Where an antenna has a single input, a network for combining the visual and aural signals is required. One type of circuit which accomplishes this function is shown in Fig. 39. The aural signal, divided by means of a balun (*bal*anced to *un*balanced network[14]), is reflected from the cavities tuned to aural frequency. These cavities are arranged so that they present a very low impedance across the line. Because of the quarter-wave separation the aural signal on the lower line in the figure travels an additional half wave to and from the cavity reversing the phase so that the signal enters the balanced antenna terminals instead of returning to the unbalanced aural input. Any aural energy which leaks past the cavities is absorbed in the terminating load.

The balanced visual signal enters the balanced antenna terminals. Any energy in the visual signal which is at the aural frequency is rejected and because of the quarter-wave separation of the cavities is reversed in phase and is absorbed by the terminating load. In order to obtain the proper visual response, a shaping cavity is sometimes associated with each aural cavity.

Filterplexer.[15] A vestigial-sideband filter is a device used with some types of transmitters to absorb the rather small lower sideband energy lying outside the 6-MHz channel. When a notching diplexer is used, it is desirable to combine the visual-sideband filter and the notching diplexer into a single unit.

This is accomplished in a manner similar to the notching diplexer described above. As shown in Fig. 40, two additional pairs of cavities are used on opposite sides to provide reject points in the portion of the lower sideband lying outside the 6-MHz channel. The rejected lower-sideband energy is dissipated in the terminating load.

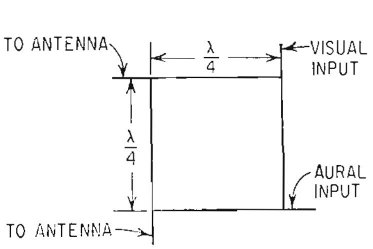

Fig. 38. Ring T diplexer schematic showing inner conductors only.

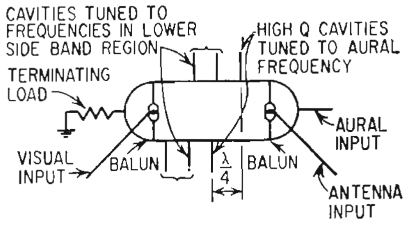

Fig. 40. Schematic of filterplexer.

[14] Balanced is sometimes referred to as push-pull, and unbalanced as push-push.

[15] Also designated as a Filtrexer.

Isolation using traveling-wave feeds. On an antenna which employs a traveling-wave-type feed, the input power is radiated as the signal proceeds away from the input along the aperture. By the time the signal arrives at the end of the aperture, it should be so low that the reflected energy from the end is quite small. In practical designs this energy is about 20 dB below the input. Therefore, if the visual signal is fed at the center of the aperture, the aural signal can be fed at the ends. The helical antenna described on page 000 uses this method of feed.

Multiple Antennas

In an area where two or more television stations are providing coverage, various advantages accrue to the broadcasters if they enter into what is referred to as a multiple-antenna installation.[16] These advantages include reduced costs of individual tower and better reception, since all receiving antennas can be oriented toward the common source of radiation. Furthermore, the fact that tall towers can be located only in limited areas, owing to air-space restrictions, offers a further incentive for a common installation.

Multiple TV Installations

The most notable multiple television installation is the Empire State tower system. At present there are nine television stations radiating signals from this structure. Three installations (in Minneapolis, Minn.; Havana, Cuba; and Hamilton, Ontario) provide three-station operation with vertically stacked antennas. Many installations provide for two stations with vertically stacked antennas.

Instead of mounting the antennas vertically, some have found it more desirable to mount their antennas on a common platform at substantially the same elevation. Illustrations of this approach can be found in Baltimore, Maryland; Dallas, Texas; Houston, Texas; and Stockton, California. These involve primarily VHF installations. There are also UHF installations in Boston, Massachusetts; Detroit, Michigan; and Washington, D.C.; and Cleveland, Ohio.

AM and TV Installations

There are occasions when an existing AM tower can be adapted for a television antenna. Usually two problems must be faced. First, a portion of the tower must be removed to accommodate the television antenna so as to minimize the detuning effect of the AM system, and second, the wind load of the television antenna over the portion of tower removed and the transmission lines running the full length of the tower is increased. The ability of the tower to withstand this load must be determined. The costs of alterations must be considered in relation to the cost of a new tower.

A further consideration is the need for isolating the television transmission lines from ground in order to mount on the AM tower. This is usually accomplished by the use of insulated hangers for one-quarter wavelength along the tower. This same problem must be faced where it is intended to mount a television tower in the proximity of an AM array. The television tower is insulator-mounted, and the transmission lines are isolated with a quarter-wave run of insulated hangers.

Systems Planning

Many times, the individual aspects of a television installation are meticulously scrutinized, and yet how they work together is given secondary consideration. An exhaustive check list would be almost endless. But a few important items are listed:

1. Detailed study of coverage taking terrain and competitive signals into account
2. Antenna location relative to population centers
3. Antenna vertical pattern design for best coverage
4. Antenna mounting methods
5. Layout of transmission lines
   a. In the vicinity of the tower top
   b. Main tower run
   c. Horizontal run to station
6. Transmitter and associated equipment locations
7. RF filter networks and load locations
8. Station layout
9. Emergency provisions
   a. Emergency antenna
   b. Emergency transmission lines
   c. Standby provisions
   d. RF switching features

A few of these will be discussed in more detail.

Propagation Study

In hilly terrain, especially at higher frequencies, shadow areas will occur which cannot be predicted from FCC curves. A method of predicting is outlined on pages 330.

Antenna Mounting Methods

Most antennas are flange mounted and manufacturers—either in their catalogues or upon request—will furnish mechanical and mounting

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[16] Predicting the Operating Characteristics of Closely Spaced Antennas on the Same Supporting Structure, by Irl T. Newton, Jr., and M.S. Siukola, presented at the 11th Annual NAB Engineering Conference, April 1957.

data for their antennas. Standard mounting bolts are usually furnished with the antenna. If a special double plate design or other design is used in the tower top, the antenna manufacturer should be advised so that the proper bolts can be furnished. If a new antenna is substituted for an old one, an adaptor plate may have to be designed and furnished by the tower manufacturer.

Layout of Transmission Lines

In the vicinity of the tower top. Usually, it is desirable to avoid as many elbows in a system as possible. However, near the tower top, it has been found advisable to have from two to four elbows at the top of the vertical run in order to provide access to the system. It also provides a measure of mechanical flexibility, depending on the horizontal length of line between elbows. This flexibility is very desirable. The amount required is dependent on the movement, due to antenna sway, expected from the lines coming down from overhead.

Where complicated circuitry involving power-dividing Ts, transformers, phasing sections, and cut-over elbows (for an emergency feature) are used, considerable thought should be exercised in planning the hanger supports and line layout in cooperation with the tower designer.

Since mismatches at or near the antenna are the most potent source of echoes, any equipment in this area should be specially optimized to a VSWR value of 1.015 or lower.

Main tower run. Normally, in tower-transmission-line runs composed of 20 ft. sections, the top section is supported with two fixed hangers spaced 10 ft. apart and the sections below on spring hangers located on 10-ft. centers. Care must be applied at installation to locate the transmission-line sections so that the hanger springs do not cross over or rub against the transmission-line flanges. When the spring hangers are installed, they should be stretched according to the chart supplied by the manufacturer. If this is not done properly, it may require an excessive pull to separate the line in hot weather and the line may not be supported adequately by the springs in cold weather. At the base of the tower, clearance must be provided to accommodate the differential expansion of the steel tower and copper transmission line.

Horizontal run to station—The length of the vertical run—which determines the amount of differential expansion between the copper transmission line and the steel tower and the length and size of the horizontal run—which determines the amount the line can bend without damage—must be taken into account. Transmission line manufacturers usually furnish curves or nomographs which provide this information. If the horizontal run is too short, it may be necessary to anchor the line near the transmitter rather than at the station wall which introduced complications. The length of the horizontal run required is an important item in the overall planning.

The horizontal run should have a protective shield from falling ice where such a condition exists.

RF Filter Networks and Load Location

The sideband filter, filterplexer, and similar networks should be located with sufficient clearance so that easy access to all portions for servicing and cleaning is possible. While ceiling mounting conserves floor space, accessibility of all elements should still be a consideration. Since many of these devices use cavities which cannot be pressurized, a clean atmosphere is important, since dust accumulation inside the cavity will eventually cause trouble. Cavities should be arranged so that they are in the same ambient temperature. A difference in height when a high-temperature gradient exists or sun heating of one cavity may result in unbalance. Since hot air is less dense than cooler air, a hot location will reduce the safety factor for voltage breakdowns.

Emergency Provisions

It has always been the desire of the broadcaster to keep the ratio of nonscheduled "off-the-air" time to schedule "on-the-air" time as small as possible—preferably zero. An efficient maintenance procedure is excellent insurance. Emergency facilities can also help to keep this ratio small. A great variety of items are available. A word of caution—do not make the emergency provisions too complex and check their operation periodically.

Emergency Antenna. The simplest emergency-antenna provision is that found in the superturnstile, where, if one portion of the antenna fails, the power going to that half can be absorbed in a load while the other half continues to provide some measure of service with a figure-eight pattern. In various antenna designs the power is distributed to the upper and lower halves through combining networks mounted at the tower top. Simple change-over equipment permits the selection of either the upper or lower half for emergency service. Relatively low-gain antennas have been used mounted on the sides of towers and some inside towers for emergency use. It must be remembered that the tower will distort the antenna pattern.

Emergency transmission line. One extra provision of insurance can be provided by the installation of a spare transmission line so located that it can be inserted in place of the main run with a minimum of change-over connections at the input and output. It is wise to use gas stops at both ends and keep it pressurized.

Standby provisions. How much insurance one wishes to buy in the form of standby equipment can be based on the losses incurred by interrupted service. Where broadcasters have expanded their operations to higher power, the replaced transmitters have been retained for standby use. In some new installations broadcasters have obtained duplicate transmitters and worked them both on alternate schedules. In addition to this excellent emergency feature, a large portion of maintenance work can be scheduled during regular working hours. A standby Diesel generator set, duplicate microwave equipment, duplicate RF networks, and duplicate tower and antenna all contribute to potentially more reliable service.

RF switching features. Perhaps the most common emergency feature is the cutback circuit from transmitter amplifier to driver. This usually is performed quite rapidly using motor-driven RF switches. Where a standby system, including transmitter and RF networks, is available but a common antenna is used, motor-driven RF switches can be inserted to transfer the input of the antenna from the main transmitter to the standby system. Many elaborate cutover and cutback systems have been proposed.

In many switching applications the speed of the motor-driven switch is not required and a manual transfer panel is adequate. To terminate various points in the RF system with a dummy load, it has been found convenient to install a single-pole double-throw switch to break open a line so that the load termination can be made by way of a separate multiposition manual-transfer panel.

TYPES OF ANTENNAS

The development of television was such that Channels 2 through 13 (54- to 216-MHz band) were assigned first and, later, with the demand for more stations, Channels 14 through 83 (470- to 890-MHz band) were assigned. The lower of these two bands, referred to as VHF, resulted in antenna types suited to those frequencies. The higher of these two bands, referred to as UHF, required a type different from those previously developed.

VHF Antenna Types

Even within the VHF band various applications dictated antennas of differing designs for both electrical and mechanical reasons.

Superturnstiles

The first antenna developed for commercial service was the Superturnstile.[17] It consists of a central sectionalized steel pole upon which are mounted the individual radiators, or "batwings." These radiators are mounted in groups of four around the pole in north-south and east-west planes to form a "section," and the sections are stacked one above the other to obtain the desired gain. Fig. 41 illustrates this construction showing a 6-section high-band Channels 7 to 13 antenna.

In this type, each of the radiators is fed separately by its own feed line to whose impedance that of the radiator is carefully matched. The feed lines, in turn, are combined at junction boxes, which perform the dual function of feeding power simultaneously to all feed lines and of transforming the combined impedance of these lines to that of the transmission line which carries the power from the base of the antenna. This latter function is achieved by the use of three-stage transformers immediately below the junction box.

At the base of the antenna at the tower top, a combining network is used when there are more than two junction boxes. These networks accomplish power division between portions of the antenna if so desired. These antennas are manu-

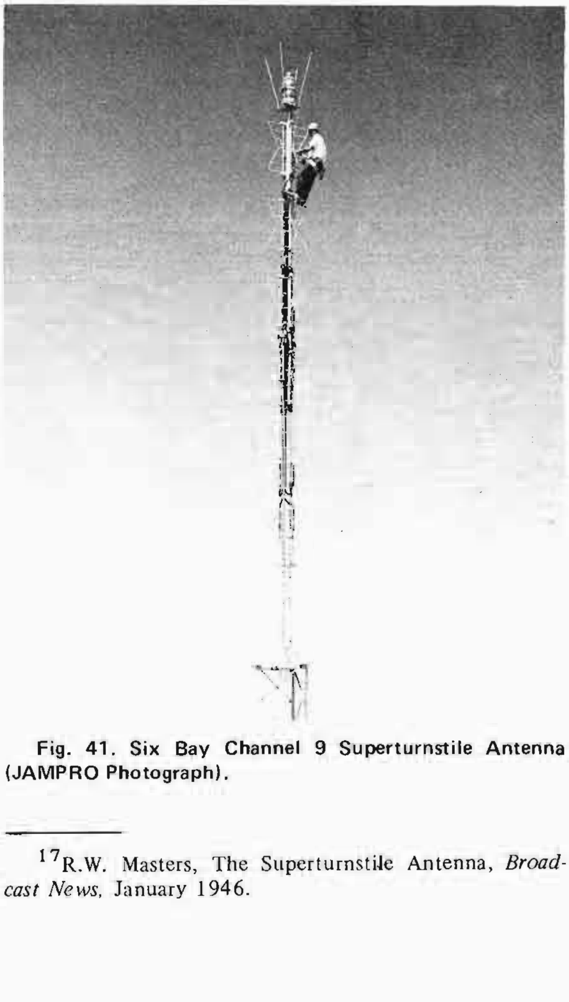

Fig. 41. Six Bay Channel 9 Superturnstile Antenna (JAMPRO Photograph).

[17] R.W. Masters, The Superturnstile Antenna, *Broadcast News*, January 1946.

factured in various gains from 3 to 12 for Channels 2 to 6 and 6 to 18 for Channels 7 to 13.[18] They can also be obtained for various types of null fill[19] (see under Vertical Patterns) and wind loading. They have also been used in stack and candelabra installations.[20] Antennas can be split by the use of additional junction boxes for emergency use and for other purposes. Elliptical azimuthal pattern can be obtained by changing the power division between the north-south and east-west planes. This antenna can also be used for two channels. A number of them are operating at Channels 4 and 5 and also in various combinations in the Channel 7-13 range. Copper feed lines instead of aluminum are available in areas where salt incrustation occurs but where there is insufficient rain to wash it off. Feed lines in both 3/4-in. and 7/8-in. sizes are available depending upon the power rating required. Special antennas can be built for higher power ratings. This antenna is currently manufactured by General Electric, JAMPRO, and RCA.

Alford Delta-Dipole Antenna

The delta-dipole antenna (see Fig. 42) consists of specially shaped, broadband dipoles mounted on reflecting panels. This special shape, which gives the dipole a delta-wing appearance, increases the effective area of the dipole arms,

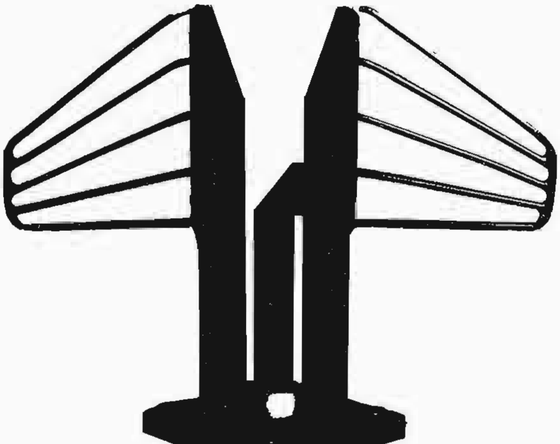

Fig. 42. Delta Dipole Antenna (Alford Photograph).

thereby increasing the bandwidth of the dipole without substantially increasing its resistance to wind pressure. Groups of dipoles and panels are arranged as required, both horizontally and vertically, so as to produce the desired horizontal and vertical radiation patterns.

This antenna lends itself to situations where it is necessary to mount an antenna around a tower or to stack several antennas one above the other. Because of its bandwidth, the delta-dipole also lends itself to situations where it is desirable to combine more than one channel in a single antenna. Both omnidirectional and directional horizontal radiation patterns may be achieved by the proper choice of power division and element phasing between dipoles in any given layer.

Because the distance between the radiating element of the dipole and the reflecting panel is large (of the order of one-quarter wavelength), ice on the reflecting panel has no significant effect on the operation of the antenna, and only parts of the dipole itself require deicing.

AMCI Slotted-ring Antenna

Description. The AMCI slotted-ring antenna is designed for VHF television broadcast transmitting service. It consists of a series of slotted rings mounted on a channel as shown in Fig. 43. The rings are lenticular in cross section with the long axis in the plane of the rings so that the wind resistance of the structure may be as low as possible. Two rods are mounted to the rings, parallel to each other, one along each side of the open portion of the rings to form a continuous slot and to act as a balanced transmission line. Fig. 44 shows a larger portion of the slotted-ring antenna mounted on a supporting mast. In certain instances, the antenna can be mounted directly on the side of a tower.

Each bay consists of two radiating elements ("half bays") arranged one above the other and

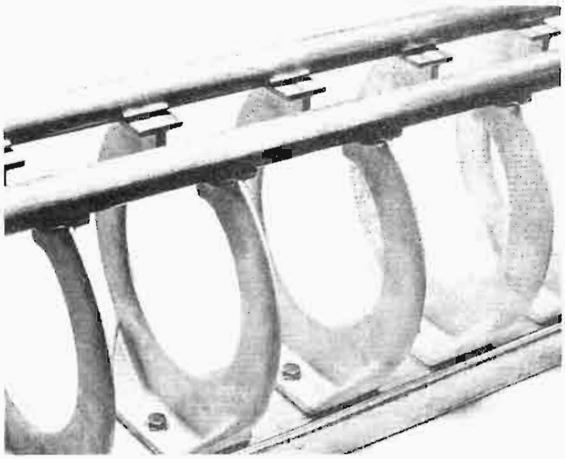

Fig. 43. Portion of a slotted-ring antenna.

[18] H.H. Westcott, New 50 KW VHF Superturnstiles, *Broadcast News,* May–June, 1953.

[19] Irl T. Newton, Jr., and H.H. Westcott, The New 12BH High Gain Antenna, *Broadcast News,* March–April, 1954.

[20] Matti Siukola, Predicting Performance of Candelabra Antenna by Mathematical Analysis, *Broadcast News,* October, 1957. R.H. Wright and J.V. Hyde, The Hill-Tower Antenna System, *RCA Engr.,* August–September, 1955.

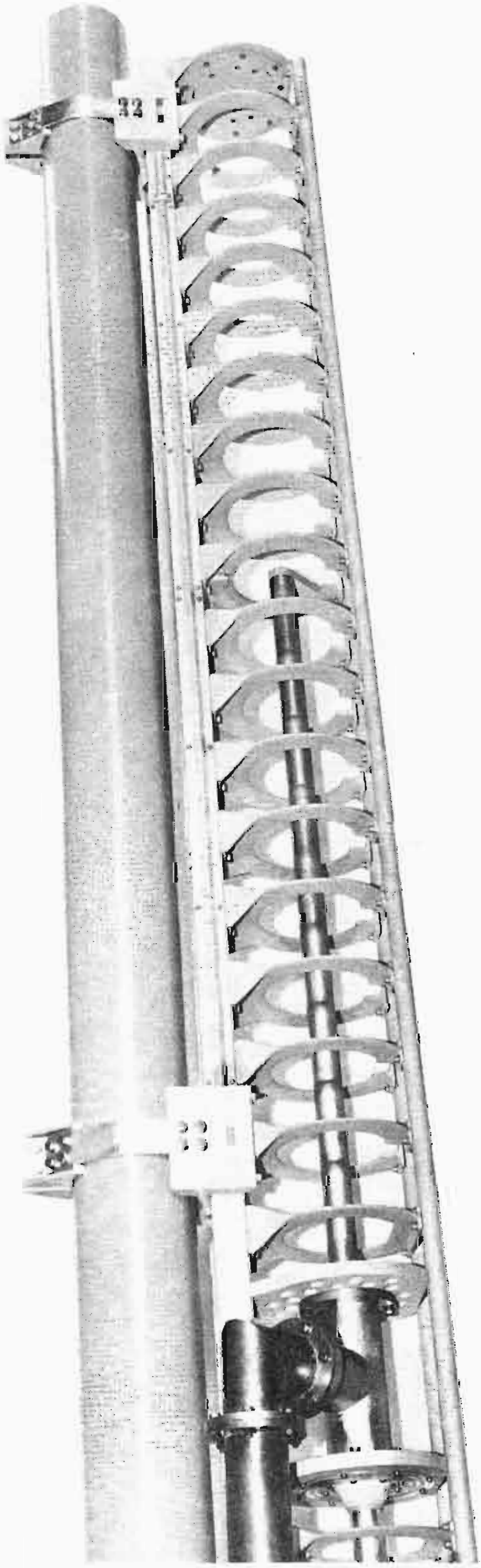

Fig. 44. Portion of a slotted-ring-antenna bay.

fed with a single 3-1/8-in.-diameter rigid coaxial transmission line.

The antenna is provided with a feeding arrangement of a type which enables each bay to handle high power and allows the entire exposed feeder along with every other active part to be deiced. When necessary, tubular sealed heaters are supplied as a part of the antenna for deicing purposes.

Each bay is approximately 3.4 wavelengths long and has an average power gain of approximately 4. As many as five bays can be stacked one above the other to give additional gain, the gain being proportional to the number of bays used.

When several bays are stacked to give a higher gain, they are joined through the use of a rigid coaxial transmission-line harness into a single feed line for the entire array. This type of feed requires only a single transmission line from the transmitter up the tower to the array.

Null fill-in and/or beam tilt, where required, are achieved through the proper selection of line transformers and transmission-line lengths in the coaxial feed lines between the bays.

The horizontal-radiation pattern of the slotted-ring antenna itself is essentially circular, with slight maxima along a diameter which passes through the slot of the antenna and with slight minima at approximately right angles to this diameter as shown in Fig. 45a. Since the potential at the point of attachment to a supporting mast is small, masts of adequate size can be used without substantially affecting the operation of the antenna or its horizontal circularity.

Directional horizontal-radiation patterns are achieved by the addition of pattern-shaping members to the basic antenna. Usually, there are two beam-shaping members connected to each alternate active ring in a directional antenna. The rings provided with these members act differently from simple rings in that a substantial portion of the current which normally flows in a ring is

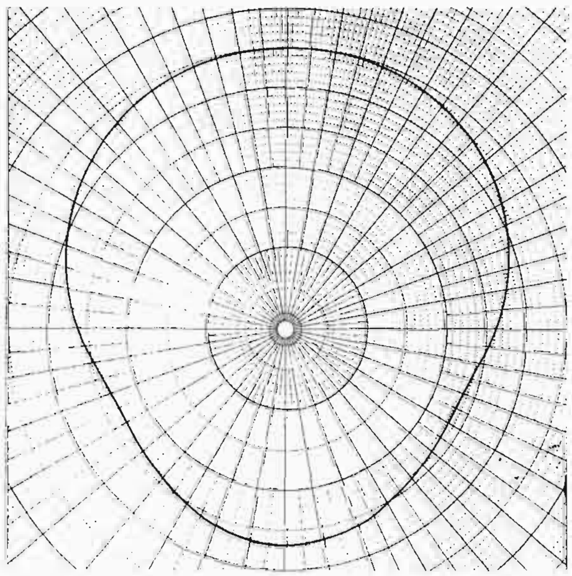

Fig. 45a. Typical omnidirectional horizontal radiation pattern, relative field.

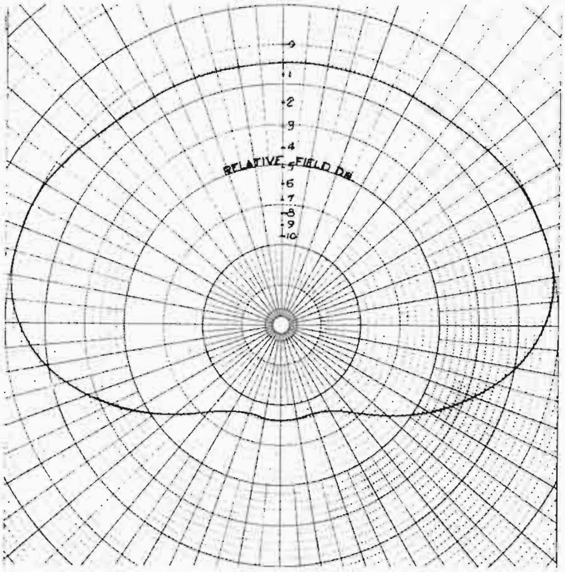

Fig. 45b. Typical directional horizontal radiation pattern, relative field.

directed into the beam-shaping member. The radiation pattern of a directional-antenna bay, then, depends on the configuration of these additional members and on the proportion of modified loops. Fig. 45b shows a typical directional horizontal pattern of a modified slotted-ring antenna.

Theory of operation.[21] The operation of the slotted-ring antenna can best be understood by considering a balanced transmission line shunted by a number of small loops or rings. It is possible by arranging the separation and cross-sectional area of the rings substantially to increase the phase velocity at which a high-frequency wave is propagated along the transmission line. Fig. 46a shows such a loaded transmission line which has been short-circuited at one of its ends and is fed with an RF source at the other. The standing waves which are set up along the line have an apparent wavelength, λa. When the number of rings along the balanced transmission line is of the order of 12 per free-space wavelength and the diameter of each ring is of the order of 0.14 free-space wavelength, the apparent wavelength will be approximately twice the free-space wavelength.

If this same arrangement is fed at the center through a length of transmission line as shown in Fig. 46b and short-circuited at both ends, then a wave propagates from the center feed point toward each of the two short circuits. The reflections from these short-circuited ends set up a standing

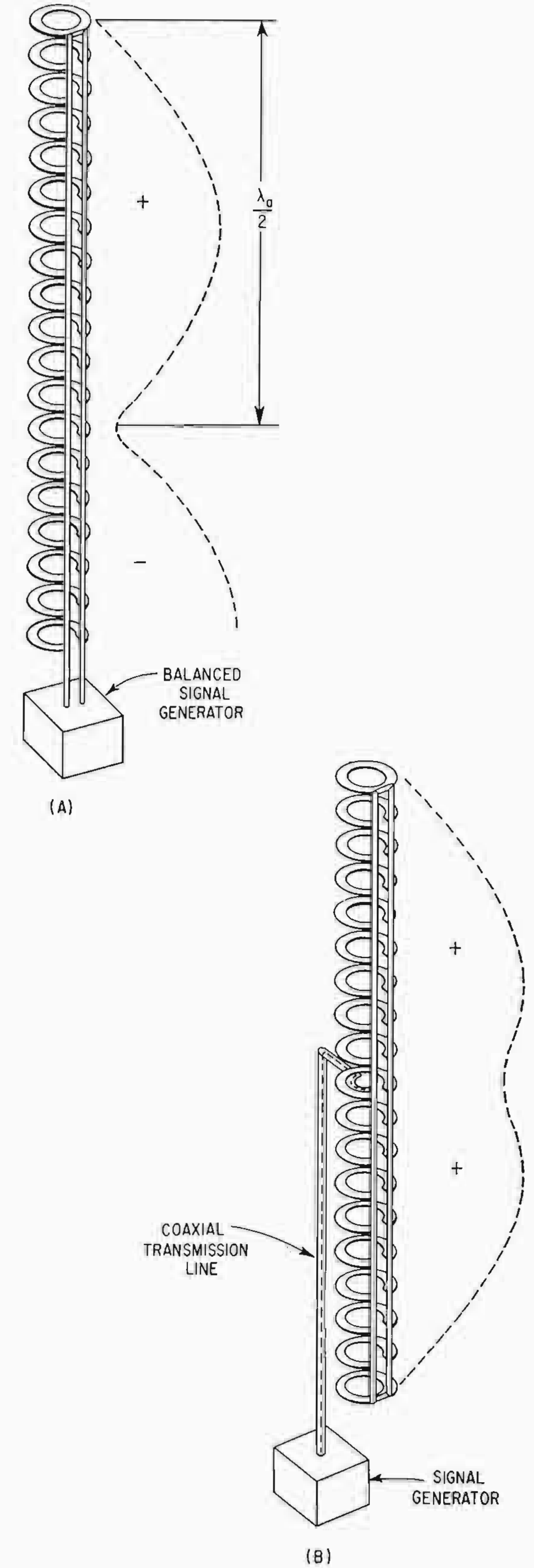

Fig. 46. (A) Balanced transmission line loaded with shunt rings. (B) unbalanced transmission line loaded with shunt rings.

[21] A. Alford and H.H. Leach, High-gain Antenna Arrays for Television Broadcast Transmission Using a Slotted Ring Antenna, *IRE Conv. Record,* part 7, pp. 87–94, 1956.

wave, and the difference of potential between the conductors of the balanced transmission line is distributed approximately as shown by the dotted line. The phase of this difference of potential is substantially constant over the entire length of the line.

The potential which exists between the balanced conductors causes circumferential currents to flow in the shunting rings. Since the potential and hence the currents are very nearly cophasal, the overall behavior of the loaded line is similar to that of an array of closely stacked loops. This fact results in a substantial concentration of the power radiated by the rings in the direction of a plane passing through the halfway point along and perpendicular to the balanced conductors.

Construction. Corrosion-resistant aluminum alloys, both wrought and cast, are the primary materials of construction in the AMCI slotted-ring antenna. Stainless-steel screws and bolts are used throughout the antenna. The total weight of a bay is approximately 300 lb. when designed to operate at Channels 7 or 8, with the higher channel bays weighing slightly less.

There are two Teflon seals per bay. The diameter of the inner conductors which pass through these seals is approximately 1-3/4 in. The outer-conductor diameters are approximately 3 in.

The antenna itself is designed to withstand wind velocities exceeding 200 mph and to present a small surface area to the wind. The antenna can be mounted on a standard mast (designed for a wind loading of 50 psf on projected flat surfaces), on special masts (designed for larger wind loadings), or, in certain instances, on the corner of a tower.

GE VHF Helical Antenna General Description

The VHF helical antenna is essentially a coil of uniform pitch wound around a usually round mast section. A left-hand and a right-hand helix are used, joined at the center.

In operation, a radio-frequency wave is established which travels between the helix wire and ground "plane" formed by the mast. The wave thus travels circumferentially around the mast, turn after turn. It progresses axially up or down the mast because of the pitch of the helix.

The antenna is designed to radiate in "side-fire" fashion, that is, the beam maximizes at right angles to the helix axis. In order to have successive turns of the helix work together to give additive side-firing fields, each helix turn has a circumferential length equal to an integral number of wavelengths. The two-wavelength turn is most commonly used because it yields good structural dimensions.

While the wave travels circumferentially around the helix, it radiates power and becomes attenuated. The attenuation rate depends on the spacing of the helix coil from the mast. A value of attenuation of 3 to 6 dB per turn is used, depending on the channel, gain, and bandwidth requirements.

In traveling axially up or down the helix, the radiating wave distributes the radiation over the length of the helix. This results in excitation of a fairly large aperture from a single feed point and so gives a considerable gain per feed point. Nominal values of gain per feed are between 3 and 5 rms over a dipole. This makes it possible to simplify the feed harness because of the fewer number of feed points required for high-gain antennas.

The turn-to-turn phase of the radiating traveling wave determines how well the side-fire beam is formed. This phase varies as the frequency changes from its optimum center value. Over a certain frequency range, there is a mode over which the beam formed is quite uniform in its main characteristics. Outside this range the beam broadens and gradually breaks up. The frequency range over which a certain sized helix can be used depends on its attenuation rate and number of turns. For example, a helix pair giving a gain of 5 per feed forms a good beam over about 6 to 7 percent frequency range. For a gain of 3 per feed, this increases naturally to about 10 percent. The beam-forming bandwidth can be increased further by suitable electrical "loading" of the helix, which alters its phase-velocity versus frequency relationship.

The radiating traveling wave does give very good VSWR characteristics because there is very little resonant energy in the helix. The wave energy reflected from the ends of the helices is down about 40 dB when it returns to the feed, and so it affects the feed impedance very slightly.

In those cases where horizontal directional patterns are desirable, the azimuthal radiation of the helix can be modified. This is usually done by attaching radial or tangential stubs directly to the helix. These stubs are short compared with a wavelength and are nonresonant.

To maintain optimum performance under icing conditions, the helical antennas can be provided with deicing means. The helix itself, being made of copperweld material, is used as the heater. Several hundred amperes of 60-cycle current are caused to flow through the helix from a transformer located at the tower top. A nominal deicing power density of about 2 watts per square inch of helix is used for normal conditions.

High-channel helical antenna, Channels 7 to 13, specific description. These antennas are built in a standard series by General Electric. Gains vary from 4 to 18, from one to four bays being used.

The mast is made from 20-24 in.-diameter steel tubing or piping, varying in thickness from 1/4 to 3/4 in. for different sections.

The helix is made from 0.365-in.-diameter copperweld material. It is supported on insulators made from Teflon or PPO. A low-loss, low-dielectric-constant material is preferred. Height of the insulators is adjustable to accommodate helix-diameter changes needed for on-channel moding.

Feed systems provide either single or two-line feed up to four bays. The standard feed harnesses use 3-1/8-in. EIA-type line as a minimum. The one-bay antenna may use 6-1/8-in. lines to permit full ERP operation from one bay, say with a 100-kw transmitter.

Nominal feed impedance at the helix is about 100 ohms. A quarter wave of 70-ohm line is used to transform this to the 50-ohm EIA standard. An elbow with end-seal mounts through a hole in the mast provides means for attaching and feeding the helix.

Mechanically, the feed harness is so arranged that pieces of harness can be lowered inside the mast after loosening bolts from outside the mast only. Fig. 47 shows a three-bay, high VHF band, helical antenna.

Traveling-wave Antenna

The traveling-wave antenna embodies principles found in the operation of the superturnstile, the slot antenna, and the helix but employs these principles in a manner which results in its being different from any of them.

In form the antenna is a coaxial line, with pairs of slots in the outer conductor spaced at intervals of a quarter wavelength throughout its length. Probes at the center of each slot distort the field

Fig. 47. Three bay, VHF high band Helical Antenna (GE Photograph).

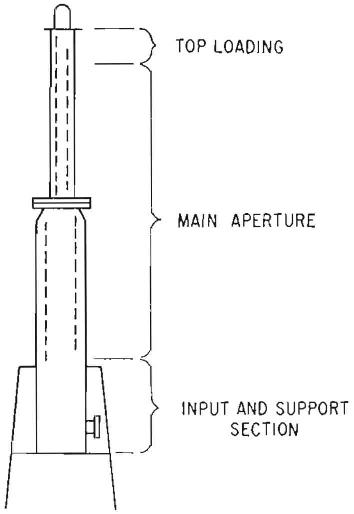

Fig. 48. The traveling-wave antenna-external appearance.

within the line to place voltages across the slots. These, in turn, drive currents on the periphery, setting up a radiated field. Attenuation of the signal by withdrawal of a portion of the power at each slot reduces it to a very low value at the upper end of the antenna. There, a special pair of slots, designed to match the line, extracts the remaining portion and radiates it.

Fig. 48 shows the physical shape of the antenna. The signal, entering through the input section (normally in the buried portion below the tower top), is progressively attenuated as it passes through the main aperture. The portion reaching the top is radiated from the "top-loading" section.

Fig. 49 shows cross sections of the antenna in the three main portions. It will be noted that the

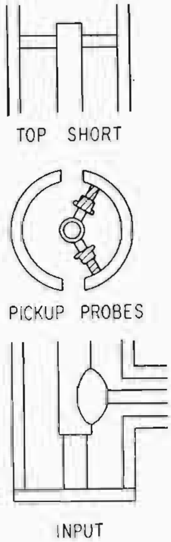

Fig. 49. Cross section of traveling-wave antenna at input, aperture, and top.

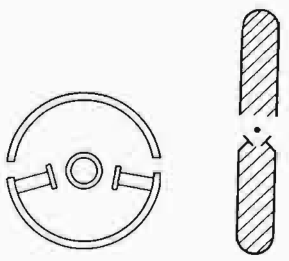

Fig. 50. Cross section of traveling-wave antenna at a slot pair level, showing resemblance to a dipole.

entire inner connector is supported by the base plate of the antenna and can be removed through this base.

Operation of the antenna can be better understood if the section of the aperture having pairs of slots are recognized as being, in effect, dipoles. Fig. 50 shows this similarity.

Successive pairs of slots are alternately in one plane and in another at 90° to it, so that the antenna can be simulated by stacked dipoles with a 90° angle between successive layers.

In a given plane, reversal of the direction of feed every half wavelength (by placing the probes on opposite side of the slots), together with the half-wave change in phase of the signal as it passes along the aperture through this distance, results in all the "dipoles" in that plane being fed in phase. The same action takes place in the other plane except that they are fed 90° out of phase with the first plane owing to their 90° displacement along the antenna. The result is shown in Fig. 51.

Each plane of dipoles radiates essentially a figure-eight pattern. Since the planes are fed in quadrature, addition of the patterns results in a circular pattern, as outlined under Azimuthal Patterns. Because of the circular cross section and the lack of obstructing radiators, the resulting horizontal pattern is almost a true circle, varying from circular by only about 0.5 dB in a typical case.

As slot spacing is actually 90° only for a specific frequency in the channel, variation in frequency across the channel would be expected to result in a progressive lag or lead in the signal as radiated from successive slots inasmuch as the spacing becomes greater than 90° for higher frequencies and less than 90° for lower frequencies. Correction for this effect would obviously be accomplished if, at each slot pair position, another circuit element were added which, with change of frequency, had the opposite effect on the phase.

Such an element is available in the form of a parallel-resonant circuit with resistive loading with its familiar reactance characteristics (Fig. 52). The resistive portion is the radiation resistance.

In the region between 1 and 2 (Fig. 52), increasing frequency results in a lower inductance (higher capacity) while decreasing frequency yields a more inductive circuit. If this circuit is placed across the transmission line at a slot position, the effect will be to cause the voltage at this position to lead the voltage at the preceding slot at high frequencies and to lag it at lower frequencies within the frequency range 1 to 2 (Fig. 52).

By adjustment of the values of inductance and capacity the slope of the response curve can be changed until a compensation is obtained over a considerable frequency range for the apparent change in line length between slot pairs due to frequency change.

The above circuit is obtained by shaping the slots to obtain the required value of inductance and capacity, the length of the slot and the shape of the end portions controlling the former and the width of the slot at the center of the latter.

A further control of the phase at each slot is obtained by the insertion between slots of compensating probes. By means of these, the phase can be made progressively more lagging from top to bottom, bringing about a downward tilt of the main beam if desired.

Omission of particular slot pairs is a method which has been used to obtain special effects such as reduction of signal at a particular angle in the vertical plane to "protect" areas where radiation is undesirable. Such a situation has arisen where important radio-frequency measurements on

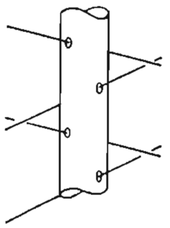

Fig. 51. Stack of half-wave dipoles which traveling-wave antenna resembles in operation.

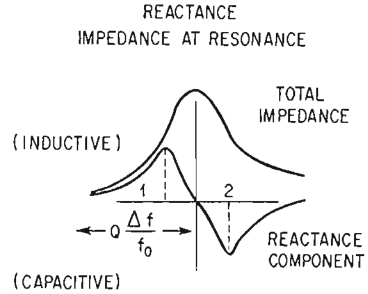

Fig. 52. Universal curve (high-Q parallel-resonant circuit).

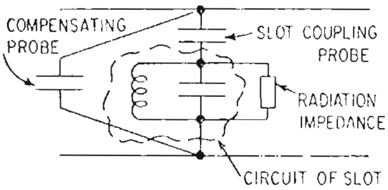

Fig. 53. Equivalent circuit of one slot pair section of traveling-wave antenna.

equipment being manufactured in a particular location would have been disturbed by the reception of television signals.

This equivalent circuit of each layer is shown in Fig. 53.

VHF Zig-Zag Antennas

The general principle is the same as that described under the UHF section on Zig-Zag antennas.

The Empire State Building in New York City has a GE installation on Channel 11 and an RCA installation on Channel 7. The length of the aperture is about four wavelengths in each case. There is also an RCA installation on Channel 9 in the John Hancock Center in Chicago. The length of the aperture in this case is six wavelengths. Another RCA installation is at KCRG which has two six-wavelength panels for a total gain of 12. The gain is about equal to the aperture in wavelengths.

The coupling probes are all set at the same depth. As a result, the same percentage of power arriving at the slot location is picked up and radiated at each slot. The amount of power so radiated is therefore decreased exponentially from the bottom to the top of the antenna, giving the effect of a constantly changing power division except for the elimination of slots necessary for the insertion of flanges, and for the change at the top-loading slots. The result is a smooth vertical pattern without any nulls. The flanges and top loading cause a small ripple in the pattern, but the effect is slight. Fig. 54 shows a typical vertical pattern of a traveling-wave antenna with a gain of 12.

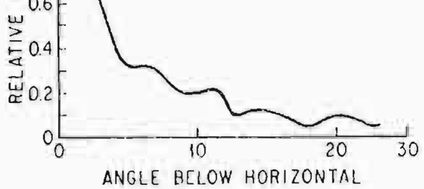

Fig. 54. Vertical field pattern of traveling-wave antenna with gain of 12.

Because the slots are a quarter wave apart, giving an impedance-compensating effect similar to that of insulators similarly spaced in a coaxial transmission line, and because the slots are only lightly coupled into the line, there is almost no reflected energy returning to the input of the antenna. The action of the top loading further reduces the chance of energy reflection. As a result the standing-wave ratio at the input is inherently low, and no input-matching transformers are required to broadband the impedance.

As the antenna is primiarly a large-size transmission line, the power-handling capacity is very high.

The antenna tubing is of steel, hot-dip galvanized. The inner conductor is copper tubing. Hardware is of stainless steel with the exception of the probes, which are of aluminum treated to resist atmospheric corrosion. The slots are covered with polyethylene covers to keep out rain, snow, and ice.

Fig. 55 shows a portion of a traveling-wave antenna being lifted to the test platform for a check of the attenuation and phase velocity. This type of high support is used to ensure that no errors are introduced by reflection from the ground. The shape of the slots employed to obtain the electrical compensation referred to above is shown.

UHF Antennas

There are three general types of antennas in the channel range from 14-70. These are the slotted cylinder types, helical types and panel types.

Slotted cylinder types. These antennas consist of a self-supporting pole using vertical slots as radiating elements. Energy is coupled to the slots

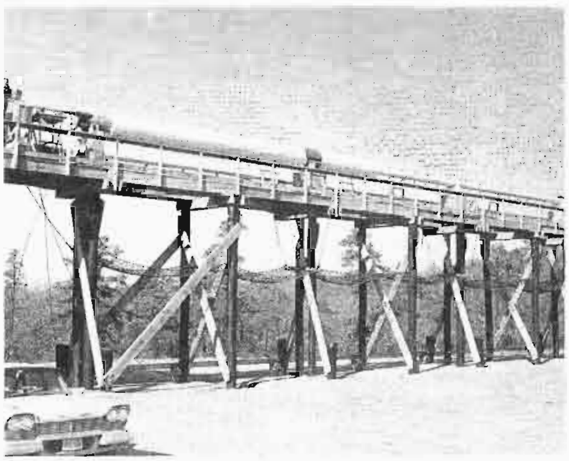

Fig. 55. Impedance Test of high band VHF Traveling Wave Antenna (RCA Photograph).

either conductively, inductively, or capacitatively from the feed system inside the cylinder so that a voltage appears across the slot. This causes currents to travel around the cylinder at right angles to the long slot dimension which generates an RF field which is horizontally polarized. The amount of cross polarization is quite small with this type of antenna. If the path around the cylinder is of such length that the current attenuates appreciably owing to radiation, the circularity is affected. Advantage is taken of this fact in designing directional antennas. To maintain the circularity required, a number of slots simimlarly fed are used at the same level. The antenna has considerable versatility in gain, beam tilt, vertical and horizontal patterns and also in power input ratings.

RCA UHF pylon antenna—gain. These antennas are built with gain values from 6 to 46. Two general types of vertical patterns are used which are designated as filled and shaped (see Fig. 4 and 5). In the filled pattern, there is one slot for each wavelength of height and the gain is approximately equal to the number of wavelengths depending upon the null fill as shown in Fig. 4 where there are 31 slots for 31 wavelengths of height. For the shaped pattern where the end layers radiate less energy—to eliminate the lobes and nulls in the fill area of the pattern—the number of layers must be somewhat higher to achieve the same gain.

Vertical patterns. A positive method of increasing the radiation at angles below the main beam is required since an antenna in which all of the radiators have equal amplitude and phase has complete nulls at periodic intervals as shown on Fig. 56. In a filled pattern, the odd nulls (1, 3, 5, etc.) are filled by power division. The even nulls are filled by the phase differential which occurs when beam tilt is introduced by shifting the feed point at the center of the antenna upwards (see Fig. 4).

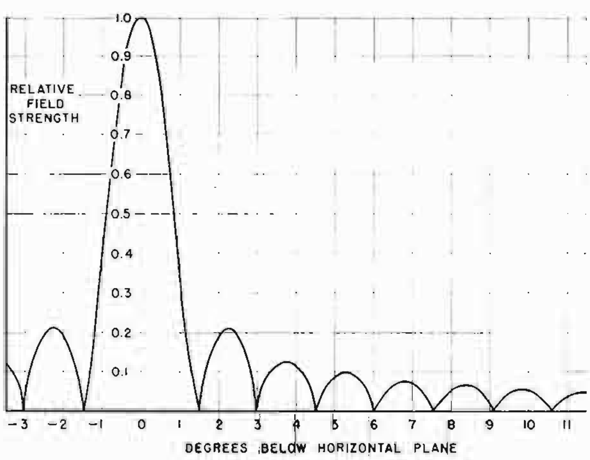

Fig. 56. Vertical pattern of an antenna having uniform distribution for an aperture of 38 wavelengths with sources in phase.

For higher gain null filled antennas, a multi-step illumination with special phasing can be used to achieve patterns in which the nulls and peaks are minimized and which have very high aperture efficiencies. A pattern of this type is shown in Fig. 57.

In a shaped pattern, in which the nulls and lobes are practically eliminated, a binomial distribution[22] is used as shown in Fig. 58 which results in a smooth vertical pattern as shown in Fig. 59. By a proper phase distribution[23] as shown in Fig. 60, a smooth vertical pattern as shown in Fig. 61 can be obtained with the required beam tilt. Fairly close correlation between calculated and measured patterns can be achieved.

Horizontal patterns. For an omnidirectional pattern a good circularity (± 1dB or lower) can be achieved by using the proper number of peripheral slots in a given layer. Commonly used directional patterns can easily be obtained by the use of one, two, or three slots which provide patterns as shown in Fig. 62. These patterns are

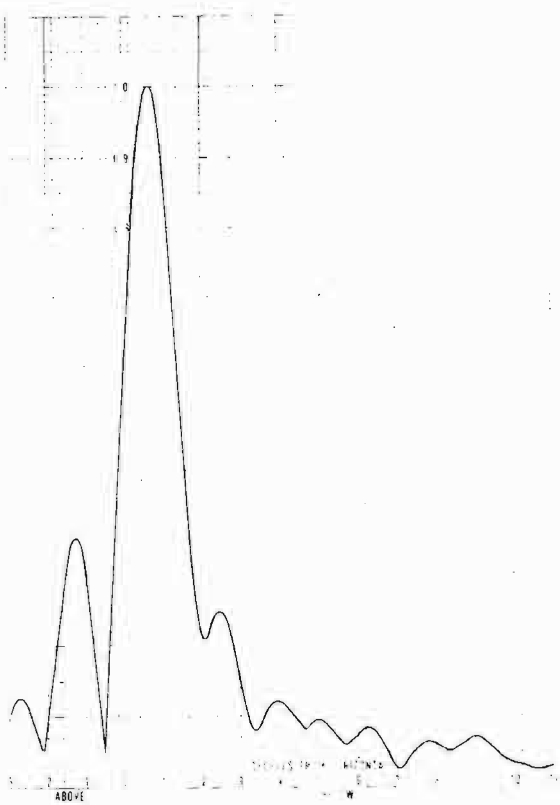

Fig. 57. TFU 50J antenna with a multi-step illumination with a gain of 44.

22 Kraus, *Antennas* Chapter 4 p. 94.

23 P.M. Woodward, A method of calculating the field over a plane aperture required to produce a given polar diagram. *Proc. Inst. Elec. Engrs.* London, 1946.

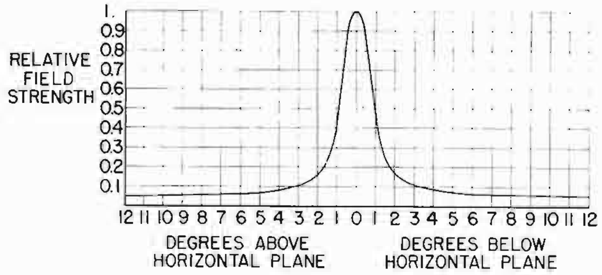

Fig. 58. Binominal distribution.

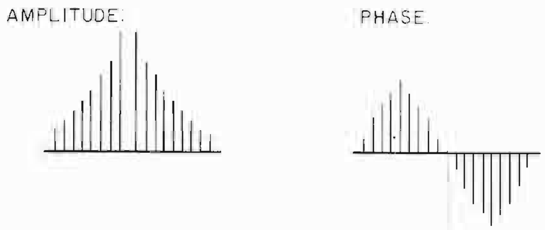

Fig. 59. Vertical pattern resulting from binominal distribution.

produced by currents flowing around the periphery of the antenna and can be calculated using classical methods. A slight variation from the calculated pattern occurs due to the phsyical width of the slot.

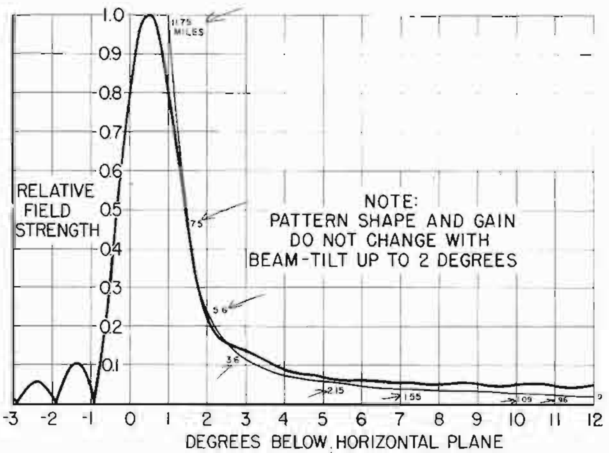

Fig. 60. Amplitude and phase distribution required to achieve a smooth pattern with minimum radiation above the horizon.

Power capability. A cross section of a typical UHF Pylon Antenna is shown in Fig. 63. The copper feed system is a single tube with a feed point near the center. Power is transmitted to the center through the lower portion which functions as a continuation of the transmission line. At the end seal, the power divides and propagates in the space between the copper feed system and the outer galvanized steel tube in a TEM mode. The

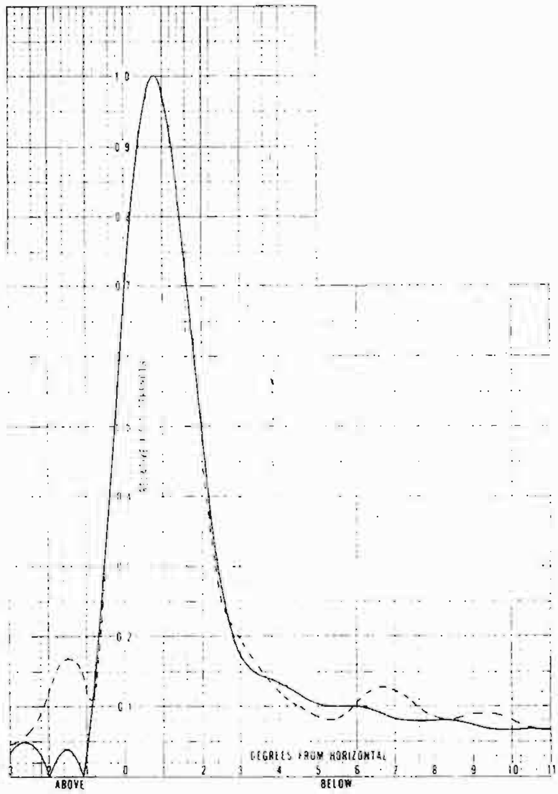

Fig. 61. TFU 35G antenna with calculated and measured values using the shaping techniques described.

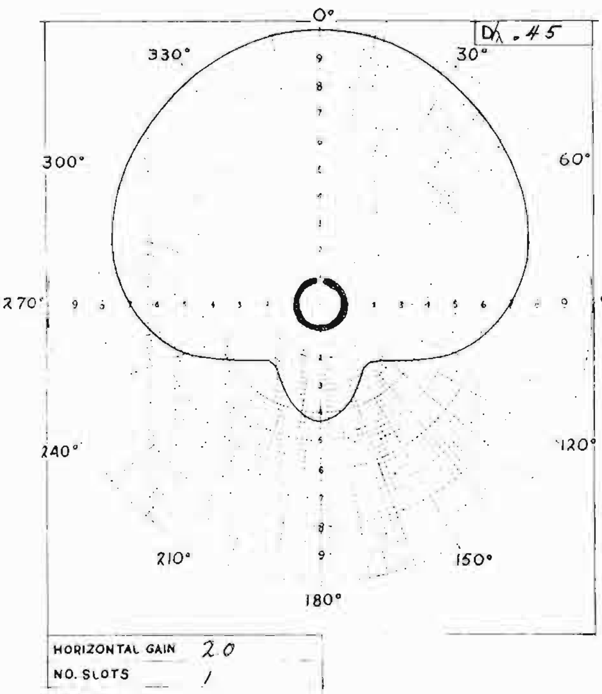

Fig. 62. Horizontal patterns achievable with slotted cylinder antennas using one, two, and three slots.

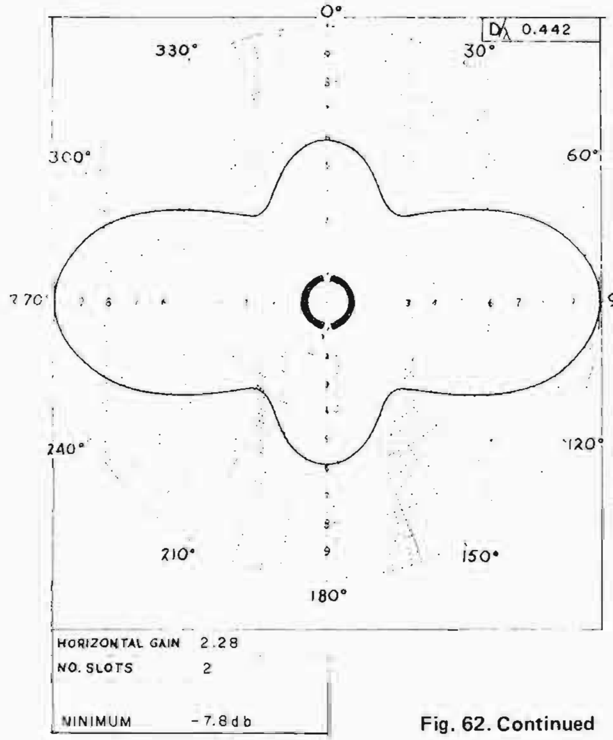

Fig. 62. Continued

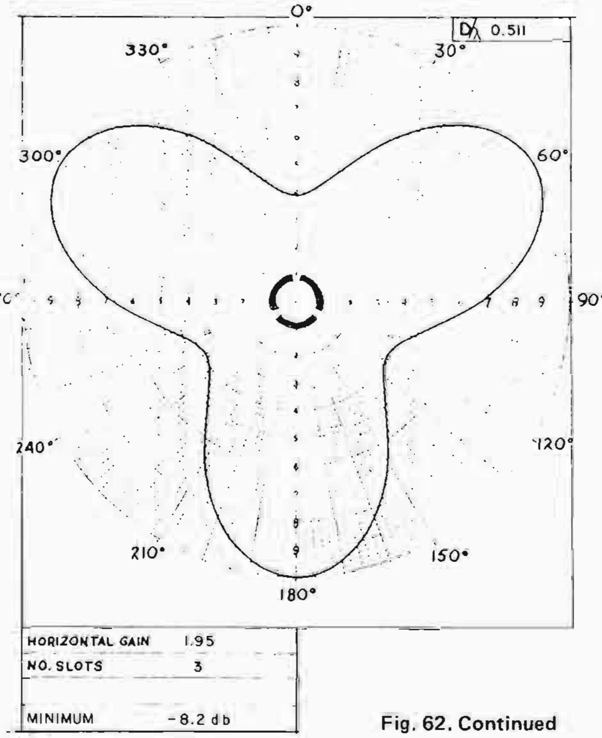

Fig. 62. Continued

energy is capacitatively coupled to the slot through cylindrical couplers placed adjacent to the slot (see Fig. 64). The power rating is determined by the diameter of the feed system.

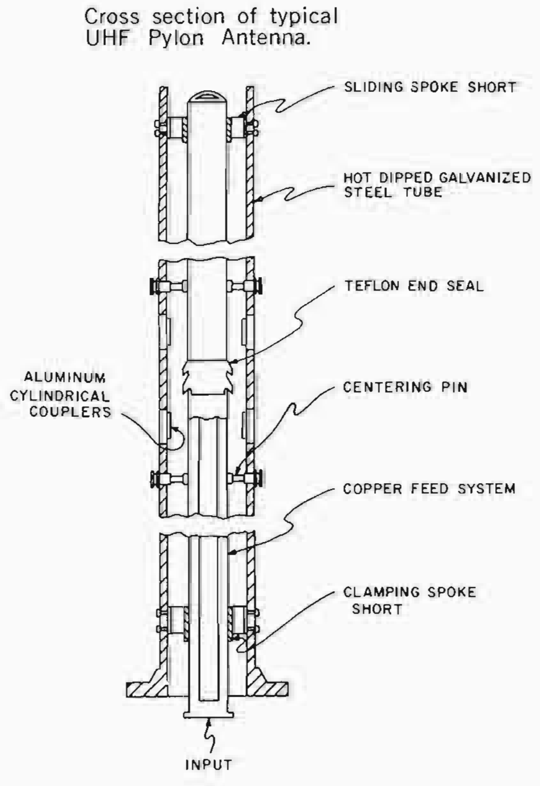

Fig. 63. Cross section of UHF Pylon Antenna.

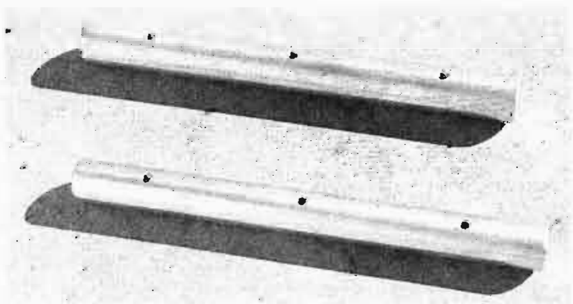

Fig. 64. Cylindrical coupling elements used in slotted cylinder antennas.

A TFU 46K antenna is shown in Fig. 65 as it is being transported to the turntable for pattern test.

Amplex UHF slotted cylinder antenna. Another type of slotted cylinder antenna is built by Ampex

Fig. 65. TFU 46K antenna being moved to the turntable location for pattern test.

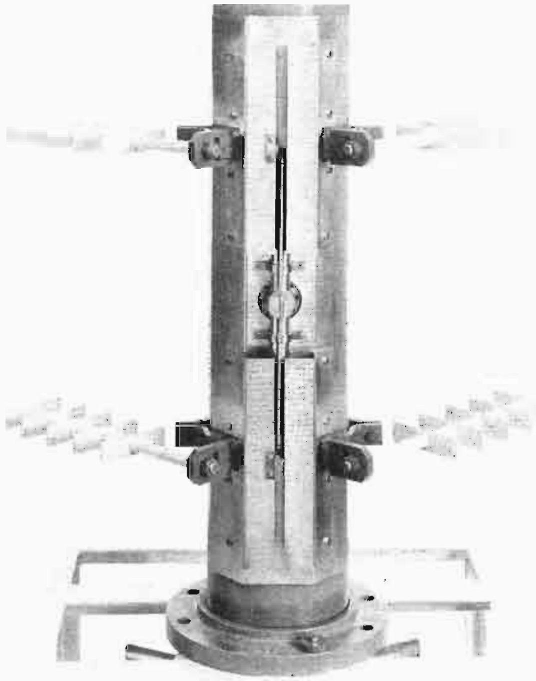

Fig. 66. Ampex Slot-Director UHF antenna. Parasitic directors are used to achieve a variety of patterns including omni-directional.

which is known as the "Slot-Director Antenna." This antenna requires only one slot for approximately one wavelength of height. An omnidirectional pattern of ± 1-1/2 dB as well as a wide variety of directional patterns are achieved by the use of parasitic (nonfed) end fire type "director." These are placed around the cylinder near each slot as shown in the photograph Fig. 66. The design and pointing of these directors determine the type of horizontal pattern achieved.

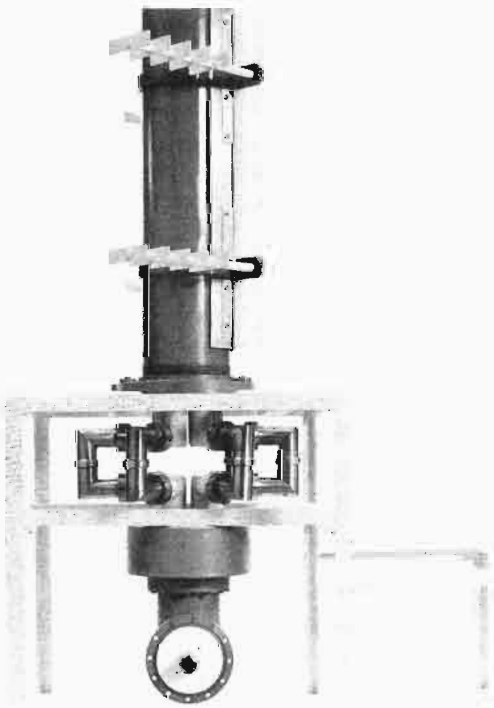

Fig. 67. Branching feed system used with Ampex Slot-Director Antenna.

Since there is only one feed point per layer, a power divider shown on Fig. 67 below the antenna permits feeding several layers with a separate feedline which permits flexibility in feed choices.

Alford Long-Slot UHF Antenna. The long-slot UHF antenna is a high-frequency version of the VHF slotted-ring antenna previously described with the principle difference being that the series of rings utilized in the slotted-ring antenna is replaced with a continuous sheet in the form of a slotted cylinder. The basic long-slot element therefore consists of a single continuous slot in a cylinder having a diameter of approximately 0.14 wavelengths and a length of approximately 1.7 wavelengths. The rms or average gain of each element is approximately 2. These cylinders are stacked one above the other to achieve the vertical gain desired and are supported by a cylindrical mast or by a specially designed truss or, in some instances, directly by the leg of the tower.

As many as 36 elements can be stacked providing vertical gains up to approximately 50 with null-fill. Shaped vertical patterns and/or beam tilt are obtained by varying the magnitude and phase of the signal fed to each element through the use of line transformers and different line lengths in the coaxial feed lines used to interconnect the elements. Fig. 68 shows the computed vertical pattern, based on measured element patterns, of an 18-element long-slot antenna when supplied with 1/2° of beam tilt and with a shaped vertical pattern.

Directional horizontal patterns are achieved by adding directionalizing sheets of "wings" to both sides of the slot. These wings divert a portion of the horizontal current that normally flows around

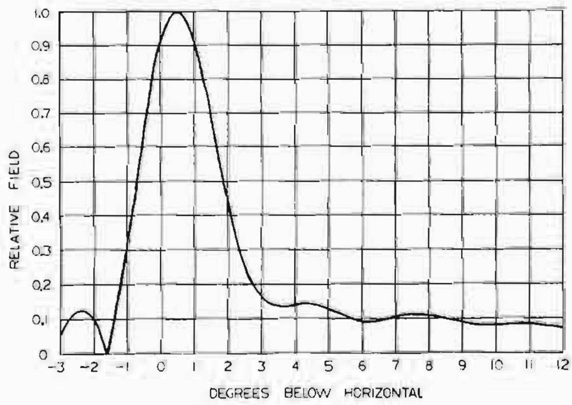

Fig. 68. Vertical field pattern of an Alford 18-element long slot UHF antenna with a gain of 25.

the basic cylinder from one side of the slot to the other. Since this diverted current contributes to the field radiated in the horizontal plane, the horizontal radiation pattern may be controlled by proper choice of wing shape and dimensions. Fig. 69 shows a 16-element directional long-slot antenna. The gain of this antenna in the direction of maximum radiation is 48.8 (16.88 dB).

Each element is covered with a radome to protect the slot from the effects of the weather. Where required, deicers can be supplied consisting of thin, vertical, high-resistance wires molded within each individual radome. These wires, when properly energized with a 60 Hz voltage, prevent the formation of ice on the radome and yet do not interfere with the horizontally polarized, radiated RF signal.

Fig. 69. A 16 element directional long-slot UHF antenna at Station WXTV, New York, N.Y. (Alford Photograph).

G.E. UHF Helical, General Description[24]

The basic operating principle of the UHF helical antenna is as already described under Helical Antennas. The UHF antenna differs from the VHF antenna primiarly in its method of feed. The helix is made from 0.247-in-diameter copperweld.

At UHF, the percentage of bandwidth becomes small, and it is feasible to end-feed the vertical array at least up to gains of 30. If matched condition is maintained along the feed as power drops off at the different bays, the beam will tilt with frequency an amount 57.3 F/fo degrees, where fo is the mid-frequency and F is the change in frequency relative to fo. With a gain of 30, a half-power beamwidth of about 1.8° is obtained and a ±1/4° tilt causes no difficulty.

UHF helical antenna, one to six bays. The basic UHF antenna bay has a gain of 5. Its length is varied with channel, so that its gain is constant. These bays are stacked together end to end, up to six.

Each bay is like a coaxial of about 90 ohms Zo, with a capacitive feed probe coupling out power to the helix. The top bay couples out all the power remaining. Impedance match is maintained throughout the feed for optimum impedance bandwidth.

Phasing of the bays relative to one another is done by relative rotation of the bays. (Because the wave travels circumferentially around, the phase varies with azimuth.) Swivel flanges are used to fasten the sections together to make this rotation easy to perform. Rotation of the upper one or two bays can even be done after erection for slight modification of pattern contouring if desired. Fig. 70 shows a typical UHF helical antenna.

Zig Zag Antennas

The zig zag principle was first disclosed by H. Chireix in "L'Onde Electrique" 7, 169, 1928. In 1952 O.M. Woodward used this principle in the design of a unidirectional antenna.[25] During the last five years the antenna has been offered by various manufacturers and is used for both VHF Channels 7-13 and UHF Channels 14-70.

It has two outstanding characteristics. One is, that a single feed point can excite an aperture of about eight wavelengths since the element itself has a dual function of radiator and feed system. It is basically a strip transmission line, but elevated

[24] *Electronics*, August, 1951, pp. 107–109.

[25] Patent No. 2, 759, 183 issued to O.M. Woodward–RCA.

Fig. 70. GE UHF Helical Antenna.

Fig. 71. Turnstables at Cazenovia Test Site (GE Photograph).

at a sufficient distance above the panel so that a controlled amount of radiation occurs. The radiation as in most traveling wave type antennas decays approximately in an exponential fashion, although this can be controlled by various means. Practically all types use radomes for weather protection.

The other feature is that it lends itself to a great variety of horizontal directional patterns in two ways. The panels facing in various directions can be excited at various amplitudes and phases, and the structure on which they are mounted can have 3, 4, 5, or more sides or have special diamond or other shapes. The panels can also be used for tangential firing around larger structures.

The antenna, as in all traveling wave types, has good impedance characteristics since the energy can be almost completely radiated without reflections by the use of various techniques. The following are descriptions of antennas of various manufacturers.

RCA Zee-Panel

The zip zag antenna is utilized by RCA to provide a variety of antenna systems. The Zee Panel Antenna Fig. 72 employs the basic zig zag element mounted on a panel. A special end-fed radiator at the far end of the element prevents reflections back to the center feed point. A variety of radiation patterns may be achieved with the appropriate arrangement and excitation of these panel radiators. Beam tilt may be obtained in each panel if required. Null fill may be achieved by proper phase and amplitude on each layer in the array and in some special cases in the individual panels.

RCA Vee Zee Panel

The Vee Zee panel antenna[26] shown in Fig. 73 is a Zee Panel antenna modified to achieve a broad horizontal pattern. Good horizontal circularity may be achieved in a special array of panels

Fig. 72. RCA Zee-Panel.

[26]U.S. Patent No. 3, 409, 893.

V-Z Panel as a side-mounted antenna—R.N. Clark and A.L. Davidson, *IEEE Transactions on Broadcasting*, January, 1967.

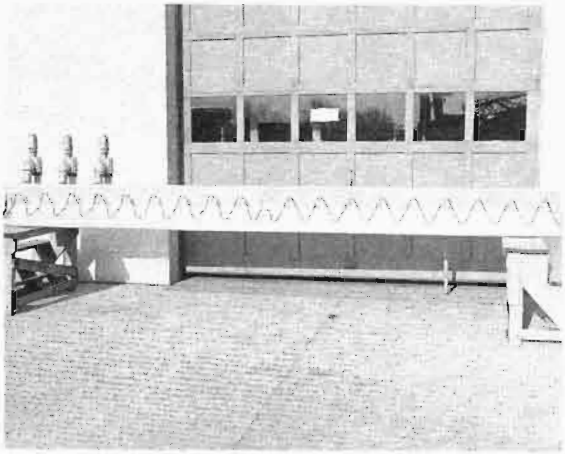

Fig. 73. RCA Vee-Zee Panel for tangential firing around towers.

mounted about a large triangular tower. The Vee Zee panel array is useful where it is desired to locate two or more separate antennas on a single tower.

RCA Polygon Antenna

The polygon antenna is another application of the zig zag antenna. The panels are welded together to form a self-supporting structure. At each layer, the feed points of each panel are electrically connected together with a strip-line network mounted to the supporting structure (see Fig. 74). A variety of horizontal patterns may be achieved with the design of the strip line network. Additional coax feed system lines connect the various layers at the proper amplitude and phase to achieve the vertical patterns desired.

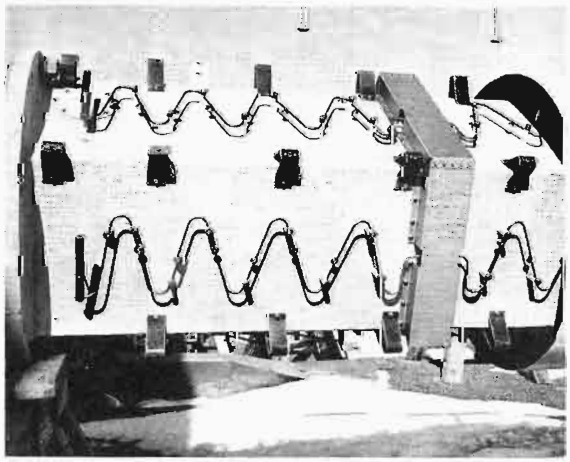

Fig. 74. RCA Polygon Antenna detail showing belt line, shell, and zig-zag construction.

G.E. Zig-Zag Panel Antenna, General Description

A panel consists of two Zig-Zag conductors bent at approximately one-half-wave intervals. The conductors are spaced about one-eighth wavelength from a rectangular mounting panel and fed at their junction at the center of the panel. Each panel is ordinarily about eight wavelengths long.

The radiation pattern of a single panel has a half-power vertical beam width of about 7.5 degrees and a horizontal beam width of about 65°. The shape of the horizontal pattern approximates a cosine-squared function.

The zig-zag panel design forms an excellent building block for directional antenna arrays.[27] Used in an array or as a single section it is often desirable to employ vertical beam contouring and electrical beam tilt for each individual panel to attain high power gain efficiency. A typical Zig-Zag antenna is shown during pattern measurements in Fig. 75.

Beam shaping is attained by using an amplitude and phase distribution over the single panel to suppress the unwanted energy above the main beam and to tilt the main beam to a desired depression angle below the horizontal.

Distributed loading of the radiating element and incremental length changes of the distance between corners are used to control the amplitude and phase distribution of the current along the panel.[28] The feed point impedance may be transformed to a convenient value such as 50 ohms by the use of a special design coupling strap to connect the radiating elements to the feed bushing.[29] Although the usual panel length is about eight wavelengths this length may be decreased to three wavelengths or so for special applications.[30]

JAMPRO UHF Zig Zag Antennas

This antenna consists of a number of panels arranged around a steel supporting tower as shown in the photograph Fig. 76. Each panel may be treated as a separate unit of the antenna. Great flexibility of horizontal and vertical patterns is available. Each panel has an eight-wavelength

[27] "Directional Zig-Zag Antenna at KERO-TV, Bakersfield, California," K.B. Hoffman and R.E. Fisk. *IEEE Transactions on Broadcasting,* Vol. BC-10, February, 1964.

[28] US Patent No. 3, 369, 246.

[29] US Patent No. 3, 375, 525.

[30] *Empire State Zig-Zag Antenna Installation and Performance,* R.E. Fisk, General Electric Co., presented at the 19th Annual Broadcasting Engineering Conference National Association of Broadcasters, Washington, D.C., 1965.

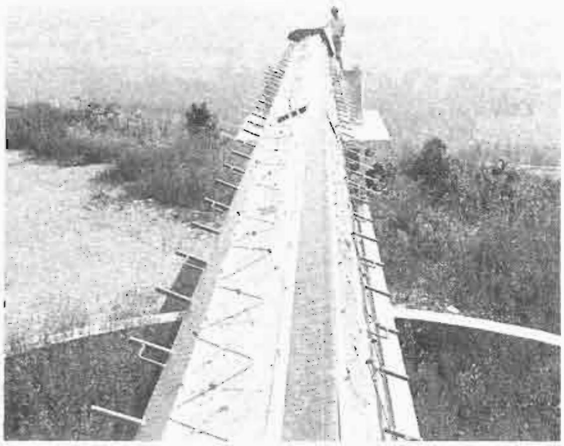

Fig. 75. GE Zig-Zag Antenna.

aperture fed from a single feed point at the center. The radiators are mounted on reinforced Teflon insulators, and grounded at the ends. The vertical pattern, is quite important in high gain antennas, and a computer program provides information for the first and second null fill which is accomplished through controlled power distribution across the entire antenna aperture. Standard UHF omnidirectional antennas have a pattern circularity of ± 2 dB.

ANTENNA TESTS

Before Shipment

Antennas are tested to meet the necessary requirements for impedance and patterns. This is usually done for all prototype antennas but not necessarily on the repeat antennas of the same type before shipment.

Custom antennas are usually impedance tested before shipment. As noted above under Antenna Specifications, the impedance is adjusted by the manufacturer to assure himself that the antenna will meet the 3 percent RF Pulse System Specification. These measurements are made under ideal conditions at the manufacturers plant to be certain that they are not influenced by other objects or the earth. From a Smith Chart Plot a judgment can be made by an experienced engineer to determine the percentage of reflection. It can also be determined by using a computer program as discussed under System Specifications.

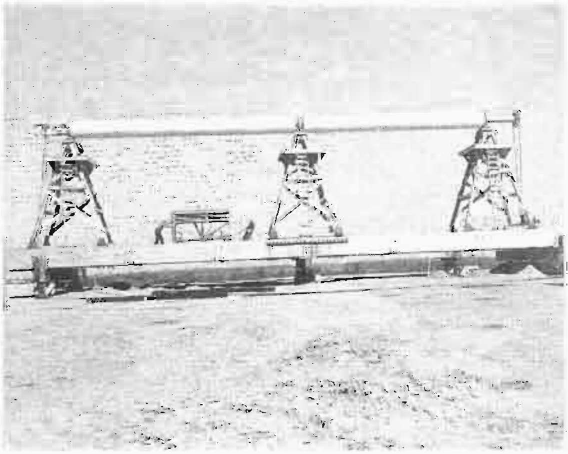

Fig. 76. JAMPRO Zig-Zag Antenna.

Pattern Tests

The object of a pattern test is twofold. One of the objectives is to determine the gain as compared with a dipole for which perhaps a substitution method could be used. The other objective, however, is to determine the amount of radiation at all vertical and horizontal angles which have an influence on the coverage. Both objectives can be accomplished by taking patterns as described under Gain, since the gains can be determined by integrating all the power flow through an imaginary sphere.

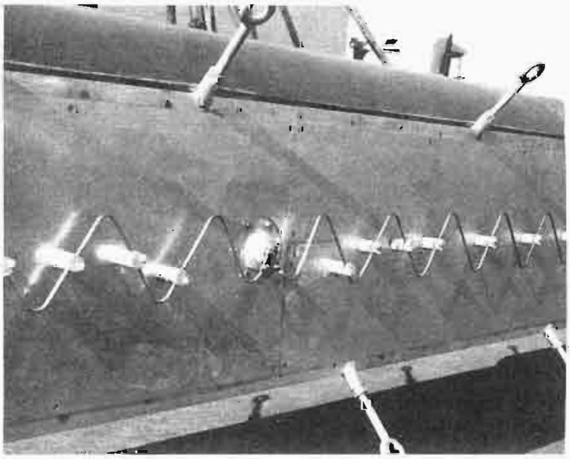

Fig. 77. Channel 32 Polygon Antenna on the 35 ton turntable which will accommodate antennas up to 180 feet in length (RCA Photograph).

To pattern-test the antenna it can be placed upon a wooden turntable which has a speed-controlled motor drive.[31] Fig. 77 shows such a turntable. From the reciprocity theorem it is possible to use the antenna as a receiving antenna as well as a transmitting antenna and obtain the same resulting pattern. This is done for the sake of convenience, since it permits the pattern recorder and the antenna under test to be located

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[31] "RCA Expands Antenna Engineering Facilities," *Broadcast News*, Vol. 128.

at the same point, thus allowing quick analysis of the results. The transmitting dipole is placed in the far field which is 2 a^2/λ in feet where "a" is aperture of the antenna in feet and "λ" is the wavelength in feet. Since the antenna is in a horizontal position on the turntable, the transmitting dipole must be placed in a vertical plane. The received signal is amplified and the patterns drawn out on the recorder. To determine gain all of the energy going through an imaginary sphere with the antenna at its center must be accounted for. Usually the area of interest in a pattern lies from about 3° above the horizontal (+3°) to about 11° below the horizontal (-11°). However, for gain determination, all energy from +90° to -90° must be taken into account. Also since some types of antennas have a degree of unwanted vertically polarized energy in addition to the desired horizontally polarized energy, this factor must also be considered. Ohmic losses in the feed system must also be considered in determining the gain.

After Shipment, before Erection

After the antenna is erected, the difficulties of working on it are greatly compounded. Since few engineers climb, the work must be done entirely by riggers, who do not have the background to do electrical testing. Furthermore, the time during which work can be performed on the antenna is very limited, owing to both scheduled operation and the weather, which frequently prevents work or even climbing. Hence, it is extremely important that tests be made on the ground before erection. Both electrical and mechanical tests should be made.

A thorough mechanical inpsection should be made to see that the required components are in their proper places and securely fastened using the specified fastening materials. The pressurized portions should be pressure-tested for a long enough period to be certain that there are no slow leaks. A loss of over 2 lb. in 24 hr. should be investigated. The fit of major mechanical assemblies should be checked on the ground, since any discrepancies during the rigging operation can become major problems.

Depending upon the antenna type, it is generally good practice to make some electrical measurements on the ground before erection. The primary purpose is to determine if anything has happened to the antenna during the shipping and reassembly process. Hence, it is basically a qualitative test rather than a quantitative one since the ideal conditions at the vendors site may not be duplicated.

The test normally used is an impedance, or VSWR, measurement made every megacycle over the television channel. Closer measurements are not necessary since for a broad-band antenna the impedance varies quite slowly with frequency.

The practice would vary with VHF antennas and UHF antennas. It is usually necessary to be above the ground by about three wavelengths to obtain meaningful measurements. Hence at UHF, a height of 6 ft. is readily achievable. Often the antenna can be tested on the shipping trestles if they are close to this height and made of wood.

For VHF, the heights required above ground are about 15 feet from Channels 7-13, and 35 ft. or so for Channels 2-6. It is manifestly impractical to provide trestles of this height for field tests. Since these antennas often have branching type feed systems, other means can be used. In the case of a Superturnstile Antenna, the E-W system and the N-S system can be separately measured for impedance at a low height by placing the plane of the radiators under measurement in a vertical plane so that the maximum field is parallel to the ground rather than into it. Since the radiators are still quite close to the ground, ideal measurements cannot be obtained and a judgment factor is required. Final touch-up of the impedance after erection can usually be made by using a variable transformer.

It should be noted, however, that the further the variable transformer is from the point in the antenna where the best match across the band exists, the more difficult it is to lower the reflected pulse value. This point is at or near the radiators for a Superturnstile antenna or after the last transformer when broadbanding techniques are used.

The action of the variable transformer is to insert a negative bump to counteract the positive bump (see Fig. 11) due to the remaining mismatch at the antenna. If the negative bump is displaced in time, by too long an intervening transmission line, it can only partially reduce the positive bump. If it is displaced more than a 100 ft. or about 0.1 microsecond it serves no purpose and only introduces a second unwanted bump.

The use of a variable transformer could in the case of a factory assembled antenna eliminate the ground test if a good mechanical inspection is made. For antennas of the Traveling Wave type for Channels 7-13, the construction is extremely rugged and a mechanical inspection only is required. This antenna has a built-in variable transformer.

When impedance measurements are made on antennas at the customer's site, there may be site factors involved such as fences, building materials, towers and other objects in the field. If the readings are of the same order, or if the Smith Chart plot is about the same but displaced, the antenna can be considered to be in good condition. To make any corrections in such a situation could correct the antenna for the site conditions which would not be present at the tower top and hence worsen the impedance. As noted above the check is qualitative to discover possible damage during shipment and not a quantitative compliance test.

The remarks above are also applicable to panel type antennas. Where possible, it is always desirable to ship antennas in one piece even through special permits and shipping arrangements are necessary.

After Erection

Overall Test

See antenna specification considerations under "System Specification Performance after Erection."

Reflectometer Test

In order to protect antenna and line components properly it is mandatory that a reflectometer be used on both visual and aural transmitters to interrupt power when the VSWR exceeds a predetermined value. If an arc occurs in the antenna system, it usualy loads the transmitter so that meter readings may fail to give a warning resulting in major damage to the antenna system.

Hence, before application of power to the antenna system the reflectometers should be checked for proper operation.

INSTALLATION

Advance Planning

The instruction book for a particular antenna usually contains considerable useful information which should be carefully read and followed. There are a number of items, however, common to most antennas which will be discussed.

Preinstallation Procedure

Usually it is advisable to have the manufacturer's serviceman take care of assembly supervision and testing. Some detailed procedure is outlined below.

Antenna Mounting Trestles

Most antennas are impedance-tested on the ground before erection. This is a wise precaution, since any corrective work, if required, is extremely difficult to accomplish once the antenna is at the tower top. The impedance of the antenna is affected by the ground, and trestles are required to obtain adequate clearance. Usually the furnishing of the trestles is the responsibility of the station, although the design is furnished by the manufacturer. They should be on hand when the antenna arrives located on reasonably level ground close enough to the base of the tower so that the antenna can be hoisted directly but far enough away so that assembly work can be done on the antenna without danger of falling objects from the tower while the riggers are working on it. The antenna should be placed so that the tower is not in the radiated field of the antenna, which would affect the impedance during the ground test. This will vary with the type of antenna and the frequency, and the manufacturer's recommendation should be obtained.

Precautions during Unpacking and Assembly

Antennas are usually heavy and appear to be quite rugged. Riggers used to handling heavy, rugged components often overestimate the ruggedness of the antenna, since many of the components can be damaged by rough handling.

If lifting lugs are not provided, the usual practice is to use cable wrapped around the mast with a 2 by 4 "corset" to protect feed lines, slot covers, or other components mounted on the pole. Special oak 2 by 4 lumber should be used for this purpose, since regular lumber crushes, causing damage to components.

Long poles can be given a "set" or internal components damaged if the pole is not properly supported over its entire length when it is lifted from a horizontal position. Strains can be set up under this condition which exceed the maximum wind-load conditions.

To ensure proper handling, a qualified rigger who has a reputation for making successful antenna installations is desirable. Some manufacturers will, if the customer desires, provide a "package" for the tower, line, antenna, and all installation work. This avoids split responsibilities and has many other advantages.

Checking Shipment

It is a wise precaution to check the shipment in detail against packing lists and see that no damage has occurred during shipment. The per-diem rate for a crew of riggers is costly, and any delays due to missing or damaged parts will prove expensive. If there is any damage or shortage, the shipper should be notified immediately.

Pressurized Equipment

Equipment that is normally pressurized should be either stored in a dry place or kept under pressure during storage. The latter will also establish whether any leaks have resulted from shipment.

Assembly

Usually the manufacturer furnishes detailed instruction for the assembly which should be carefully followed.

Special tools are sometimes furnished or called for in certain operations which should be used.

Since the antenna is primarily a piece of electrical equipment, cleanliness at points of electrical contact is mandatory.

Electrolysis can occur if proper hardware specified is not used.

Forcing parts into place will usually result in future difficulties. The reason should be investigated.

All hardware should be tight and secure.

If anything does not appear to be correct, consult the manufacturer rather than take a chance.

If any field welding is required, certified welders should be used, since failure could result in loss of human life.

Tests before Erection

It is extremely important that certain tests both mechanical and electrical be performed before the antenna is erected, since the difficulties of working on it after erection are greatly compounded. These tests are described under After Shipment, before Erection.

Erection

The erection procedure should be left in the hands of a qualified rigger. It is highly desirable to erect the antenna in one piece when this is feasible. If not, the rigger must be thoroughly instructed in the assembly procedure. The orientation of the antenna should be carefully established and well marked so that there is no misunderstanding.

In some antennas when transmission lines pass through the top plate of the tower, orientation is doubly important.

Vertical Alignment

For flange mounting triangularly shaped stainless steel shims should be used fitted between the mounting bolts. Vertical alignment is best checked with transits from several directions. Allowance must be made for wind deflection and sun benching. Accurate vertical alignment is especially important at UHF, where beamwidths are much narrower owing to the use of higher gain antennas.

Tests before Application of Power

These tests are important to ensure that the over-all requirements are met and also to be certain that the system is ready to receive power. Much damage can be done if there are loose or open connections or if the reflectometer circuits in the transmitter are not properly adjusted.

MAINTENANCE

Daily Operation

A drop in gas pressure (in excess of 2 lb. in 24 hr.), an increase in VSWR as indicated by the reflectometer, or the appearance of an echo on the monitor indicates an unusual condition in the antenna system.

Gas leaks can usually be located by sectionalizing parts of the system. An increase in VSWR may denote icing or a change or failure of some part of the system. Power should be reduced when the VSWR rises, since the power-handling capability is inversely proportional to the standing-wave ratio.

The appearance of an echo is a symptom of some change in the system which should be investigated. New pulse techniques will make the location of faults much simpler.

Semiannually

A qualified rigger who is thoroughly familiar with all the aspects of the line and antenna should inspect the system. He should inspect for signs of corrosion, loose clamps or hardware, condition of slot covers, need for paint, physical damage, etc., as the particular antenna requires.

In superturnstile antennas it is advisable to take resistance readings between the inner and outer conductor for each side of the line. Any significant change from the initial readings should be investigated.

As a general guideline, no work should be performed on an antenna while power is on. In the case of a multiple antenna system where antennas are at the same level, the power should be off for all antennas on the platform.

RF fields from UHF antennas are particularly dangerous for two reasons: due to the shorter wavelength, local heating in the body is more likely to occur without an awareness that it is happening and could have serious results. Also, since a maximum power of five megawatts can be radiated, UHF stations are now approaching this value which is 16 times as high as for the Channel 7-13 range, and 50 times as high as for the Channel 2-6 range.

15

The Measurement of FM and TV Field Strengths (54-890 MHz)

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The coverage of a broadcasting station and the technical quality of the service provided are determined by the received signal and field strengths. Presently available methods of estimating field strengths within the service ranges of FM and television stations are only approximate, and even the best methods of calculating field strengths often fail to take into account variations due to important local conditions. For operating stations the best determination of station coverage is provided by properly made field-strength measurements.

This part describes equipment and techniques for measuring field strengths over the frequency ranges employed for FM and television broadcasting. These services are assigned to several bands between 54 and 890 MHz as shown in Table 1.

TABLE 1

Frequencies Employed for FM and Television Broadcasting

Service	Frequencies, MHz	Channel Nos.	Channel Bandwidth
TV	54–72	2–4	6 MHz
TV	76–88	5–6	6 MHz
FM	88–108	201–300	200 kHz
TV	174–216	7–13	6 MHz
TV	470–809	14–69	6 MHz

The quality of service is related to the field strength by considerations of receiver sensitivity and noise figure, receiving antenna gain and transmission-line loss, and tolerable signal-to-noise ratios. The required fields vary with the class of service and frequency assignment. Interfering signals from other transmitters on the same or adjacent channels may limit service to higher values of field strength. Table 2 lists values of median field strength required for various grades of FM and television service in the absence of interfering signals as established by the Federal Communications Commission's Technical Standards.[1] There are also included revised estimates of the fields required in the television bands to provide acceptable grades of service based on the practical experience of operating stations and the findings of the Television Allocations Study Organization (TASO).[2] These latter have not as of the present date (Sept. 1, 1974) been officially adopted by the Commission.

Note: Superscript numbers refer to References at end of the chapter.

TABLE 2

Median Field Strengths Required for Various Grades of Service in the Absence of Interfering Signals

FM Broadcasting (All Channels)

Grade of service	μv/m	dbu[a]
Principal city	3,160	70
Urban	1,000	60

Television Broadcasting (FCC Technical Standards)

Grade of service	Ch. 2–6		Ch. 7–13		Ch. 14–83	
	μv/m	dbu	μv/m	dbu	μv/m	dbu
Principal city	5,000	74	7,000	77	10,000	80
Grade A	2,500	68	3,500	71	5,000	74
Grade B	225	47	630	56	1,600	64
(Based on TASO Data)						
Primary	250	48	1,400	63	7,500	75
Secondary	50	34	200	46	630	56
Fringe	20	26	55	35	180	45

[a]This abbreviation was coined by the FCC for television service and signifies the field strength in decibels above 1 μv/m. 0 dbu = 1 μv/m.

Service is defined in Table 2 in terms of the median field at a receiving antenna at a height of 30 ft. above ground. In these frequency bands, the field usually varies appreciably with antenna height, generally tending to increase with increasing antenna height. However, the variation in field with height may not follow simple laws, as discussed more fully in subsequent paragraphs.

The presence of trees, buildings, and terrain irregularities[3-7] often results in considerable variation in the signal from one location to another, even within relatively small areas. The variation in field strength with location must be taken into account in measuring the field strengths as well as in specifying service. Service is usually defined in terms of the *median value* of field strength, which is the value exceeded for at least 50 percent of the time at the best 50 percent of the receiving locations.

The results of field-strength-coverage surveys are customarily presented as contour maps, showing lines of constant median field strength which represent the outer limits of various grades of service. A typical map of measured television-station coverage is shown in Fig. 1. Methods of preparing contour maps are described in detail under the heading "FCC Standard Method."

Much of the present knowledge of wave propagation in these frequency bands has been derived from field-strength-coverage surveys on operational FM and television stations. The information gained from these commercial coverage surveys has added to the body of scientific knowledge, but field-strength-measurement surveys employing special techniques are often needed to supply data for special propagation problems. Examples of such special techniques are discussed under "Recommended TASO Method for Special Studies."

BASIC EQUIPMENT PRINCIPLES

Field strengths in the VHF and UHF bands (30 to 3,000 MHz) are ordinarily measured by determining the voltage which the field induces in a half-wave dipole. The basic relationships can be expressed in several forms. The power transferred between two half-wave dipoles in free space separated by a distance d is given by

$$\frac{P_r}{P_t} = \left(\frac{1.64\lambda}{4\pi d}\right)^2 \qquad [1]$$

where P_r = received power
P_t = transmitted power
λ = wavelength in same units as d

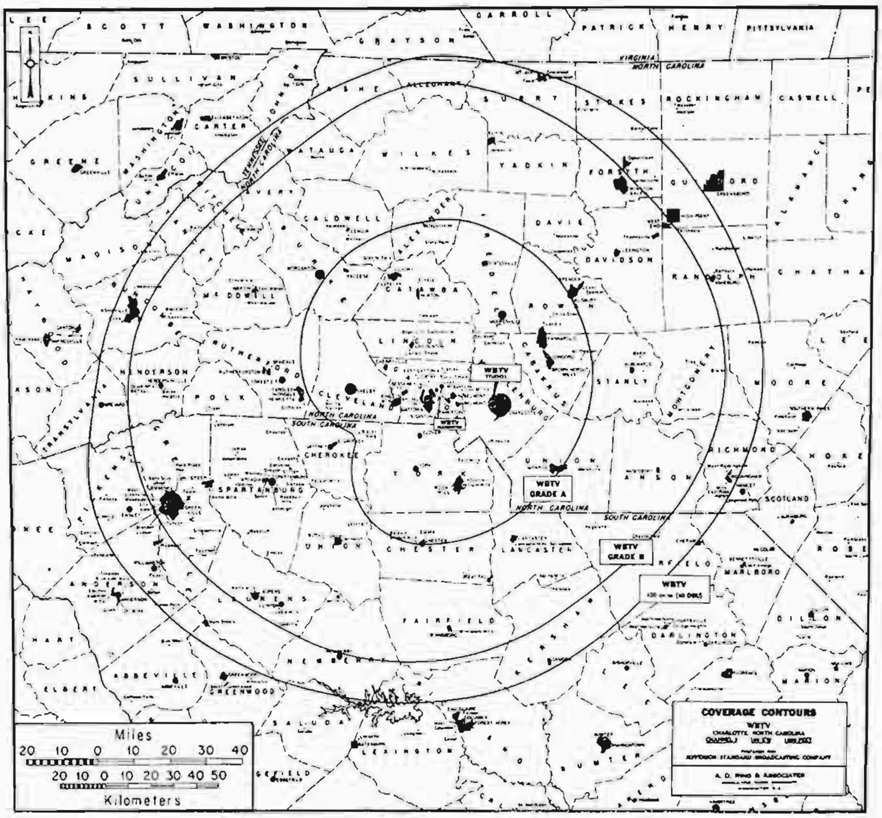

Fig. 1. Map showing measured service contours for an operation television station. (Courtesy of Jefferson Standard Broadcasting Company.)

In terms of the field at the receiving dipole, the power delivered to a matched load by a half-wave dipole in a field of E volts/m is

$$P_r = (0.186E\lambda)^2 \quad \text{watts} \qquad [2]$$

where λ is expressed in meters. For a resistive load of R ohms, the voltage V developed across a matched load by a dipole in a field E is

$$V = \frac{E\lambda\sqrt{R}}{53.7} \qquad [3]$$

The fundamental problem presented, therefore, is that of measuring the developed RF voltage by a practical instrument of acceptable accuracy.

Fig. 2 is a graph showing the available power and voltage developed across a matched 50-ohm load as a function of frequency for a half-wave dipole in a uniform field of 1 volt/m at the frequency indicated. This graph summarizes the relationships shown in Eqs. 2 and 3.

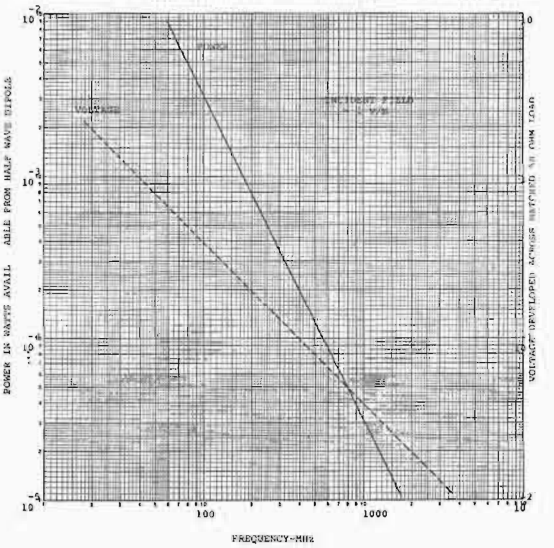

Fig. 2. Power and voltage extracted by a half-wave dipole in a field of 1 volt/m as a function of frequency in megahertz.

The voltage-measuring device is ordinarily separated from the antenna by a length of cable. The cable may introduce losses, and any impedance mismatch must be sufficiently small that calibration errors are not introduced by differences between the antenna and cable impedance and the internal impedance of the calibrating oscillator.

PRACTICAL FIELD-STRENGTH METERS

Fig. 3 is a block diagram of a practical field-strength meter. The antenna delivers its received power to a transmission line leading to the receiver input. If the receiver input is unbalanced to ground, a balance-to-unbalance transformer ("balun") is required. The transmission line between the antenna and the receiver is shielded to avoid stray pickup.

The RF attenuator shown serves two purposes: to avoid overloading of the receiver input on strong signals and to improve the impedance match when the receiver input impedance is substantially different from the characteristic impedance of the transmission line. It is frequently omitted when not required for either of these purposes.

The signal at the receiver input is amplified and converted to the intermediate frequency. Amplification and attenuation at the intermediate frequency permit operation over a wide range of field strengths; further range is provided by the receiver gain control. The rectified receiver output operates the indicating meter.

In operation, the attenuators and gain control are adjusted to provide an on-scale reading of the

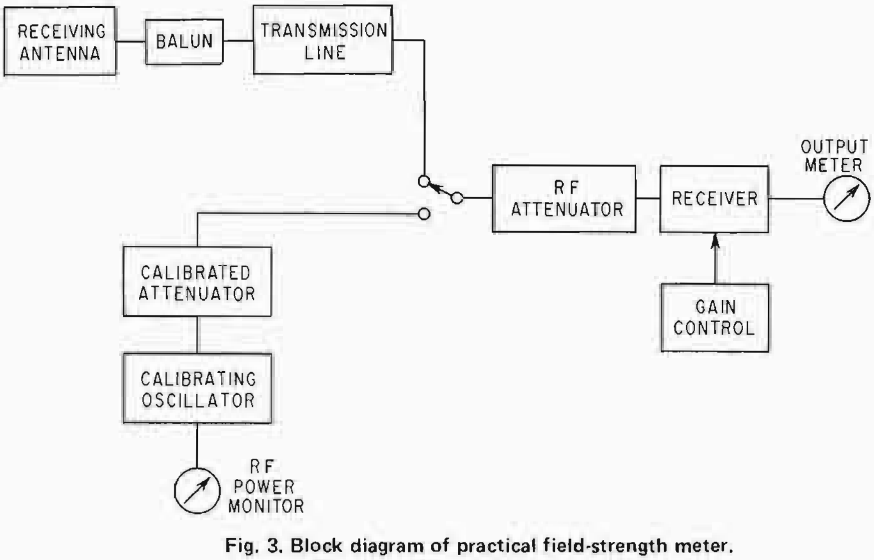

Fig. 3. Block diagram of practical field-strength meter.

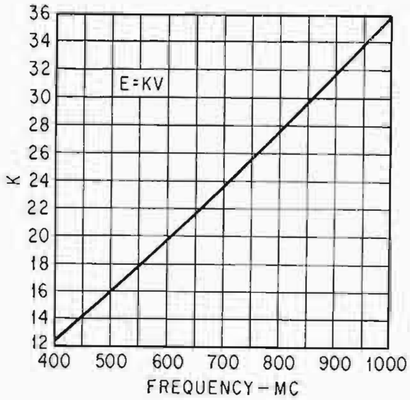

Fig. 4. Graph of K for typical UHF field-strength meter. $E = KV$

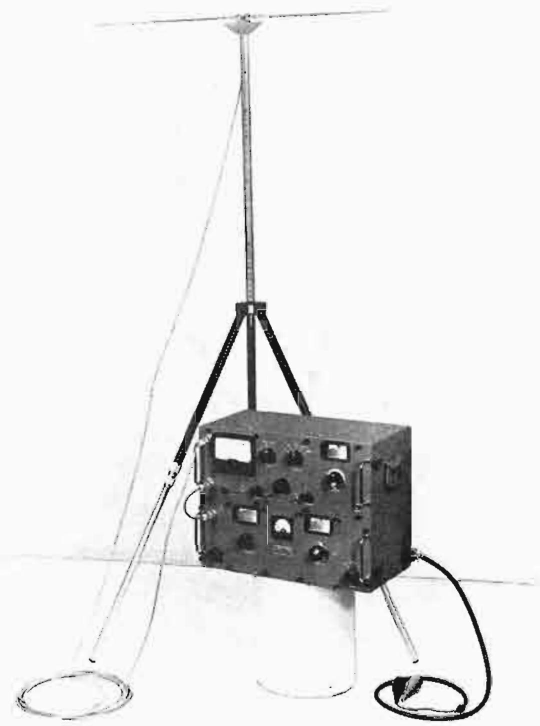

Fig. 5. A VHF field-strength meter of professional quality. (Courtesy of Nems-Clarke Company.)

indicating meter. The receiver input is then switched between the output of the transmission line and the output of the calibrating oscillator, which is tuned to the frequency being measured. The output of the calibrating oscillator is adjusted to a predetermined fixed value using the RF power monitor, and the calibrated attenuator is adjusted until the indicating meter deflection is the same as that obtained from the antenna and transmission line.

For this condition, the voltage at the output of the calibrated attenuator is the same as that from the antenna and transmission line. By taking line and balun losses into account and applying Eq. 3 above, the field at the antenna required to produce this voltage can be determined. The relationship between field strength and receiver input voltage is usually expressed as $E = KV$, where K is a function of frequency. Fig. 4 is a typical graph showing values of K for a UHF field-strength meter.

A typical commercial field-strength meter of professional quality is shown in Fig. 5. The instrument shown is a Nems-Clarke type 107-A, covering the VHF FM and television band from 54 to 216 MHz. A companion instrument, similar in appearance, covers the UHF television band from 470 to 890 MHz.

Accurate instrument calibration is essential in measuring RF fields. During use, the calibration of the instrument described is provided by the calibrating RF voltage source, which is usually an integral part of the field-strength meter (see Fig. 5). The calibration of the oscillator and the over-all calibration of the instrument as a whole must in turn be established and maintained by reference to laboratory standards.

The most direct laboratory calibration of the complete field-strength meter is established by generating a known standard field in which the receiving antenna is placed. Standard-field ranges have been developed and constructed at both UHF and VHF[8] and are sometimes used in primary calibration of field-strength meters. Most commercial laboratory calibrations, however, are made by removing the dipole elements from the standard antenna and applying a known RF voltage at the proper frequency to the dipole terminals in series with an impedance equal to the receiving-antenna impedance. The calibration of the balun, line, and receiver is established in terms of this applied voltage, which is then related to field strength through Eq. 3.

The calibration of the internal reference oscillator section includes the calibration of both the oscillator proper and the variable-output attenuator. The attenuator is usually of the inductively coupled piston type,[9] which depends only on its dimensions for proper functioning; this can be checked against the correct dimensions or against a laboratory standard attenuator. The oscillator can be compared with a standard oscillator, or its output can be measured with a laboratory standard such as a bolometer bridge.[10] This calibration is normally performed only by the manufacturer.

If measurements are made on the visual carrier of a television station, the difference between the peak and average powers of the transmission must be taken into account. This can be done by establishing a calibration in terms of average power for a still scene (such as test pattern or black picture), or a peak-reading voltmeter can be employed to indicate the level of the synchronizing peaks. Such peak-reading voltmeters are an integral part of many of the commercial field-strength meters such as the one illustrated in Fig.

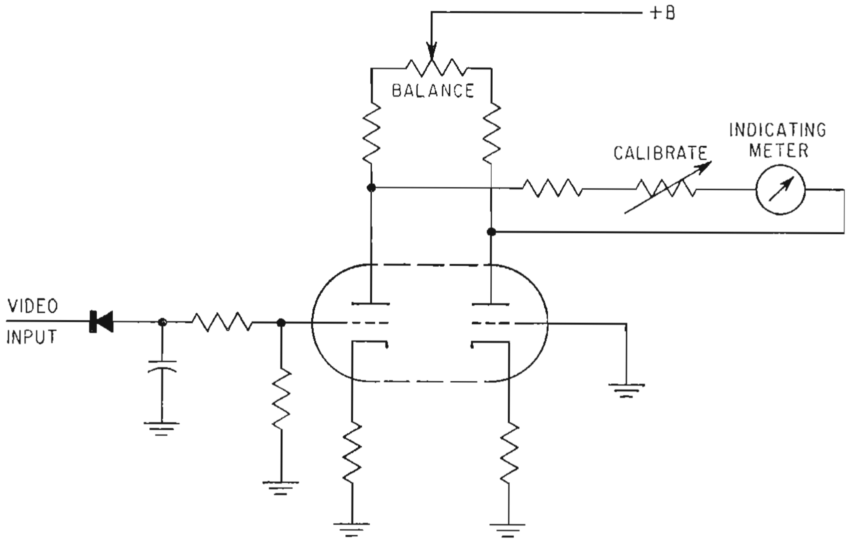

Fig. 6. Schematic diagram of bridge circuit for reading voltage corresponding to synchronizing peaks. The component values in the grid circuit are chosen to provide a long time constant.

5. A schematic diagram of a typical peak-reading voltmeter is shown in Fig. 6.

In addition to the field-strength meter, several accessory items are needed in making a field-strength survey. The principal items and their use are described in the following paragraphs and include (*a*) a special receiving antenna, (*b*) an antenna-supporting mast, (*c*) a chart recorder, and (*d*) power supplies. The size and weight of the equipment usually dictate that it be mounted in an automobile or light truck. Fig. 7 shows a large station wagon containing permanently mounted equipment for field-strength surveys.

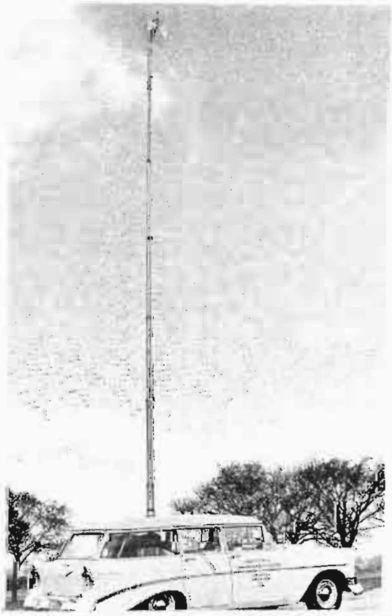

Fig. 7. Station wagon equipped for making field-strength-coverage measurements showing 30-ft hydraulic mast. A UHF receiving antenna is mounted on the mast. (Courtesy of Association of Maximum Service Telecasters, Inc.)

RECEIVING ANTENNAS

The measurement survey can be made by employing the standard dipole antenna furnished with the field-strength meter, or other antennas can be utilized. An antenna which is essentially omnidirectional in the horizontal plane does not require orientation as the vehicle is moved. Fig. 8 shows a typical nondirectional receiving antenna designed for this purpose. Directional receiving antennas can be employed when their gain is needed (principally for UHF measurements) or when their rejection is desired to eliminate unwanted signals from sources other than the transmitter being measured.

The antenna employed for the measurements must be calibrated on the measurement vehicle.[11] The received field is first measured using the standard dipole antenna removed from the vehicle. The antenna to be used in making the survey is then mounted on the vehicle at the height to be employed in making the survey, and the receiver input voltage determined with the receiving antenna at the same spot in the field. If an omni-

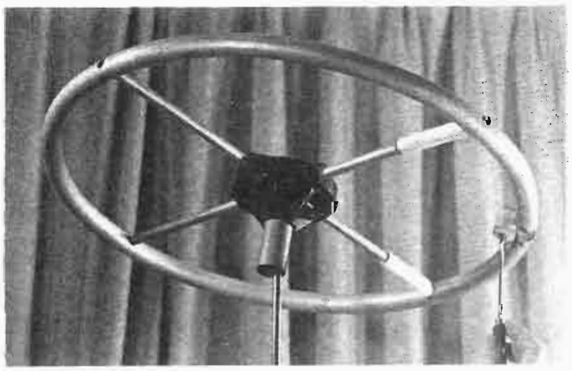

Fig. 8. Nondirectional VHF receiving antenna for making coverage surveys.

directional receiving antenna is employed, the circularity of the pattern of the antenna as mounted on the vehicle must be determined. Unless the vehicle can be rotated, this can be done by driving the vehicle in a small circle in an area of uniform field and recording the received signal.

The gain of the service antenna can be established relative to the dipole antenna by means of measurements with the antennas stationary, but more consistent results are often obtained by making short mobile runs over identical paths and recording the signals from the two antennas. For either procedure, the voltage gain of the service antenna G_s relative to the standard dipole antenna G_d is $G_s/G_d = V_s/V_d$, where V_s and V_d are the voltages delivered to the receiver input using the service and standard dipole antennas, respectively.

If the transmission line or balun between the antenna and receiver is different from the standard cable and balun supplied with the instrument, the antenna calibration must include the cables and baluns.

ANTENNA-SUPPORTING MAST

The receiving antenna is ordinarily supported at a height of 10 to 30 ft. above ground, depending on the measuring technique employed. For the 10-ft. height, a simple mast of metal tubing can be used. For the 30-ft. height, a special mast is required to raise and lower the antenna, and the mast arrangement should permit the vehicle to move over limited distances with the mast elevated.

The measuring unit shown in Fig. 7 employs a telescoping mast of five sections of aluminum tubing[a] elevated by low-viscosity oil forced in under pressure; the mast descends under gravity when the pressure is relieved. A handle inside the vehicle permits the mast to be rotated to orient the receiving antenna.

CHART RECORDER

For measurements made with the vehicle in motion, a chart recorder is employed. The chart can be driven from the vehicle speedometer or a drive motor. The pen element of the chart recorder is driven by a galvanometer coil; excitation of the galvanometer is provided by a dc amplifier, which may be built into the field-strength meter or may be a separate accessory.

When the chart recorder is employed, the recorder pen element must be calibrated against the receiver output indicator of the field-strength meter. The d-c amplifier is adjusted for balance at the ends of the meter scale, and a calibration curve is prepared for intermediate values.

Power Supplies

The power drain of the measuring equipment can be fairly substantial, especially if much accessory equipment is employed. It is usually preferable to provide a power source for the measuring equipment separate from the vehicle battery. This may consist of a separate battery bank to operate the meter and accessories, or a separate 115-v. ac generator may be mounted in the vehicle.

MEASURING PROCEDURES AND TECHNIQUES

The FCC FM and TV Technical Standards prescribe measuring methods to be employed in making measurements to be submitted to the Commission. These methods are also usually employed in making station-coverage surveys, although variations from the official procedure are frequently taken. The Television Allocations Study Organization report recommends a number of changes in the FCC procedure and also recommends the testing of a radically new measurement technique. The following paragraphs summarize the present requirements of the Commission's Standards and indicate the changes recommented by TASO. The proposed revised method is also described.

FCC STANDARD METHOD[12]

The Commission's Technical Standards require field-strength-measurement surveys to be made with mobile equipment along roads following as closely as possible to radial lines from the transmitter, laid out along bearings separated by 45° beginning with true North. Measurements are required out to a point in each direction somewhat beyond the field-strength contour which it is desired to establish. Continuous recordings of the field strength are made along the roads employing the chart recorder. A minimum chart speed of 3 in. per mile is required. Fig. 9 shows a sample of a typical chart recording obtained by this method.

The completed recorder charts are divided into not less than 15 sections in each direction. Each section of the chart is analyzed to determine the median (50 percent) field for each section. The chart median values are then converted to received field strength by combining the individual calibrations of the antenna, transmission line, field-strength meter, dc amplifier, and chart recorder as discussed above.

The received fields must be corrected for the field expected at a receiving antenna height of 30 ft. above ground. The Commission's Standards do not specify the conversion factor to be employed, but it has been common practice to assume the field strengths to increase linearly with antenna

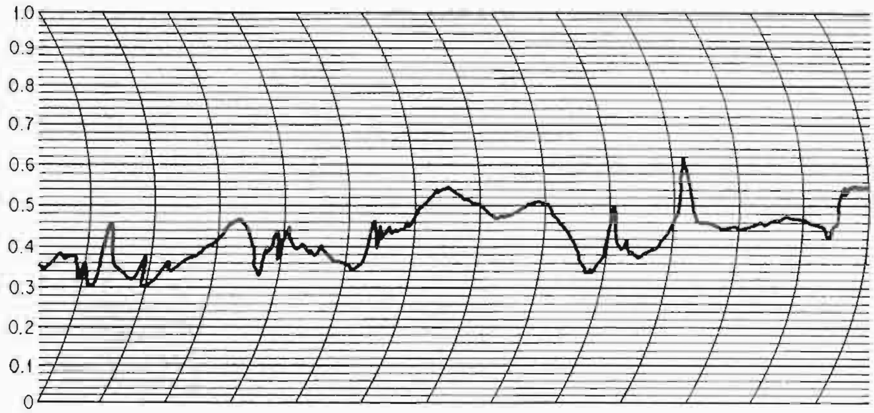

Fig. 9. Sample of typical recording chart showing the chart record obtained in making mobile field-strength recordings.

height, as indicated by classical propagation theory. For this assumption the relationship between the field E_{30} which would be expected at 30 ft. and the field measured at a receiving antenna height H_r is $E_{30}/E_H = 30/H_r$. For example, the ratio of the field at 30 ft. to the field at 10 ft. is 30/10 = 3.0, or 9.5 db.

The median fields as established in accordance with the procedure described above are plotted as a function of distance from the transmitter, and a smooth curve is drawn through the plotted points. Fig. 10 is a typical graph showing the plotted field strengths as a function of distance from the transmitter, together with the smooth curve through the plotted points. The dashed curve in Fig. 10 is the predicted field strength calculated using the propagation curves and prediction methods specified in the FCC Television Broadcast Technical Standards.[13]

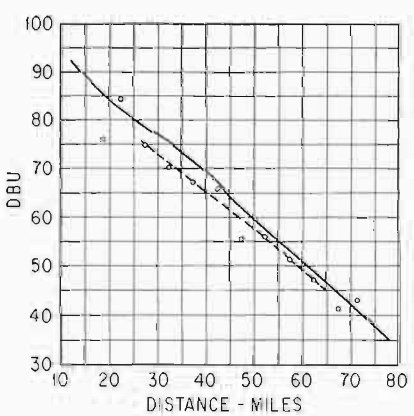

Fig. 10. Graph of measured field strength vs. distance for a typical radial route series of measurements. Each circle represents the median value of field strength for a 5-mile recording interval. The dashed line is a best-fit curve through the points. The solid line is the expected field strength computed using the FCC F(50,50) curves.

Individual graphs of median field strength versus distance as shown in Fig. 10 are prepared for each of the directions along which the measurements were made; the distances to the desired field strength contours, selected from Table 2, are determined in each direction. These distances are then plotted on a suitable map, and contours are drawn to produce a finished map such as shown in Fig. 1.

TASO RECOMMENDED CHANGES IN FCC PROCEDURE

TASO has recommended that the radial route-measuring pattern be modified to permit wider discretion in the selection of the measuring routes. A minimum of eight routes is recommended, selected to encounter representative terrain and to permit reasonable interpolation between adjoining radials. Additional routes, including branch routes, are recommended where needed.

In the analysis of the recorder tapes, TASO has recommended that the sections of the route chosen for analysis be as uniform as possible, with a minimum length of 2 miles.

One of the most important changes recommended by TASO in the present procedure is in the antenna height-gain correction factor. The application of the linear height-gain function discussed above is recommended only in relatively flat terrain, and in rolling or rough terrain the following height-gain factors (in decibels) are recommended to convert from 10- to 30-ft. fields:

Channel	*Smooth Unobstructed Terrain*	*Rolling Hilly Terrain*	*Rough Terrain*
2–6	9.5 dB	8 dB	7 dB
7–13	9.5	7	5
14–83	9.5	5	2

NEW METHOD RECOMMENDED BY TASO FOR FIELD TRIALS

TASO has also recommended field trials of a radically new method of measurement. The measuring pattern for this method is laid out as a series of five concentric circles centered on the transmitter rather than along eight radial lines as now employed. Four hundred measuring points are established on these five circles distributed in approximate proportion to the square root of the radii of the circles.

Field-strength measurements are to be made at each of the 400 points so located. If the designated point is inaccessible, the measurement should be made at a location as close to the designated spot as possible and as nearly as possible at the same ground elevation. Each of the 400 measurements is to consist of a single spot measurement made with the receiving antenna at a height of 30 ft. above ground.

The data collected are to be analyzed by dividing the area surveyed into eight or more sectors not exceeding 45° in width. These sectors are to be chosen so as to include reasonably homogeneous terrain insofar as possible. For each constant-radius arc within each sector, the mean value of the spot measurements is determined.[b] This analysis provides five values of field strength as a function of distance in the direction of each section, from which curves of mean field strength versus distance for the sector can be drawn. Linear interpolation can be employed for intermediate distances between adjoining circles.

RECOMMENDED TASO METHOD FOR SPECIAL STUDIES

For purposes of scientific investigation of field-strength behavior, measurements are often required employing special techniques. One such method, recommended by TASO in making measurements to be analyzed in terms of the terrain profiles between the transmitting and receiving antennas, is briefly outlined in the following paragraphs.

A precise radial line is laid out from the transmitter on topographic maps to the distance to which measurements are to be made.[c] Along this radial line, measuring locations are marked at exact 2-mile intervals, beginning at exactly 10 miles from the transmitting antenna. The actual measurements are made precisely on the radial, at locations as close as possible to the exact 2-mile marks established as described.

The individual measurements consist of short mobile runs (100 ft. along the road) at each location so chosen, with the receiving antenna at the 30-ft. height. The chart recorder is used, and the median, minimum, and maximum values of the field for each recording are determined from the chart recording.

PRACTICAL PROBLEMS ENCOUNTERED IN MAKING FIELD-STRENGTH SURVEYS

Before any field-strength-measurement survey is undertaken, the radiated power of the transmitting installation must be established as closely as possible. The transmitter output power should be determined by means of the dummy load and maintained as closely as possible to the proper value throughout the survey. The radiated power is established from the measured transmitter output power, taking into account the antenna power gain and the transmission line and diplexer losses.

The use of a 30-ft. receiving antenna mounted on a vehicle requires special permission from police or highway authorities in most states. These requirements vary among the individual states, but full details can be obtained from the state police or highway headquarters in the various state capitals.

The operation of a 30-ft. mast presents safety hazards which require the exercise of utmost caution in the use of an elevated mast. The TASO field-strength measuring specification includes a special appendix dealing with safety requirements. When measurements are made with an elevated antenna, the need for caution must be borne in mind at all times.

FADING OF SIGNALS NEAR THE RADIO HORIZON

Fairly substantial variations in field strength with time are frequently noted near and beyond the radio horizon. These variations may be relatively rapid, occurring over a period of a few minutes, or slow variations may appear over periods of several hours. Average field strengths in this region are usually lowest during winter afternoons, and higher average fields may be observed during the evening hours and during summer. The variations in field strengths with the passage of time must be taken into account in planning and making field-strength-coverage surveys.

The observed fluctuation of the field near the horizon is believed to be due principally to variations in the refractivity gradient of the lower atmosphere, which in turn is determined by the temperature, humidity, and barometric-pressure gradients. Measurements for coverage surveys should not be made beyond the radio horizon during periods when unusual conditions of temperature, humidity, and barometric pressure are believed to prevail. In particular, such measurements should not be made during changing weather conditions or if weather fronts are known to be in the area.

The variations in field with time often result from causes which are not readily apparent, and it is frequently difficult to determine whether typical propagation conditions prevail. One method which has been proposed and tried with some success is that of establishing fixed recording stations in one or more directions, at locations near the expected outer limit service, and recording the received signal over a period of several days. These recordings will give an indication of the signal to be expected under average conditions; the coverage survey measurements beyond the horizon can be made during a period when the recordings indicate propagation conditions to be typical. Measurements should not be made on days when these recordings indicate excessively high or excessively low field strengths.

REFERENCES

1. Federal Communications Commission: FM Technical Standards, Sec. 73.311(c); TV Technical Standards, Secs. 73.683(a) and 73.685(a).
2. "Engineering Aspects of Television Allocations," Report of the Television Allocations Study Organization to the Federal Communications Commission, Mar. 16, 1959.
3. LaGrone, Alfred H.: "Forecasting Television Service Fields," Final Report TASO/UT Contract, Dec. 31, 1958.
4. Brown, G. H., J. Epstein, and D. W. Peterson: Comparative Propagation Measurements; Television Transmitters at 67.25, 288, 510 and 910 Megacycles, *RCA Rev.,* vol. 9, no. 2, pp. 177-202, June 1948.
5. Bullington, K.: Radio Propagation Fundamentals, *Bell System Tech. J.,* vol. 36, no. 3, pp. 593-626, May, 1957.
6. Peterson, D. W., and J. Epstein: A Method of Predicting the Coverage of a Television Station, *RCA Rev.,* vol. 17, no. 4, pp. 571-582, December, 1956.
7. Head, H. T.: "The Influence of Trees on Television Field Strengths at Ultra-High Frequencies."
8. Greene, Frank M.: "Calibration of Commercial Radio Field Strength Meters at the National Bureau of Standards," *Natl. Bur. Standards Circ.* 517, December, 1951. Greene, Frank M., and Max Solow: Development of Very-high Frequency Field-intensity Standards, *Natl. Bur. Standards Research Paper* RP2100, vol. 44, May, 1950.
9. Terman, F.E.: "Radio Engineers' Handbook," McGraw-Hill Book Company, Inc., New York, 1943.
10. Schrack, R. A.: Radio-frequency Power Measurements, *Natl. Bur. Standards Circ.* 536, Mar. 16, 1953.
11. Greene, Frank M.: Influence of the Ground on the Calibration and Use of VHF Field Intensity Meters, *Natl. Bur. Standards Research Paper* RP2062, vol. 44, February, 1950.
12. Federal Communications Commission's Rules, Secs. 73.314 and 73.686.
13. Federal Communications Commission's Rules, Sec. 73.684.

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Field-Strength Measurements (540-1600 kHz)[1]

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In the dawn of broadcasting after its beginning in the early 1920's when wavelength was checked by a Kolster Decremeter, power was estimated from the product of plate voltage and plate current, and antennas were flat tops or cages hung on a roof; broadcasters sought more quantitative means of describing a station's service area. Expressions such as "You're coming in loud and clear" or the more flattering "You're coming in like a ton of bricks" needed to be reduced to a more accurate and uniform system of description.

This quest for precise information about coverage and service spawned the development of the field strength meter. Initially, the meter consisted of a standard signal generator and a stable loop antenna receiver—an apparatus so bulky that usually it was permanently mounted in a car. The question of determining the location of a measurement point was easily resolved since where the car couldn't go, no measurements were made. Later in the twenties, Western Electric packaged the whole field strength meter into one unit about the size of a piano, portable enough to be carried in a medium sized truck.

The metamorphosis of the present day field strength meter began sluggishly in the early thirties when RCA placed the meter unit in two boxes with handles and billed the unit as "portable." One box contained the field strength meter itself and the other held an assortment of dry batteries, loops, and plug-in coils. This "advancement" in the state of the art was analogous to mounting shoulder straps on the regular kitchen refrigerator and calling it a "portable cooler." Although the improvement was small, it signaled the beginning of a trend to develop a truly portable field strength meter. Measurement points, however, still had to be confined to places accessible by car.

In the late thirties Jim McNary in cooperation with Federal Telephone and Radio Corporation reduced the size and weight of the meter to something slightly less than backbreaking, but this meter was still far from what the engineer needed to do a really adequate job. The tripod was heavy and very bulky. The power supply usually consisted of an external motorcycle battery which had to be carried along with the unit and recharged each night. In the early days the measurement field car encountered few power line problems but, with the expansion of rural electrification, more and more locations accessible by car became unsuitable for accurate field strength measurements. This was before the day of the four-wheel drive jeep. Consequently, it became necessary frequently to climb fences and cross fields to reach measurement points which were clear of power or telephone lines. The real problem, therefore, in making directional antenna measurements was to survive the first week of lugging the Federal meter—a week which usually left one in superb physical condition with that good feeling of a man fresh out of boot camp.

Prayers for a really portable field strength meter were answered shortly after World War II in the form of an expensive, calibrated, miniature tube receiver with "A" and "B" batteries, called the 120-A (B, C, D or E), or WX-2 (A, B, C, D or E) depending on whose nameplate it bore. It was developed by Allen Clarke of Silver Spring, Maryland. Self-contained, direct reading throughout the broadcast band and a little larger than the present day meter, it almost made the task of measuring field strength easy. The only apparent

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[1]This chapter on field strength measurements represents a revision of an earlier article by the late Dr. Robert E. L. Kennedy [*NAB Engineering Handbook*, Fifth Edition (1960), Section 2, Part 9], portions of which have been incorporated with some emendation in the present writing. Much new and useful material, however, has been added.

[2]Special thanks to the members of the staff who worked so diligently in the composition of this chapter: Ihor "Slim" Sulyma, Stanley Leslie, Larry Ellis, Stephen Dutka and to the other members of the staff who kept the wheels turning.

drawback of this meter was the fact that it was so portable that measurement points no longer had to be located along roads and cross-county hiking became the vogue.

The 120-E or WX-2E model has been superseded by a slightly smaller, lighter, and completely solid state field strength meter. Present models feature a built-in speaker, meter illumination, and a simpler calibration system. These units are capable of measuring field strength in the 540 to 5000 kilohertz range (to include the third harmonic of a 1600 kHz station) and permit measurement of spurious radiation levels as well as harmonic radiation levels. Typical models such as the Potomac Instruments Type FIM-41 field strength meter use only six D cell batteries as a power source.

The Solar Electronics Co. Model 7007-1 field strength meter, similar to the Potomac Instruments FIM-41, has been developed with a built-in means of verifying the calibration if a calibrated signal generator is used. Such a feature is very useful but the depth of the meter is approximately 14 centimeters greater than that of the FIM-41 when the loop is in the measuring position. Those who are accustomed to holding up the meter with one hand to make a measurement will find the 7007-1 must be handled differently. The loop opens at right angles to the meter front panel permitting a single person to hold the meter firmly against his body even in strong winds.

Wilkinson Electronics, Inc., supplies a Type 4N1 field strength meter with built-in rechargeable batteries and 110-volt ac charger. The batteries also may be charged from a 12-volt dc source.

A much smaller, lighter and less expensive unit developed by Delta Electronics (Model FSM-1) is crystal controlled for a particular station's carrier frequency. Such a unit makes it relatively simple for a station to measure its field voltage since the first step (tuning) of the calibration procedure is eliminated. This particular meter measures only 14 X 20 X 13 centimeters and weighs approximately 2 kilograms.

The meters discussed above are given as typical examples of currently available field strength measuring units to illustrate the different features. Before purchasing a field strength meter, one should consider the latest meters offered.

Although the present field strength meters appear to be quite adequate for the job and emphatically represent a vast improvement over the antiquated units of early broadcasting, unforeseen betterments in the near future may well make today's units old-fashioned. Further improvements such as reductions in size and weight certainly will be made and readily accepted.

FIELD STRENGTH MEASUREMENTS IN GENERAL

Reasons for Measurements

Although there are many reasons for taking field strength measurements, the following are considered the most common:

1. Location of contours of specified strength or the determination of the quality of service;
2. Determination of the interference range of a station;
3. Proof of performance of a directional antenna;
4. Proof of efficiency of a nondirectional antenna;
5. Survey of site—to determine the adequacy of a proposed transmitter site;
6. Determination of the amplitude of the radio frequency harmonic radiation of a station;
7. Determination of the level of spurious radiation from a station;
8. Measurement of the skywave signal strength from a distant station;
9. Determination of ground conductivity;
10. Determination of the source of radio noise or reradiation.

The proper and acceptable procedure for taking field strength measurements is outlined in detail in Section 73.186 of the FCC Rules and Regulations. One might wish to read this section before continuing with this article. Section 73.186, however, only partially details the requirements for good, supportable and accurate field strength measurements. Along with the instructions given in the FCC Technical Standards, there are many more factors to be considered and applied that make the difference between sound and questionable data. Some of these factors are applicable to all field strength measurements and some assume greater importance in specific applications of field strength measurements.

Proofs of Performance

There are three classifications of proofs of performance for AM directional antenna systems presently recognized by the Federal Communications Commission. They are a complete proof of performance, partial proof of performance, and a skeleton proof of performance. The distinction between each is clearly defined in the FCC Rules and Regulations. All three classifications require that field strength measurements be made on all radials specified in the original construction permit plus any selected supplementary radials.

A complete proof of performance is rarely executed except immediately following the original construction of the facility or upon making major changes. FCC Section 73.186(a)(1) clearly points out the spacing of field strength measurement points for a complete proof of performance as:

1. Normal Conditions: up to 2 miles (3.2 km), every .1 mi. (160 m); 2 to 6 mi. (9.6 km), every .5 mi. (800 m); 6 to 15 mi. (24 km) or 20 mi. (32 km), every 2 mi. (3.2 km); beyond 20 mi. (32 km) a few additional measurements (if needed).
2. Favorable Conditions: rural unobstructed areas, 18 to 20 measurements.
3. Unfavorable Conditions: Urban or obstructed areas, as many unobstructed measurements as possible at even smaller intervals than under normal conditions.

It is necessary, therefore, to take approximately 40 measurements per radial under normal conditions (1 above), 18 to 20 measurements per radial under favorable conditions (2 above) or as many unobstructed measurements as possible under unfavorable conditions (3 above). However, it is suggested that as many points as possible be taken so as to allow a few unrepresentative points to be judiciously omitted. In general it is advisable to provide more measurement points on protection or monitor point radials than on other radials.

Partial and skeleton proofs of performance are taken at intervals following the complete proof and are compared with the complete proof to show any change from the original operating conditions of the array. Insofar as possible all reported measurements should be for the same points as originally measured in the complete proof. Monitor point measurements must be included in every proof of performance. A partial proof of performance must have at least ten measurement points on each radial—all normally within 3 to 15 kilometers of the array. A skeleton proof of performance must contain at least three to five points on each radial.

What follows is a discussion of the factors that should be considered to assure that all field strength measurements are valid and consonant with the FCC Technical Standards. It should be noted that there are many fine points that must be considered which make the whole field strength measurement procedure much more complicated than merely following the instructions outlined in Section 73.186.

SYSTEM OF MEASUREMENT

Before covering the particulars of the proper field strength measurement procedure, some clarification should be made on the question of the acceptable measurement system and the proper units of measurement to be used. This is necessary to prevent the use of dimensionally inconsistent forms of measurement.

Unit Symbols

Units of measurement used in this article are consistent with the standard unit symbols from IEEE Standard No. 260 1967 (ANSI Y1019-1969) and amendments to date, and are consistent in nearly all respects with the recommendations of the International Organization for Standardization (ISO) and with the International Electrotechnical Commission (IEC) for International Standard (SI) units.

Metric Measurements

In the early days of radio broadcasting and communications, stations transmitted on a wavelength of so many meters. The international distress frequency for ships at sea was 600 meters. Broadcast stations operated in the range from 200 meters up to 545 meters. There was no thought of transmitting on a wavelength of 750 feet. Instead, metric measurements were utilized. Unfortunately, for the establishment of universal metric measurement units, stations switched to a more recognizable nomenclature using frequency for designating broadcast emissions such as 1000 kilocycles per second instead of wavelengths. The "per second" was frequently dropped and only the term "kilocycles" was commonly used.

Now the standard expression for frequency is "hertz," named for the famous scientist Gustav Hertz and carrying the units of cycles per second. Hence, kilocycles per second became "kilohertz," a preferred term which is now well established. For FM the more convenient term of megahertz (million hertz) rather than the old form of megacycles per second is used. These terms are conveniently abbreviated Hz, kHz, and MHz with the H capitalized in honor of Herr Hertz.

Many broadcasters do not realize that in most other respects broadcasting has been using metric units from its inception. For instance, our transmitters operate with plate currents in amperes, millimperes, and microamperes while our utility power plants operate with megamperes. Similarly, a plate voltage is measured in volts or kilovolts and field strength voltage is given in millivolts or microvolts per meter. These are all units of the metric measurement system—fundamental and deeply entrenched in all aspects of electronics. Similarly power is given in watts, kilowatts, milliwatts, megawatts, or microwatts. Current and voltage units (the amp and volt, respectively) are also named for two greats of science—Andre Marie Ampere and Count Alessandro Volta. These units are conveniently abbreviated as:

Frequency: Hz	one hertz [formerly cycle per second]

	kHz	1000 hertz–one kilohertz [formerly kilocycle(s) per second]
	MHz	1,000,000 hertz–one megahertz [formerly megacycles per second]
Current:	A	ampere
	mA	milliampere, 1/1000 ampere
	μA	microampere, $1/10^6$ ampere
	MA	megamperes, 1,000,000 amperes
Voltage:	v	volt
	kv	kilovolt, 1000 volts
	mv	millivolt, 1/1000 volt
	μv	microvolt $1/10^6$ volt
Field Strength:	mv/m	millivolts/meter
	μv/m	microvolt/meter

The pertinent prefixes for metric system units used in broadcasting are as follows:

Prefix	*Multiple*	*Symbol*
Giga	10^9	G
Mega	10^6	M
Kilo	10^3	K
centi	10^{-2}	c
milli	10^{-3}	m
micro	10^{-6}	μ

You can see it's a case of upper and lower case. A Western Union keyboard will no longer serve and the shift key takes on a new significance. For instance, (mS) is a conductivity we have; (MS) is a conductivity we would like to have; while (ms) is a millisecond. Since most of us don't have megaseconds, (Ms) doesn't even tell us whether a lady is married or single.

Many pages have been written verifying the spelling of the metric unit as "meter" although many prefer the spelling of "metre." For the changeover to metric units of length, meter also may be spelled "metre," and the National Bureau of Standards suggests that all combinations be accented on the first syllable, i.e., kil'o·me'ter or simply kilo'-meter.

Adoption of the use of metric measurement units has been recommended by the U.S. Department of Commerce. Legislation to adopt the metric system was passed by the U.S. Senate in 1972 and by several state legislatures in 1974. The Elementary and Secondary Educational Act, signed by President Ford in August 1974, contains in Section 404 the statement that "Increased use of the metric system in the U.S. is inevitable, and such a metric system will become the dominant system of weights and measures in the U.S." Metric distance units such as kilometers and meters instead of miles and feet are being used by such governmental agencies as NASA, the National Park Service (Mesa Verde), the FAA (Obstruction Marking and Lighting, AC 70/7460-1C), etc.

Conversion to metric units by U.S. industry is now accelerating at such a rapid pace that before this handbook is in circulation very long, the old English measurement units may be quite obsolete.

Factors to permit conversion of metric units back to the old English system are presented below:

1. Multiply centimeters by 0.3937 to obtain inches
2. Multiply meters by 3.2808 to obtain feet
3. Multiply kilometers by 0.6214 to obtain miles
4. Multiply square kilometers by 0.3861 to obtain square miles.

The writer has for several years filed FM engineering applications for construction permits and for new standard AM broadcast stations with metric measurement units. Fortunately, the United States Geological Survey (USGS) and the National Oceanic and Atmospheric Administration (NOAA) maps have metric as well as mileage scales but, unfortunately, until recently all elevation contours have been in feet. Unless military metric maps or the new issue Alaska maps (which have metric contours) are involved, it is necessary to convert the elevation values from feet to meters. A pocket electronic calculator with a constant key or automatic constant feature has greatly facilitated conversion of English contour values to metric units.

The FCC, in conjunction with broadcasters and consulting engineers, should establish new metric standards for broadcast engineering calculations as soon as possible. It would seem the time is long overdue for the broadcasting industry to join with the growing numbers of American industries in converting to the primary use of metric measurement units.

Field Strength versus Field Intensity

Early in the development of broadcasting it was widespread to encounter the term "field strength" of a given broadcast station, but later FCC curves were released initially utilizing the term "field intensity." Hence, for a period of time, it was assumed that field intensity was the more professional term to use when referring to measured or calculated voltage; i.e., Graphs 1 through 20, FCC Rules and Regulations Section 73.184, refer to "Ground Wave Field Intensity vs. Distance" and Fig. 1 of Section 73.190 bears the title "Average Sky-Wave Field Intensity." It should be noted, however, that later FCC graphs do not contain the term "field intensity." The National Bureau of Standards has standardized the use of field *strength* to denote field voltage and reserved the term "intensity" for reference to field power measurement. Since the field strength meter measures the field *voltage* and not the field power, it follows that, according to national standards, field strength is the correct term for such measurements.

Conductivity Symbols

For many years conductance was measured in terms of mhos (ohms spelled backwards) and conductivity was usually measured in millimhos per meter (abbreviated mmhos/m). Such designation appears in FCC Section 73.184 on Graphs 1 through 20. Standardization has altered the correct nomenclature to replace the term mho with the SIEMENS (in honor of Siemens). The correct unit of conductivity is, therefore, millisiemens per meter (abbreviated mS/m) and is so used in this presentation.

TECHNIQUE—AN OVERVIEW

The procedure used in obtaining useful and accurate results in the analysis of field strength data is relatively simple for proofs of performance. First, radials are laid out from the transmitter site on the best available maps (topographic preferred). Discrete unobstructed measurement points are then located along each radial in accordance with the FCC requirements mentioned earlier. Next, measurement data for each radial are obtained with a field strength meter. Field strength then can be plotted against distance for each radial on special charts. These plots enable one to determine the various ground conductivities along a given radial and the unattenuated field at 1 kilometer for a given bearing. Measurements are made for both the nondirectional and directional modes of operation. Final evaluation of the initial complete proof of performance results will enable good monitor point locations and alternatives to be selected.

LAYOUT OF RADIALS AND LOCATION OF MEASUREMENT POINTS

Map Selection

First one obtains the most accurate map or maps available for the path(s) to be measured. US Geological Survey maps are preferable if they are of recent issue and/or are the result of an adequate survey. The most preferred maps are recently issued USGS 7-1/2 minute topographic quadrangle maps. The map should say: "This map complies with National Map Accuracy Standards" on the lower edge. If these are not available, county road maps may be employed.

However, some state or county road maps are not very accurate; consequently, distances should be checked by a calibrated automobile odometer before relying on them. Many cartographical errors in the placement of roads, rivers, bridges, railroads, buildings and other landmarks have been encountered which were incorrectly located by almost a kilometer.

Sometimes 7-1/2 minute topographic maps are not available for the desired location. USGS 15-minute maps often are so old that they do not show present features. In such cases, it may be necessary to lay out the radials on 15-minute maps as well as on country road maps in order to facilitate accurate location of landmarks and/or measurement points. When original measurement point locations are shown on older maps, extensive construction or changes may make it extremely difficult to find landmarks which may no longer exist. Redrafting the radials accurately on late edition maps or even new 7-1/2-minute maps, if presently available, may assist in finding as closely as possible the original points. Sometimes one encounters real dilemmas when the original maps were inaccurately drafted and new county maps and 7-1/2-minute maps show significant discrepancies.

Aerial Photographs

In some areas where roads are almost nonexistent, aerial photographs should be procured. Do not assume that specified scales for these photos are correct but verify the exact scale by correlation with known landmarks or 7-1/2-minute map distances. The radials should be carefully drawn on the aerial photos. Stereo aerial photos may be procured from map-making services with such a scale as to permit the location and identification of objects as small as fence posts.

Surveying

The services of a surveying team have sometimes been required to ascertain measuring point locations in the field when suitable maps or aerial photos could not be obtained.

Nautical Locations

Radial field strength measurement point location determination on lakes or oceans depends on nautical navigational methods, sight bearing and/or automatic direction finder bearings with triangulation calculations. Problems of this nature represent a special case and cannot be covered in sufficient detail in this article.

Precautions

On the map one should carefully locate the transmitting antenna site. Any significant error in the antenna location will result in a distorted pattern and consequently inaccurate radial data. Then a meridian (true north line, 0° True) is projected carefully through the transmitter site. With the site as the origin and with a large protractor, one lays out the radial bearing(s) and continues its projection for at least 30 kilometers from the site.

When measurements are made over a long path, progressive errors may be encountered as the radial extends over a large number of maps. Graphically it is difficult to maintain a bearing with a path covering a large number of maps. It has been found that use of spherical trigonometric calculations to determine accurately the geographical coordinates of several points on a given bearing for each map permits precise radial location. Computer time sharing services readily permit such calculations.

Selection of Measurement Points

After all radials are laid out on the maps and/or photos, one selects along the radial the appropriate number of possible measurement points that the particular job requires. Consideration should be given to accessibility and if it can be determined from the maps, surrounding terrain (see Fig. 1a to 1b). It is always easier going to a measurement point than looking for a good place to make a measurement. Planning the route can greatly speed up the collection of data. If after the measurement of the radial is completed and for one reason or another, there is a need for additional points, one will need only to "look for" those few points.

It is a good idea to mark on the map kilometer points for reference purposes as Point No. 2 on Fig. 1a and Point No. 5 on Fig. 1b. If in the course of running the radial one comes across a good looking point, its distance can be quickly determined in the field by using a small scale and the reference kilometer mark.

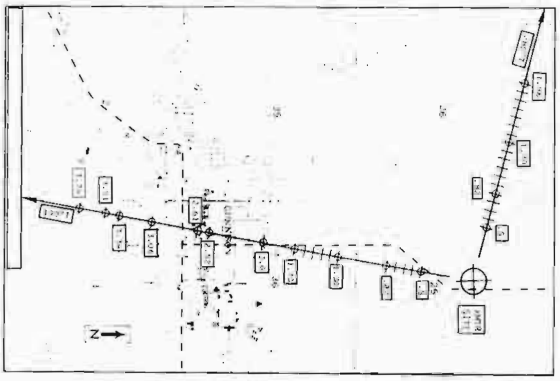

Fig. 1a. Typical radial with number measuring points.

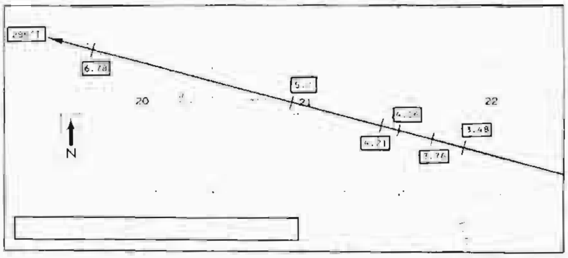

Fig. 1b. Typical radial in rugged terrain.

Retention of Aerial Photos and Field Maps

Notwithstanding the fact that over the years construction changes frequently make the original measurement point maps hopelessly obsolete, a copy of the original proof of performance maps should be retained by one's consultant for a permanent record. Aerial photographs likewise should be carefully preserved.

A set of these exhibits also should be maintained at the broadcast station for use by personnel in conducting annual measurements. Often station copies are mislayed or lost with personnel changes and the consultant's copies may be incorporated in the preparation of a new or updated station set.

LOCATION OF MEASUREMENT POINTS IN THE FIELD

Having accurately located the radials on the proper maps, one must now locate and mark the measurement points in the field. This task usually consists of locating a great number of points close to the antenna system and a lesser number of points at greater distances.

FCC Section 73.186 specifies that measurements be made at approximately 160 meter intervals within 3 kilometers of the antenna system. When topographic conditions permit, many measurement points may be located along a radial using a nonmetallic chain and/or a measuring wheel.

The most useful procedure in locating measurement points in the field is to first lay out the radial using a transit to maintain the proper bearing and surveyor's high visibility vinyl flags to mark the radial. Accurate distance measurements then can be made starting at the tower along the radial using a chain and/or measuring wheel (see 285°T radial on Fig. 1a) whichever terrain or circumstance permits. Measurement points then may be marked with flags of a color different from those marking the radial itself.

To be as accurate as possible in determining measurement points chaining should begin from known distance locations. These locations are points where the radial crosses a road, railroad grading or other pertinent, semipermanent features whose distances are determined from the topographic maps. Chaining then may proceed from this point toward and away from the antenna.

In certain types of terrain it is essential to have three people equipped with hand held two-way radios to facilitate making sure all distance measurements are along the radial.

CONSIDERATIONS AT THE TRANSMITTER

Prior to making the actual field strength measurements some consideration should be given to the antenna system itself to assure that proper operation is attained in both the directional and nondirectional modes. One should also take cognizance of the near field effects of the antenna system. Failure to check these items at the outset of the field work can render the field strength measurement data absolutely useless.

Impedance Measurement

It is suggested that all types of proofs of performance be made only after an accurate impedance measurement and possible readjustment of the common-point impedance. The calibration accuracy of the common-point ammeter and of all the base current meters must be known. An accurate determination of the input power to the antenna system and the base current ratios is impossible without the above information. Changes in transmitter efficiency may indicate that the common-point or antenna base impedance has changed.

Constant Operating Parameters

Of course, the exact licensed or specifically authorized power must be fed into the common point of the antenna system at all times during which field strength measurements are being made. Hence, the common-point current, plate voltage, and plate current must be constantly observed to insure constant power. Additionally the common-point impedance, the phases, base current, and/or loop ratios and remote base current ratios should be in conformance with the authorized parameters. The field measurements will be of no value if the power into the antenna system is allowed to fluctuate or system parameters are out of tolerance.

Tower Isolation

A satisfactory procedure for making nondirectional measurements on a directional antenna system begins by having all unfed towers in the array properly isolated or detuned. Isolation is achieved in electrically short towers (90° or less) by "floating" them, provided the tower lighting isolation and static drain circuits are of sufficiently high impedance. Towers of electrical height exceeding 1/4 wavelength (90°) must be detuned by the insertion of a detuning circuit from tower to ground to provide isolation. Isolation is necessary to prevent any mutual impedance from being reflected into the input of the nondirectional fed tower. If this isolation is not properly achieved, the "nondirectional" measurement may represent an appreciably directional effect which yields a distorted circular pattern.

However, obtaining nearly equal measured field strength values at equal distances from the tower does not necessarily mean that a nondirectional pattern exists. Careful evaluation of the measurement point values with respect to conductivity variances is required. Normally, a uniformly circular nondirectional pattern verifies proper isolation of unfed towers.

Near Field Measurements

When the electrical height of a vertical antenna differs significantly from 90°, field strength measurements close to the tower must be corrected for proximity effect. It will be found that, in the near field, short towers will provide field strength readings that are too high while very high towers will be characterized by lower than normal field strengths. Hence, field strength readings close to short towers must be corrected (lowered) to obtain the true field and vice versa for high towers. Tower heights between 80° and 100° should not require correction of measured fields at distances beyond two wavelengths. As an example, for tall towers of 225° measured field strength readings should be corrected for proximity effects at distances closer than four wavelengths. Beyond these noted distances measurements require no significant corrections since far field conditions are dominant.

The appendix at the end of this section presents curves of proximity effects from which measured field strength readings may be corrected. The appendix also supplies the equation for calculating the proximity effect corrections which may be programmed for fast and accurate computer calculations.

USE OF THE FIELD STRENGTH METER

Calibration

At the core of making successful field strength measurements is the proper use of the field strength meter. Paramount is the advice that the manufacturer's instructions should be thoroughly studied and closely followed. In addition, the meter should be periodically calibrated against a laboratory standard. Fine adjustments to the meter circuitry are made at this time to insure the accuracy of the meter. A few other comments are in order on the actual use of the field strength meter.

One important consideration is that the field strength meter should be calibrated for the received frequency immediately prior to the making of every field strength measurement. It should be noted also that if the meter is not oriented toward the antenna, an erroneous radial field strength will be obtained.

Extreme caution must be exercised when attempting to calibrate a field strength meter in an area where a high rf field strength (near field) is present. Closely following the manufacturer's instructions will permit the most accurate measurements possible to be made. Often one can calibrate the field strength meter 5 to 8 kHz away from the measured frequency, then simply adjust the receiver for a maximum signal and the calibration will be sufficiently close for an accurate measurement. Failure to insure that high field voltages do not affect the accuracy of meter calibration may lead to very large errors in the measurement of field strengths. Adherence to the manufacturer's standard calibration instructions is sufficient for far field measurements.

In order to expedite the field strength measurements for a proof of performance, several persons may take measurements at different locations simultaneously. To insure that all meters are functioning properly, it is wise to compare readings from all field strength meters at a common measurement point before, during and after the completion of the measurements. If all meters agree closely on all occasions, one may assume that the meters have been functioning properly.

Care of Field Strength Meter

During travel by car, it is advisable to place the field strength meter on the floor. Although a seat may be well padded, a sudden stop may cause the meter to tumble to the floor. When making measurements with a meter mounted on a tripod, a sudden gust of wind may topple the meter. In the presence of high winds, it may be necessary to have an assistant steady the meter; however, it should be verified that the proximity of the assistant does not alter the actual measured field. Meters should be removed from the tripod while being carried in a car to avoid damage due to strain and stress. Repair of a damaged meter and/or recalibration costs may easily exceed one tenth the replacement cost of the meter. The units should not be subjected to rain or snow. Some earlier type units have unsealed meter indicator movements which allow high winds to deflect the needle. In short, field strength meters are delicate instruments and, as such, they should be afforded ample protection against physical damage.

MEASUREMENT TECHNIQUE

The final step in the field work is the collection of the measurement data. The radial bearing is of primary importance but measurement point locations must be described with reference to landmarks so that the distance to each point may be determined accurately. With the bearing and distance to a given point known, it is only necessary then to obtain a sufficient number of measurement points. However, there are a few other things to remember in making measurements or in trying to find a suitable measurement site.

Of immediate concern is the question of just how close to the antenna system one can take field strength measurements that will not have to be corrected for the near field effects of the antenna. Corrections for the near field effects were discussed earlier and for now it will suffice to say that for nondirectional measurements (for towers of 100° or less) one may begin making measurements at a distance from the antenna of approximately five (5) times the height of the tower. For directional measurements about ten (10) times the separation between the extremities of the array should be allowed.

Errors Due to Interference from Other Stations

At the outset extreme caution must be exercised when taking field strength measurements to avoid obtaining erroneous data due to interference from other broadcast stations. To avoid possible problems from skywave interference, field strength measurements should be taken only during noncritical daytime hours (between 2 hours after local sunrise and 2 hours before local sunset). Long distance groundwave field strength measurements should be made about midday when minimum skywave interference occurs. A fluctuating level of field strength is a good indication of interference. Monitoring the audio output of the field strength meter is also an excellent idea since vacillating audio quality at a carrier strength of several millivolts is a good indication of interference. The tuning of the field strength meter may be varied to check for adjacent channel interference.

Effects of Terrain

The most marked effect on field strength is that caused by terrain. The field strength of a radio signal propagating over level ground of uniform soil composition (constant ground conductivity) will be attenuated at a theoretically predictable rate as shown in Graphs 1 through 20 of FCC Section 73.184. Other factors, however, can significantly affect the attentuation rate.

The most predictable effect on the attenuation rate results from changes in ground conductivity along the propagation path of a radio signal. A change in soil type such as from clay soil to gravel will usually result in a change in ground conductivity causing a change in the rate of signal attenuation. Thus a set of field strength measurements along a given radial may reflect attenuation rates characteristic of several different ground conductivities. It should be noted that such geographic features as mountain ranges, oceans, and plains usually present drastic changes in ground conductivity which significantly affect the measured field strength. One can only note the effects of ground conductivity on the measured field strength and accept them since this factor cannot be controlled once a transmitter site has been chosen.

Other factors affecting the measured field strength will have the overall effect of increasing or decreasing the apparent or effective ground conductivity and should therefore be minimized since they have little actual effect on the true ground conductivity.

The terrain along a propagation path will have a significant effect upon the field strength at a given measurement point. Field strength measurements made in rolling or hilly terrain will generally yield higher measured field strengths at higher elevations and lower values at lower elevations. This fluctuation of measured field strength with elevation is due in part to shadowing of the radio signal at standard broadcast frequencies.

In a similar manner, trees or other dense foliage greatly attenuate the signal. When making field strength measurements, one should therefore avoid unusually high or low places as well as heavily foliated areas. In addition field strength measurements should be made beyond such regions if possible to smooth out the effect of exceptionally high or low measurements encountered within these regions. In rolling terrain more measurements should be taken to compensate for the irregularities, and in rugged terrain it is necessary to take as many measurements as possible in spite of the increased difficulty. Sufficient radial measurements must be made to obtain the average or true radial field.

Field strength measurements made from a station in a valley with a path which includes a sharply rising mountain or mesa such that the direct line of sight path extends far above the surface of the ground have yielded excessively high signal strengths. This very high signal strength results from the "bowl" effect of the terrain to be discussed later. At greater distances from the antenna the path may extend to valleys, reverse slopes, and perhaps cross several ridges. Extensive measurements over such an extended path supply an effective conductivity and unattenuated value to confirm the path as a whole.

Radio propagation at standard broadcast and lower frequencies in portions of the inland passage from Seattle to Alaska as well as in other coastal regions of Southeastern Alaska demonstrates the amazing effects of terrain. Often reception or transmission from some regions is almost impossible even when stations are very close to each other. Yet when one station (a ship) moves only a short distance, communication may be achieved and may continue at distances far beyond the normal range of daytime communication without significant attenuation.

Urban areas with buildings, power lines, pavement, and other such construction also provide greater attenuation of radio signals. The main effect of power lines, telephone lines, pipe lines, and large metallic objects (including building structures, automobiles, etc.) is the absorption and/or reradiation of the radio signal producing a locally distorted electric field. When such obstructions lie between the measurement points and the transmitting antenna, the effect is to produce a lower measured field strength than would exist had the signal passed over unobstructed level ground. For these reasons one should avoid making field strength measurements in the vicinity of large buildings, power, or telephone lines (whether buried or not), pipe lines and large metallic objects. It should be noted that underground pipelines may cause exceptionally high measured field strength values and indicate erratic or little attenuation. These nuisances are usually shown on topographic maps and are normally marked with painted stakes where they cross rights of way. Power or telephone lines and pipe lines are particularly troublesome when they run almost radially from the transmitter site and/or parallel to measurement radial bearings. Metallic objects also can be the source of reradiated signals and should be avoided all the more. Minimum distances from commonly encountered objects likely to cause reradiation or distortion of the electric field are as follow:

5 meters (16.4 ft.) from any automobile or wire fence
15 meters (49.2 ft.) from tall trees
25 meters (82.0 ft.) from telephone lines
45 meters (145.6 ft.) from low voltage power lines
230 meters (754.6 ft.) from steel towers or high voltages power lines.

A good rule of thumb is to stay clear of such obstructions by at least 10 times the obstruction height. Care should be taken to avoid having such objects between the field strength meter and the transmitting antenna when making a measurement.

Radial and/or monitor point measurements always must be made with the plane of the field strength meter loop in line with the antenna since, under normal conditions, this yields the maximum field strength reading. This directional feature of the field strength meter can be used to determine if a measurement is being made at sufficient distance from obstacles. One has only to note the direction of the approaching wavefront (the direction of the maximum reading). If the maximum reading is not coming from the direction of the antenna, the presence of reflected signals is probable. One should also note the depth of the null as the unit is rotated. If the null is not sharp and deep, the measurement may be uncertain.

Mountainous terrain, as well as representing a substantial change in ground conductivity, may also produce very strong reflections of radio signals to the extent that the reflected signals may mask the true radial field strength along some parts of a radial. One may partially correct for the reflected signal level by orienting the plane of the field strength meter loop antenna toward the transmitter antenna.

The factors mentioned above should be considered collectively. For instance, field strength measurements made on the far side of a mountain range or ranges will be extremely low due to both shadowing of the terrain and the excessively low ground conductivity. Some of the measured field strength could be the result of reflected radiation. Field strength measurements in deep canyons, cutbanks, tunnels, etc., establish very low effective ground conductivity and high signal attenuation.

Environmental Effects

Changes in ambient conditions such as extremely high or low temperature, ice, snow, and changes in soil moisture content or water table depth have been found to adversely affect a directional antenna system. Even a good sampling loop can give an erroneous reading if covered with several centimeters of ice or snow. Often the antenna system anomalies will disappear upon the return of normal environmental conditions. One should keep in mind that if a directional antenna system is tuned and adjusted during abnormal or unusual environmental conditions (such as flooding, heavy wet snow, or drought), it may not be satisfactorily adjusted for normal conditions.

Field strength measurements taken after changes have been made in the antenna system should be accomplished under environmental conditions similar to those existing at the time the original measurements were made. Likewise, both directional and nondirectional measurements must be made under similar environmental conditions.

One way to insure similar environmental conditions is to make initial nondirectional measurements sufficient to establish the actual ground conductivity and permit determination of proper directional fields. Then, the final measurements of nondirectional and directional modes may be made by sequentially switching the antenna system from one mode to the other at specific time intervals. Hence, field strength measurements for all modes of operation may be made at a given point within minutes and under identical environmental conditions.

Logging

For more meaningful tabulation and comprehension of data, the measurement point reference number may preferably be chosen to be the same as its distance from the transmitter. One should, upon making a measurement, record the point number (the distance), field reading, time at which the measurement was made (to the nearest minute), date, and sufficiently describe the exact spot for future measurements (see Fig. 2). The particular point should be marked on the map with a line crossing the radial. Later, if necessary, a more accurate distance may be determined using a precision scale. The true radial bearing likewise should be logged along with the serial number of the field strength meter for each group of measurements.

FIELD STRENGTH MEASUREMENTS

LOCATION GUNNISON Co
RADIAL °T 193° T
F.S. METER - FIM-41 #103

STATION KVNJ
Frequency 1000 KHz
Power 1000 WATTS
Date 740515
Operation ND

Point # and Distance	Reading mV/m	Time	Point Description
.50	1310	0950	40m E of INTERSECTION, N SIDE OF ROAD
.58	1141	1000	35m NE OF FARM HOUSE
.66	1090	1006	37m SE OF FARM HOUSE
.74	947	1014	130m S OF FARM HOUSE
.82	832	1020	12 m E OF WOODEN WATER TOWER
1.30	522	1102	160m S OF MAIN ST & CR32 – 105m INTO FIELD
1.38	494	1110	POINTS LOCATED USING TRANSIT AND CHAIN.
1.46	467	1117	
1.54	458	1125	
1.62	398	1133	
1.70	388	1140	
2.52	245	1302	CENTER OF WELD RD & 13th ST
2.61	238	1319	15m INTO SCHOOL GROUNDS – NW OF MARKET & 13th ST
3.06	214	1337	MIDDLE OF RACE TRACK – IN CENTER OF #3 TURN
3.34	213	1342	S MOST EDGE OF RACE TRACK
3.51	177	1423	165m E OF INTERSECTION – 30m S OF AIRPORT RD
3.74	181	1503	CENTER OF AIRPORT RUNWAY #74 180m W OF PAVEMENT END

Fig. 2. Example of radial measurement log.

This logging accuracy must be maintained since the actual field conditions (which cannot be read from the maps) will substantially affect the final selection of measurement points, and one may not always be able to take measurements where originally planned.

PLOTTING AND ANALYSIS OF DATA

Plotting

The values of field strength which have been measured can be plotted now as a function of distance. For this task a commercially available graph paper may be used for the following plotting methods:

1. If one wishes to employ the charts of groundwave field strength found in Part 73 Radio Broadcast Services (September 1972 Edition) or the "FCC Broadcast Engineering Charts" available from the Superintendent of Documents; the data can be plotted on K&E paper No. 359-127G, "Ground Wave Field Intensity." This paper has the same logarithmic scale as that employed in the above FCC documents, and the data which have been measured can be matched directly against the appropriate FCC graph for the frequency involved. By matching the abscissa of the plotted data with that of the FCC graph and by sliding the ordinate information data up and down as described in Section 73.186, the "best fit" may be obtained. This allows determination of both the unattenuated field at 1 mile and the conductivity along the radial path. On a light table or against a window one then marks the inverse distance field and traces the apparent conductivity.

2. For those who prefer a slightly higher order of accuracy, one should refer to Graph 20 of the above publications, "Ground Wave Field Strength vs. Numerical Distance over a Plane Earth." Use of this graph allows construction of a new family of attenuation curves at the exact frequency for any desired value of conductivity and also for several values of dielectric constant. For each value of conductivity and its associated value of dielectric constant, the numerical distance in terms of R[1.61 km (1 mile)] must be computed from the equations shown on Graph 20 for vertical polarization. After drawing the inverse distance line on the graph paper, one must match this line with the equivalent line on Graph 20 while simultaneously holding the 1.61-km distance line on the computed numerical distance value. One then draws the attenuation curve most closely approaching the calculated value of "b" from Graph 20, interpolating where necessary. This is repeated for each value of conductivity and dielectric constant chosen.

For convenience it is most practical to assume one value of dielectric constant, compute the numerical distance for several values of conductivity, and plot this family of curves on one graph sheet. If other values of dielectric constant are assumed, the same conductivities assumed before should be computed and a separate graph employed for this family of curves. The plotted radial data then can be matched to these sets of curves.

3. If a still higher order of accuracy is desired, the curves shown on Graph 20 can be transferred to K&E No. 359-127G. Using this paper and having Graph 20, one can construct the families of attenuation curves as outlined in the second method above. The principal advantage gained by the use of this latter method is that the data are well spread out and can be analyzed more precisely.

If the data have been prepared by the first method above, a radial plot similar to Fig. 3a is obtained. When a sufficient number of such radials have been completed to determine the nondirectional pattern and are analyzed, the directional data can then be accurately plotted and evaluated.

The straight line of negative slope in Fig. 3a and 3b, 4 and 5 is the inverse distance line, the intercept of which at a distance of 1 mile (Fig. 3a) or 1 kilometer (Fig. 3b) gives the unattenuated field in millivolts per meter at that particular distance. The same measured field voltages appear plotted on Figs. 3a and 3b. The ordinate scale of millivolts per meter is common to all figures. The abscissa scale divisions of Fig. 3a are the same as the mileage scale in FCC Section 73.184 Graphs 1 to 19 inclusive. The measured nondirectional fields yield an unattenuated field of 434.959 or approximately 435 mv/m.

The upper plot in all exhibits is the nondirectional data while the lower plot shows the measured directional field voltages. If there is more than one directional pattern utilized at a broadcast facility, all plots for a given radial should be plotted on the same graph to easily facilitate analysis and comparison of directional with nondirectional measurements.

On Fig. 3b a similar horizontal scale has been shifted laterally such that an abscissa of 1 mile on Fig. 3a falls on the 1.609347 value of the kilometer scale of Fig. 3b. The 1 kilometer intercept then becomes 700 mv/m for the nondirectional data plot.

Thus it may be seen that the inverse distance or unattenuated field at 1 kilometer is related to the value at 1 mile by the simple inverse relationship of the two distances which are 1 kilometer and 1.61 kilometer, i.e., $700 = 435 \times 1.61$. Similarly the 1-mile value may be obtained from the 1-kilometer value as follows: $435 = 700/1.61$.

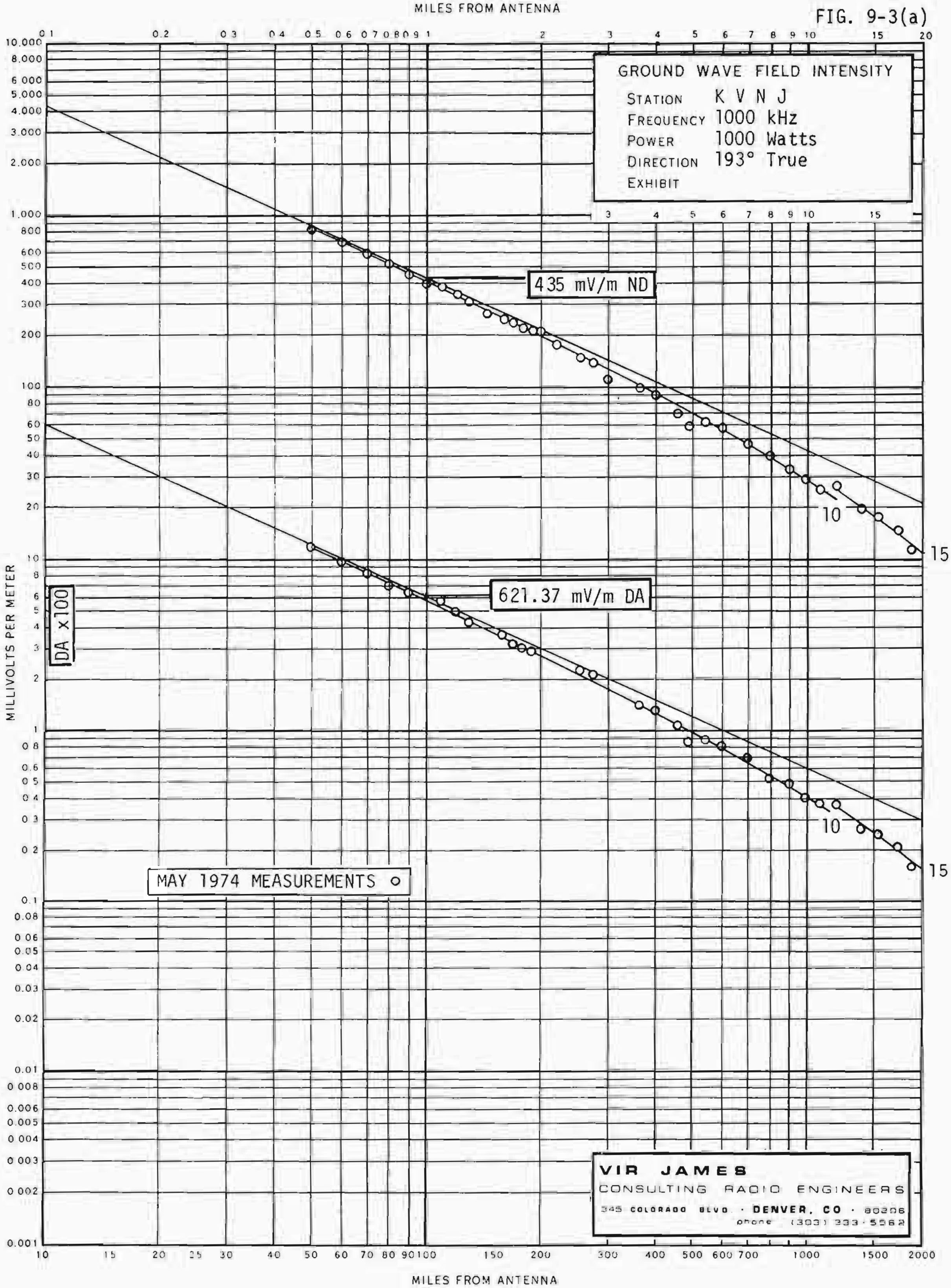

Fig. 3a. Inverse distance and measured fields; nondirectional (upper), directional in major lobe (lower), mileage scale.

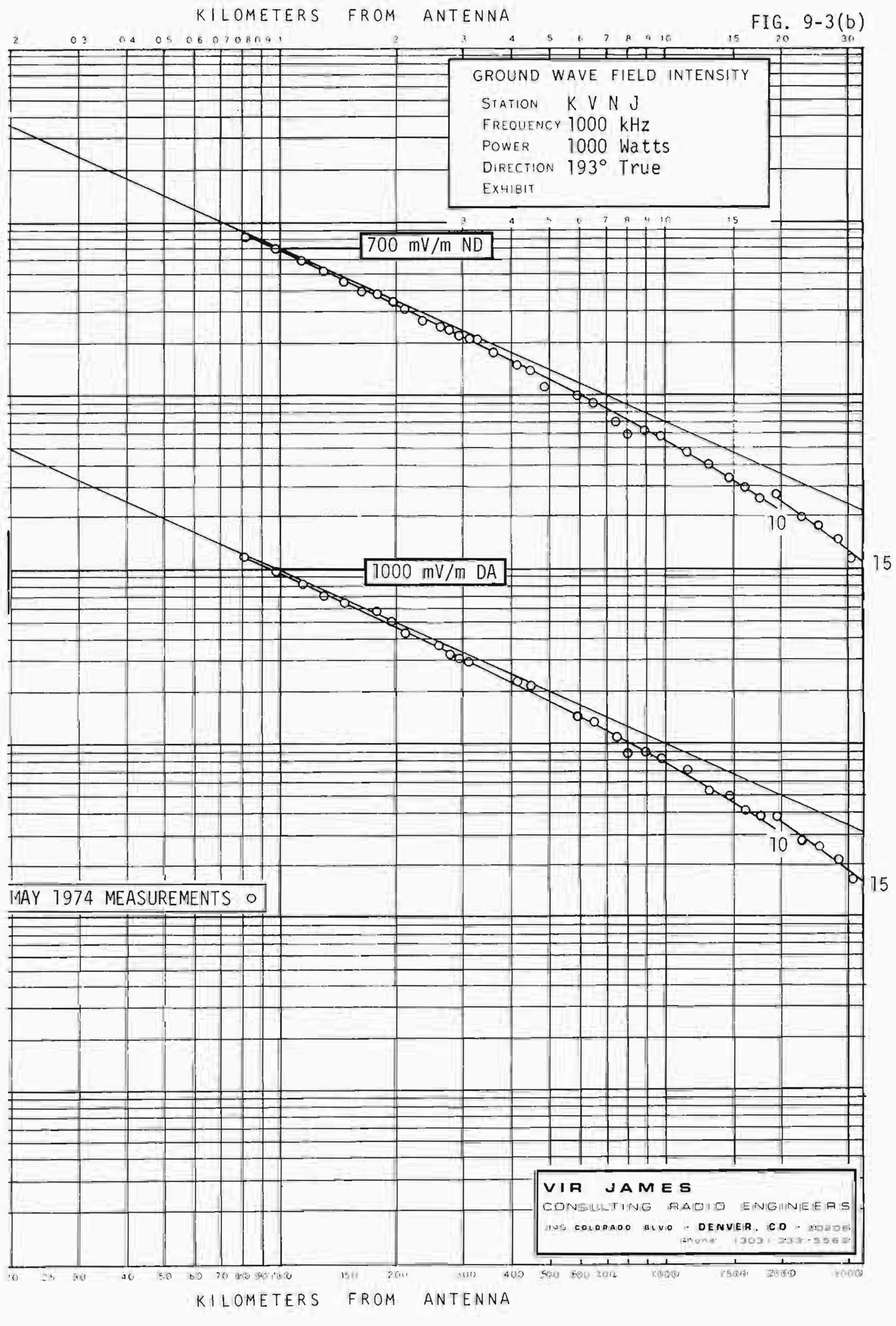

Fig. 3b. Inverse distance and measured fields; nondirectional (upper), directional in major lobe (lower), kilometers scale.

Hence, one may convert the unattenuated values at 1 kilometer to those at 1 mile by dividing by 1.61 and vice versa.

Hence, it may be seen that the FCC Section 73.184 Graphs 1 to 19 may be adapted easily to metric measurements by sliding the mileage scale to the left by a factor of 1.609347 or approximately 1.61 and labeling the shifted mileage scale in kilometers. One must remember then that the 1-kilometer intercept unattenuated field will be approximately 61 percent larger than the 1-mile unattenuated field. These simple factors may be used to relate all unattenuated or pattern values from kilometers to miles or inversely to refer to kilometers.

In view of conversion to metric units, Figs. 4, 5, and 6 have been shown with kilometers as distance units.

Analysis for a Specific Frequency

The FCC has presented common conductivity values in FCC Section 73.190, Fig. R3. Section 73.186 Graphs 1 through 19 were prepared indicating conductivity effects of certain frequency ranges. With a sufficient number of accurate measurement pints, the common conductivity can be determined by the previously mentioned plotting methods. However, for critical interference studies requiring extremely accurate conductivities, Graph 20 should be incorporated for the preparation of conductivities at a particular frequency (see Fig. 4, 10.6 mS/m out to 16 km, 7.3 mS/m to 32 km). Numerous additional measurement points must be taken and critically evaluated to determine the conductivity between the given values.

Analysis of Data with Scattering

The same methods are used in the plotting of the directional data. In some instances, as shown in Fig. 5a, a wide scattering of the measured values will appear and drive one out of one's mind. In most cases, there will be scatter only in the directional data. The scatter (shotgun effect) is usually emphasized where one or more of the following conditions prevail:

1. Widely spaced arrays in terms of frequency;
2. Deep nulls;
3. Poor soil conductivity, rugged or mountainous terrain;
4. Metallic obstacles near the path;
5. Power lines or reradiation from other towers;
6. Reradiation from obstacles near the antenna;
7. Buried pipelines running radially from the antenna near the path.

Under such circumstances it is necessary to obtain as much data as possible and depend upon the most probable grouping of measurements to determine the directional field. Often the points at the greater distances give the best comparison with the nondirectional field values. In contrast, Fig. 3b shows data taken on the same array but in the direction of maximum directional radiation. One should observe that there is little or no scatter in this directional data. These data are typical.

Severe scattering in mountainous terrain on measurements of very deep null radials has been encountered. Here the measured field supported by measured data at 80-meter intervals displays a pronounced standing wave pattern of significant amplitude. This superimposed wave shape effect upon the attenuated signal versus distance plot usually decreases at greater distances from the antenna.

Fig. 5b shows field strength measurement data frequently encountered in mountainous terrain. In the region between 2 and 6 kilometers, measured fields greatly exceed the inverse distance line. Analysis of this measured data clearly illustrates the "bowl" effect of terrain upon field signal strengths. AM broadcast stations usually are located in valleys where the ground conductivity is higher. Situations may exist where the signal path is for the most part high above ground with measuring points up the face of a mountain or mesa; consequently, free space effects rather than ground attenuation predominate. Indeed, the signals seem to be gathered up or amplified by the terrain much as a corner reflector, parabolic or horn antenna increases the effective radiated power. Hence, this region of very high signal level is not indicative of the true overall radial unattenuated field strength and must be disregarded in the overall analysis of the radial.

Data Presentation for Comparison

Field strength measurement data for periodic proofs or specially requested FCC proofs should be compared with the last previous complete proof of performance data. The most effective way to show directional stability or verify the validity of the pattern is to present the original data and the newly measured data in such a manner as to facilitate visual comparison of the plotted data. The following methods greatly facilitate the comparison of plotted data:

1. Screening the original data and graph with the new data plotted in solid color (see Fig. 6a);
2. Drawing different size points corresponding to the various years' measurements (see Fig. 6b);
3. Overprinting with the new data in a different color.

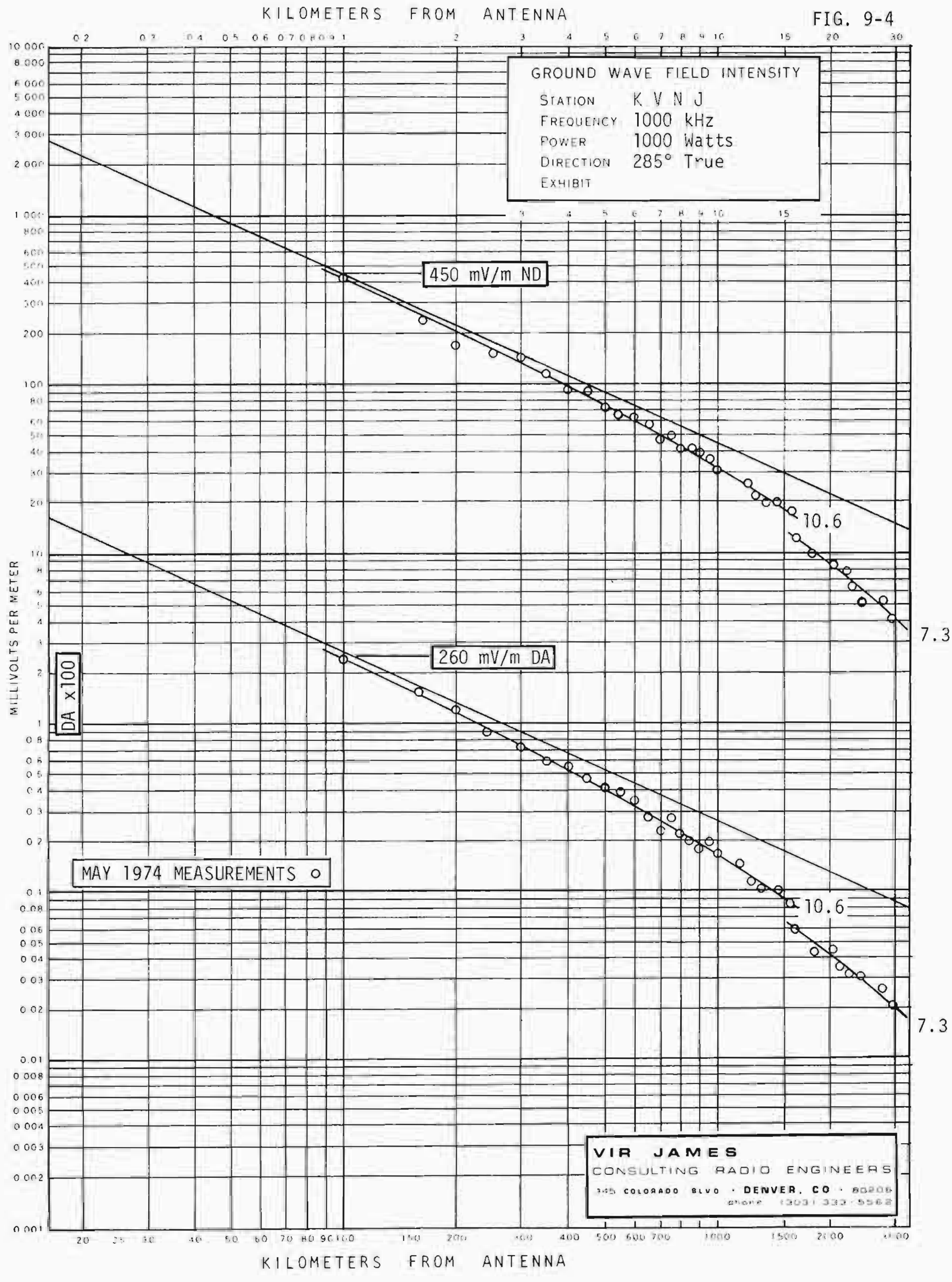

Fig. 4. Inverse distance and measured fields; with computed conductivities.

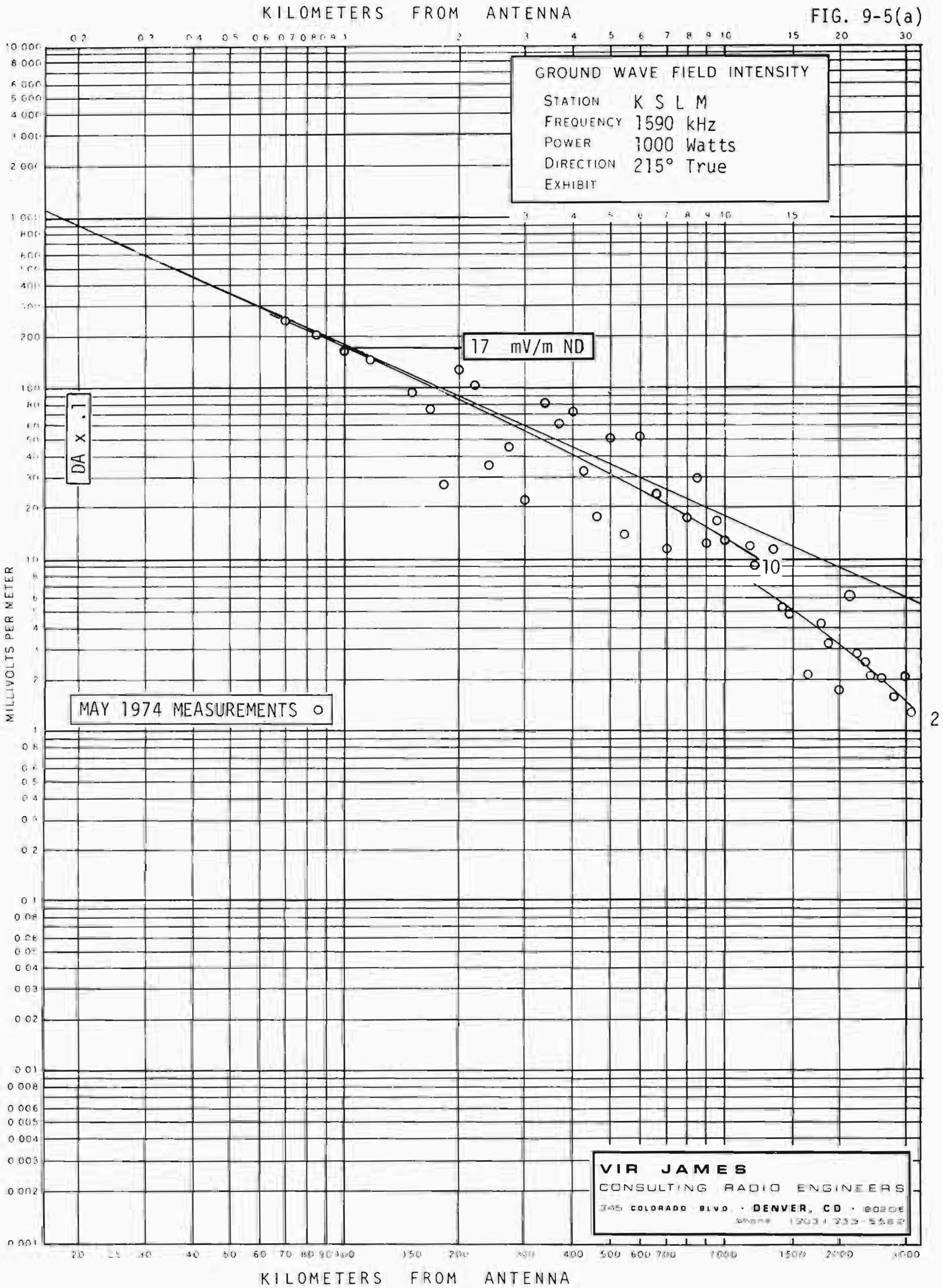

Fig. 5a. Inverse distance and measured fields; directional operation on radial of protected null, showing increased scattering.

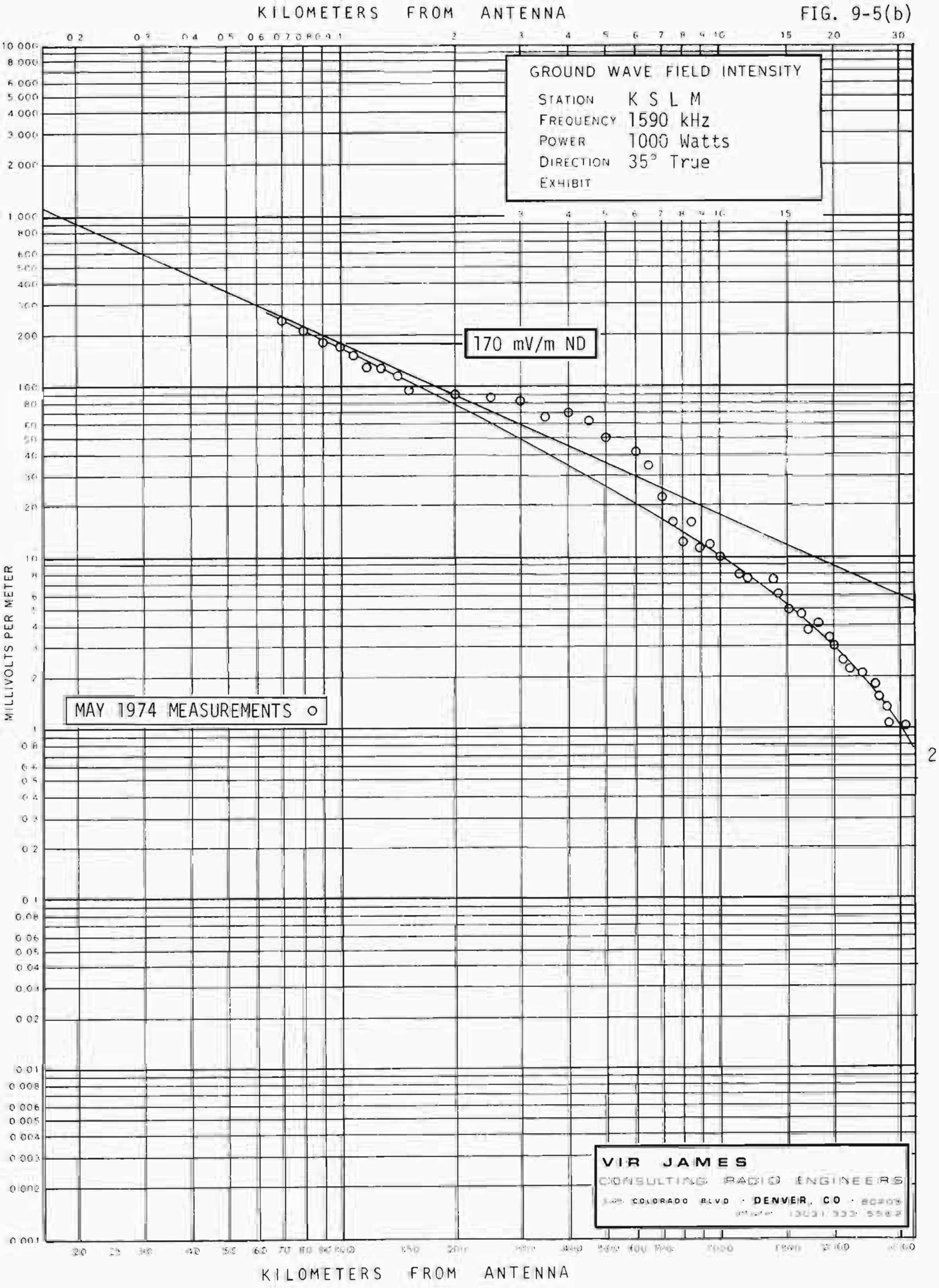

Fig. 5b. Inverse distance and measured fields; directional operation on radial, showing "bowl effect."

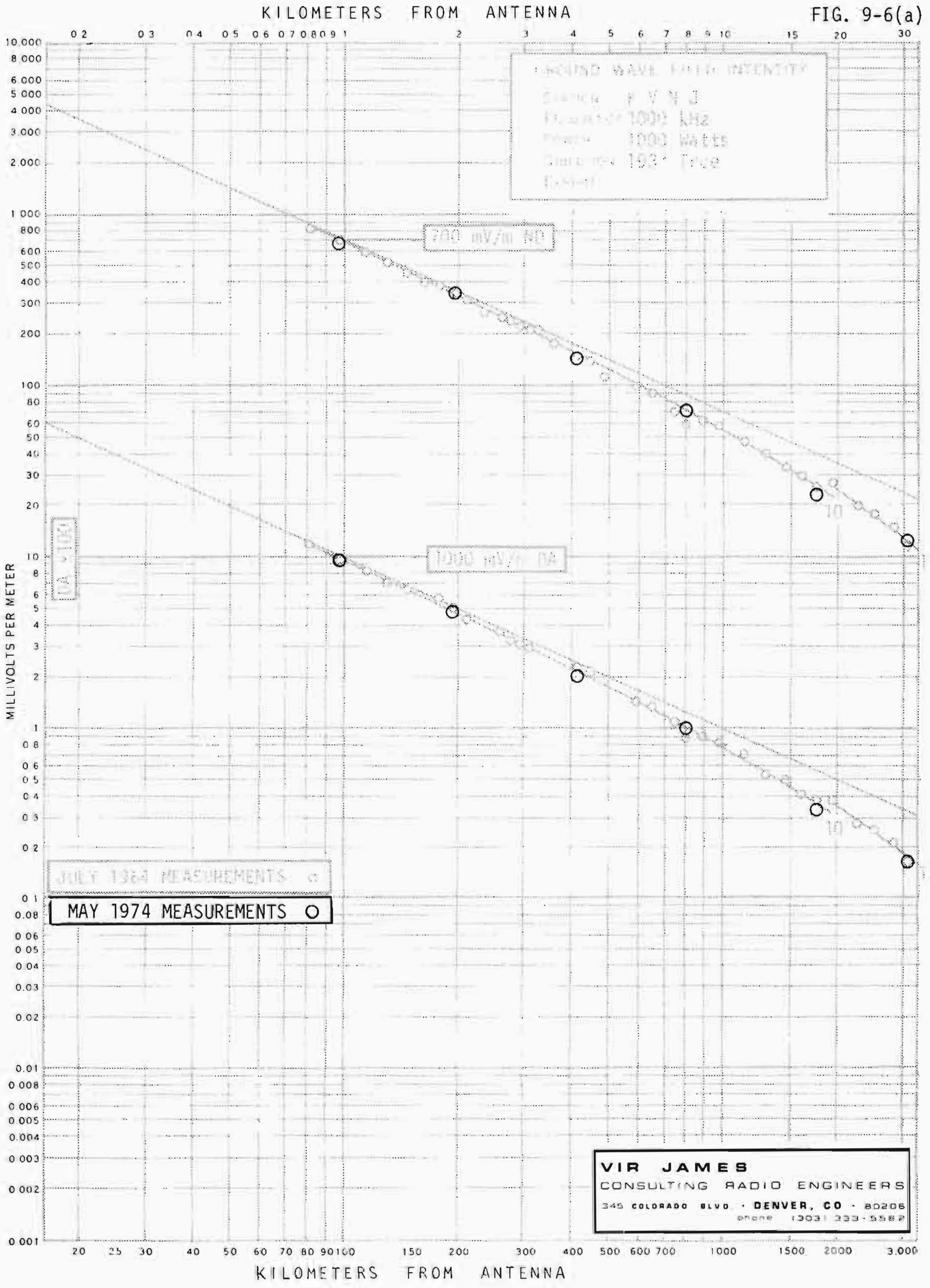

Fig. 6a. Inverse distance and measured fields; comparison of various years data by screening.

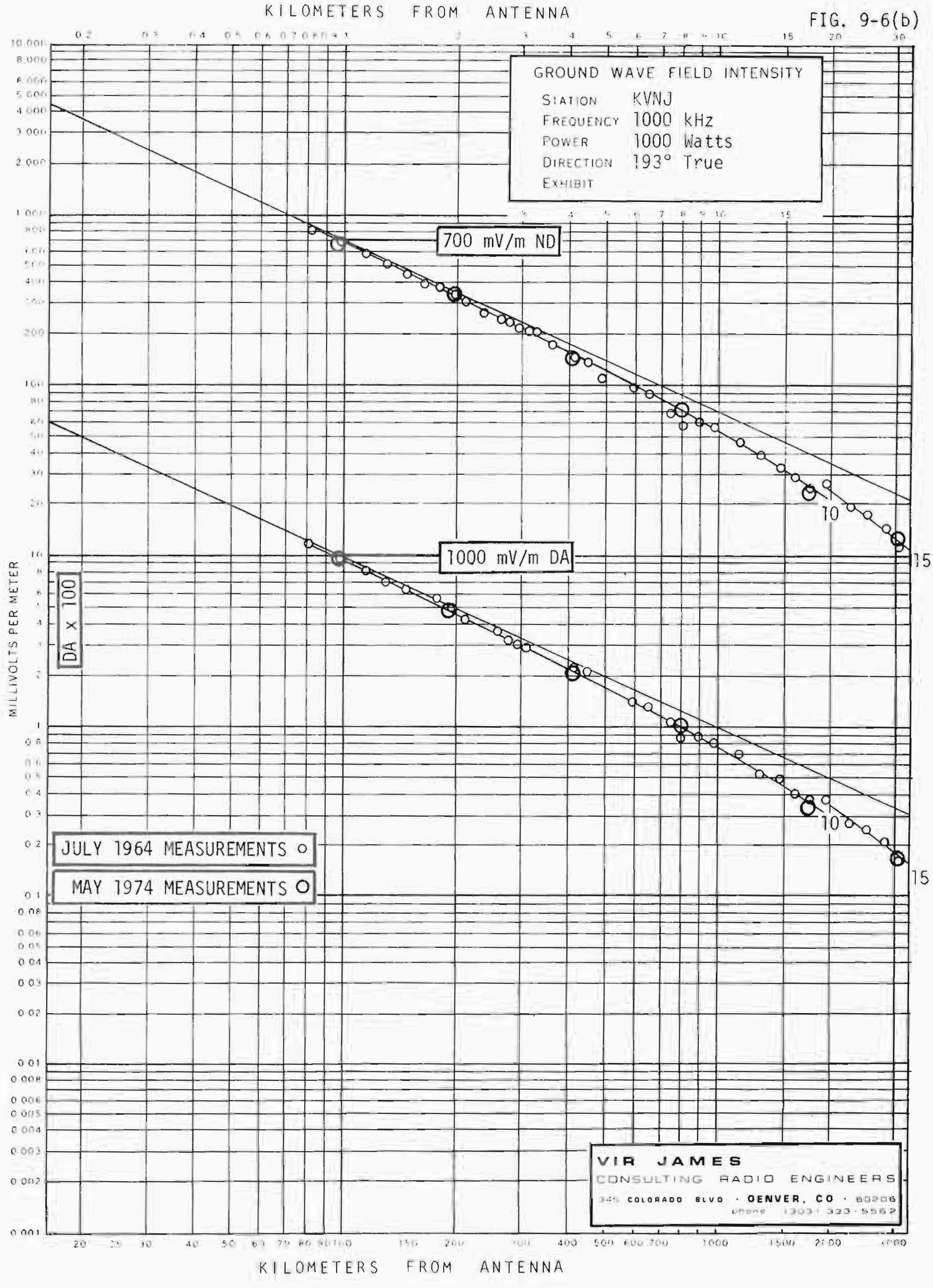

Fig. 6b. Inverse distance and measured fields; comparison of various years data by different size points.

SELECTION OF MONITORING POINTS

The next order of business is to locate the "monitoring points" required on the prescribed radials. At least one such point and preferably one or two alternate points must be established on each such radial. They must be easily accessible, clear of obstacles and likly to remain so. The measured values at the point should lie reasonably close to the attenuation curve shown on the graph of the measured data, and there should be some readily identifiable object nearby that will show in the photograph of the point. The description of the point itself should be clear and the route from the transmitter to the point should be specified along main highways or well-traveled and marked roads. Fig. 7 illustrates a good monitoring point.

OTHER USEFUL MEASUREMENTS WITH A FIELD STRENGTH METER

Establishing Coverage

Most of what has been discussed so far has dealt exclusively with the collection of data for a proof of performance. It should be mentioned that the modern field strength meter has many other useful applications as noted at the beginning of this article.

A station's coverage, for instance, may easily be established by measuring the field strength along a given radial until the desired signal level has been reached and passed by a reasonable margin. Normally eight radials are measured to establish the coverage area. Fairly abrupt changes in conductivity can extend the average contour distance beyond that anticipated on the basis of just passing the desired signal value. Such field conditions can at times yield some surprising coverage results.

Fig. 7. Typical monitoring point location. Note freedom from overhead wires, underground cables, easily referenced location, etc.

Preliminary and Actual Interference Measurements

The field strength meter is also useful in making preliminary interference measurements. Measurements of interference contours in accordance with FCC Section 73.186 often are both extensive and expensive, the probable outcome of which may be determined by conducting "preliminary" measurements. For such preliminary measurements it is convenient to plot connecting radials between broadcast facilities on charts such as Sectional Aeronautical Chart (SAC) or a World Aeronautical Chart (WAC). Along the routes of the connecting radials nearby airports may be chosen as good sites for these initial measurements. It is helpful to calculate the predicted measured field strength at each airport for two or three assumed ground conductivities. A man with a field strength meter may then conveniently fly to the airport, land, and take a reading in a relatively short time at fairly low cost.

These measurements may ascertain the actual ground conductivity (low to avoid interference, high to prove coverage). Should the preliminary measurements indicate unfavorable conductivity results, the high cost of the detailed measurements would thus be avoided. Favorable results would justify a complete set of measurements along the radial that should be located and recorded similar in procedure to a directional antenna proof of performance extended to the required distances. In addition to the connecting radials between facilities, supplemental radials and/or "stub" radials also should be plotted to confirm conductivities to service areas. Of course, it is necessary to provide all the detailed measurements and analyses for filing with the FCC in accordance with Section 73.186 to substantiate the actual conductivity or contour.

To determine measured service contours or contour overlap of stations A and B, field strength measurements are made from A toward B and from B toward A as outlined in FCC Section 73.186. Field strengths of both stations should be measured at each point if possible, unless interference prevents measurement of both stations. Where pertinent contours subtend significant angles, it may be necessary to measure several radials out from each station to precisely locate critical portions of each contour.

Connecting radials determine a contour location or conductivity along the radial and for a short arc on either side of the radial. If a given service or contour area is not too large, measurements of the connecting radial plus two short or stub radials may be sufficient to delineate the location of the service area or interference contour. Stub radials should begin at field levels of approximately one-half the pertinent contour value and extend to field strengths approaching twice that of the contour. When plotted, field strength values substantiate the connecting radial conductivity and contour. The exact location of the contour may be obtained from the plot of the measured data. Stub radials normally must be measured from each station unless one station has a very small service area such that the connecting radial will verify all necessary portions of the contour.

Interference or service contour measurements in general are similar to proof of performance field strength measurements except that radials are extended as outlined above. The precautionary measures to be observed have been discussed previously. Measurement points beyond 20 kilometers should be taken only at specifically identifiable points. Where landmarks definitely establish a point, a field strength measurement should be taken. Such points may be separated by 6 to 20 kilometers. Inspection of the graph of Fig. 3b will provide a guide for measurement point spacing to insure a satisfactory curve. The field strength versus distance plot may be extended beyond 30 kilometers by also plotting the distance data using the lower kilometer scale (20 to 3000 kilometers).

Site Survey

The use of the field strength meter to conduct a site survey is similar to a nondirectional proof of performance with a low effective radiated power. Usually a short or temporary antenna system is set up at a prospective site with a low power transmitter to permit making field strength measurements on a radial through the major market areas. In some instances a directional proof of performance at low power may be required. In either case, the proof of performance procedures outlined above apply.

Harmonic and Spurious Radiation Measurements

One of the most useful additional applications of the field strength meter is that of measuring the harmonic and spurious radiation levels from a station. Some of the new field strength meters have the capability of measuring field strength on frequencies up to 5.0 MHz. This allows measurements of many of the harmonics of broadcast frequencies at least up to the third harmonic on 1600 kHz. Harmful harmonics above the third are normally not encountered. A good procedure for harmonic radiation measurements is to calibrate the field meter about 1.0 kilometer, or 10 times the separation of the two most distant elements of the array (whichever is the greater), away from the antenna system and measure the magnitude of the fundamental and harmonics radiated. One may then calculate the harmonic attenuation in dB with reference to the fundamental. This is the method preferred by the FCC for ascertaining that harmonic radiation is within the allowable limits of Section 73.40. The limitation for radiation 75 kHz or more from carrier is

$$43 + 10 \log P\,(\text{watts}) \text{ or } 80 \text{ dB}$$
(whichever is greater).

In the past, attempts have been made to measure harmonic and nonharmonic spurious radiation by using a communications receiver. This has proven to be an inaccurate and therefore futile endeavor. Spurious radiation can be measured most easily with a spectrum analyzer. This permits direct observation of the frequency domain of the transmitter output. A modern well-shielded and highly selective field strength meter also may be used to measure spurious radiation. FCC limitations for spurious radiation are specified as follows:

Greater than 30 kHz from carrier	35 dB below carrier
15-30 kHz from carrier	25 dB below carrier

Older types of field strength meters also may be used to obtain absolute values of harmonic radiation. Such early field meters as the RCA TMV-75B, RCA 308-B, Federal 101 with high-frequency loops or the more recent Stoddard, Empire Devices, Polarad, or equivalent units will serve to provide accurate measurements of harmonic or spurious radiation.

Skywave Signal Measurements

The measurement of skywave signals from distant stations by individuals has lapsed into obsolescence in recent years. The Commission has consistently held that such data will not be admitted in contested hearings and are admissible only in "rule-making" proceedings. Since there have been no such proceedings recently, no skywave data have been required. Moreover, the FCC and the Central Radio Propagation Laboratory of the Bureau of Standards have collected such data for years and have a myriad of data for every bit that an individual could assemble. Hence, there is little reason to collect and analyze the data. Individuals, therefore, need not plan on repetitiously making their own skywave field strength measurements.

SUMMARY OF IMPORTANT CONSIDERATIONS IN FIELD STRENGTH MEASUREMENTS

The preceding material expounds the most important aspects of making accurate and reliable field strength measurements. It should be emphasized, however, that it would be nearly impossible in such a short writing to fully explain all of the details. One should, therefore, at least give full consideration to the following suggestions:

1. Read the rules of the FCC and understand them before beginning;
2. Obtain accurate and up-to-date maps and check them;
3. Verify the antenna site on the maps;
4. Use a recently calibrated meter or check it against another meter which has been recently calibrated;
5. Review the meter calibration procedures;
6. Start out with fresh batteries or have a spare set available;
7. Verify proper operating parameters of the directional array or nondirectional tower;
8. Maintain a constant transmitter output power;
9. Make certain the car odometer used is reading properly;
10. Stay on the radial;
11. Do not skimp on the number of measurement points even at larger distances;
12. Accurately describe each point so that it can be found later;
13. Make certain the meter is tuned to the proper carrier and not receiving interference;
14. Mark measurement points on maps accurately;
15. Record date, time serial number of meter, point number or distance, radial bearing and point description;
16. Treat the meter with tender loving care;
17. Measure field strengths during noncritical daytime hours;
18. If possible, recheck monitor points or other reference points before beginning a long radial measurement trip.

FUTURE ROLE OF FIELD STRENGTH MEASUREMENTS

Since the Fifth Edition of the *NAB Engineering Handbook* was issued in 1960, there have been two "freezes" declared by the FCC covering standard AM broadcast applications. The first was from 1962 to 1964 and the second from 1968 to 1973. The latter AM freeze was only partially lifted effective April 1973. The AM freeze is still frozen essentially solid for over 90 percent of the existing AM stations which might wish to increase their power or change frequency.

Many frequencies remain essentially unused and certainly underused as far as vast areas of the conterminous US is concerned, and it has been truly said that such unused frequencies represent in fact a vast wasteland of channels. Furthermore, at such time as existing stations are permitted to increase their power, change frequencies or to make major changes, additional AM field strength measurements may be required to actually measure service and interference contours.

Not prohibition but utilization provides increased radio services to the American people—more efficient utilization should be the goal to provide radio service for all areas of the country. Field strength measurements will play an ever increasing role in maximizing the utilization of radio broadcasting services. As each new station is authorized, or each power increase approved, the necessity of field strength measurements increases.

In this section an effort has been made to cover most of the facets of field strength measurements which increasingly will be required in the future and to aid engineers in avoiding the most common pitfalls of field strength measurements. It is hoped that the techniques revealed in this section will prove helpful in making the field strength measurement procedure a logical routine rather than an esoteric art.

APPENDIX A

Application of Proximity-Effect Curve[a]

1. The curve in Fig. A shows the amount by which the measured field strength, as measured by a field strength meter which employs a shielded loop, will depart from an inverse distance function because of induction field or proximity effect due to measuring close to the antenna.

2. It is based upon the calculation of the horizontal component of magnetic field close to an antenna, after the manner of Dr. George H. Brown.

3. It can be used first as a guide determining how close one can measure to a given antenna before the correction due to proximity would be expected to exceed a given percentage.

4. It can be used to correct for the error due to proximity before plotting field strength measurements to determine accurately the inverse distance fields. This permits measurements to be made sufficiently close to the tower to eliminate the effects of conductivity.

Derivation

1. G.H. Brown, Directional Antennas, *IRF*, January 1937, on page 81 and in Formula 7 gives the general formula for the magnetic flux density at any point in space from a vertical radiator over a perfectly conducting earth. By restricting this point P to the earth's surface, certain simplifica-

[a]Silliman, Moffet, and Rohrer.

tions can be made in Brown's formula. Specifically Z goes to zero and $r_1 = r_2$ and $r_0 = x$.

2. The simplified formula becomes:

$$B_\phi = \frac{j2 \times 10^{-9} I_0}{r_0 \sin kG} \left[\epsilon^{-jkr_1} - \epsilon^{-jkr_0} \times \cos kG\right]$$

where $k = \dfrac{2\pi}{\lambda}$

3. Now when the distance r_0 becomes so great that $r_0 \approx r_1$

$$B_\phi(\text{far field}) = \frac{j2 \times 10^{-9} I_0}{r_0 \sin kG} \left[1 - \cos kG\right] \times \epsilon^{-jkr_0}$$

4. Now let $57.3kr_1 = r_1$ (degrees); $57.3kr_0 = r_0$ (degrees); $57.3kg = G$ (degrees).

5. Also convert from exponential to trigonometric form.

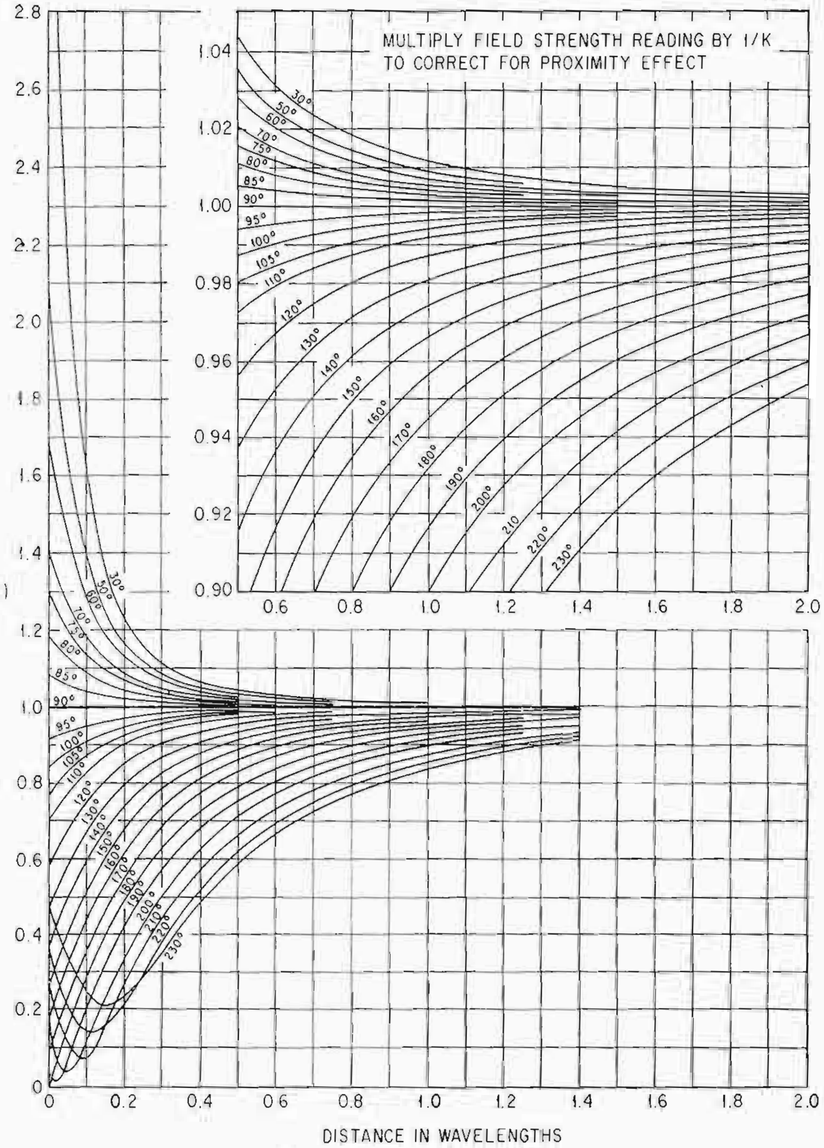

Fig. A. Proximity effect for various tower heights.

6. The resulting ratio is

$$\frac{B_\phi}{B_\phi(\text{far field})} = K = \frac{[\cos r_1 - \cos G \times \cos r_0]^2 + [\sin r_1 - \cos G \times \sin r_0]^2 \Big|^{1/2}}{[1 - \cos G]}$$

7. Therefore:

$$\frac{\text{Field measurement}}{K} = \text{adjusted field}$$

17

Standard Broadcast Transmitters

R.S. Bush
AM Engineering Design
Gates Broadcast Equipment Division
Harris Corporation
Quincy, Illinois

The most recent decade has probably witnessed more dramatic and unusual changes in AM transmitters than has occurred during the four past decades of AM Broadcasting. It is the intent of this chapter to present as much factual information as possible on the more important changes. Specific examples of these advanced designs with respective benefits will be discussed.

The following are some of the most impressive innovations found in transmitters presently being delivered by transmitter manufacturers.

Transistors

The use of transistors as important functional elements has increased in AM transmitters. This trend is certain to continue. Compared to tubes, transistors have inherent advantages of higher reliability, more linear operating characteristic, low power consumption, and reduced extraneous circuit elements which makes them desirable for audio and RF circuits.

High Plate Efficiency Circuitry

This method of increasing plate conversion efficiency is presently used by two manufacturers and is proving an important innovation from the standpoint of longer tube life and increased modulation capability.

Askarel Filled Modulation Transformers

Within the last few years, several transmitter manufacturers have employed Askarel filled modulation transformers virtually eliminating modulation transformer failures. While there is nothing new about Askarel filled modulation transformers, it is included in this discussion of advances because its use provides all of the advantages of an oil filled transformer without eliminating many of the advantages of a dry type. Its size is very nearly the same as the dry type because it takes advantage of many of this decade's improvements in insulating materials.

Pulse Duration Modulation

A modulation technique which develops the audio power required to modulate a conventional Class C RF amplifier by recovering the audio signal from a pulse train whose duty cycle varies with the amplitude of the modulating signal. The technique allows utilization of high efficiency Class D service for the modulator versus low efficiency linear service as employed in conventional high level modulators.

Progressive Series Modulation

A high efficiency form of series modulation which includes two active pass elements in series with the RF amplifier stage. One pass element provides positive peak modulation, while the other modulates the RF in the negative direction. The technique requires no modulation transformer or reactor and no filter reactor. The technique is particularly applicable in solid-state transmitters to amplitude modulate Class D solid-state power amplifiers.

MODULATION SYSTEMS

The following types of modulation systems are employed in broadcast transmitters at this time. They are considered separately from discussions of respective transmitters so the transmitters themselves may be evaluated on their individual merits without the confusion of simultaneously evaluating modulation systems.

Screen Grid Modulation

In this method the screen grid potential of tetrode PA tubes is varied with the modulating signal by direct coupling of the modulator stage to the screen grid.

Screen grid modulation is also called Efficiency Modulation because the conversion efficiency of the modulated PA stage varies with the modulation. At carrier conditions where the plate voltage swing is only one-half maximum the conversion efficiency is 33 percent whereas at 100 percent modulation, the plate voltage swing is maximum and the efficiency is approximately 80 percent or which is comparable to the conversion efficiency of a Class C amplifier.

The advantages of Screen Grid Modulation are low audio power requirements, no large audio transformers or reactor, and capability for addition of overall feedback to the modulated stage for improved fidelity.

Phase to Amplitude Modulation

In this system, the phase of the RF signal is modulated with the audio signal at low levels to two similar amplifier chains in such a manner that when the phase is advancing in one chain, it is retarding in the other. The resultant outputs then are combined in the load to produce an amplitude modulated signal.

At carrier level, the phase of the outputs of the two RF channels are adjusted 135° out of phase. During modulation the phase shift of both amplifier chains are linearly varied with the modulation signal plus and minus 22½° above and below the carrier condition, but in opposite direction from each other. If the amplitudes are equal, then at 100 percent negative modulation the two chains are 180° different in phase and therefore cancel. Similarly, on 100 percent positive peaks the two chains are 90° apart in phase.

Because of the shifting phase relationship between the two output tubes, the load impedance of each tube varies widely during modulation. In order to maintain reasonably constant efficiency of the modulation cycle, the RF driver stages of the two amplifier chains are also modulated.

Conventional Methods

The most common modulation system is still high-level plate modulation. Few changes have occurred in these tried and tested systems except for the use of pulse duration modulation. Increasing emphasis is being placed on positive modulation percentages greater than 100 percent. One hundred percent negative amplitude modulation peak is when the carrier amplitude becomes zero. Positive peak modulation is then reference to negative peaks so that 100 percent positive peak modulation occurs when the positive excursion of the modulation signal equals the negative excursion at 100 percent. Consequently, any positive excursion greater than the negative swing is defined to be more than 100 percent positive modulation.

Note: Modulation percentage relates to carrier amplitude at the instant of modulation. This means that any percentage of modulation applied to the positive swing of the carrier must consider the carrier shift present at that instant. For example, if a transmitter modulating 100 percent on negative peaks had a 5 percent carrier shift, then 100 percent positive peaks would indicate only 90 percent when referred to the carrier amplitude before modulation occurred.

Pulse Duration Modulation (PDM)

The simultaneous requirement for low cost, broad frequency response, low distortion and high efficiency has resulted in a modulation system which utilizes a new approach for obtaining the audio power for high level plate modulation. The new modulation system (PDM) obtains its improved performance by operating a modulator tube in series with an RF power tube. High efficiency is obtained by operating the modulator tube in a saturated switching mode, or Class D.

The amplitude of the audio signal is determined by the percentage of time the modulator tube is conducting (duty cycle). The tube current is a square wave function whose duty cycle (pulse width) is varied as a function of audio amplitude. A 70 kHz square wave is presently used in one system.

The fundamental component of the square wave is filtered leaving the amplified audio and a dc component which is the modulated plate voltage for a Class C final amplifier.

Progressive Series Modulation (PSM)

In solid-state AM transmitters the use of series modulators is attractive due to their simplicity and the ability to divide the modulation circuitry into sections to be used with similarly divided RF amplifier modules. In addition, a series modulator can be designed that is dc coupled, yielding improved transient response, automatic power control, and the ability to change between two operating powers without carrier interruption.

To improve the efficiency of the technique, two pass elements are used instead of one. One element modulates the carrier in the negative direction, the other in the positive direction. This reduces the time that each pass element is conducting and thus reduces the power dissipated in each device. During carrier conditions, for example, only one device conducts, supplying a lower voltage to the RF amplifier. The other device is in a quiescent state and only conducts during positive modulation conditions that require higher applied voltage.

The result of this technique is the simplicity of Class B modulation, the performance of a simple series modulator and good efficiency.

CONTINENTAL ELECTRONICS 317C 50 kw TRANSMITTER

The 317C transmitter employing tetrodes, 4CX35000C, in both the carrier and peak tube positions with screen modulation of both tubes results in a highly efficient transmitter.

A 90° phase lag network connects the plates of the two PA tubes together and a similar arrangement is used on the grids. One tube supplies all of the power output for carrier conditions while the second tube becomes operative only to supply peak power during positive modulation. Both tubes operate in a Class C mode. A positive bias is applied to the screen of the carrier tube and a small negative bias to the screen of the "peak" tube. In this way the "carrier" tube is modulated negatively during the negative half of the modulation cycle, while the "peak" tube is modulated upward during the positive half of the modulating cycle.

Plate voltage does not increase with positive modulation so a higher plate voltage than usual, 16 kv, is used to increase plate efficiency. The high efficiency of the PA plus the low modulating power required results in a high overall efficiency for the 317C. See Table 1.

The Continental 50 kw transmitter is self-contained except for a housing which contains the high voltage plate transformer, a Wye-Delta switch, and a plate voltage regulator.

A simplified schematic of the 317C transmitter is shown in Fig. 2.

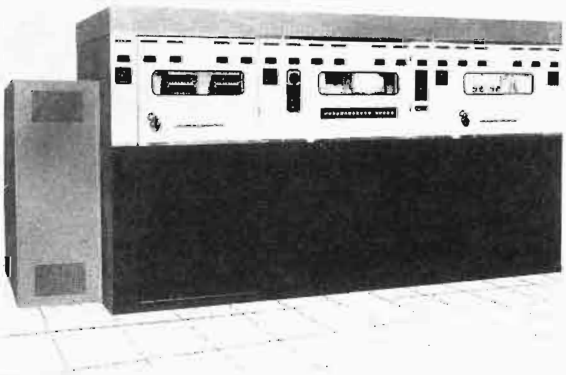

Fig. 1. Front view of the Continental 317C 50 kw Transmitter (Courtesy Continental Electronics Co.).

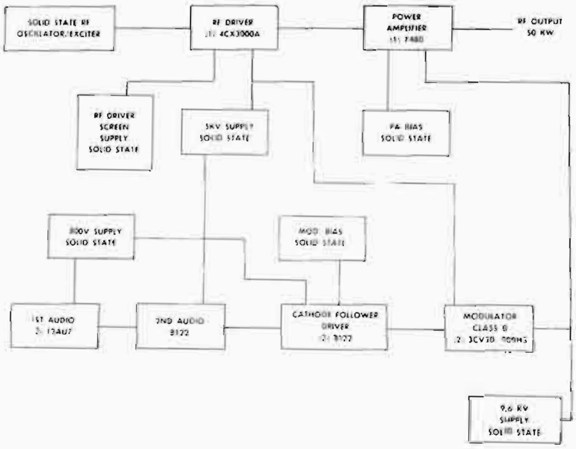

Fig. 2. Simplified schematic Continental 317C Transmitter (Courtesy Continental Electronics Co.).

HARRIS MW-50 TRANSMITTER

The Harris MW-50 transmitter features high level plate modulation employing pulse duration modulation (PDM). The transmitter is air cooled and uses only 5 tubes and is self contained in two cubicles with the exception of external high voltage power supply.

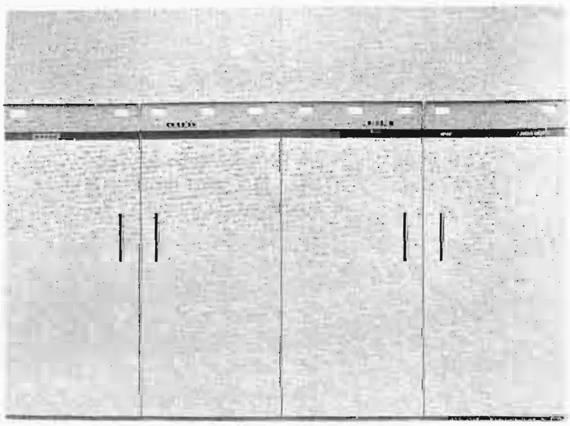

Fig. 3. Front view Gates VP-50 50 kw Transmitter (Courtesy Gates Radio Co.).

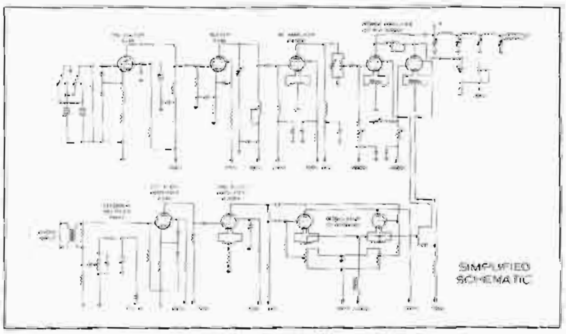

Fig. 4. Block diagram-Gates VP-50 Medium Wave Transmitter (Courtesy Gates Radio Co.).

The RF power amplifier employs a 4CX35000 operating Class C and is modulated by audio voltages developed by another 4CX35000 operating in Class D switching mode as a pulse amplifier.

The modulation method employed allows reproduction of complex modulation waveforms representative of highly-processed audio.

The modulator driver and RF driver tubes are 4CX1500A's. All lower level stages are solid state.

Control and protective circuits limit plate voltage applied to the RF power amplifier during an overload condition to 10 milliseconds duration and provide fault indication. VSWR protection and metering is employed.

A block diagram is shown in Fig. 4.

THE RCA BTA-50H1 TRANSMITTER

This 50 kw broadcast transmitter uses the phase-to-amplitude modulation system called "Ampliphase" by RCA. It is an air-cooled transmitter using 6697 tubes in the final of each 25 kw RF amplifier chain. The RF chains each share a common oscillator using an 807 tube which drives a variable resistance type of phase modulator.

A drive regulator samples the audio signal, amplifies and couples it to the grids of the second IPA stage. It consists of two 6A67s and four 807 tubes. It varies the drive to the final amplifiers to assure maximum plate efficiency over the complete audio cycle and contributes to overall linearity.

Fig. 5. Front view of the RCA BTA-50H1 50 kw Transmitter (Courtesy RCA Broadcast Products Division).

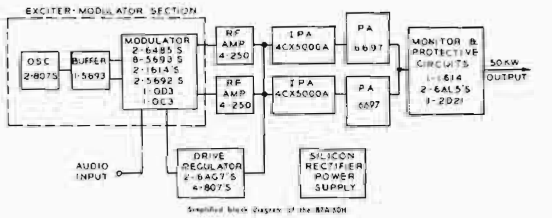

Fig. 6. Simplified Block diagram RCA BTA-50H1 Transmitter (Courtesy RCA Broadcast Products Division).

TABLE 1

Specifications of 50 kw Transmitters

	Continental 317C	RCA BTA-50H1	Gates MW-50
Physical Data			
Height	78"	84"	78"
Width	144"	181"	144"
Depth	54"	63"	48"
Weight	6600 lbs.	12000 lbs.	6445 lbs.
PA Tubes	(2)4CX35000C	(2)6697	(1)4CX35000C
Type of Modulation	Screen Grid	Phase to Amplitude	Pulse Duration
Type of Cooling	Forced Air	Forced Air	Forced Air
Power Consumption			
0% Mod	82 kw	94 kw	80 kw
AVG% Mod	92 kw	100 kw	87 kw
100% Mod	120 kw	130 kw	110 kw
Performance			
A.F. Response	±1.5dB 30–10K	±1.5dB 30–10K	±1.5dB 30–10K
A.F. Dist.	3%	3%	3%
A.F. Noise	−60 dB	−60 dB	−60 dB
Carrier Shift	Less than 3%	Less than 5%	Less than 2%
VSWR Protection	Yes	Yes	Yes
External Components	Power Transformer	Wall mounted Switch gear and Dist. Transformer Plate Transf.	H.V. Power Supply Wall mounted Circuit Breaker

Control circuits in the BTA-50H1 provide a choice of single button or step by step starting, automatic timing and sequencing of starting operations. Fault location is provided by indicating flags on each of the overload relays plus a system of lamps to indicate the status of the interlocks. A reflectometer is provided to protect the transmitter against abnormal loads.

An installation consists of four cubicles making up the main transmitter, wall mounting switch gear, and three high voltage plate transformers.

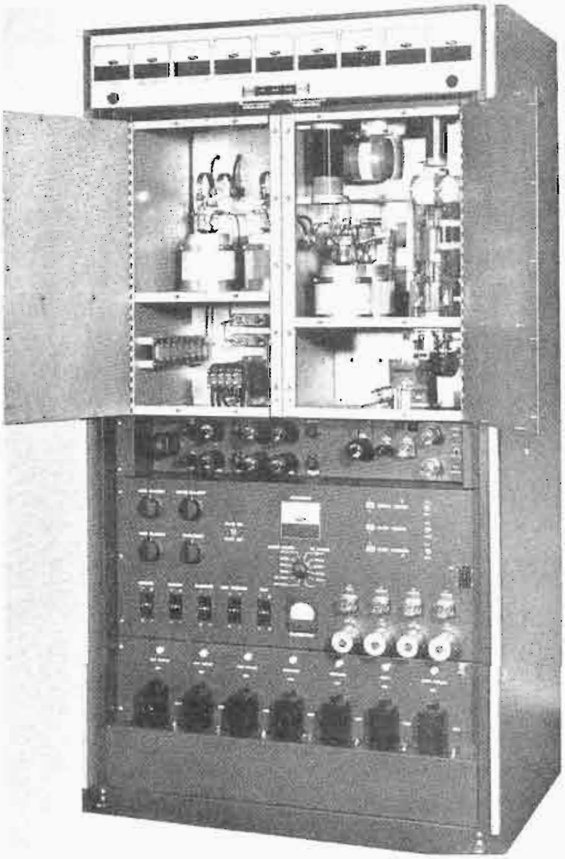

Fig. 7. Front view AEL AM-15KA 15 kw Transmitter with doors open (Courtesy American Electronic Laboratories, Inc.).

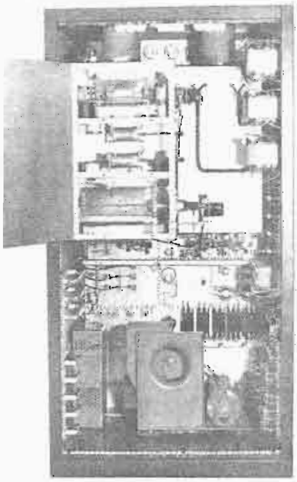

Fig. 8. Rear view AEL AM-5KA 5 kw Transmitter with door removed (Courtesy American Electronic Laboratories, Inc.).

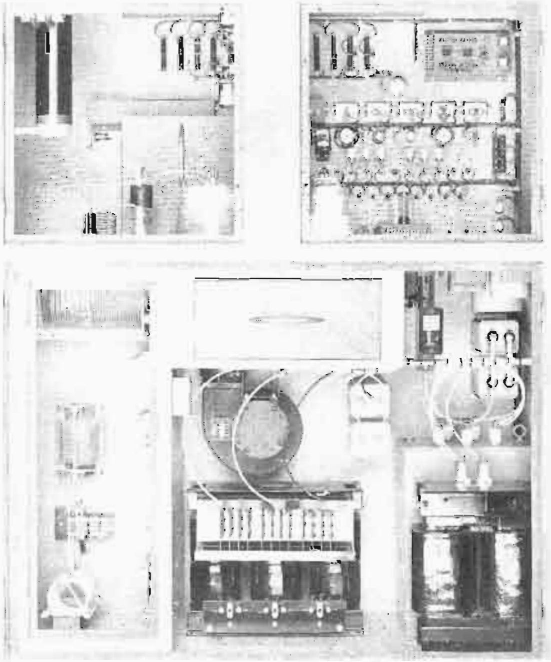

Fig. 9. Rear view Model FB-10J Bauer.

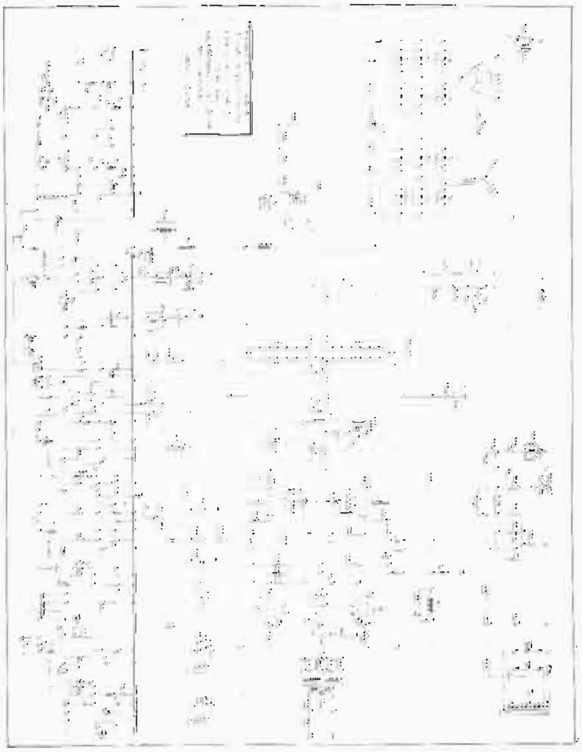

Fig. 10. Simplified schematic Bauer FB-10J Transmitter.

5 AND 10 kw TRANSMITTERS

Presently there are several (6-8) manufacturers of 5 and 10 kw AM transmitters. Of these, six maufacturers make a single transmitter adding only a second PA tube to produce a 10 kw transmitter from a 5 kw unit. CCA and Visual use different types of tubes for the PA and modulators in their 10 kw transmitter than in their 5 kw unit. All manufacturers use silicon rectifiers in their power supplies.

Six 5 kw transmitters are self-contained, while AEL and Visual place their high voltage power supply and heavy iron cored components in a separate container. RCA has an externally mounted plate transformer for their 10 kw transmitter.

Five manufacturers use tubes throughout except for the power supply rectifiers. Collins uses solid state circuitry up to the RF driver of the final amplifier and solid state audio stages up to the modulators. The Continental and Harris 5 and 10 kw transmitters provide VSWR protection. Power reduction facilities are included in the CCA, Collins, and Harris transmitters.

The Harris 5 kw transmitter employs pulse duration modulation and incorporates only two tubes in the design. The transmitter features built-in power supplies and high efficiency.

Fig. 11. CCA AM5000D 5 kw Transmitter (Courtesy CCA Electronics Corp.).

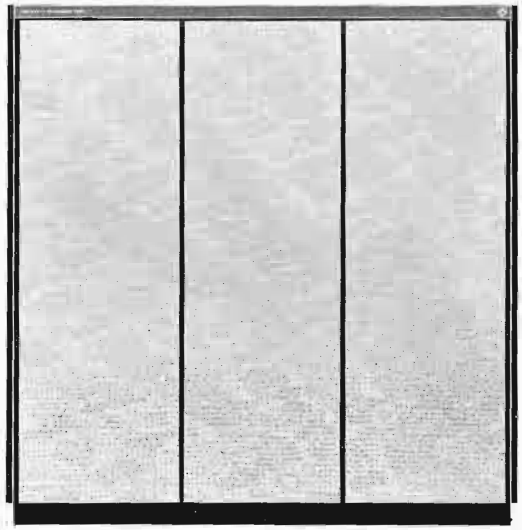

Fig. 13. Collins 830E-1 front view.

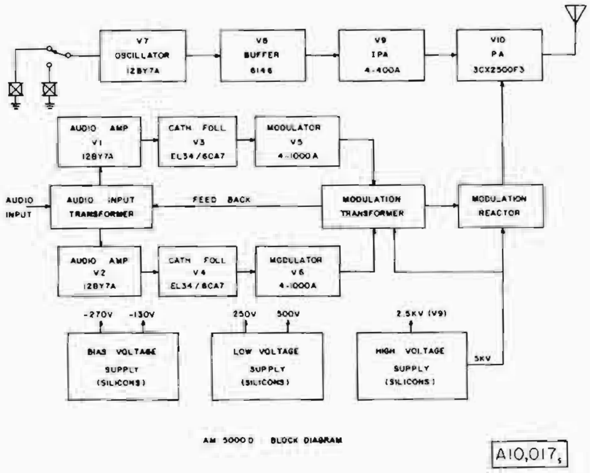

Fig. 12. CCA AN15000D block diagram.

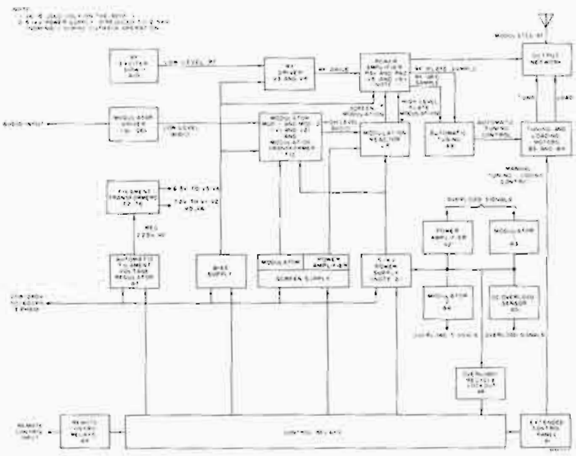

Fig. 14. Simplified block diagram Collins 820E/F 5/10 kw Transmitter (Courtesy Collins Radio Co.).

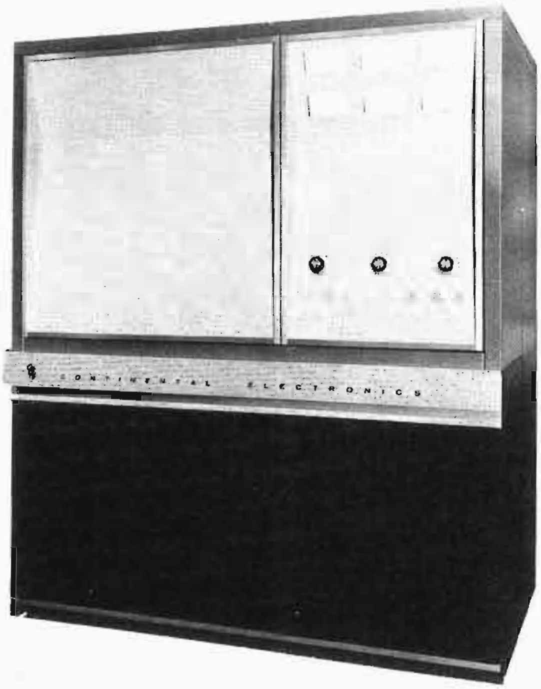

Fig. 15. Front view of the Continental 315C/316C 5 or 10 kw Transmitter (Courtesy Continental Electronics Mfg. Co.).

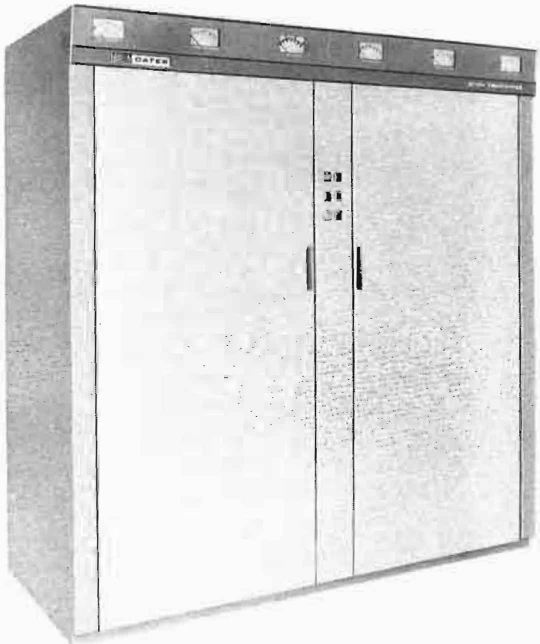

Fig. 17. Front view of the Gates BC10H kw Transmitter (Courtesy Gates Radio Co.).

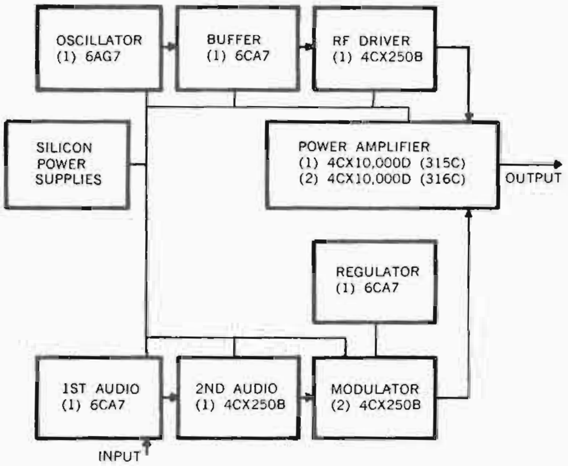

Fig. 16. Continental electronics Type 315C and 316C 5 and 10 kw Transmitters.

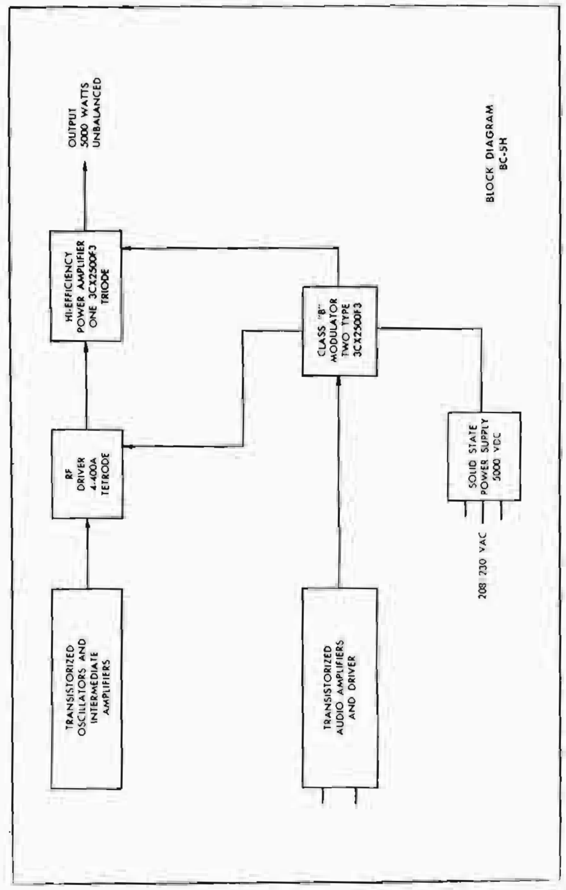

Fig. 18. Block diagram of the Gates BC-5H 5 kw Transmitter (Courtesy Gates Radio Co.).

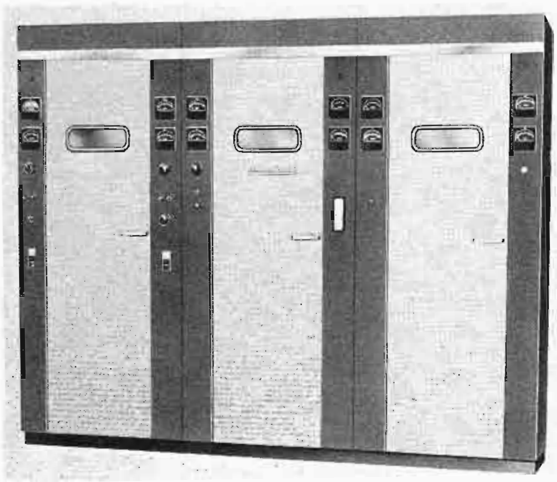

Fig. 19. Front view RCA BTA 5U1/10U1 5 or 10 kw Transmitter (Courtesy RCA Broadcast Equipment Division).

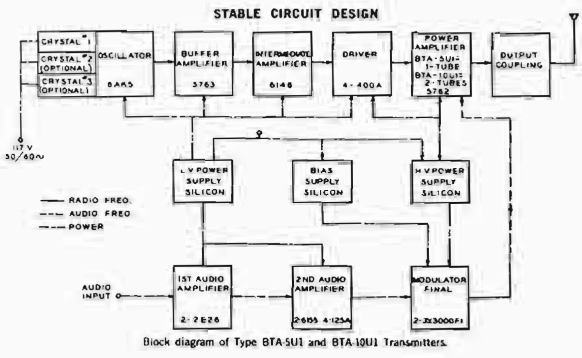

Fig. 20. Collins 820E/F1 Automatic Tuning simplified Schematic.

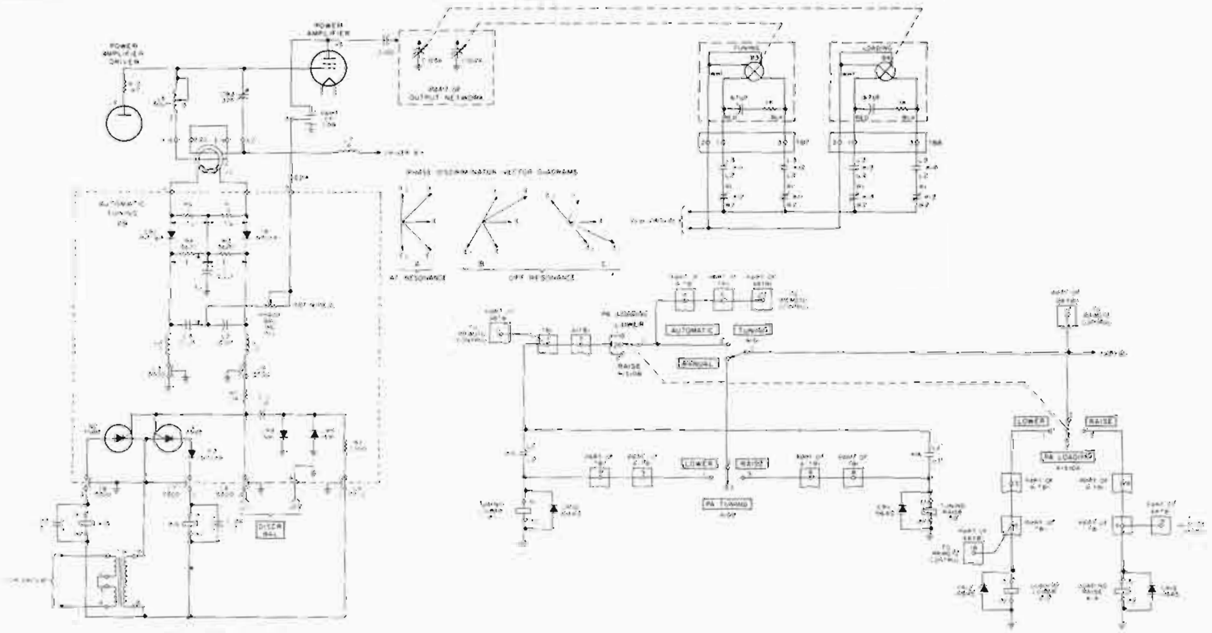

Fig. 21. Simplified schematic of a Collins automatic tuning (Courtesy Collins Radio Co.).

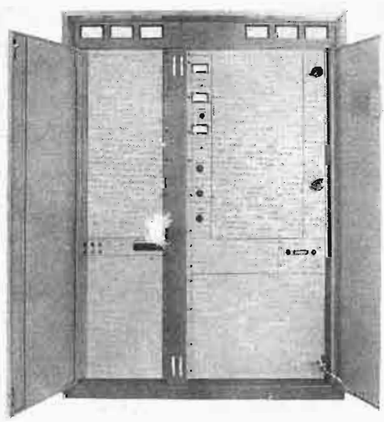

Fig. 22. Visual AM-5K-A 5 kw Transmitter (Courtesy Visual Electronics Corp.).

1000 WATT TRANSMITTERS

All 1 kw transmitters are self-contained with power reduction to either 500 watts or 250 watts as a standard feature except Visual, which accomplishes power cutback with an add-on kit. All use silicon rectifier power supplies. AEL, Bauer, Harris, and Visual provide a built-in dummy antenna. AEL, Bauer, and Collins regulate the filament voltages. Harris and RCA use bilevel modulation to improve carrier shift of their tube-type transmitters.

The Harris solid-state transmitter employs Progressive Series Modulation (PSM), which requires no modulation transformer, reactor, or filter inductor and is dc coupled.

TABLE 2

Specifications of 5 kw Transmitters

Data	AEL AM-5KA	Sparta FB-5J	CCA 5000D	Collins 820E-1	Continental 315C	RCA BTA5L1	Harris MW-5
Physical Data							
Height	76"	75"	76"	69"	78"	77"	78"
Width	57"	60"	68"	67½"	66"	70"	72"
Depth	33"	29"	32"	32"	34"	32"	32"
Weight	1500 lbs.	2000 lbs.	3500 lbs.	2000 lbs.	1900 lbs.	2500 lbs.	1250 lbs.
PA Tubes	7237	4CX5000A	3CX2500F3	4CX5000A	4CX10000	3CX5000H3(2)	3CX2500F3
Type of Mod.	Hi-Level	Hi-Level	Hi-Level	Hi-Level	Screen-Gnd	Phase to Amplitude	PDM
Power Consumption							
0% Mod	12 kw	10.6 kw	Not listed			12 kw	9.4 kVA
Avg% Mod	15 kw	12.0 kw	Not listed				
100% Mod	18 kw	15.5 kw	14.0 kw	18.5 kw	16.5 kw	18 kw	13.0 kVA
A.F. Response	±1.5 dB 50–10K	±1.5 dB 30–12K	1.5 dB 30–10K	±1.5 dB 50–10K	±1.5 dB 30–12K	±1.5 dB 30–15K	±1.0 20–10K
A.F. Distortion	2.5%	3%	2%	3%	2.5%	2.0%	2.0%
A.F. Noise	−55 dB	−60 dB	−55 dB	−60 dB	−60 dB	−60 dB	−60 dB
Carrier Shift	2%	3%	3%	3%	2%	3%	2%
External Components							

TABLE 3

Specifications of 10 kw Transmitters

	AEL AM-10KA	Bauer FB-10J	CCA AM-1000D	Collins 820F-1	Continental 316C	Gates BC10H	RCA BTA10U1	Visual AM-10K-A
Tubes Used								
Osc	12BY7A	12BY7A	12BY7A	Solid State	6AG7	Solid State	6AK5	12BY7A
1st R.F.	6146	12BY7A	6146		6AG7		5763	6146
2nd R.F.		12BY7A					6146	
3rd R.F.	4-400A	8236	4-400A	6146B(2)	4CX250B	4-400	4-400	4-400
Power Amplifier	7237(2)	4CX15000A	3CX10000A3	4CX5000A(2)	4CX10000D(2)	3CX2500F3(2)	5762(2)	3CX10000A3
1st A.F.	12BY7A(2)	EL-34(2)	6CA7(2)	Solid State	6CA7	Solid State	2E26(2)	6146(2)
2nd A.F.	6146(2) 6CB5(4)				4CX250B		4-125A(2)	
Modulator	7237(2)	4CX5000A(2)	4CX3000(2)	4CX5000A(2)	4CX250B(2)	3CX250UF3(2)	3X3000F1(2)	4CX5000A(2)
Physical Data								
Height	76"	75"	76"	69"	78"	78"	88"	76"
Width	40"	60"	68"	69"	66"	72"	116"	57"
Depth	33"	29"	32"	67-7/16"	34"	32"	32"	33"
Weight		2500 lbs.	4000 lbs.	2450 lbs.	2150 lbs.	2500 lbs.	5300 lbs.	1600
Power Consump.								
0% Mod	19 kw	19 kw	Not listed	Not listed	Not listed	18.5 kw	17.5 kw	18.9 kw
Avg% Mod	23 kw	22 kw				21.0 kw	21.0 kw	22.5 kw
100% Mod	31 kw	27 kw	28 kw	32.0 kw	30 kw	27.5 kw	26.0 kw	25.0 kw
Power Cutback	+ Accessory	+ Accessory	Included	Included	+ Accessory	Yes	+ Accessory	+ Accessory
VSWR Protect.	No	No	No	No	No	Yes	No	No
Bi Level Mod	No	No	No	No	Yes	Yes	No	No
A.F. Response	±2.0 dB 40-12K	±1.5 dB 30-12K	±1.5 dB 30-10K	±1.5 dB 50-10K	±1.5 dB	±1.5 dB 30-12K	±1.5 dB 30-10K	±1.5 dB 50-10K
A.F. Dist.	2.5%	3.0%	2.0%	3.0%	3.0%	2.5%	2.5%	2.5%
A.F. Noise	−57 dB	−60 dB	−55 dB	−60 dB	−60 dB	−60 dB	−60 dB	−55 dB
Miscellaneous	Ext. Pwr. Comp.	Self-contained	Self-contained	Self-contained	Self-contained	Self-contained	Trans. Ext.	H.V. Pwr. Mod. Trans. & Mod. Reactor External

The performance specifications of all 1 kw transmitters are comparable as can be seen from Table 4. All tube-type 1 kw transmitters are high level modulated Class C power amplifiers. The Harris MW-1 employs Class D transistor RF power amplifiers.

All tube-type transmitters except the Harris BC-1H employ tetrodes, or pentodes as in the Collins 820D-1, in the final amplifier. The BC-1H utilizes a triode.

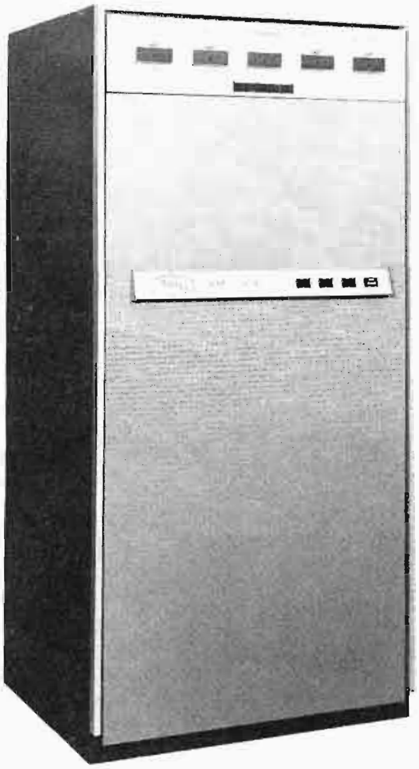

Fig. 23. AEL AM-1KA (1000 watt) Transmitter (Courtesy American Electronic Laboratories).

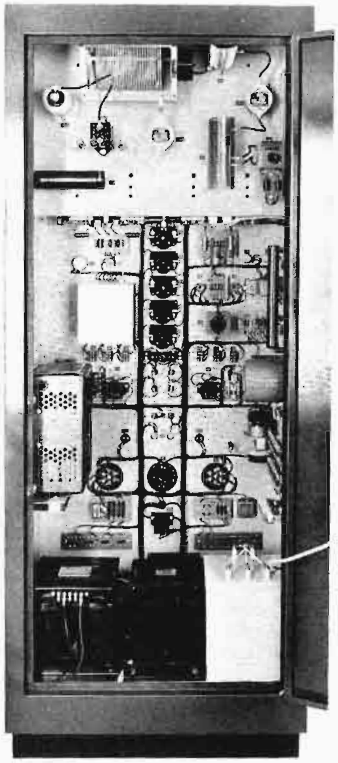

Fig. 24. Rear view, Bauer 707 (1000 watt) Transmitter (Courtesy Bauer Communications Products Division of Granger Associates).

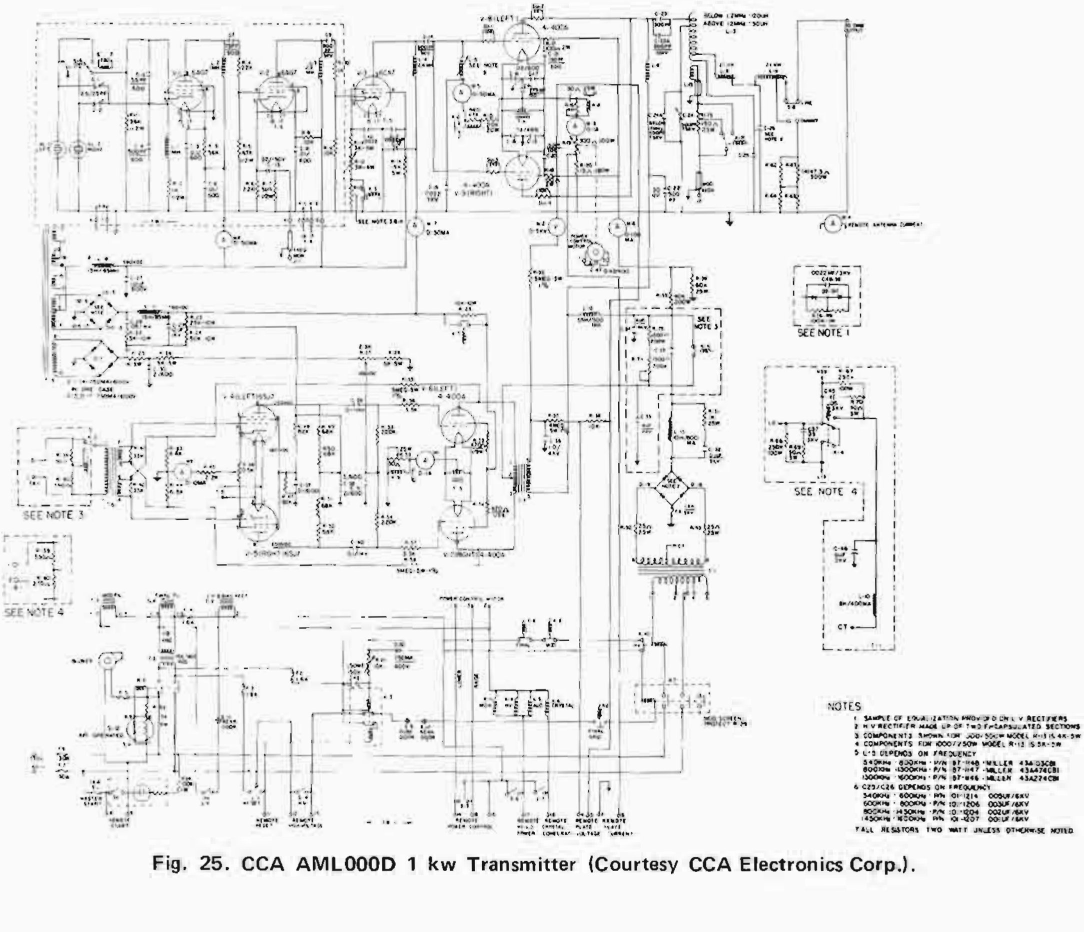

Fig. 25. CCA AML000D 1 kw Transmitter (Courtesy CCA Electronics Corp.).

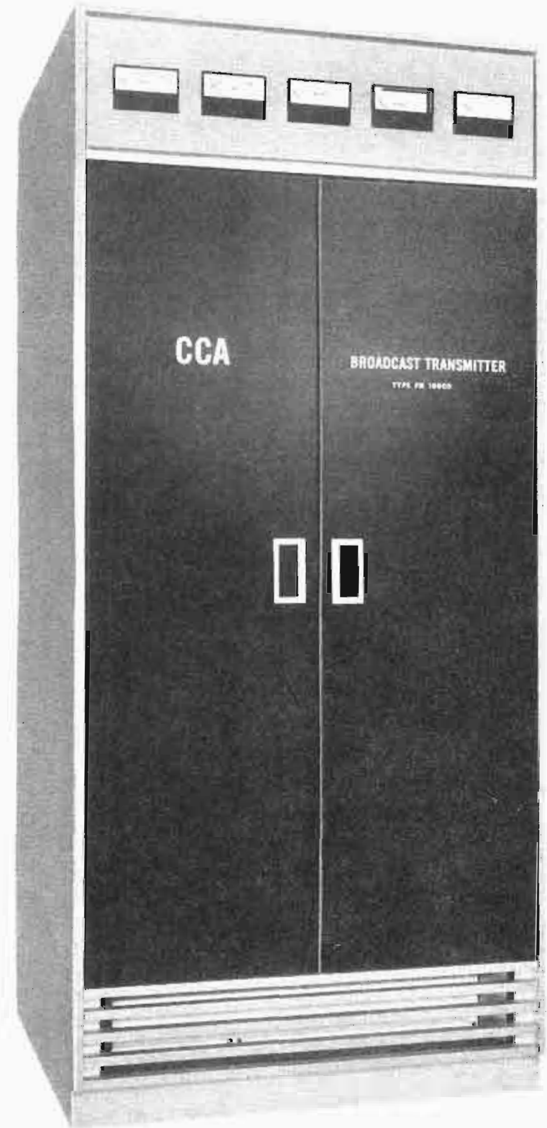

Fig. 26. CCA AM1000D 1 kW Transmitter (Courtesy CCA Electronics Corporation)

Fig. 28. Simplified block Collins 820D1 1 kw Transmitter (Courtesy Collins Radio Co.).

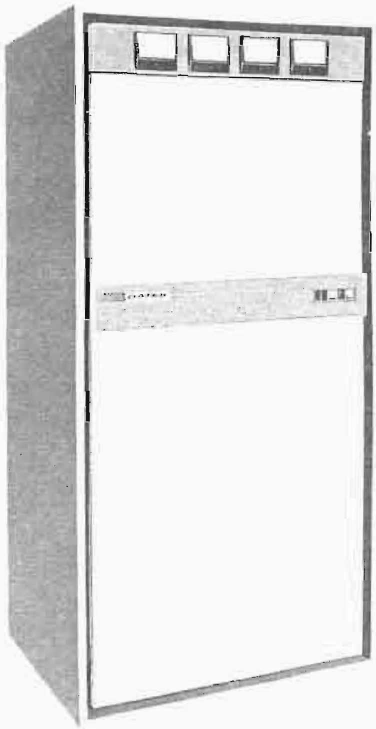

Fig. 29. Gates BCLG (1000 watt) Transmitter (Courtesy Gates Radio Co.).

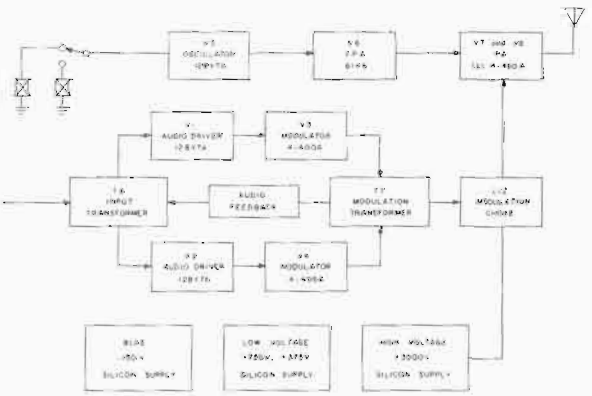

Fig. 27. CCA AM-1000D simplified block diagram.

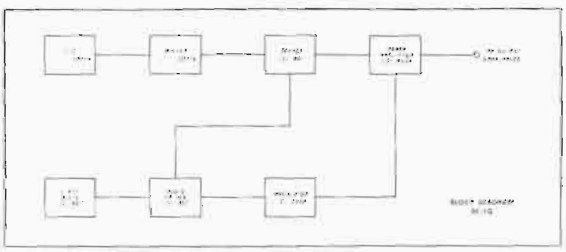

Fig. 30. Gates BC1G Transmitter (Courtesy Gates Radio Co.).

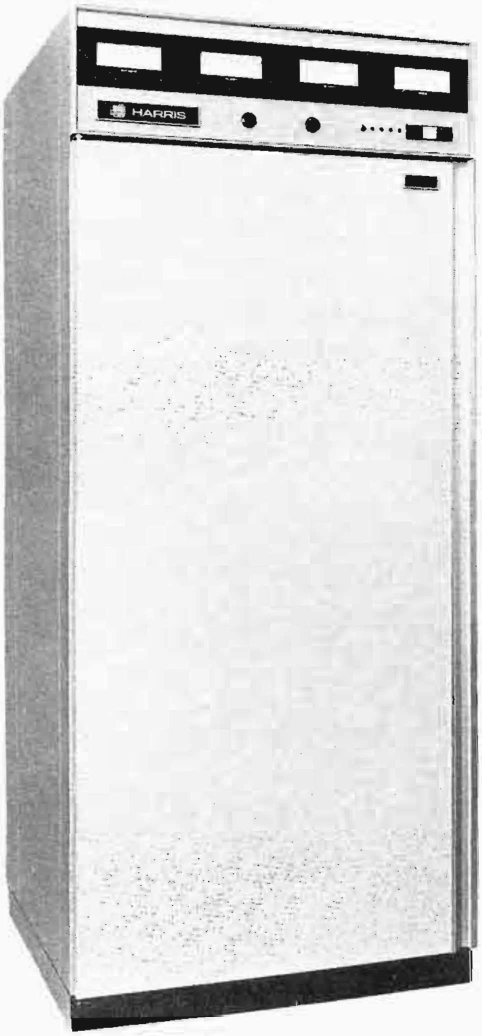

Fig. 31. Harris 1 MW-1—the world's first FCC type accepted (1000 watt) Transmitter 100% solid-state broadcast transmitter.

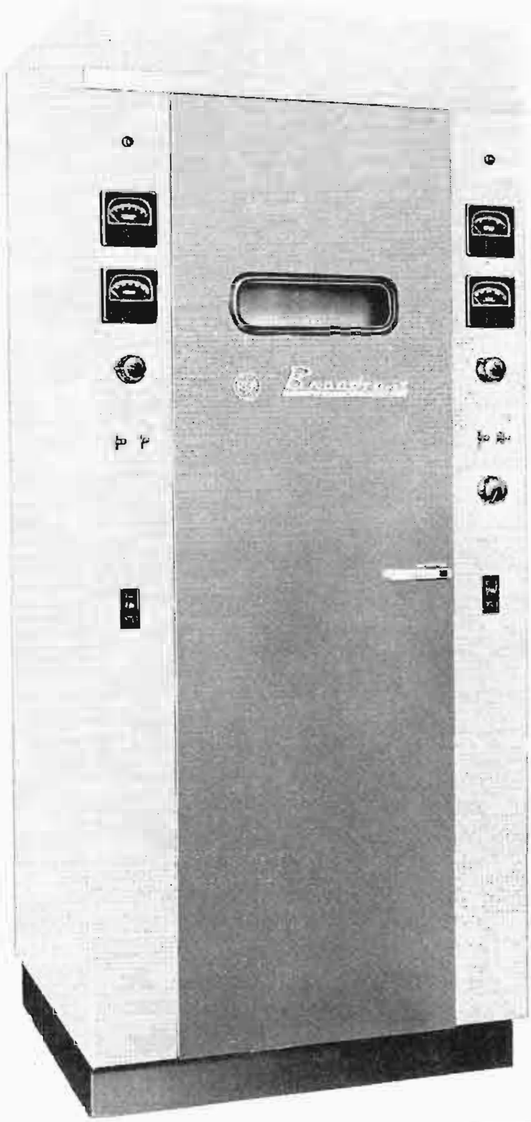

Fig. 33. RCA BTA 1R2 (1000 watt) Transmitter (Courtesy RCA Broadcast Products Division).

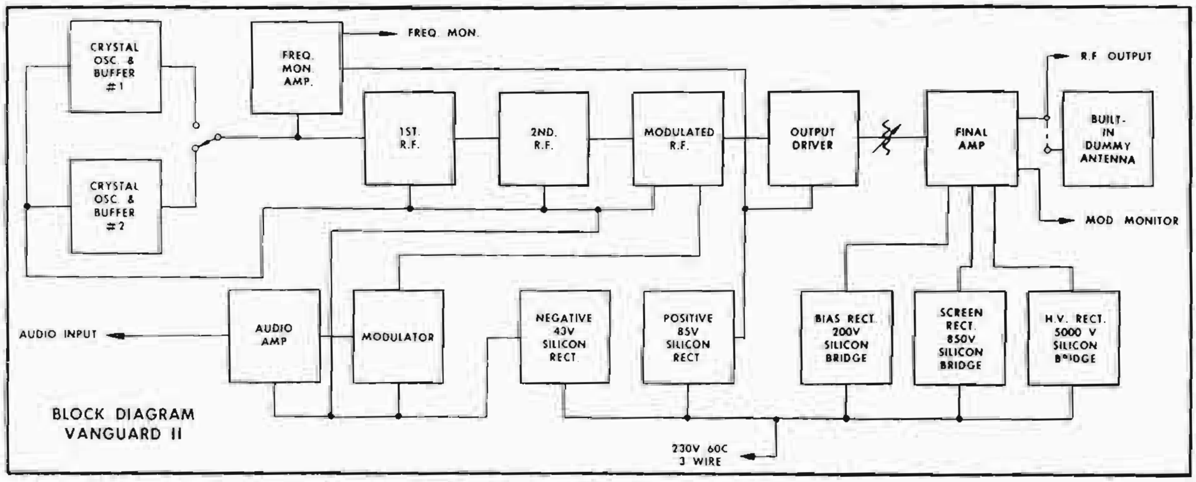

Fig. 32. Harris MW-1 block diagram.

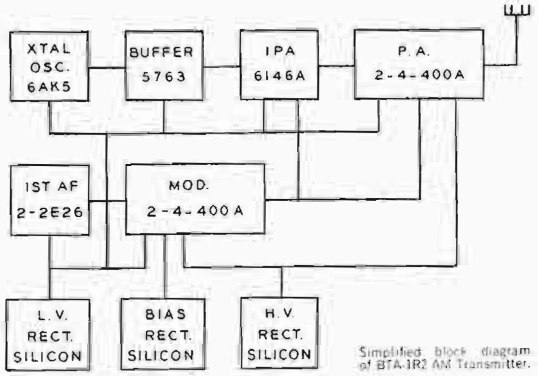

Fig. 34. Simplfieid block diagram BTA-1R2 AM Transmitter (Courtesy RCA Broadcast and Communications Products Division).

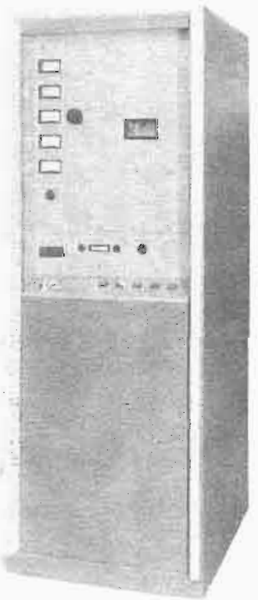

Fig. 35. Visual AM-1K-A 1 kw Transmitter (Courtesy of Visual Electronics Corp.).

COLLINS 820D-1 TRANSMITTER

One recently designed 1 kw transmitter on the market is the Collins 820D-1. It is a high-level modulated transmitter and utilizes solid state circuitry in all RF stages ahead of the PA tube, a pair of 5-500A's, and solid state audio amplifiers to drive two 5-500A modulators.

The exciter is Collins' 310W-1 presently used in their 5 and 10 kw transmitters. This exciter uses a crystal oscillator without ovens operating in the 2.1 MHz to 4.3 MHz region. The crystal controlled oscillator is frequency divided to the AM broadcast frequency with integrated circuits.

The 820D-1 transmitter output network is designed as a three node bandpass filter. The first node is tuned by a motor driven variable capacitor while loading is a fixed inductor adjustment with power output controlled by a plate voltage adjustment. The important advantage of this circuit is a symmetrical passband response which reduces distortion at the higher modulation frequencies.

A third advantage of the 820D-1 is the availability of an automatic power output control. This added accessory will sense the RF Output current to control a servo system, which adjusts the plate voltage control to hold the power output at a predetermined value.

The 820D-1 has its metering and control functions located on a separate panel which may be mounted remotely from the main transmitter chassis.

HARRIS MW-1 TRANSMITTER

The first FCC type accepted solid-state 1 kw transmitter is manufactured by Harris Corporation. This transmitter is 100% solid state, including the PA and modulator.

TABLE 4

Specifications of 1 kw Transmitters

Data	AEL AM-1KA	CCA AM-1000D	Collins 820D-1	Gates BC1H	Gates MW-1	RCA BTA-1R2	Sparta 707
Physical Data							
Height	70"	76"	69"	72"	72"	84"	75"
Width	34"	34"	41"	31½"	31½"	34"	30"
Depth	28"	32"	23-1/8"	31½"	31½"	32½"	25"
Weight	–	1000 lbs.	1100 lbs.	770 lbs.	595 lbs.	1700 lbs.	800 lbs.
PA Tube	4-400(2)	4-400(2)	5-500(2)	833(2)	N/A[a]	4-400(2)	4-400(2)
Power Consump.		100% 4000W	0% 2200W 100% 3400W	0% 2600W 100% 3850W	100% 3000W	0% 2900W 100% 3900W	0% 2900W 100% 3900W
A.F. Response	±1.5 dB 30-10K	±1.5 dB 30-10K	±2 dB 50-10K	±1.5 dB 30-12K	±1.0 dB 20-10K	±1.5 dB 30-10K	±1.5 dB 30-12K
A.F. Distortion	3% 40-10K	1.5% 100-7.5K	3% 50-7.5K	2.5% 50-10K	1.5% 20-10K	2% 50-10K	2% 50-10K
A.F. Noise	–58 dB	–55 dB	–60 dB	–60 dB	–60 dB	–60 dB	–60 dB
Carrier Shift	5%	3%	3%	3%	2%	3%	3%
Dummy Load	Yes	No	No	Yes	Yes	No	Yes

[a]Solid State Transmitter.

Series modulation of Class D transistor RF amplifiers is employed, using Progressive Series Modulation (PSM).

Output power is generated in 12 redundant modules, each of which has its own modulator. PA efficiency approaches 90% without the use of special waveshaping. Failure of one module still permits continuous operation at 1 kw. Operation is maintained at lower power with fewer modules. Fault indicators are provided to identify a failed module.

The series modulator, which is dc coupled, provides excellent transient response, dc feedback for automatic control of output power, the ability to switch between any two predetermined power levels without carrier interruption and single knob power adjustment capability over a wider range.

The transmitter features fast VSWR protection, quiet air cooling, built-in dummy load, built-in voltage regulator for brown-out protection and complete remote control capability.

VAPOR PHASE COOLING

Cooling by vapor takes advantage of the latent heat of vaporization of water. Raising the temperature of one pound of water 1°F requires one BTU; however, changing a single pound of water at 212°F to steam vapor takes 970 BTUs. Thus, vapor cooling will remove nearly 20 times as much energy as a circulating water system.

As power is applied to the tube anode, dissipation heats the water to 212°F. Further heating causes the water to boil and change to steam. This vapor is passed through a heat exchanger, where it is condensed to a liquid. The condensed water is returned to the boiler reservoir for reuse.

Water losses are compensated for by the reserve tank, which will replenish the boiler if the water level drops one-quarter inch. Tube anodes have a constant supply of water with fail-safe protection. The vapor system operates near atmospheric pressure and is fully vented.

The main advantages of vapor cooling are quieter operation, most efficient removal of heat from tubes, not dependent on blowers, and greater freedom from dust and dirt.

FORCED AIR COOLING

Many power tubes are cooled by air forced thru fins of an external anode. Each tube has specifications as to the volume of air and static pressure

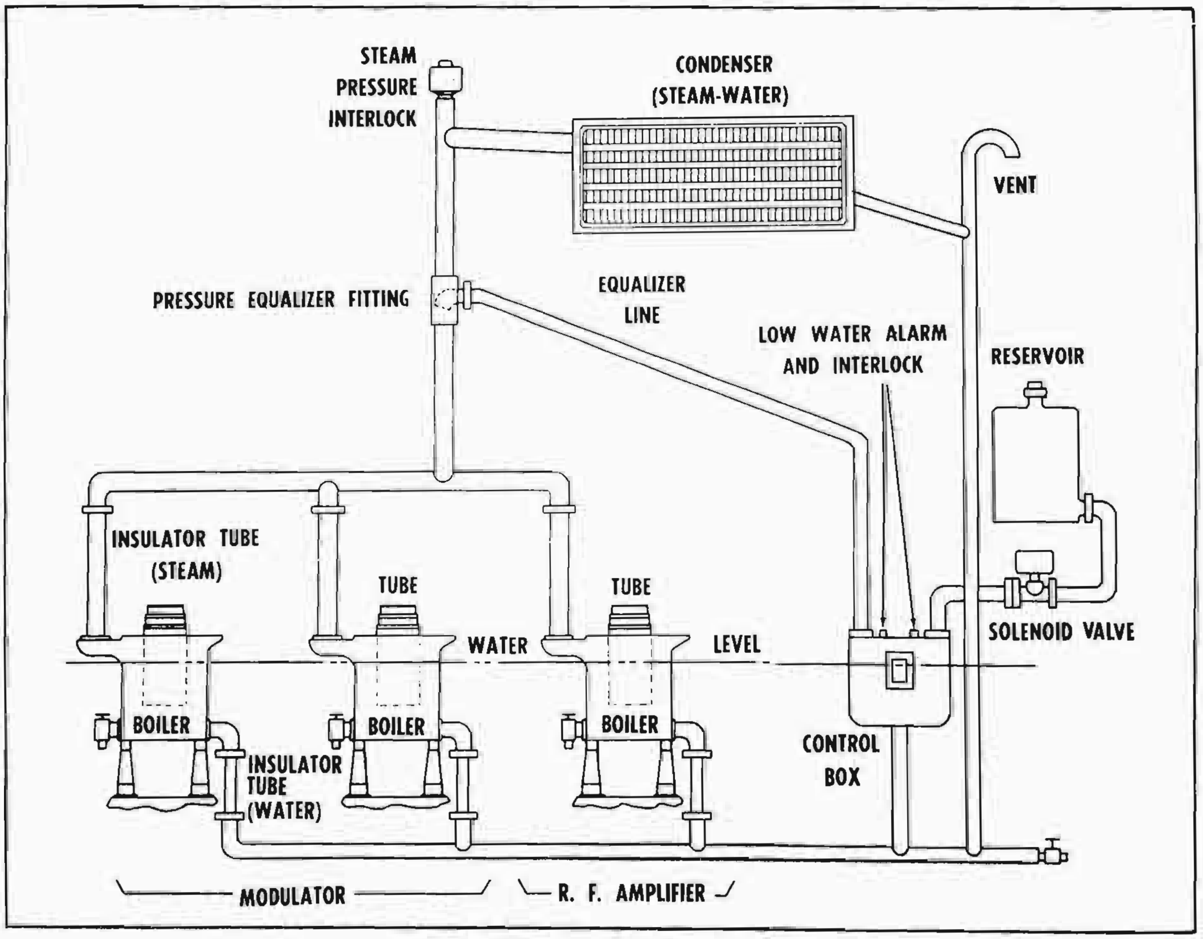

Fig. 36. Vapor phase cooling system illustration (Courtesy Gates Radio Co.).

required by the tube for a given dissipation. Fin types range from open tubes requiring large air volume at low pressure to smaller and closely spaced fins which require less air volume, but at considerably higher pressure.

The blower should not only allow for the air pressure drop of the tube, but also for ducts and air filters. Cooling efficiency decreases with altitude so that for high elevations higher capacity blowers must be used. Cooling efficiency also decreases with dust accumulation. Therefore, cleaning of the radiating fins of tubes is important.

Efficient air cooling is imperative for extended tube life.

CARE AND PROTECTION OF SILICON RECTIFIERS

Semiconductor rectifiers have almost universally replaced tube rectifiers in broadcast transmitters power supplies. Their care and protection is somewhat different than tubes so special attention should be given to them.

The rectifiers are capable of withstanding the high voltages because several diodes are connected in series. It is advisable to check individual diodes in each bank at regular intervals to insure that the full voltage capability of the rectifier is maintained.

Current carrying capacity of a given solid state rectifier depends upon the removal of heat from the diode junction. For this reason, it is important that rectifiers are kept clean where removal of heat is by air flow. It is also important that they are maintained in good thermal contact with any surface where this surface is used as a heat sink.

CARE OF TUBES

Power tubes should be inspected on arrival for shipping damage. Glass tubes should be examined around the seals for possible cracks. Filament should be checked for continuity and tests for short circuits made between the elements.

They should be placed in the transmitter for test as soon as possible. Allow 15 minutes with ON only filament voltage, then 15 minutes with reduced plate voltage, followed by a 15-minute interval with full voltage, after which modulation can be gradually applied. Residual gas may cause a virtual short circuit condition. If this occurs, reduce plate voltage and repeat break-in sequence.

Filament voltages should be maintained within the limits specified by the tube manufacturer. Some filaments, such as thoriated tungsten, may be damaged as much by under-voltage as over-voltage.

Hours of service records should be kept on each tube. Short tube life should call for an appraisal of operating conditions, both mechanical and electrical. Spare tubes should be placed in service for a day at four to six months intervals to reduce any gas accumulation.

TROUBLESHOOTING

Successful troubleshooting of any equipment follows these three steps in order given:

1. Define the problem;
2. Determine the cause of the problem;
3. Select the best solution.

The first step is usually the most difficult and is always the most important. Often, when the actual problem is determined, the other steps become automatic and easy. For example, if a resistor is burned out, this is an effect and until the problem causing the resistor to burn out is determined, the real difficulty cannot be corrected.

A very common failure in troubleshooting is treating symptoms rather than causes. Take time to determine exactly the problem and time will be saved in administering the solution.

Know the instruction book on the transmitter. Especially, understand the control circuit system of the transmitter. Knowing the sequence of the control circuit relays and their function many times provide excellent clues to the source of the problem.

Keep an accurate record of all operating voltages in the transmitter as you have measured them. These may be slightly different than those given in the instruction book.

Finally, an accurate and detailed diary or log of difficulties or unusual operating conditions together with cause and cure is extremely useful for future reference.

18

FM Broadcast Transmitters

Warren B. Bruene[1] and
Technical Staff of the
Vice President for Engineering
Collins Radio Company
Dallas, Texas

HISTORY OF FM BROADCASTING[2]

Although the principle of frequency modulation has been known for a long time, the advantages for broadcasting were not generally realized until the 1930's, largely as a result of the extensive FM development work done by Major Edwin H. Armstrong.

Among the advantages of FM are freedom from static and fading, and the ability of an FM receiver to capture the stronger of two signals transmitted on the same carrier frequency.

In 1940, following extensive public hearings, the Commission established the FM Broadcast Service and set aside 40 channels in the 42 to 50 MHz band with commercial operation scheduled to begin January 1, 1941. Although World War II stopped all nonmilitary radio construction, more than 40 FM stations continued to serve some 400,000 receivers. To eliminate the interference problems resulting from skywave reflection in the prewar FM band, the Commission moved the FM Broadcast Service to the 88 to 108 MHz band in 1945, thereby increasing the number of available channels to 100. However, the expected growth of FM broadcasting did not materialize. Since conversion of prewar FM receivers to the new band was not practical, purchase of a new receiver was the only way to receive the new FM stations. Television appeared to offer much more to the consumer than FM radio, since most FM stations merely duplicated the programming of an affiliated AM station. Despite the potential for a quality broadcast service, there was little public demand for new FM receivers and virtually no public reaction when FM stations dropped popular programs from their schedule or were off the air due to equipment failures. It is not surprising, therefore, that in May 1950, there had been only 16 new FM license applications during the previous 15 months in which 259 FM stations ceased operations.

During 1949 and 1950, some 35 FM stations began transit radio and storecasting experiments in an effort to make FM broadcasting pay. Although these "broadcasts" represented a backward step in programming standards, they appeared a desirable alternative to letting the FM Broadcast Service expire. These early ventures in the use of FM to provide nonbroadcast services to subscribers did not use multiplex techniques and consequently could not be received on all FM receivers. However, the use of a "beep" tone permitted the volume level of certain receivers to be turned up or down in accordance with the requirements of the particular type of subscriber. Beginning in 1955, the Commission permitted FM licensees to engage in certain types of nonbroadcast services on a multiplexed basis under a Subsidiary Communications Authorization (SCA). Multiplexed operation permits the reception of this service on special receivers in the stores, factories, etc., of subscribers without interference to the regular FM broadcast program. Our present FM stereo system is an extension of these multiplex techniques, and provides for the inclusion of one SCA channel in addition to the stereo transmission.

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[1]The author thanks his associates who assisted in the preparation and review of this section and in particular Charles E. Dixon for his contribution of the section on *Performance Measurements*. Permission to use the material in the section on history by John T. Robinson and L. Glenn Whipple is gratefully appreciated. The contribution of the photographs and block diagrams by the manufacturers of the transmitters shown in the section on Transmitter Descriptions is acknowledged and appreciated.

[2]This section on history is extracted with permission of the author from the paper "FCC Regulations Governing the Audio Fidelity Characteristics of FM Broadcast Equipment," by John T. Robinson and L. Glenn Whipple of the FCC, which was presented October 18, 1967, at the 33rd Convention of the Audio Engineering Society, July 1968, Vol. 16, No. 3.

It should be pointed out that the Commission considers the unauthorized reception and use of these private subscription services to be a violation of Section 605 of the Communications Act. Such violations will be referred to the Department of Justice where appropriate and may subject the user to the criminal penalties provided for in the Communications Act.

Considerations in Determining Whether to Authorize Stereo Operation

The first clear showing of widespread public interest in FM multiplex stereo broadcasting was expressed in 1958 in an FCC Rule-Making proceeding which was concerned primarily with the uses of multiplexing under SCAs. Also in 1958 and 1959, the FCC received several petitions to permit stereo broadcasting.

The FCC engineers felt that one of the first things to be done was to find out whether stereophonic reproduction of program material was really worthwhile; that is, whether it actually did improve the realism of the program from the standpoint of the listener. In pursuing this, the FCC reviewed published material by researchers including George W. Stewart, Dr. Harry F. Olson, Dr. Harvey Fletcher and others, who investigated the various factors involved in localization of a sound by a listener, and published the results of much study and experimentation. The Commission and high fidelity enthusiasts everywhere are indebted to these gentlemen for their pioneering work in this field. After this study, several conclusions seemed appropriate:

1. The achievement of realism in reproduced sound requires the fulfillment of four fundamental conditions: first, the frequency range of the system must permit all of the audible components of the original sound to be reproduced; second, the volume range of the system must enable reproduction of the entire range of intensity of the sounds without noise or distortion; third, the reverberation characteristics of the original sound must be conveyed to the listener; and fourth, the spatial impressions must be conveyed to the listener. A monaural or monophonic system cannot satisfy this fourth requirement.

2. While a stereo system employing three or more channels is generally conceded to be superior to a two-channel system in reproduction of speech and moving sound sources, a two-channel system can give good satisfaction for orchestral reproduction.

3. The frequency range of each channel of the system adopted should be as good as that required by present FM broadcast standards, and the frequency-response characteristics should be as alike as possible in the channels.

Therefore, it seemed desirable to go ahead with the study of stereo systems for FM broadcast stations.

Adoption of Stereophonic Broadcasting in the United States

The United States system for FM multiplex stereo transmission was adopted by the FCC in 1961. The choice of systems followed a lengthy rule-making proceeding and study. A considerable amount of technical information and field test data for several proposed systems were provided to the FCC by an EIA committee, the National Stereophonic Radio Committee (NSRC). Engineers from equipment manufacturers, broadcasters, record manufacturers, and the FCC took part in the deliberations of the committee and the field tests which it conducted, all of which spanned a period of more than two years. During this period, it was necessary for FCC engineers to study and analyze many proposed systems. Some of the proposed systems were complete with signal specifications and equipment, while others were merely suggestions unaccompanied by engineering analysis or equipment designs. Still other systems or schemes were proposed and later dropped by their proponents in favor of modified or improved versions. All of this was reduced to six systems which were field tested by the National Stereophonic Radio Committee in the summer of 1960 using the transmitting facilities of station KDKA-FM, Pittsburgh, Pennsylvania, with receivers at Uniontown, Pennsylvania. The US system was adopted after a study of the field test results, together with an analysis of the theoretical capabilities of the systems tested.

Criteria Met by the US System

The system selected was found capable of meeting these important criteria:

1. Audio response of 50 to 15,000 Hz is preserved in both output channels.
2. Signal-to-noise ratios in both audio output channels are equal.
3. The information present in both input channels is reproduced in monophonic receivers.
4. Degradation in signal-to-noise ratio as received by monophonic receivers is minimal.
5. Electrical separation is maintained between the stereo channels throughout the audio frequency range.

FEATURES OF FM

Reduced Noise

The 88 to 108 MHz FM broadcast band is relatively free of atmospheric and other noise interference. Emission at these frequencies is not propagated great distances by ionospheric refraction as it is in the 550 to 1600 kHz AM band. Therefore, noise from lightning discharges is limited to substantially line-of-sight distances and is vastly lower and almost negligible. Man-made noise is a far greater source of noise, particularly in urban areas. The level of man-made noise falls off at increasing frequencies so that the microvolts-per-meter noise level is on the order of one-tenth as great in the FM band as in the AM band.

In addition, FM has an improvement factor compared to AM that is proportional to the frequency deviation ratio. This factor is illustrated in Fig. 1. There is a sharp threshold in signal level above which noise and interference are suppressed, which results in an improved S/N ratio. This same effect causes a weaker FM signal on the same channel to be suppressed, resulting in greatly reduced cochannel interference.

For greater noise reduction, pre-emphasis is employed whereby the audio frequency components above about 2.1 kHz are boosted in amplitude 6 dB per octave before being applied to the modulator. Flat frequency response is restored in the receiver by attenuating the higher frequencies the same amount they were boosted in the transmitter. High frequency components of noise are attenuated, resulting in greatly reduced background noise. This is discussed in more detail under FM Theory.

The net result of the above factors is the attainability of a much better signal-to-noise ratio. The lower background noise means that a signal of higher quality and wider dynamic range can be enjoyed.

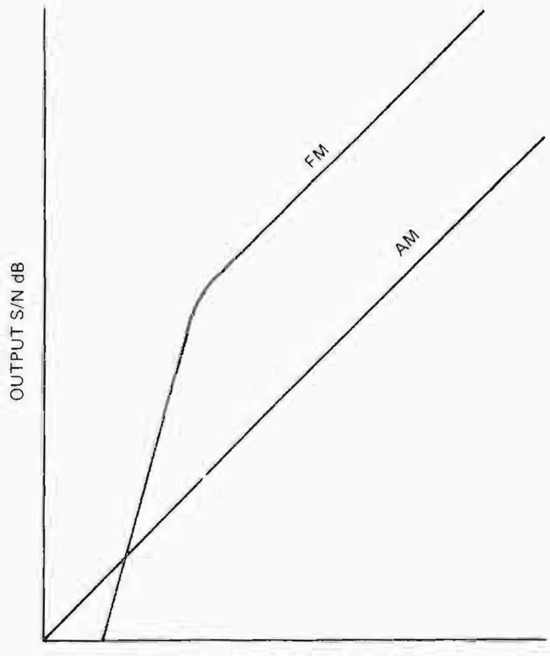


Fig. 1. FM improvement factor.

High Fidelity

Fidelity is defined as the degree to which a system, or a portion of a system, accurately reproduces at its output the essential characteristics of the signal which is impressed upon its input. The large market for hi-fi equipment is ample evidence that the public enjoys high-quality reproduction. Many individuals spend a great deal of money to have high-quality equipment in their homes.

Uniform frequency response over the audible range of at least 50 Hz to 15 kHz, very low amplitude distortion (harmonic and intermodulation), very low noise level, and good transient response (uniform time delay versus frequency) are necessary for hi-fi performance. The FM channel authorizations provide for adequate audio frequency range and a low-noise radio path. The rest of the performance is a matter of equipment design. It is much more feasible to design hi-fi characteristics into FM broadcast transmitters than AM broadcast transmitters. The FCC, therefore, has established minimum performance standards that assure hi-fi performance. Transmitter manufacturers strive to produce transmitters that exceed these minimum standards as far as practical, and broadcast stations strive to maintain the maximum performance capability of their equipment to provide truly hi-fi programs for the listener.

Stereophonic Transmission

A higher level of realism and listener enjoyment is provided by stereophonic transmission. Again, the wide channel allocations and inherent nature of FM permitted development of a practical stereo broadcasting system. This provides a means for the broadcast industry to provide the public with the same quality of hi-fi that they have available on stereo records and tape.

SCA

The wide channel bandwidth authorized for FM broadcasting makes it feasible to multiplex one or two subsidiary (SCA) channels together with the main transmission. Degradation of the main signal is kept small by limiting the percentage of modulation allocated to the SCA channels to 30 percent with monophonic broadcasting and 10 percent with stereophonic broadcasting. SCA provides an important source of revenue to many stations as well as a useful service to the community.

FCC TRANSMISSION STANDARDS

Some of the FCC Rules and Regulations covering transmitter performance are reproduced here to show the basic requirements. Because they are subject to change, an updated set of Rules and Regulations should be consulted regarding matters of importance.

73.254 Required Transmitter Performance

(a) The construction, installation, operation and performance of the FM broadcast transmitting system shall be in accordance with 73.317.

(b) The licensee of each FM broadcast station shall make equipment performance measurements at least once each calendar year: Provided, however, That the dates of completion of successive sets of measurements shall be no more than fourteen months apart. One set of measurements shall be made during the four-month period preceding the filing date of the application for renewal of station license. Equipment performance measurements shall be made with equipment adjusted for normal program operation and shall include all circuits between the main studio microphone terminals and the antenna circuit, including telephone lines, pre-emphasis circuits and any equalizers employed, except for microphones, and without compression if a compression amplifier is installed. The measurement program shall yield the following information:

(1) Audio frequency response from 50 to 15,000 Hz for approximately 25, 50 and 100 percent modulation. Measurements shall be made on at least the following audio frequencies: 50, 100, 400, 1000, 5000, 10,000 and 15,000 Hz. The frequency response measurements should normally be made without de-emphasis; however, standard 75 microsecond de-emphasis may be employed in the measuring equipment or system provided the accuracy of the de-emphasis circuit is sufficient to insure that the measured response is within the prescribed limits.

(2) Audio frequency harmonic distortion for 25, 50 and 100 percent modulation for the fundamental frequencies of 50, 100, 400, 1000, and 5000 Hz. Audio frequency harmonics for 100 percent modulation for fundamental frequencies of 10,000 and 15,000 Hz. Measurements shall normally include harmonics to 30,000 Hz. The distortion measurements shall be made employing 75 microsecond de-emphasis in the measuring equipment or system.

(3) Output noise level (frequency modulation) in the band of 50 to 15,000 Hz in decibels (dB) below the audio frequency level representing a frequency swing of 75 kHz. The noise measurements shall be made employing 75 microsecond de-emphasis in the measuring equipment or system.

(4) Output noise level (amplitude modulation) in the band of 50 to 15,000 Hz in dB below the level representing 100 percent amplitude modulation. The noise measurements shall be made employing 75 microsecond de-emphasis in the measuring equipment or system.

(c) The data required by paragraph (b) of this section, together with a description of instruments and procedure signed by the engineer making the measurements, shall be kept on file at the transmitter and retained for a period of two years, and shall be made available during that time upon request to any duly authorized representative of the Federal Communications Commission.

73.267 Operating Power: Determination and Maintenance

(a) *Determination.* The operating power of each station shall be determined by either the direct or indirect method.

(1) Using the direct method, the power shall be measured at the output terminals of the transmitter while operating into a dummy load of substantially zero reactance and a resistance equal to the transmission line characteristic impedance. The transmitter shall be unmodulated during this measurement. If electrical devices are used to determine the power output, such devices shall permit determination of this power to within an accuracy of ±5 percent of the electrical indicating instrument of the device. If temperature and coolant flow indicating devices are used to determine the power output, such devices shall permit determination of this power to within an accuracy of 4 percent of measured average power output. During this measurement the direct plate voltage and current of the last radio stage and the transmission line meter shall be read and compared with similar readings taken with the dummy load replaced by the antenna. These readings shall be in substantial agreement.

(2) Using the indirect method, the operating power is the product of the plate voltage (E_p) and the plate current (I_p) of the last radio stage, and an efficiency factor, F as follows:

$$\text{Operating power} = E_p \times I_p \times F$$

(3) The efficiency factor, F, shall be established by the transmitter manufacturer for each type of transmitter for which he submits data to the Commission, over the entire operating range of powers for which the transmitter is designed, and shall be shown in the instruction books supplied to the customer with each transmitter. In the case of composite equipment, the factor F shall be furnished to the Commission with a statement of the basis used in determining such factor.

(b) *Maintenance.*

(1) The operating power shall be maintained as near as practicable to the authorized power and shall not be less than 90 percent nor greater than 105 percent of authorized power except as indicated in paragraph (c) of this section.

(2) When determined by the direct method, the operating power of the transmitter shall be monitored by a transmission line meter which reads proportional to the voltage, current, or power at the output terminals of the transmitter, the meter to be calibrated at intervals not exceeding 6 months. The calibration shall cover, as a minimum, the range from 90 to 105 percent of authorized power, and the meter shall provide clear indications which will permit maintaining the operating power within the prescribed tolerance or the meter shall be calibrated to read directly in power units.

(c) *Reduced power.* In the event it becomes technically impossible to operate with authorized power, the station may be operated with reduced power for a period of 10 days or less without further authority of the Commission: Provided, That the Commission and the Engineer in charge of the radio district in which the station is located shall be immediately notified in writing if the station is unable to maintain the minimum operating schedule (specified in 73.261) with authorized power and shall be subsequently notified upon resumption of operation with authorized power.

73.268 Modulation

The percentage of modulation shall be maintained as high as possible consistent with good quality of transmission and good broadcast practice. In no case is it to exceed 100 percent on peaks of frequent recurrence. Generally, it should not be less than 85 percent on peaks of frequent recurrence; but where necessary to avoid objectionable loudness modulation may be reduced to whatever level is necessary, even if the resulting modulation is substantially less than 85 percent on peaks of frequent recurrence.

73.269 Frequency Tolerance

The center frequency of each FM broadcast station shall be maintained within 2,000 cycles per second of the assigned center frequency.

73.310 Definitions

Center frequency. The term "center frequency" means:

(1) The average frequency of the emitted wave when modulated by a sinusoidal signal.

(2) The frequency of the emitted wave without modulation.

Effective radiated power. The term "effective radiated power" means the product of the antenna power (transmitter output power less transmission line loss) times:

(1) the antenna power gain, or

(2) the antenna field gain squared.

Where circular or elliptical polarization is employed, the term effective radiated power is applied separately to the horizontal and vertical components of radiation. For allocation purpose, the effective radiated power authorized is the horizontally polarized component of radiation only.

Frequency modulation. A system of modulation where the instantaneous radio frequency varies in proportion to the instantaneous amplitude of the modulating signal (amplitude of modulating signal to be measured after pre-emphasis, if used) and the instantaneous radio frequency is independent of the frequency of the modulating signal.

Frequency swing. The instantaneous departure of the frequency of the emitted wave from the center frequency resulting from modulation.

Multiplex transmission. The term "multiplex transmission" means the simultaneous transmission of two or more signals within a single channel. Multiplex transmission as applied to FM broadcast stations means the transmission of facsimile or other signals in addition to the regular broadcast signals.

Percentage modulation. The ratio of the actual frequency swing to the frequency swing defined as 100 percent modulation, expressed in percentage. For FM broadcast stations, a frequency swing of ±75 kHz is defined as 100 percent modulation.

(a) *Stereophonic broadcasting.*

Cross-talk. An undesired signal occurring in one channel caused by an electrical signal in another channel.

FM stereophonic broadcast. The transmission of a stereophonic program by a single FM broadcast station utilizing the main channel and a stereophonic subchannel.

Left (or right) signal. The electrical output of a microphone or combination of microphones placed so as to convey the intensity, time, and location of sounds originating predominately to the listener's left (or right) of the center of the performing area.

Left (or right) stereophonic channel. The left (or right) signal as electrically reproduced in reception of FM stereophonic broadcasts.

Main channel. The band of frequencies from 50 to 15,000 Hz which frequency-modulate the main carrier.

Pilot subcarrier. A subcarrier serving as a control signal for use in the reception of FM stereophonic broadcasts.

Stereophonic separation. The ratio of the electrical signal 'caused in' the right (or left) stereophonic channel to the electrical signal caused in the left (or right) stereophonic channel by the transmission of only a right (or left) signal.

Stereophonic subcarrier. A subcarrier having a frequency which is the second harmonic of the pilot subcarrier frequency and which is employed in FM stereophonic broadcasting.

Stereophonic subchannel. The band of frequencies from 23 to 53 kHz per second containing the stereophonic subcarrier and its associated sidebands.

73.317 Transmitters and Associated Equipment

(a) *Electrical performance standards.* The general design of the FM broadcast transmitting system (from input terminals of microphone preamplifier, through audio facilities at the studio, through lines or other circuits between studio and transmitter, through audio facilities at the transmitter, and through the transmitter, but excluding equalizers for the correction of deficiencies in microphone response) shall be in accordance with the following principles and specifications:

(1) The transmitter shall operate satisfactorily in the operating power range with a frequency swing of 75 kHz, which is defined as 100 percent modulation.

(2) The transmitting system shall be capable of transmitting a band of frequencies from 50 to 15,000 Hz. Pre-emphasis shall be employed in accordance with the impedance-frequency characteristic of a series inductance-resistance network having a time constant of 75 microseconds. (See Fig. 2 of 73.333.) The deviation of the system response from the standard pre-emphasis curve shall lie between two limits as shown in Fig. 2 of 73.333. The upper of these limits shall be uniform (no deviation) from 50 to 15,000 Hz. The lower limit shall be uniform from 100 to 7,500 Hz, and 3 dB below the upper limit; from 100 to 50 Hz the lower limit shall fall from the 3 dB limit at a uniform rate of 1 dB per octave (4 dB at 50 Hz); from 7,500 to 15,000 c/s the lower limit shall fall from the 3 dB limit at a uniform rate of 2 dB per octave (5 dB at 15,000 Hz).

(3) At any modulation frequency between 50 and 15,000 Hz and at modulation percentages of 25, 50, and 100 percent, the combined audio frequency harmonics measured in the output of the system shall not exceed the root-mean-square values given in the following table:

Modulating frequency:	*Distortion percent*
50 to 100 Hz	3.5
100 to 7,500 Hz	2.5
7,500 to 15,000 Hz	3.0

(i) Measurements shall be made employing 75 microsecond de-emphasis in the measuring equipment and 75 microsecond pre-emphasis in the transmitting equipment, and without compression if a compression amplifier is employed. Harmonics shall be included to 30 kHz.

(ii) It is recommended that none of the three main divisions of the system (transmitter, studio to transmitter circuit, and audio facilities) contribute over one-half of these percentages since at some frequencies the total distortion may become the arithmetic sum of the distortions of the divisions.

(4) The transmitting system output noise level (frequency modulation) in the band of 50 to 15,000 Hz shall be at least 60 dB below 100 percent modulation (frequency swing of ±75 Hz). The measurement shall be made using 400 cycle modulation as a reference. The noise-measuring equipment shall be provided with standard 75 microsecond de-emphasis; the ballistic characteristics of the instrument shall be similar to those of the standard VU meter.

(5) The transmitting system output noise level (amplitude modulation) in the band of 50 to 15,000 Hz shall be at least 50 dB below the level representing 100 percent amplitude modulation. The noise-measuring equipment shall be provided with standard 75-microsecond de-emphasis; the ballistic characteristics of the instrument shall be similar to those of the standard VU meter.

(6) Automatic means shall be provided in the transmitter to maintain the assigned center frequency within the allowable tolerance (±2,000 Hz).

(7) The transmitter shall be equipped with suitable indicating instruments for the determination of operating power and with other instruments as are necessary for proper adjustment, operation, and maintenance of the equipment (see 73.320).

(8) Adequate provision shall be made for varying the transmitter output power to compensate for excessive variations in line voltage or for other factors affecting the output power.

(9) Adequate provision shall be provided in all component parts to avoid overheating at the rated maximum output power.

(10) Means should be provided for connection and continuous operation of approved frequency and modulation monitors.

(11) If a limiting or compression amplifier is employed, precaution should be maintained in its connection in the circuit due to the use of pre-emphasis in the transmitting system.

(12) Any emission appearing on a frequency removed from the carrier by between 120 kHz and 240 kHz, inclusive, shall be attenuated at least 25 dB below the level of the unmodulated carrier. Compliance with this specification will be deemed to show the occupied bandwidth to be 240 kHz or less.

(13) Any emission appearing on a frequency removed from the carrier by more than 240 kHz and up to and including 600 kHz shall be attenuated at least 35 dB below the level of the unmodulated carrier.

(14) Any emission appearing on a frequency removed from the carrier by more than 600 kHz shall be attenuated at least $43 + 10 \text{ Log}_{10}$ (Power, in watts) decibels below the level of the unmodulated carrier, or 80 decibels, whichever is the lesser attenuation.

73.319 Subsidiary Communications Multiplex Operations: Engineering Standards

(a) Frequency modulation of SCA subcarriers shall be used.

(b) The instantaneous frequency of SCA subcarriers shall at times be within the range 20 to 75 kHz: Provided, however, That when the station is engaged in stereophonic broadcasting pursuant to 73.297, the instantaneous frequency of SCA subcarriers shall at all times be within the range 53 to 75 kHz.

(c) The arithmetic sum of the modulation of the main carrier by SCA subcarriers shall not exceed 30 percent: Provided, however, That when the station is engaged in stereophonic broadcasting pursuant to 73.297, the arithmetic sum of the modulation of the main carrier by the SCA subcarriers shall not exceed 10 percent.

(d) The total modulation of the main carrier, including SCA subcarriers, shall meet the requirements of 73.268.

(e) Frequency modulation of the main carrier caused by the SCA subcarrier operation shall, in the frequency range 50 to 15,000 Hz, be at least 60 dB below 100 percent modulation: Provided, however, That when the station is engaged in stereophonic broadcasting pursuant to 73.297, frequency modulation of the main carrier by the SCA subcarrier operation shall, in the frequency range 50 to 53,000 Hz, be at least 60 dB below 100 percent modulation.

73.322 Stereophonic Transmission Standards

(a) The modulating signal for the main channel shall consist of the sum of the left and right signals.

(b) A pilot subcarrier at 19,000 Hz plus or minus 2 Hz shall be transmitted that shall frequency modulate the main carrier between the limits of 8 and 10 percent.

(c) The stereophonic subcarrier shall be the second harmonic of the pilot subcarrier and shall cross the time axis with a positive slope simultaneously with each crossing of the time axis by the pilot subcarrier.

(d) Amplitude modulation of the stereophonic subcarrier shall be used.

(e) The stereophonic subcarrier shall be suppressed to a level less than one percent modulation of the main carrier.

(f) The stereophonic subcarrier shall be capable of accepting audio frequencies from 50 to 15,000 Hz.

(g) The modulating signal for the stereophonic subcarrier shall be equal to the difference of the left and right signals.

(h) The preemphasis characteristics of the stereophonic subchannel shall be identical with those of the main channel with respect to phase and amplitude at all frequencies.

(i) The sum of the side bands resulting from amplitude modulation of the stereophonic subcarrier shall not cause a peak deviation of the main carrier in excess of 45 percent of total modulation (excluding SCA subcarriers) when only a left (or right) signal exists; simultaneously in the main channel, the deviation when only a left (or right) signal exists shall not exceed 45 percent of total modulation (excluding SCA subcarriers).

(j) Total modulation of the main carrier including pilot subcarrier and SCA subcarriers shall meet the requirements of 73.268 with maximum modulation of the main carrier by all SCA subcarriers limited to 10 percent.

(k) At the instant when only a positive left signal is applied, the main channel modulation shall cause an upward deviation of the main carrier frequency; and the stereophonic subcarrier and its sidebands signal shall cross the time axis simultaneously and in the same direction.

(l) The ratio of peak main channel deviation to peak stereophonic subchannel deviation when only a steady state left (or right) signal exists shall be within plus or minus 3.5 percent of unity for all levels of this signal and all frequencies from 50 to 15,000 Hz.

(m) The phase difference between the zero points of the main channel signal and the stereophonic subcarrier sidebands envelope, when only a steady state left (or right) signal exists, shall not exceed plus or minus 3 degrees for audio, modulating frequencies from 50 to 15,000 Hz.

Note: If the stereophonic separation between left and right stereophonic channels is better than 29.7 dB at audio modulating frequencies between 50 and 15,000 Hz, it will be assumed that paragraphs (l) and (m) of this section have been complied with.

(n) Cross-talk into the main channel caused by a signal in the stereophonic subchannel shall be attenuated at least 40 dB below 90 percent modulation.

(o) Cross-talk into the stereophonic subchannel caused by a signal in the main channel shall be attenuated at least 40 dB below 90 percent modulation.

(p) For required transmitter performance, all of the requirements of 73.254 shall apply with the exception that the maximum modulation to be employed is 90 percent (excluding pilot subcarrier) rather than 100 percent.

(q) For electrical performance standards of the transmitter and associated equipment, the requirements of 73.317(a)(2), (3), (4), and (5) shall apply to the main channel and stereophonic subchannel alike, except that where 100 percent modulation is referred to, this figure shall include the pilot subcarrier.

FM MODULATION THEORY

In FM the instantaneous frequency (rate of change of phase) of the rf output wave differs from the carrier frequency by an amount proportional to the instantaneous value of the modulating wave. For example, consider a 100-MHz carrier wave FM modulated by a 1000-Hz audio tone and assume that 1-volt input causes ±20-kHz frequency deviation on the positive and negative audio tone peaks. If the audio input amplitude is increased to 2 volts, the peak deviation will become ±40 kHz, and will vary in sine-wave fashion from one peak deviation to the other and back again at the 1000-Hz rate. In FM broadcasting, the FCC has established that a frequency deviation of 75 kHz shall constitute 100 percent modulation.

An important term to understand in FM is modulation index. With a sinusoidal modulating wave, the modulation index

$$m = \frac{\text{frequency deviation}}{\text{modulating frequency}}$$

An FM rf output wave contains many sideband frequency components, theoretically an infinite number. They consist of pairs of sideband components spaced from the carrier frequency by multiples of the modulating frequency. When the modulation index is small (< 0.5) the second and higher order sidebands are small so that the output consists essentially of the carrier and the pair of first order sidebands. (See Fig. 2a.) The transmitter rf output power remains constant with modulation, so the power in the carrier is reduced by the amount of power in the sidebands. In other words, the sum of the squares of the carrier voltage amplitude and all of the sideband voltage amplitudes must equal the square of the unmodulated carrier amplitude.

As the modulation index (or signal level) is increased, the higher order sidebands become more prominent. The amplitude of the carrier and the sidebands can be expressed mathematically by the use of Bessel functions.

$e(t) =$	total rf output voltage
$+EJ_0(m)\cos\omega t$	carrier
$+EJ_1(m)\cos(\omega+\rho)t$	first order upper sideband
$-EJ_1(m)\cos(\omega-\rho)t$	first order lower sideband
$+EJ_2(m)\cos(\omega+2\rho)t$	second order upper sideband
$+EJ_2(m)\cos(\omega-2\rho)t$	second order lower sideband
$+J_3(m)\cos(\omega+3\rho)t$	third order upper sideband
$-J_3(m)\cos(\omega-3\rho)t$	third order lower sideband
-------------------------	higher order sidebands

where

m is the modulation index,
ω is the carrier frequency, and
ρ is the modulating frequency.

The Bessel functions $J_0(m)$, etc., which express the amplitude of the various frequency components can be found in mathematical tables. Fig. 3 shows how the carrier and first eight pairs of sideband components vary with modulation index. (This is simply a plot of Bessel functions.)

In a monophonic FM broadcast transmitter, the modulation index can become very high. With a 50 Hz audio input signal of sufficient amplitude to produce 75 kHz deviation (corresponding to 100 percent modulation), the modulation index

$$m = \frac{75000}{50} = 1500$$

With 15,000 Hz input at 100 percent modulation, the modulation index

$$m = \frac{75000}{15000} = 5$$

Fig. 2b and 2c illustrate the frequency components present for modulation indexes of 5 and of 20. The number of significant sideband components becomes very large with large modulation indexes. The total bandwidth occupied extends beyond ±75 kHz from the carrier depending upon the modulating frequency. This

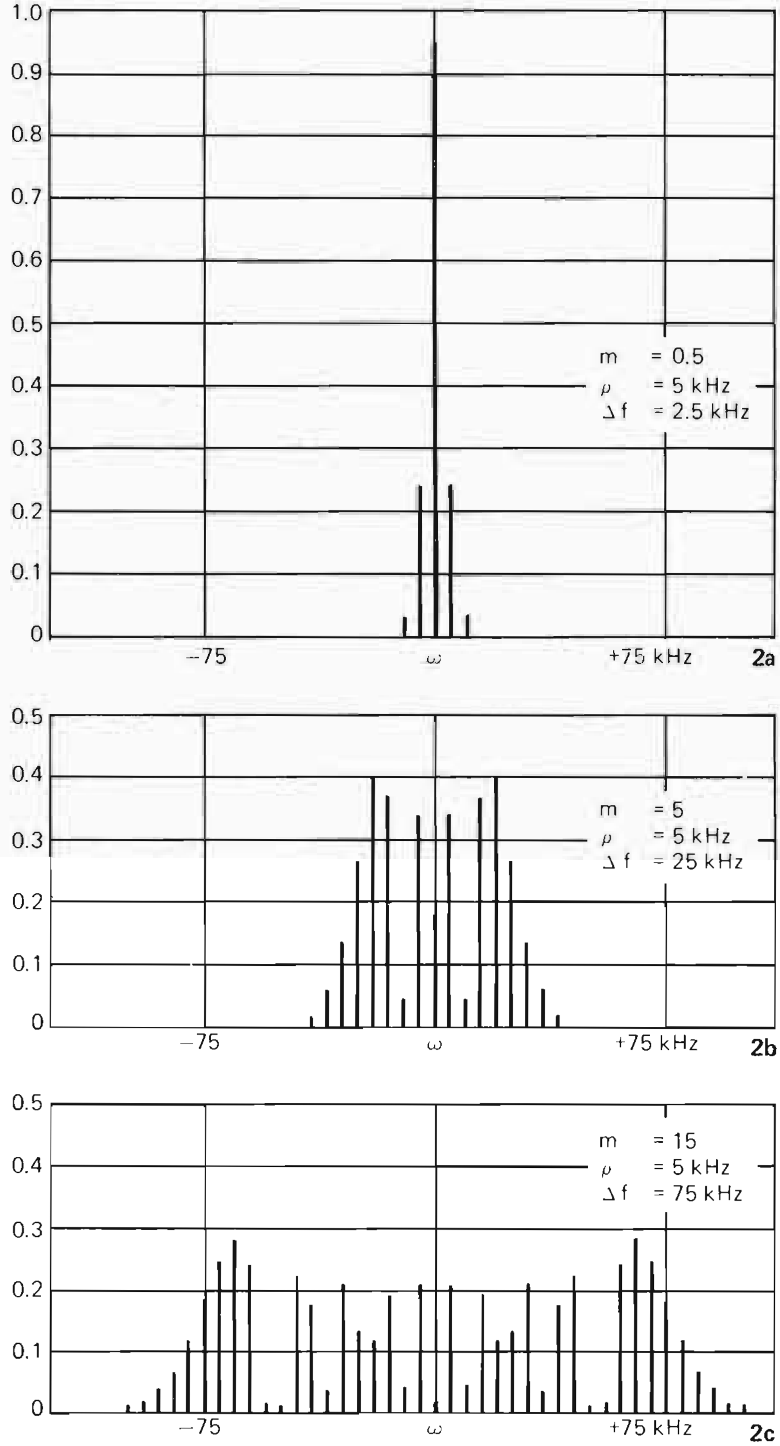


Fig. 2. RF spectrum with modulation indexes of 0.5, 5.0, and 20.0.

single tone modulating frequency analysis is useful in understanding the general nature of FM and for making tests and measurements. When program modulation is applied, there are many more sideband components present and they are varying so much that sideband energy becomes distributed over the occupied band rather than appearing on discreet frequencies.

Referring to Fig. 3, note that the carrier amplitude goes to zero and reverses sign at several values of modulation index 2.4048, 5.5201, and 8.6537. This relationship can be used to measure

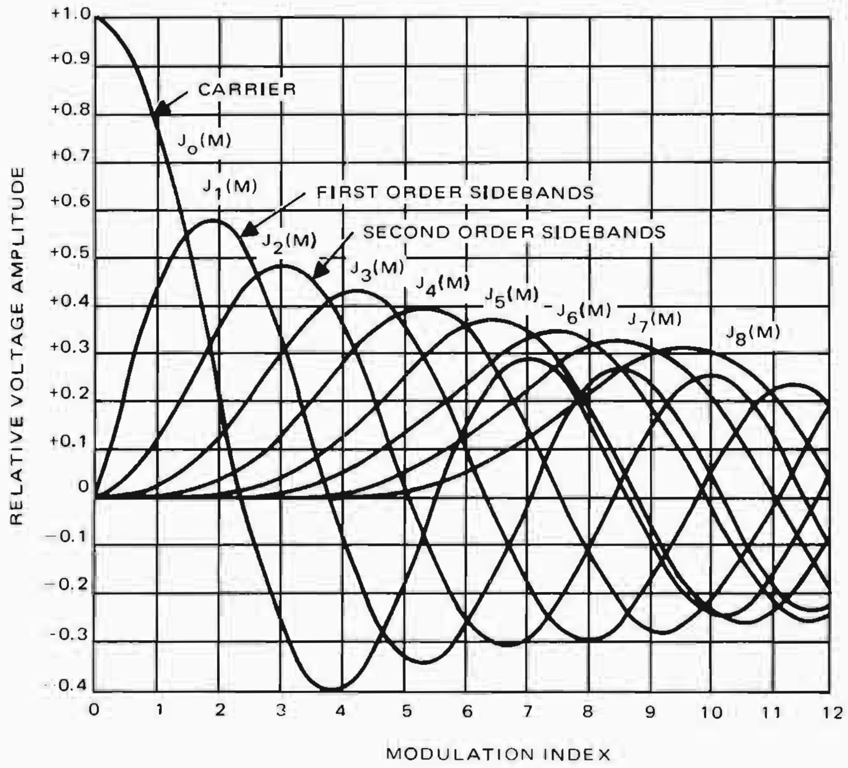


Fig. 3. Relationship of carrier and sideband amplitudes to modulation index.

frequency deviation. It we want to measure the audio input level required to achieve 75-kHz deviation, we can apply an audio tone of $\frac{75000}{8.6537}$ or 8,666 Hz and increase the audio level until the carrier disappears the third time. At this audio level the deviation is 75 kHz. The carrier amplitude detector must have sufficient selectivity to separate the carrier from the sidebands, of course. A listing of some of the more useful points of carrier disappearance is given in Table 1. This method can be used to check the accuracy of a modulation monitor, for example.

A frequency (or phase) modulated wave can be multiplied or divided, and this also multiplies or divides the frequency deviation and the modulation index.

TABLE 1

Modulation Indexes That Produce the First Seven Carrier and First Order Sideband Disappearances and the Corresponding Audio Modulating Frequencies That Produce These Same Disappearances When the Deviation Is 75 kHz

Disappearance	Modulation index		Freq. for 75 kHz dev.	
	Carrier	1st sideband	Carrier	1st sideband
1st	2.405	3.852	31,188	19,320
2nd	5.520	7.016	13,587	10,670
3rd	8.654	10.173	8,667	7,372
4th	11.792	13.323	6,360	5,629
5th	14.931	16.470	5,023	4,554
6th	18.071	19.616	4,150	3,823
7th	21.212	22.760	3,536	3,295

In PM, the modulating signal causes the *phase* of the carrier wave to vary according to the instantaneous amplitude of the modulating signal. There is a very simple but important relationship between PM and FM. If the audio frequency response is made to fall off 6 dB per octave across the entire audio band and is used to phase modulate a carrier, the resulting modulated output will be identical to that of a frequency modulated carrier. This principle was used in many FM broadcast transmitters prior to the advent of stereo broadcasting. The principal advantage was that the carrier frequency could be generated by a stable crystal oscillator. The amount of low distortion phase modulation was quite limited in most systems so it was necessary to start with a low crystal oscillator frequency and multiply it many times (such as 864) to achieve 75 kHz deviation with 50 Hz audio modulation. This technique has been abandoned in favor of direct FM in all new FM broadcast transmitter exciters designed to accommodate stereo transmission.

PRE-EMPHASIS

The standards adopted for FM broadcasting require the use of pre-emphasis. The standard pre-emphasis curve is defined as an ideal RC

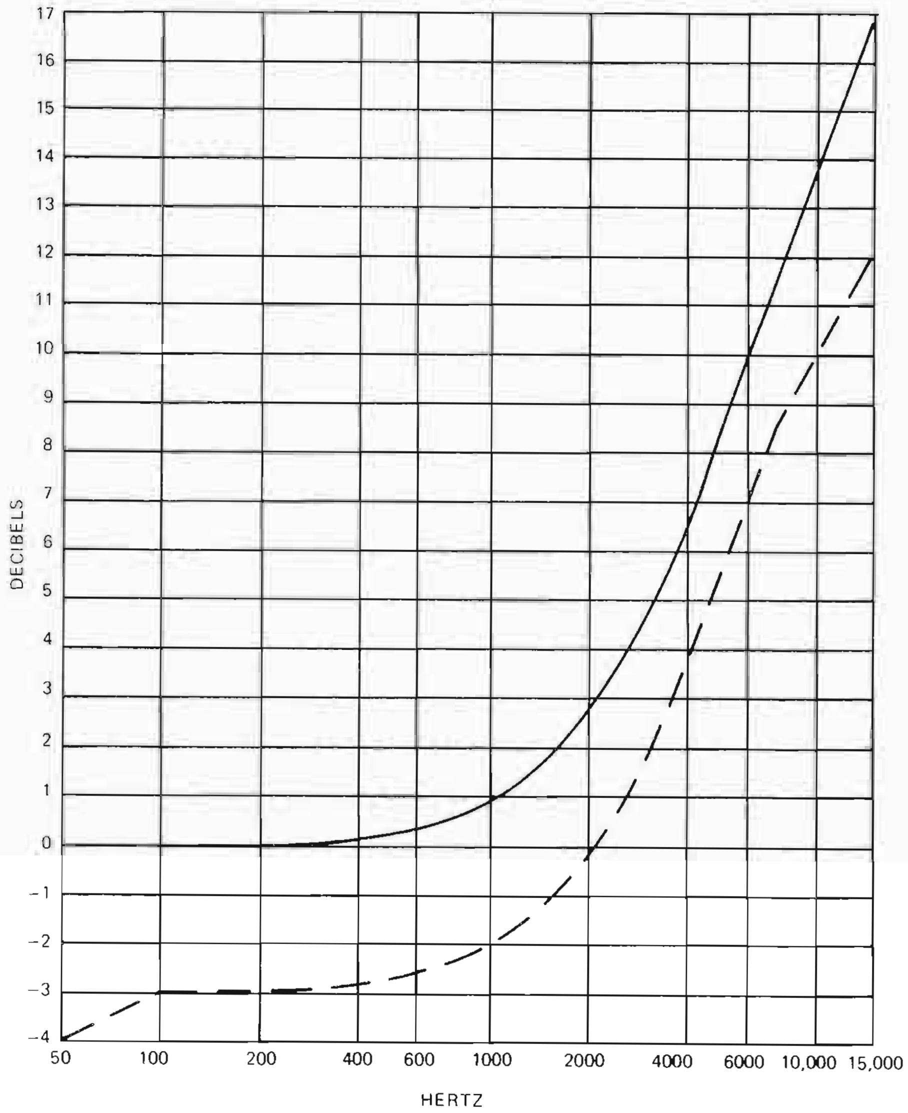


Fig. 4. Standard 75-microsecond pre-emphasis curve (solid line) and tolerance limits (solid and dashed lines).

network with a time constant of 75 microseconds. The 3-dB point is at

$$f = \frac{1}{2\pi RC} = \frac{1}{2\pi\, 75 \times 10^{-6}} = 2{,}122 \text{ Hz.}$$

The 75-microsecond curve and the tolerance allowed is shown in Fig. 4.

The reduction in receiver output noise due to the use of pre-emphasis in monophonic transmission is illustrated in Fig. 5. The noise voltage in a narrow band (for example, 1 Hz) increases directly with frequency, therefore, the power spectral density increases as the square of frequency as shown. When pre-emphasis is used, the noise voltage is attenuated above 2.1 kHz so that it remains constant with frequency. The power spectral density is, therefore, also constant above 2.1 kHz. The area between these curves represents the noise power that is removed by the use of pre-emphasis. This diagram indicates the importance of pre-emphasis for high-fidelity transmission because the high-frequency noise would be very much greater without it.

Pre-emphasis is practical because program energy tends to peak around 1 kHz and falls off fairly rapidly at the higher frequencies. For this reason, the higher frequencies can be boosted in amplitude without causing much increase in modulation level. There is some increase, however, so the net improvement due to pre-emphasis is the ratio of the areas under the two curves of the diagram less this small reduction in audio input level required to keep within the 100 percent modulation limit.

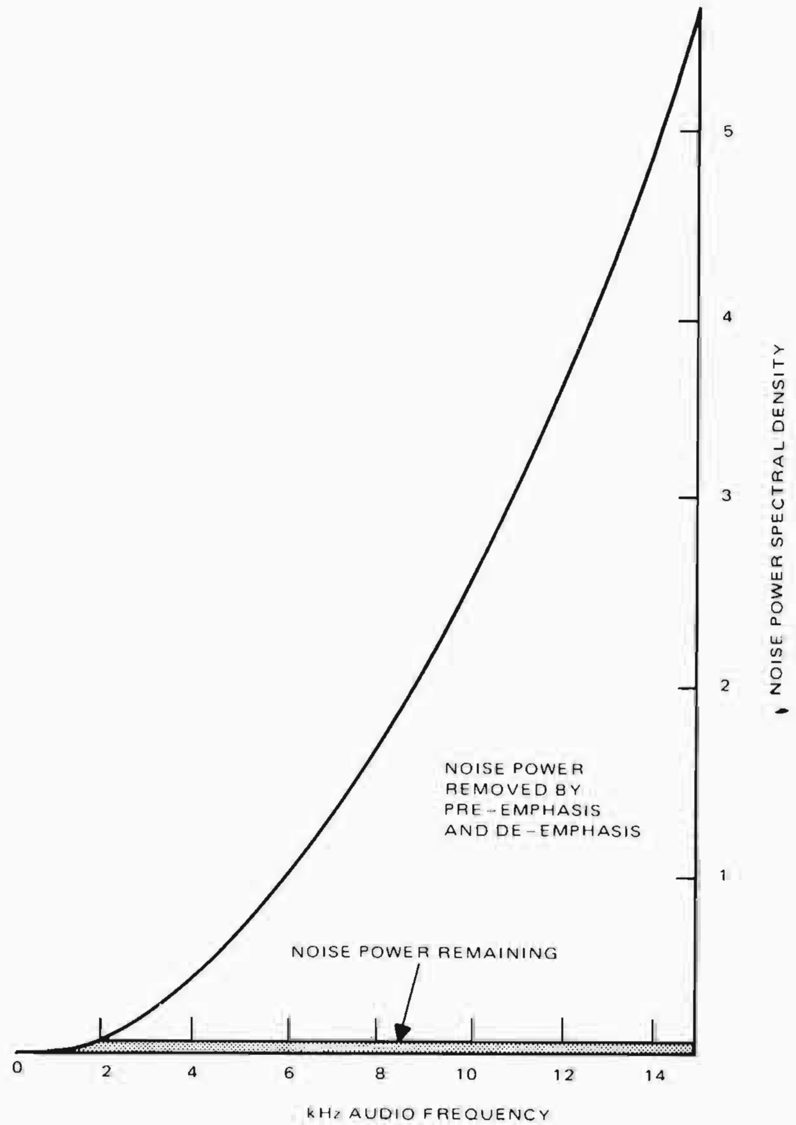


Fig. 5. Noise power spectral density before and after de-emphasis in receiver.

THE STEREO BASEBAND SIGNAL

Fig. 6 shows the composite baseband signal that is used to frequency modulate the carrier. (An SCA channel is also shown but will be left for later discussion.) The L and R (left and right) stereo input channels are added together to provide the basic modulation which is suitable for reception by monophonic FM receivers. The monophonic receivers use this L+R modulation in the 50 to 15,000 Hz range but discard the pilot carrier and L-R signals used for stereo.

For stereo reception an additional signal consisting of an L-R signal is needed. This is the same as the L+R except that the phase of the R channel is reversed. This L-R signal is converted to a double sideband suppressed carrier (DSBSC) signal centered on the subcarrier frequency of 38 kHz. The subcarrier is suppressed to avoid wasting modulation capability. It is necessary, however, to reinsert the 38 kHz subcarrier at the receiver in order to demodulate the DSBSC L-R signal. This inserted carrier must be on the exact frequency and very nearly in the exact phase relationship to the sidebands as exists with the signal generated in the exciter. Therefore, a pilot carrier is transmitted.

Since audio frequencies at 50 Hz and below are very close to the 38 kHz subcarrier frequency, it would be difficult to filter out a pilot carrier at that frequency. The detected pilot carrier would also have a better signal-to-noise ratio by 6 dB if its frequency were halved. For these reasons, a pilot carrier at 19 kHz (half of 38 kHz) is

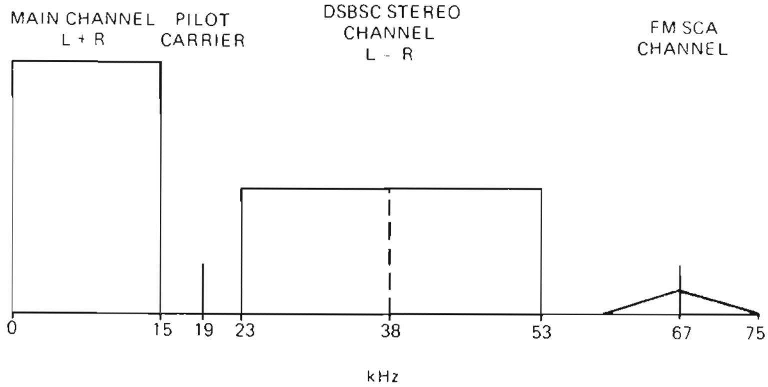


Fig. 6. Composite stereo baseband signal including an SCA channel.

transmitted at an 8 to 10 percent modulation level. This frequency is well removed from the required audio sidebands so that it can be readily separated from them and simply doubled to provide the desired subcarrier injection in the receiver.

In the receiver the demodulated L-R signal is combined with the L+R signal to obtain the separate L and R channels again.

$$(L+R) + (L-R) = 2L$$
$$(L+R) - (L-R) = 2R$$

For good stereo reception it is necessary that the L and R channels remain well separated (that is, audio in one channel shall not appear in the output of the other channel). The FCC requires 29.7 dB separation (which was about the best achievable when the rules were adopted). Exciters soon became available which were capable of better than 35 dB separation.

In order to maintain good separation, it is necessary that the amplitude and phase of the L+R and L-R paths be nearly identical and the phase of the pilot carrier correct.[3] The channel separation as a function of these three factors is given in the following equation.

separation dB =

$$20 \log_{10} \left[\frac{(\cos\theta + \frac{S}{M}\cos\phi)^2 + (\sin\theta)^2}{(\cos\theta - \frac{S}{M}\cos\phi)^2 + (\sin\theta)^2} \right]^{1/2}$$

where

M is the gain of the main L+R path
S is the gain of the stereo L-R path
ϕ is phase error of reinserted 38 kHz subcarrier that is twice the phase error of the 19 kHz pilot carrier
θ is difference in phase between L+R and L-R paths.

[3] Lawrence C. Middlekamp, "Stereophonic Separation in Transmission" IEEE Transactions on Broadcasting Vol. BC-14, No. 3, Sept. 1968, and "Measurement of the Phase of the Stereophonic Subcarrier in FM Stereophonic Transmission." *Journal of the Audio Engineering Society*, April 1967, Vol. 15, No. 2.

The effect of each alone upon the separation is shown in Fig. 7. In practice, loss of separation is due to some of each. Therefore, to achieve 35 dB separation, the amplitudes must match to about 1 percent and the phase to about 1° over the entire audio range from 50 Hz to 15 kHz. The phase of the pilot carrier should be within 4°. These are very stringent requirements. For this reason, designers keep the amount of circuitry in the separate L+R and L-R paths to a minimum.

Matrixing the L and R channels in this manner has a further advantage in that when the two transmission paths have unequal signal-to-noise ratios, the S/N on the L and R channels will be equal. This situation is less objectionable than having unequal S/N in the L and R channels. In the adopted system, the S/N is inherently much better in the L+R path than in the L-R path. This means that in weak signal conditions it may be possible to obtain good monophonic reception of a stereophonic broadcast even though stereophonic reception is poor. Some receivers are designed to switch to monophonic reception automatically in weak signal conditions.

An examination of an oscilloscope display of the stereo baseband signal will point up several important relationships. First consider a 1 kHz test tone applied to the L input only and pilot carrier turned off. Fig. 8a illustrates the ideal baseband signal. The baseline through the diagram will be a straight line for the ideal case of no distortion and perfect separation. Three frequency components are present: 1 kHz, 37 kHz, and 39 kHz. The latter two are each 1/2 the voltage amplitude of the first.

The picture will look the same when an R-only, 1 kHz tone is applied, although the phase of the two high-frequency components will be reversed.

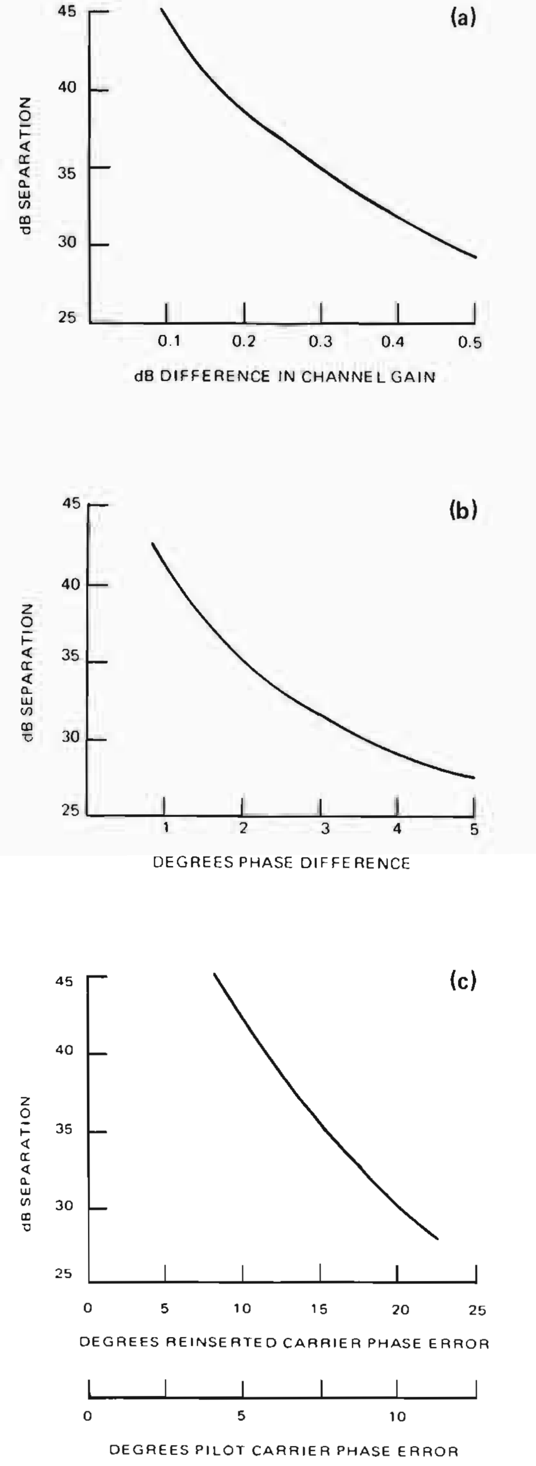


Fig. 7. Stereo separation versus (a) amplitude difference between main and stereo channels, (b) phase difference between main and stereo channels, and (c) error in phase of pilot or reinserted carrier.

Fig. 8b illustrates the case when the L and R inputs are identical. The only frequency present is 1 kHz because the signal in the L-R stereo channel is zero. Note that adding the R signal of the same amplitude as the original L signal does not change the peak amplitude.

Fig. 8c illustrates the case when L and R inputs are equal in amplitude but in phase opposition. The only components present are the DSBSC stereo channel components of 37 kHz and 39 kHz. Again note that the peak amplitude stays exactly the same. This means that the percentage modulation would also be the same because it is directly related to the peak amplitude of the baseband signal.

The baseband signal components have phase coherence so they add almost exactly in phase on signal peaks. This means that if the L and R audio input signals have no phase coherence the level transmitted in the L+R channel is one half or 6 dB less than that which would be transmitted by a monophonic transmitter.

Adding the pilot carrier to the above three cases gives the results shown in Fig. 9. The phase of the pilot carrier is such that a pilot carrier peak never occurs simultaneously with an L-R subchannel peak. As a result of this coherent phase relationship, the pilot carrier contribution to total modulation is not a direct arithmetic sum but depends upon the instantaneous L-R subchannel modulating level. For 90 percent subchannel modulation (L=-R) and 10 percent pilot carrier modulation—the total modulation is approximately 97.1 percent instead of 100 percent. (It is about the same for an L or R only test signal. To achieve 100 percent modulation, the audio must be increased about 0.25 dB.) For 90 percent main channel modulation (L=R) and 10 percent pilot carrier modulation, the total is 100 percent because in normal use there is no phase coherency between the signal and pilot carrier.

When program material is transmitted, the net loss in S/N to monophonic receiver going from monophonic to stereophonic transmission will probably be considerably less than the 6.25 dB loss in a single L or R test tone case but more than the 1 dB loss in the L=R case. It depends upon the L and R program input signals being somewhat more in phase rather than out of phase or noncoherent.

STEREO MATRIXING TECHNIQUES

There are two basic techniques used for obtaining the L+R and L-R signals. The simplest matrix circuit to understand is shown in Fig. 10a. The voltage outputs of the L and R transformers are simply added. Fig. 10b shows a bridge matrix technique which properly loads the transformers and allows the use of identical transformers. The other is a switching technique described in the following paragraphs.

It is a well-known fact in communications theory that the original signal can be recon-

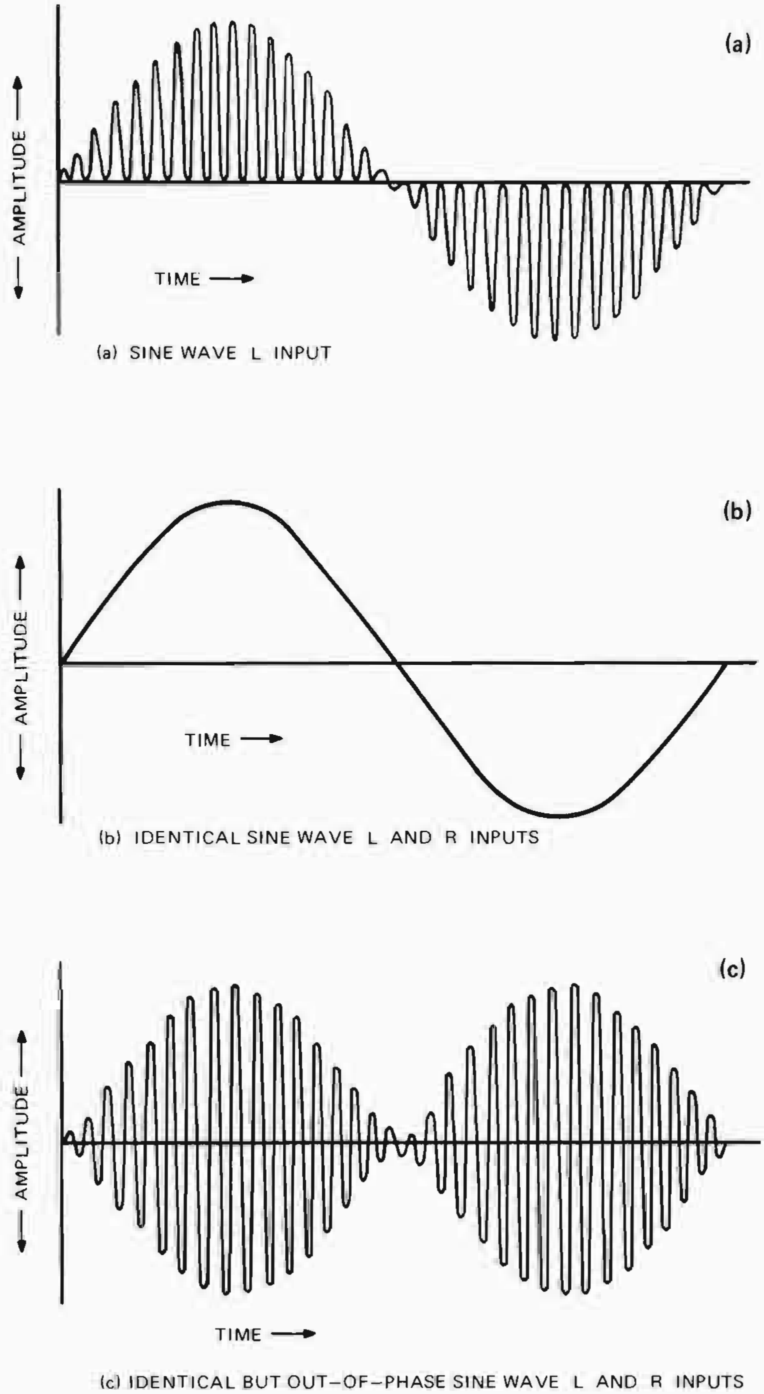


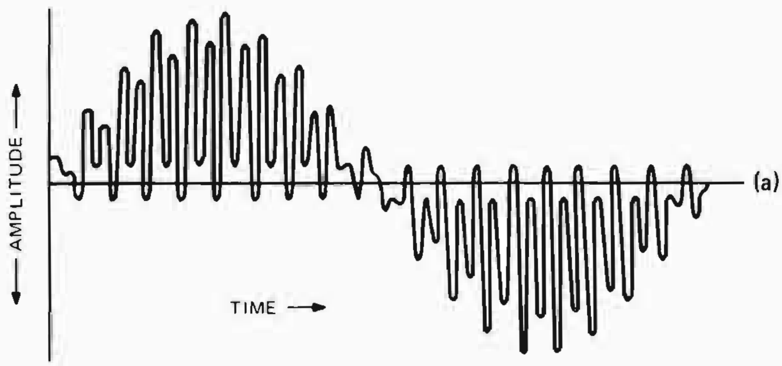
Fig. 8. Diagram of oscilloscope display of stereo baseband signal with (a) sine wave L input, (b) identical sine wave L and R inputs, and (c) identical but out-of-phase sine wave L and R inputs.

structed from samples of the signal amplitude, providing the samples are taken at a rate that is at least twice the frequency of the highest audio frequency component. Fig. 11a shows a sine-wave audio tone being sampled or switched on 50 percent of the time and off 50 percent of the time at a 38-kHz rate. The equation for this chopped audio waveform is

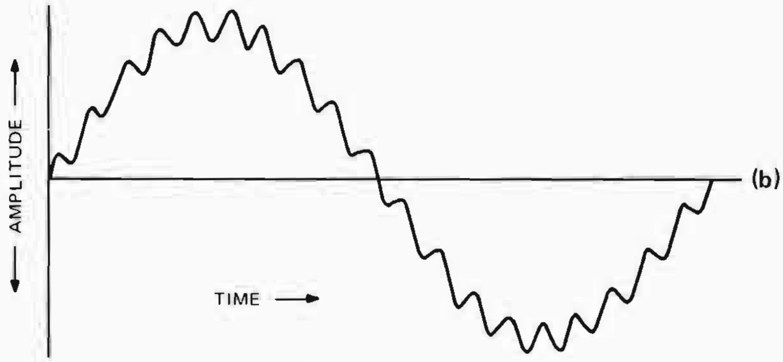
$$e = 1/2 \sin \rho t \qquad \text{audio}$$

$$+ \frac{1}{\pi} \left[\sin (\omega + \rho)t + \sin (\omega - \rho)t \right] \qquad \text{DSBSC}$$

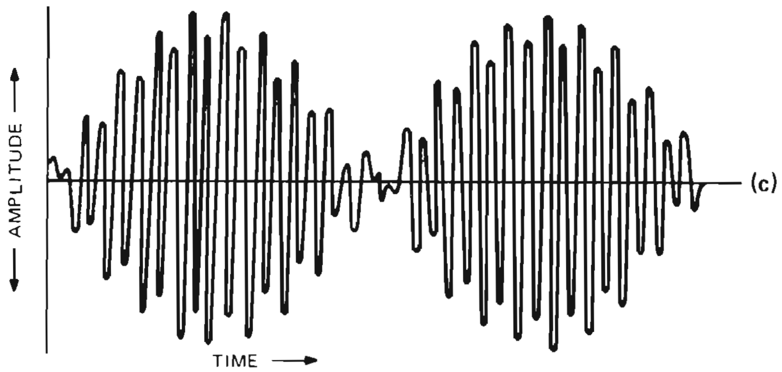
$$- \frac{1}{3\pi} \left[\sin (3\omega + \rho)t + \sin (3\omega - \rho)t \right]$$



(a) SINE WAVE L INPUT WITH PILOT



(b) IDENTICAL SINE WAVE L AND R INPUTS WITH PILOT



(c) IDENTICAL BUT OUT-OF-PHASE SINE WAVE L AND R INPUTS WITH PILOT

Fig. 9. Addition of pilot carrier to the same signals in Fig. 8.

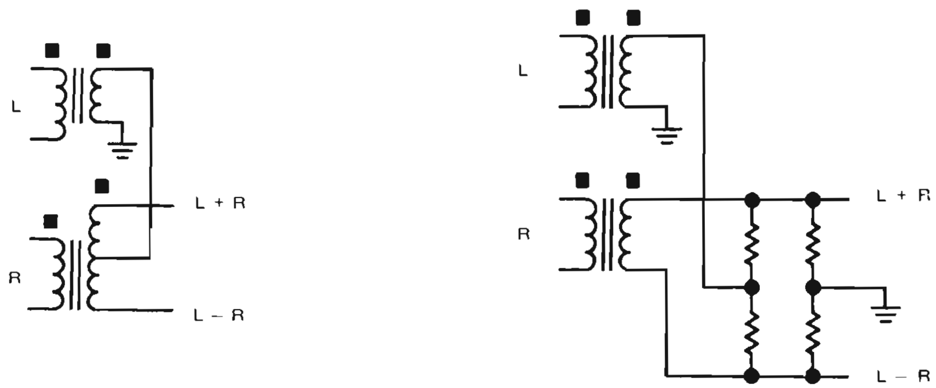


Fig. 10. Phaser addition methods to stereo matrixing.

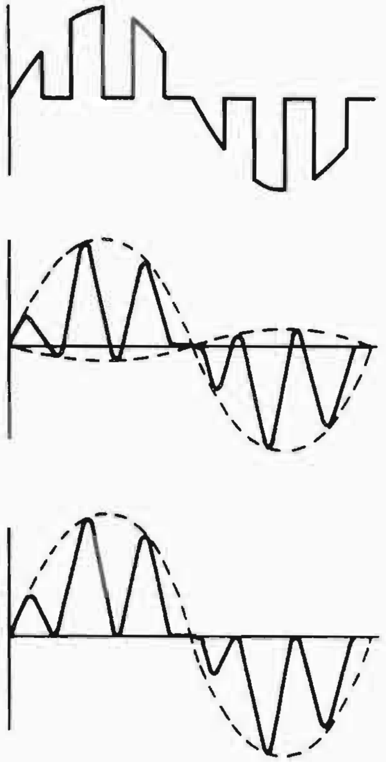


Fig. 11. (a) Output of switching type balanced modulator with sine-wave audio input and 38-kHz switching rate. (b) After removal of higher order sidebands. (c) Equal fundamental and DSBSC amplitudes.

Note that it contains the original audio at half amplitude and the double sideband suppressed carrier (DSBSC) components needed for the L-R stereo signal plus additional DSBSC terms around the 3rd, 5th, 7th, etc., harmonics of the 38 kHz switching frequency. If we filter off the third and all higher order sidebands, we get the wave shown in Fig. 11b. This is exactly the desired signal for stereophonic transmission except that the DSBSC signal is larger (when demodulated) by a factor of $\frac{4}{\pi}$. This can be overcome by simply adding enough of the input audio to the output signal to make the two equal in amplitude (Fig. 11c).

In stereo exciters that use this scheme (Figs. 31, 36, and 44) the L and R signals are sampled at alternate half cycles of the switching frequency by a double balanced modulator as shown in Fig. 12. The output contains the desired (L+R) and (L-R) DSBSC signals plus the undesired higher order products which are removed by a 53 kHz low-pass filter.

The 53 kHz low-pass filter is required to have a linear phase shift with input frequency (equal time delay at all frequencies up to 53 kHz) as well as a very flat passband amplitude response. This keeps the correct phase relationship between the L+R and L-R paths which is necessary to maintain channel separation as previously discussed.

In some exciters the 38 kHz switching frequency is obtained by dividing by two the output of a 76 kHz crystal oscillator. It is divided again to obtain the 19 kHz pilot carrier. This is simply added to the output of the 53 kHz filter to provide the desired baseband stereo signal which is used to directly frequency modulate an rf oscillator.

SCA MULTIPLEX

The FCC Rules and Regulations permit the use of frequency modulated subcarriers for subsidiary communications multiplex operation. The subcarrier frequencies are not specified, but 67 kHz is perhaps most widely used. When stereo is not broadcast, a second subcarrier at 41 kHz is often used. When broadcasting stereo, the subcarrier should not modulate the main carrier over 10 percent and when broadcasting monophonic, the sum of SCA subcarrier modulations of the main carrier should not exceed 30 percent.

The requirement that any frequency modulation of the main carrier due to SCA operation shall, in the frequency range of 50 to 15,000 Hz for monophonic or 50 to 53,000 Hz for stereophonic broadcasting, be at least 60 dB below 100 percent modulation places limits on the SCA modulation. For example, consider the case of stereo broadcasting with an SCA subcarrier at 67 kHz which is at the maximum subcarrier level of 10 percent modulation. Referring to Fig. 6, note that the subcarrier is 14 kHz above the 53 kHz edge of the stereo channel. Any SCA modulation above 14 kHz of course results in a first-order lower sideband component appearing in the stereo channel. Second- and third-order sideband components are also significant and must be kept down to an amplitude of 1 percent of the subcarrier amplitude. (Ten percent is 20 dB, which subtracted from 60 dB leaves 40 dB, which is 1 percent.) Fig. 13 shows the maximum deviation for single tone SCA modulation that complies with the Rules and Regulations. (This curve is derived from the modulation index that produces sideband components of 0.01 as found in Bessel function tables.) The lower corners of the "saw teeth" establish the limits. For example, a 4.67 kHz SCA modulating tone produces a third order sideband component at 1 percent amplitude when the SCA frequency deviation is 3.7 kHz.

Pre-emphasis of either 75 or 150 microseconds is commonly used with SCA modulation. In this case, the frequency response over the range of interest (above 3 kHz) rises at a rate of 6 dB per octave. The maximum amplitude for the SCA

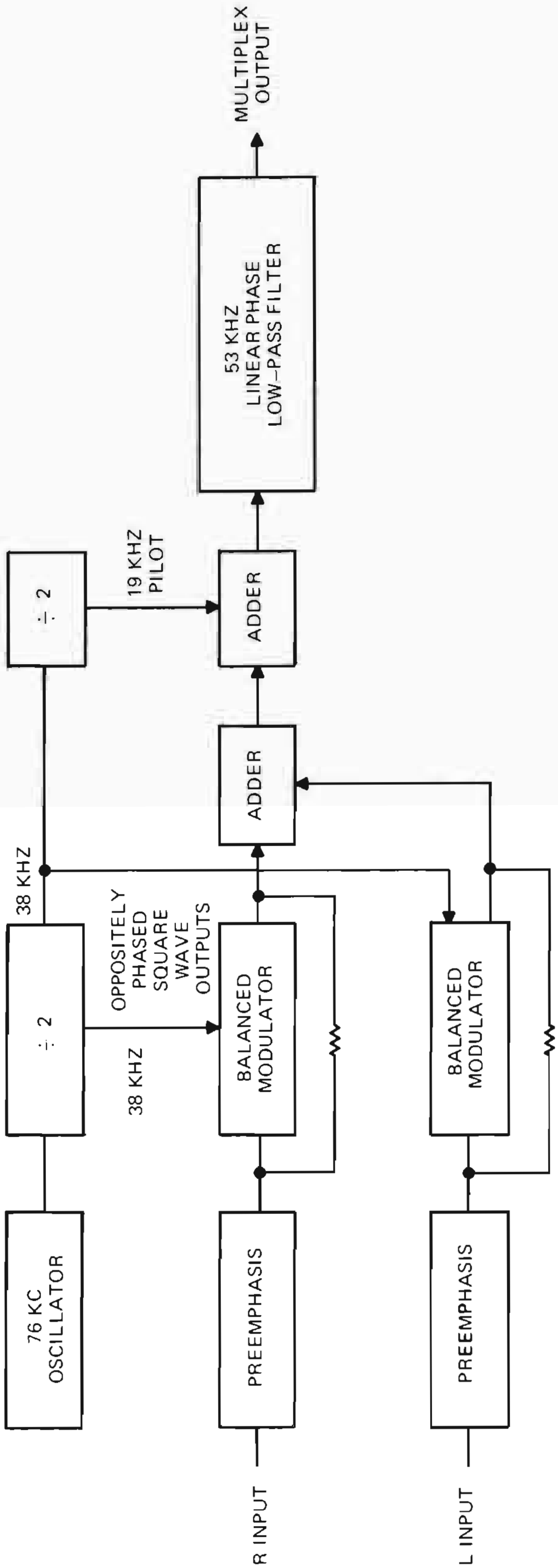


Fig. 12. Switching balanced modulator technique of stereo matrixing.

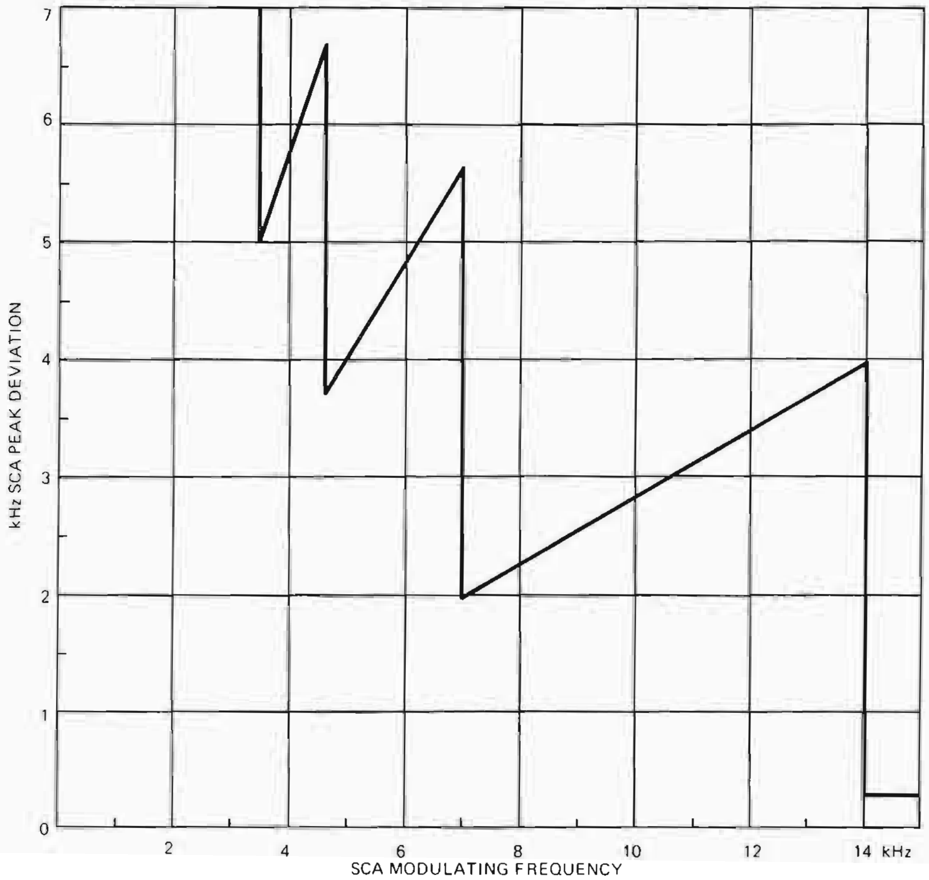


Fig. 13. Maximum deviation of 67-kHz, 10 percent amplitude SCA subcarrier with stereo broadcasting.

audio signal before being pre-emphasized is shown by the diagram in Fig. 14. This diagram indicates that frequencies above 5 kHz should be attenuated to assure compliance with the FCC regulation when program material is transmitted on the SCA channel. It is recommended practice to limit SCA modulation to 5 kHz and the peak deviation to 3.5 kHz during stereophonic broadcasts.

It is desirable to keep the SCA carrier amplitude and the frequency deviation as high as allowed in order to achieve maximum signal-to-noise ratio.

A common problem in SCA transmission is crosstalk of the main channel into the SCA channel. To minimize this condition, the exciter must have very low amplitude distortion because harmonics and intermodulation products of the main modulating signal may fall into the SCA band. The distortion must be down to the order of 0.1 percent to achieve a 40 dB S/N ratio in the SCA channel. The rf amplifiers must have very linear phase characteristics across the entire bandwidth of the transmitted signal. This requires proper tuning and neutralization. A high SWR on the antenna transmission line may also cause trouble. The receiver performance requirements are also stringent and multipath signal pickup should be minimized by using directional receiving antennas.

STEREOPHONIC SIGNAL-TO-NOISE RATIO

An important feature of the stereophonic system adopted by the FCC is that the loss in S/N to monophonic reception of a stereophonic broadcast is not great. The exact amount depends upon the nature of the signal being transmitted, but with regular program material, the loss is probably about 4 dB.

In the special case where a single test tone is fed to both L and R inputs in phase, there is no L-R signal so all of the signal appears in the main L+R channel. The level is lower by the pilot carrier amplitude which amounts to 0.7 to 0.9 dB loss.

In the case when an audio tone is applied to either the L or R input only, there is a loss of 6 dB plus 0.5 to 0.6 dB due to the pilot carrier. The

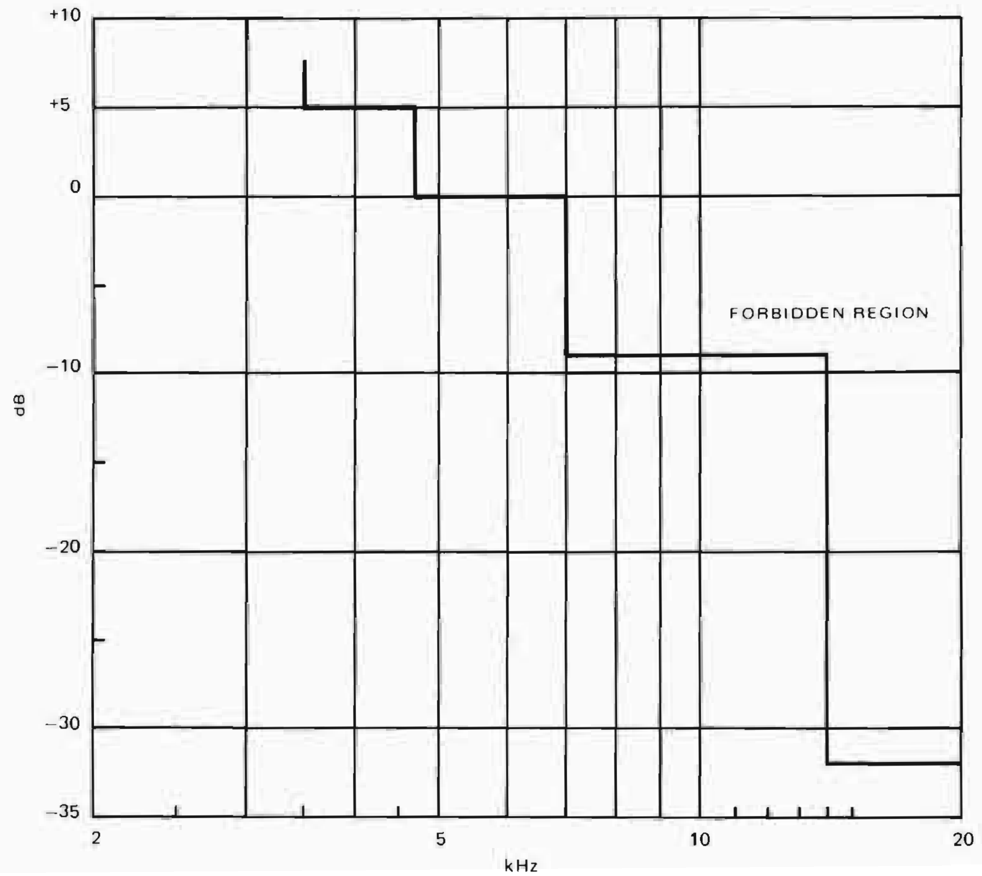


Fig. 14. Maximum frequency response of SCA modulation before pre-emphasis for a 67-kHz subcarrier frequency and stereo broadcasting on the main channel.

6 dB loss is due to the fact that the L-R component requires half the peak modulation availability. The loss for the pilot carrier is a little less because it doesn't add directly in phase with the "38 kHz" L-R component.

The loss will normally be somewhere between these two cases when broadcasting regular program material. It depends upon the extent that the L and R inputs have the same frequency components that are more in-phase than out-of-phase.

The S/N in stereophonic reception of a stereo signal is much poorer (by about 20 dB) from monophonic reception of the same signal depending on receiver audio bandwidth. The noise level in the L-R stereo channel is much greater and when combined with the L+R channel in the receiver, the noise level of the separate L and R audio channels is much greater. The reason for this is illustrated in Fig. 15. The power spectral density of noise in the discriminator output increases as the square of baseband frequency. (This assumes that the noise power spectral density is flat across the receiver bandwidth such as normally caused by receiver front end noise.) When the L-R and L+R channels are combined

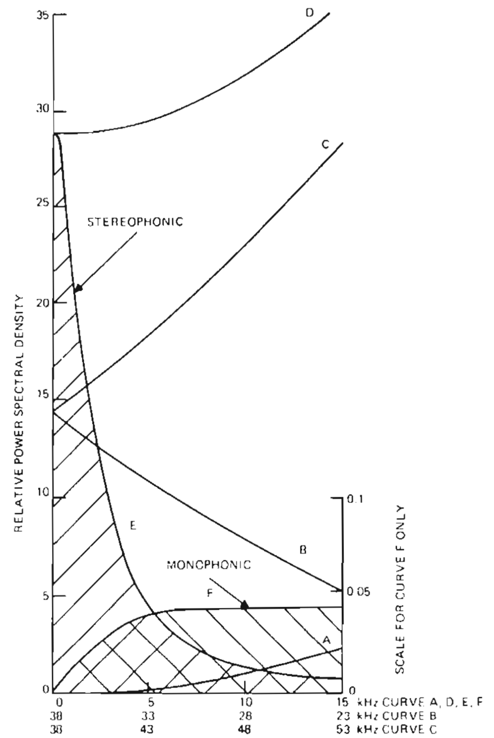


Fig. 15. Noise power spectral density curves before and after de-emphasis in stereo and monophonic reception.

in the receiver to produce the separate L and R audio channels, the noise power adds as illustrated. Deemphasis is then applied to the separate L and R audio channels resulting in the power spectral density shown for stereophonic reception. The ratio of the area under this curve to the area under the monophonic reception curve converted to decibels less 3 dB gives the difference in S/N between monophonic and stereophonic reception of the same broadcast signal. The stereophonic outputs are 2L and 2R compared to L+R monophonic output giving a 6 dB advantage due to voltage addition, with two stereophonic outputs the noise power is twice leaving the 3 dB difference.

Another factor which contributes to an improved signal-to-noise ratio is the use of automatic audio-level-controlling amplifiers and audio peak limiters. Their purpose is to keep the percentage of modulation high, which is very helpful in AM where the received S/N is normally much poorer. In FM it can be equally effective in improving received S/N and in making the station sound louder when tuning across the FM band. This improvement is not needed so much in FM broadcasting. Some program material needs the wide dynamic range afforded by FM for full effectiveness. The standards for FM broadcasting were set up to achieve good high fidelity capability so good judgment should be exercised in the amount of audio compression and peak limiting used.

AUTOMATIC FREQUENCY CONTROL

The frequency stability of direct FM oscillators is not good enough to meet the FCC frequency tolerance limit of 2,000 Hz. This requires an automatic frequency control system of some kind that uses a stable crystal oscillator as the reference frequency. Several different schemes are employed by the various manufacturers.

The modulated oscillator should have good long-term stability (within practical limits) to avoid the need of excessive control loop gain. It also needs good short term stability (that is, < 1 second) because the control loop time constant must be long enough that the AFC circuit does not try to remove desired low-frequency audio modulation. The audio frequencies are usually attenuated below 20 Hz so they will not interfere with the AFC operation.

There are three basically different AFC schemes currently in use. One scheme is shown in Figs. 31 and 45. The modulated oscillator output frequency is divided by 2^{14} (which is 16,384) to obtain a frequency in the 6-kHz region. A crystal oscillator operating on 2^{-10} or 1/1024 of carrier frequency is divided by 24 or 16 to arrive at the same frequency. The two frequencies are compared in a phase detector to develop an output voltage for controlling the carrier frequency of the modulated oscillator. The reason for dividing the modulated oscillator frequency so far down is to lower the modulation index sufficiently to avoid carrier disappearance and remove most of the modulation. A 50 Hz audio input producing 100 percent modulation of a carrier divided this much results in a modulation index of only 0.0916. The phase detector output is filtered to further remove all frequency components above a few Hz so that the AFC circuit does not try to remove low-audio frequency modulation.

Figs. 39 and 50 illustrate an AFC scheme where the modulated oscillator frequency is converted downward to a 200 or 400 kHz region. The signal at this if. frequency still contains the full ±75-kHz modulation and there are sideband frequencies extending beyond that. This FM if. signal wave is shaped into pulses and a counter type detector is used to produce the error correcting signal. Again enough integration time or low pass filtering must be used to minimize response to low audio frequencies.

The other scheme is used in the exciter shown in Fig. 36. The 14 MHz modulated oscillator output is compared with a 14 MHz reference crystal oscillator. This is accomplished by alternately sampling one and then the other at approximately a 5 Hz rate using a synchronous switching scheme and a discriminator for the detector. Errors due to discriminator drift and AFC amplifier dc drift are thereby eliminated. The modulation in the discriminator output during the periods when the modulated oscillator is being sampled is cancelled by feeding the original baseband modulating signal into the discriminator output out of phase. The remaining signal is filtered and the ±dc component is used to keep the oscillator on frequency.

FM EXCITERS

The function of the exciter is to generate and modulate the carrier wave with the one or more inputs (mono, stereo, SCA) in accordance with the FCC standards. Stereo transmission places the most stringent performance requirements upon the exciter. Most, if not all, exciters now being manufactured are designed to meet the FCC stereo requirements. They are modulized or unitized so they can be procured for just mono or mono plus SCA transmission. Later conversion to stereo can be accomplished simply by adding the necessary modules or units.

Before the advent of stereo broadcasting, most of the FM exciters employed phase modulation techniques. Some of these were adapted to stereo but it was difficult to achieve and maintain the performance standards for stereo separation. All manufacturers now employ direct FM systems. Each manufacturer has a different variation but they all have the same basic requirements and characteristics.

All exciters being manufactured will produce at least 10 watts output so they can also be used as the transmitter for the 10 watt educational stations. For higher power outputs, the exciter is used to drive a power amplifier.

TRANSMITTER POWER OUTPUT REQUIREMENT

The FCC regulates the power of FM broadcast stations in terms of effective radiated power (ERP). The ERP authorized applies to the horizontally polarized component of radiation. Elliptical or circular polarization is also permitted, in which case the ERP of the vertically polarized component may be as great as the authorized horizontal component. This means that twice as much actual power may be radiated.

The transmitter power required can be reduced by increasing the gain of the antenna. There is, of course, an economic tradeoff between the cost of a higher gain antenna versus the cost of a larger transmitter and the added primary power costs. For the higher ERPs, it is common to use antennas with up to 12 elements which provide a power gain of about 12.5 (or 6.3 in each polarization).

The long transmission lines associated with the tall towers commonly used are a source of considerable power loss. For example, the efficiency of 2000 ft. of 3-1/8 in. coax is 62.5 percent.

FM transmitters are designed to operate over a range of power outputs so that with a few basic sizes any required power output can be furnished. Popular maximum ratings range from 250 watts to 40 kilowatts. Forty kilowatts is a practical maximum because that is about all a 3-1/8-in. coaxial transmission line will carry and because it is more economical to achieve the maximum of 100-kilowatts ERP with circular polarization by means of sufficient antenna gain.

The authorized power for educational stations is 10 watts. Most exciters are designed with a power output of 10 watts so they can be used as the complete transmitter for educational stations with the addition of an rf harmonic output filter.

RF POWER AMPLIFIER PERFORMANCE REQUIREMENTS

The basic function of the power amplifier is to amplify the power of the exciter output to the authorized transmitter power output level. Most of the overall transmitter performance characteristics are determined by the exciter but a few are established or affected by the power amplifier characteristics.

1. The output at harmonics of the carrier frequency is almost completely a function of the attenuation provided by the output tank circuit and output filters. The limit in decibels is 43 +10 $\log_{10}$ power or 80 dB whichever is less. (This is 73 dB for 1 kw output and 80 dB for 5 kw and higher.)

2. The major source of AM noise usually originates in the last power amplifier stage. The FCC limit is 50 dB below 100 percent modulation.

3. The rf power output control which must keep the output within +5 percent and -10 percent of authorized output is achieved in the final power amplifier.

4. Inadequate bandwidth particularly with respect to phase linearity across the signal bandwidth can reduce stereo separation and cause SCA crosstalk.

Note: The presence of standing waves on the transmission line to the antenna may also react on the power amplifier to cause degraded stereo separation and SCA crosstalk.

The power amplifiers should provide trouble-free service and be easy to maintain and repair. Good overall efficiency is also desirable to keep down the primary power consumption.

POWER AMPLIFIER CIRCUITS

The amplitude of an FM signal remains constant with modulation so that efficient Class B and C amplifiers can be used. Most exciters being manufactured at this writing use transistors to generate the 10 to 20 watts of output power. It is technically feasible to develop transistor amplifiers for any required higher power but they are not yet economically competitive. A great deal of circuitry is involved because it takes the combined output of a great many transistors to produce a few kilowatts of power output. For this reason, the following discussion will relate to vacuum tube amplifier circuits.

FM broadcast power amplifier circuits have evolved to two basic types. One uses tetrode or pentode tubes in a grid driven circuit and the other uses high mu zero bias triodes in cathode driven (grounded grid) circuits.

CATHODE-DRIVEN TRIODE AMPLIFIERS

The high-mu triodes being used in FM amplifiers were originally developed for linear SSB amplifiers. Their characteristics are well adapted to FM broadcast use because the circuit is very simple and no screen or grid bias power supplies are required. Fig. 16 shows one basic circuit configuration. In this case, the grid is connected directly to chassis ground. Dc grid current is the

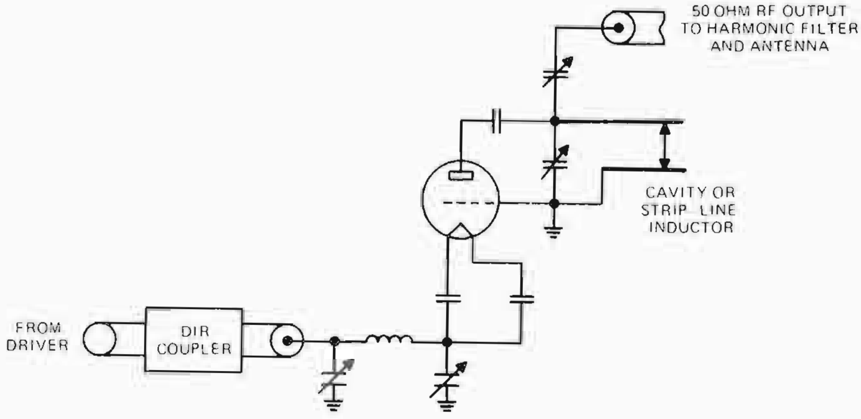


Fig. 16. Cathode-driven triode power amplifier.

difference between dc cathode current and dc plate current. The output tank circuit is a shorted coaxial cavity which is capacitance loaded by the tube output and stray circuit capacitance. A small capacitor is used for trimming the tuning and another small variable capacitor is used for adjusting the loading. A pi-network matches the 50 ohm input to the tube cathode.

These triodes are usually operated in the Class B mode in order to achieve maximum power gain, which is on the order of 20. They could be driven into Class C operation by providing for grid bias. This would increase plate efficiency but at the expense of increased drive power.

Most of the drive power is fed through the tube and appears in the stage output. This increases the apparent efficiency so that the efficiency factor given by the manufacture in conformance to the FCC regulations may be higher than the actual plate efficiency of the tube. For example, assume 10,000 watts of rf power output of which 500 watts was fed through with an assumed plate efficiency of 70 percent for the 9,500 watts generated by the final stage, the final dc plate input is 13.57 kw; the apparent efficiency of $\frac{10.00 \text{ kw}}{13.57 \text{ kw}}$ or 73.7 percent, which would be the legal efficiency factor.

Since most of the drive power is fed through the tube, any changes in loading of the output circuit will affect the operation of the input tuning and driver operation.

There is rf drive voltage on the cathodes (filaments) of cathode driven tubes, so some means must be used to keep it out of the filament transformer. One method employs rf chokes since the inductance can be very low. The other commonly used method feeds the filament power up through the input tank circuit inductor.

Apparently none of the cathode driven amplifiers being marketed require neutralization. The high-mu triodes being used have an advantage of about one order of magnitude regarding the need for neutralization.

It is necessary that the grid-to-ground inductance both internal and external to the tube be kept very low to maintain this advantage, however. Omission of neutralization, of course, will allow a small amount of reaction of the output circuit upon the input circuit through the plate-to-filament capacitance path, but it is not noticeable because of the large coupling between the input and output circuits through the electron stream of the tube.

Cathode driven stages are normally used only for the higher power stages. The first stage in a transmitter is nearly always a tetrode because of its higher power gain.

GRID-DRIVEN TETRODE AND PENTODE AMPLIFIERS

A small tetrode tube such as the 4CX250B or 8122 is commonly used as the only amplifier stage in 250 watt transmitters and in the driver for higher power stages. The largest one-tube transmitter available at this writing uses a 5CX1500A to deliver 2 kw. Higher power outputs require two stages.

Transmitters using tetrode amplifiers throughout usually have one less stage than those using triodes. Since tetrodes have very high power gain, they are driven into Class C operation for higher plate efficiency. Against these advantages is the requirement for screen and bias power supplies.

Fig. 17 shows a schematic of a grid-driven tetrode amplifier. In this example, the screen is operated at dc ground potential and the cathode (filament) is operated below ground by the amount of screen voltage required. This is called grounded-screen operation. It has the advantage that stability problems due to undesired reson-

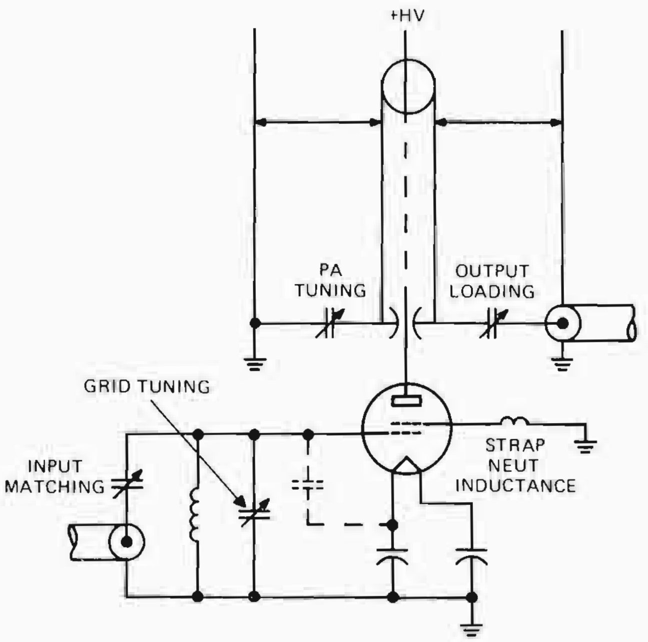


Fig. 17. Grid-driven grounded screen tetrode power amplifiers.

ances in the screen bypassing capacitors are eliminated. With filament type tubes, it is necessary to use filament bypass capacitors anyway; although with grounded-screen operation, they have the dc screen voltage across them. Coaxial cavity input and output circuits are shown. The circulating current is spread over large surfaces so the losses are very low. These cavities are basically shorted transmission line sections which resonate the tube input and output capacitances. Their lengths are preset to the desired carrier frequency and then small variable capacitors are used to trim them into resonance. Capacitive coupling to the 50 ohm output is used for mechanical convenience. The 50 ohm input is tapped onto the grid circuit inductor to provide the correct impedance match.

The grid circuit is usually loaded with added resistance. The purpose is to broaden the bandwidth of the circuit by lowering the circuit Q and to provide a more constant load to the driver. It also makes neutralizing less critical so that the amplifier won't become unstable and oscillate even with the output circuit completely unloaded.

Cathode or filament lead inductance from inside the tube, through the socket and filament capacitors to ground, can heavily load the input circuit. This is caused by rf current flowing from grid to filament through the tube capacitance and then through the filament lead inductance to ground. This produces an rf voltage on the filament which in effect causes the tube to be partly cathode driven. This undesired extra drive power can be minimized by series resonating this path by proper choice of filament bypass capacitors.

The larger high gain tetrodes need accurate neutralization for best stability and performance. This is accomplished very simply by placing a small amount of inductance between the tube screen and ground. This inductance is usually in the form of several short adjustable length straps. The principle involved is that the rf current flowing from plate to screen in the tube also flows through this screen lead inductance. This results in a small voltage on the screen of the opposite phase which capacitively couples to the control grid just enough to neutralize the small amount of plate to grid capacitance present.

INTERSTAGE COUPLING CIRCUITS

Separate driver plate and final grid rf circuits are commonly used and coupled together by a coaxial transmission line. Impedance matching is usually accomplished by one of the means shown in Figs. 18a, 18b, and 18c. In order to keep from having excessive current in the interconnecting transmission line the coupling circuits must be matched to the transmission line impedance. Directional wattmeters are normally placed in the line to measure forward and reflected power from which standing wave ratio can be established. The SWR is established entirely by the match at the load end of the transmission line. At the input end of the line the driver plate output circuit matches the transmission line load to the desired load on the driver tube.

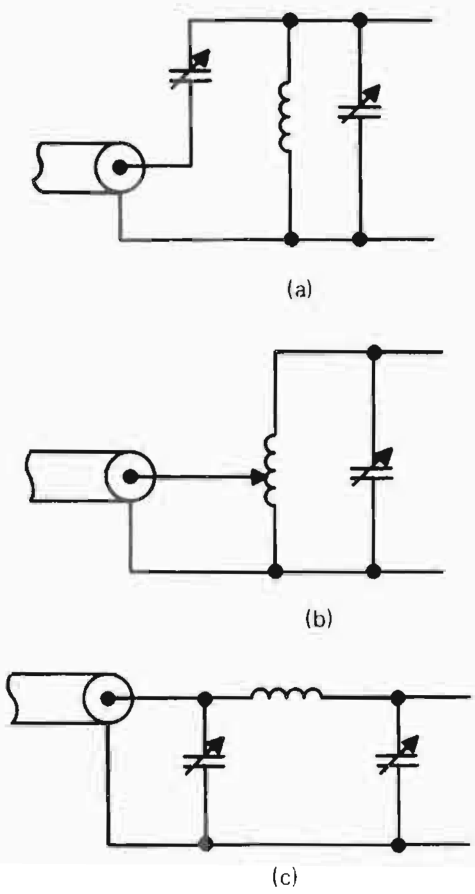


Fig. 18. Interstage rf coupling circuits.

This transmission line matching problem is eliminated in some transmitters by locating the driver tube close to the final tube so that simple coupled circuits can be used. This eliminates the need to go through the intermediate impedance of a transmission line.

OUTPUT COUPLING CIRCUITS

Usually the output circuit consists basically of just a high-Q cavity, strip line, or inductor to resonate the tube output capacitance. To this is added a means of trimming the tuning and a means of adjustable coupling to the output transmission line. The tank circuit loaded Q is kept as low as practical to minimize circuit loss and, also, to keep as wide an rf bandwidth as practical.

The plate tank circuit does not provide enough harmonic attenuation to meet FCC regulations, a harmonic filter is used for this purpose. The FM band is narrow enough that one low pass filter design can be used for any carrier frequency. The filters for low power transmitters may employ lumped elements (coils and capacitors), but filters for high power employ distributed element or transmission line techniques. The art of filter design is very highly developed and this technology is well documented in the microwave literature.

Design theory will not be covered here but it is pointed out that when two filters (such as the output cavity and the harmonic filter) are connected together by a transmission line, the total harmonic attenuation realized will vary with interconnecting line length.[4] The attenuation of separate harmonic filters is specified for the case where the source impedance and load impedance are equal to the transmission line impedance the filter was designed for. Test instruments provide this situation. In actual use, however, the source and load impedances are nowhere near 50 ohms and tend to lie near the outside edge of a Smith chart. If an unfortunate length of line is selected, it can be corrected by changing the line length 2 feet or so. When the filter is designed into the transmitter cabinet, the line length between the tank circuit and harmonic filter is fixed at a value known to be satisfactory by the transmitter manufacturer.

HYBRID COMBINING TWO RF AMPLIFIERS

It has become quite popular at the 20 kw and 40 kw power level to combine the output of two power amplifiers. The important advantage is that the broadcast transmission is not interrupted when one amplifier fails. The radiated signal strength merely drops 6 dB until the failed amplifier is repaired and put back on the air. A dual amplifier costs more than a single amplifier for a given total power output, but there are the economic advantages of reducing lost air time and eliminating the need for a separate standby transmitter. Some stations go one step further and install dual exciters also so that if one exciter fails, the other one can be quickly switched into service.

Fig. 19 shows a block diagram of a pair of combined amplifiers and dual exciters. (The exciters cannot be operated in parallel like the amplifiers because their rf outputs would have to be on exactly the same carrier frequency and almost exactly in phase under all modulation conditions.) The exciter in use feeds a power splitter which transforms one 50 ohm input into two 50 ohm outputs with half power going to each. The exciter must have enough power output capability to drive both power amplifiers, of course. The length of coax from the power splitter to the amplifier inputs must be exactly the same

[4]There is a class of filters called absorptive filters which are independent of the source impedance of harmonic energy.

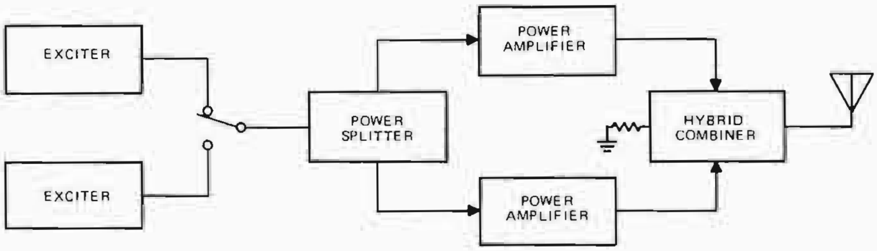


Fig. 19. Block diagram of transmitter with two power amplifiers, a hybrid combiner and dual exciters.

length so that the amplifiers will be fed in phase. The amplifier inputs should properly terminate the input coax in all conditions even when the amplifier is turned off.

The output hybrid combiner effectively isolates the two amplifiers from each other. Tuning adjustments can be made on one amplifier including turning it on and off without appreciably affecting the operation of the other amplifier. The degree of isolation achieved depends mostly upon the SWR on the transmission line to the antenna. Good isolation is necessary so that when one transmitter fails, the other will continue to operate normally instead of in a mistuned condition. This really does not place an added burden on the antenna system because it is desirable to keep the SWR down to 1.1 to 1 to maintain good stereo separation and low SCA crosstalk anyway.

Hybrid combiners are basically 4-port devices. Two of the ports are the two 50 ohm inputs, the sum port is the 50 ohm antenna output terminal, and the difference port goes to a dummy load. When the power fed to each of the two inputs is equal and in phase, the total power is delivered to the sum port (antenna). This holds true even if there are standing waves on the antenna coax. The input ports will present a load to the transmitters with the same SWR as on the antenna coax. If, however, the two inputs from the separate amplifiers are not equal in amplitude or exactly in phase, there will be some power dissipated in the difference port dummy load. The match in input power and phase is not at all critical as shown in Fig. 20, and the power lost in the difference port load can be easily reduced to a negligible value by touching up the amplifier tuning.

When one transmitter fails, the result is that half of the working amplifier output goes to the antenna and the other half is dissipated in the difference port load. This is why the radiated output drops to one-fourth power or by the 6 dB mentioned earlier.

For perfect amplifier isolation, the load impedance on the sum and difference ports must be exactly the same. This is approached in practice by providing a 1.0 to 1 SWR termination on the difference port and then getting the SWR on the antenna feed coax as low as possible by means of trimming the antenna match. This keeps the input port impedances from changing too much when one amplifier fails or is off for any reason.

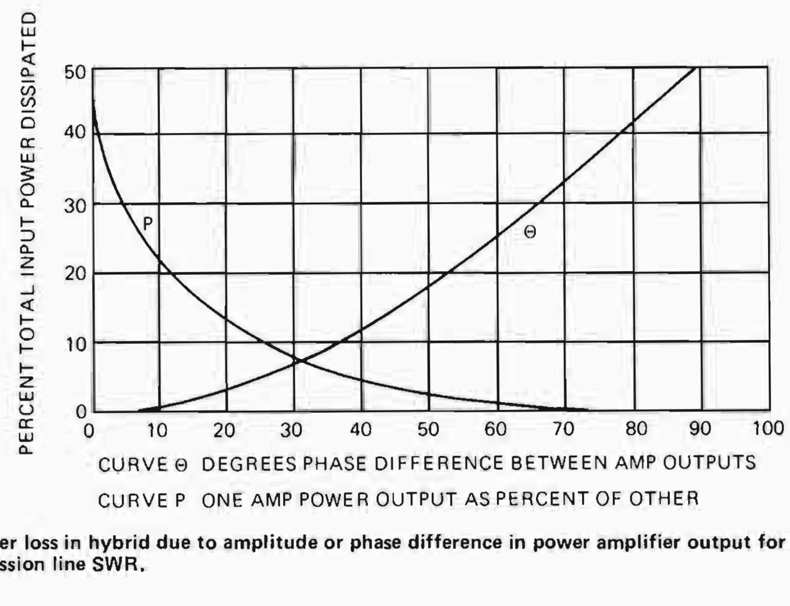


Fig. 20. Power loss in hybrid due to amplitude or phase difference in power amplifier output for the case of 1.0 to 1 antenna transmission line SWR.

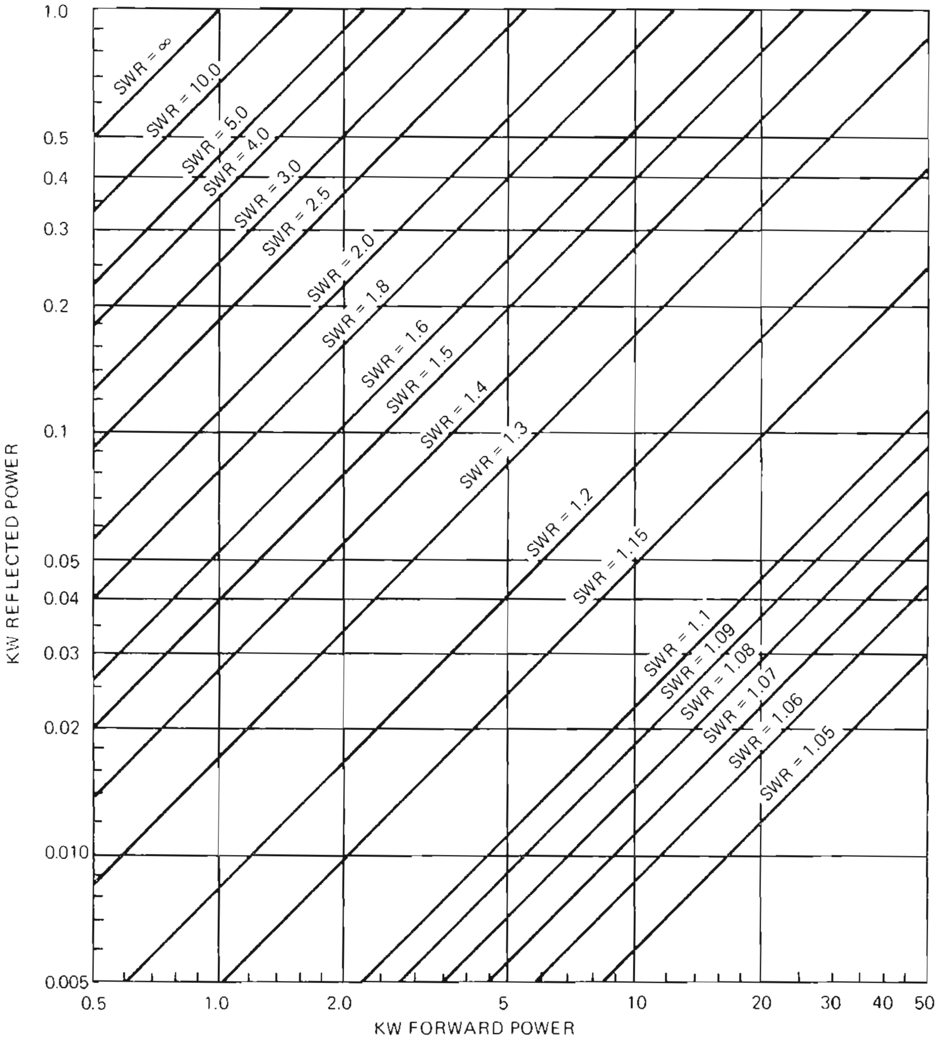


Fig. 21. Chart of SWR versus forward and reflected power.

DIRECTIONAL WATTMETERS

Directional wattmeters are instruments that measure the forward P_F and reflected P_R power in a transmission line. The net power delivered to the load (antenna) is $P_F - P_R$. The standing wave ratio (SWR) on the transmission line can be computed with the following formula.

$$\text{SWR} = \frac{1 + \sqrt{\frac{P_R}{P_F}}}{1 - \sqrt{\frac{P_R}{P_F}}}$$

This relationship is shown graphically in Fig. 21 so the SWR can be obtained without computation.[5]

[5] W. B. Bruene, "An Inside Picture of Directional Wattmeters," April 1959, QST.
Bird Electronic Corporation Catalog.

The standing wave is due to the presence of two components of power, one traveling toward the load and the other, having been reflected by the load mismatch, traveling back toward the generator.

$$P_F = \frac{E_F^2}{Z_o} = I_F^2 Z_o$$

$$P_R = \frac{E_{F_R}^2}{Z_o} = I_F^2 Z_o$$

$$P = P_F - P_R$$

The subscripts F and R are used to denote forward and reflected and Z_o is the characteristic impedance of the transmission line. P is the net power absorbed by the load (transmission line loss and antenna radiation).

Since the forward and reflected voltage and currents are traveling in opposite directions, they

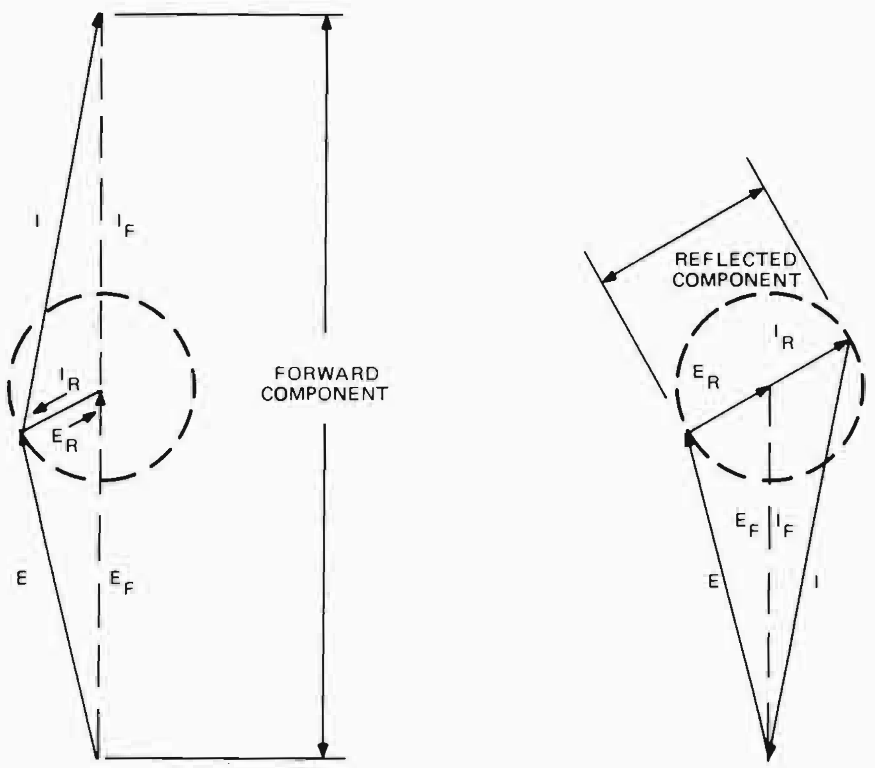


Fig. 22. Phasor addition of voltage and current samples to separate forward and reflected components.

will add in phase at some point along a line of sufficient length to produce a voltage maximum. One-quarter wave length along the line in either direction the forward and reflected components are out of phase and produce a voltage minimum. The forward and reflected components of current, also, add to produce a current standing wave. The magnitude of the standing wave is defined as:

$$SWR = \frac{E_{max}}{E_{min}} = \frac{I_{max}}{I_{min}}.$$

At the point of reflection (for example, the load mismatch), the phase of the reflected current is reversed 180° from the forward current. The reflected voltage does not have this phase reversal. This displaces the voltage and current standing waves by 90° along the line so that the E_{max} and I_{min} occur at the same points and E_{min} and I_{max} 90° away.

The fact that the reflected current is reversed in phase makes it possible to measure forward and reflected power separately. A small voltage is obtained (usually by inductive coupling) which represents the current in the transmission line. To this is added a sample of the voltage across the line. The samples are adjusted to be exactly equal when the line is terminated with its characteristic impedance (that is, no standing waves and, hence, no reflected components). These two rf samples are added, which gives an rf voltage proportional to the forward components of voltage and current as illustrated in Fig. 22. The forward components of the samples are equal and in phase but the reflected components of voltage and current balance out. By reversing the phase of the current sample, the reflected components add while the forward components balance out. These voltages representing the forward or reflected voltage and current are usually rectified to feed a meter. The meter scale is calibrated to read the square of its input so that P_F of P_R are read out directly.

The SWR on an FM antenna transmission line must be kept down to the order of 1.1 to 1 for good stereo performance. It takes very little reflected power to produce substantial SWR as shown in Fig. 23. For this reason the reflected power is usually read on a more sensitive meter position. Troubles in the antenna system such as loose connections or icing may cause excessive SWR. Instruments[6] are available that monitor reflected power and energize an alarm if it becomes excessive. As long as the transmitter power output is fairly constant, the use of reflected power to indicate excessive SWR is simple and adequate.

[6]Watcher RF Power Monitor/Alarm, Bird Electronic Corporation.

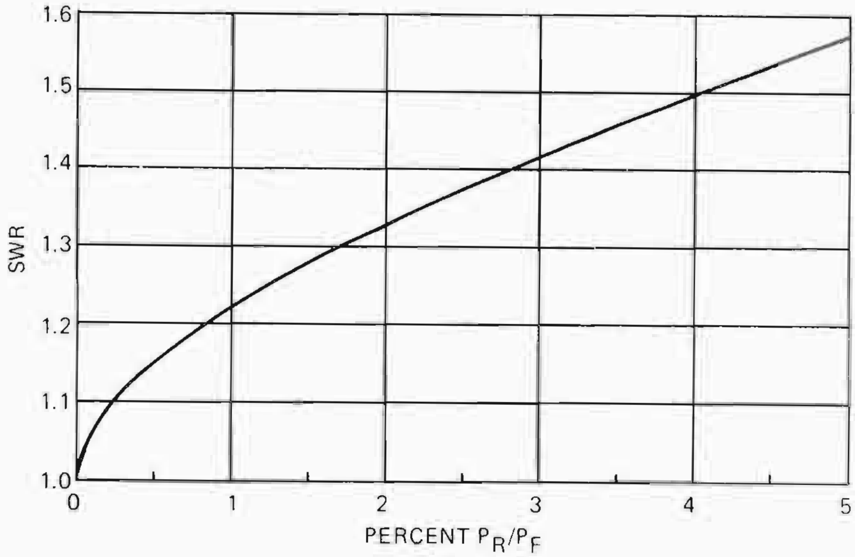


Fig. 23. Relationship of SWR to ratio of reflected power to forward power.

TRANSMITTER DESCRIPTIONS

Brief descriptions and photographs of several FM broadcast transmitters are shown to show the general appearance of the equipment and the basic circuits employed. The basic circuits and principles have been discussed in a general way in previous discussion. Since the FCC requires type approval, it can be expected that all satisfy FCC requirements. No attempt will be made to compare equipment specifications or to evaluate the features offered by the various manufacturers. The reader is cautioned that the transmitters and exciters described in this section may be superseded by newer models at any time. The manufacturers should be contacted directly for more complete information on their latest models.

Figs. 24 and 25 are photographs of the AEL FM-3KB 3-kw transmitter and Model 2202 FM exciter manufactured by American Electronic Laboratories, Inc. Fig. 26 shows block diagrams of the exciter and the Model 2203 Stereo Generator. The exciter uses direct FM of an oscillator operating on carrier frequency. They also manufacture a solid state SCA Generator Model 2204. AEL manufactures seven transmitter models which are rated to cover all power output levels from 250 watts to 40 kw. Some use tetrode and others use zero bias triode final amplifiers. Representative block diagrams are shown in Fig. 27 and Fig. 28.

Fig. 29 is a photograph of Bauer Model 603 3 & 5 kw FM Broadcast Transmitter with the front door open and Fig. 30 shows a view of the Model 660 FM Exciter manufactured by Bauer Communication Products Division of Granger Associates. Fig. 31 shows block diagrams of the FM exciter and of the stereo generator. The exciter

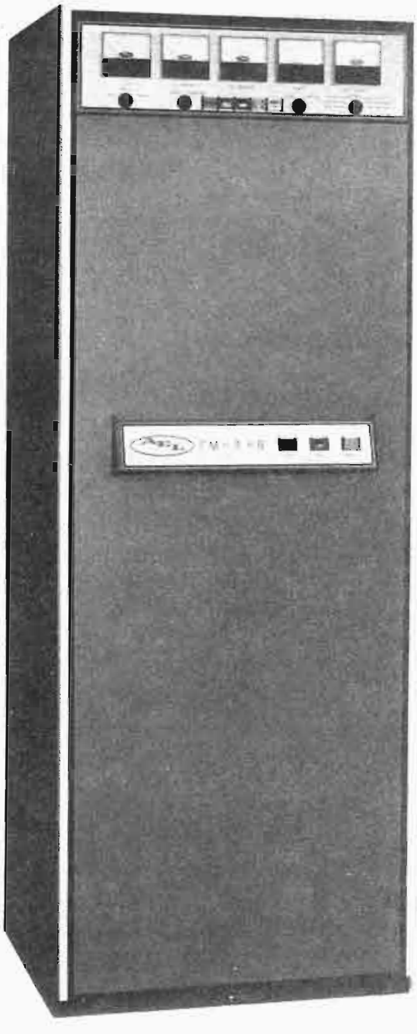


Fig. 24. American Electronic Laboratories Model FM-3KB 3-kw Transmitter.

Fig. 25. American Electronic Laboratories Model 2202 FM Exciter.

consists of a power supply which is built into the chassis plus three to five modules; the standard rf amplifier and exciter modules, a choice of monaural or stereo generator and two optional SCA generators. Direct FM is used with the oscillator operating at carrier frequency. The reference crystal oscillator operates at 2^{-10} or $\frac{1}{1024}$ of the carrier frequency. The FM oscillator and crystal oscillator frequencies divide down to a common

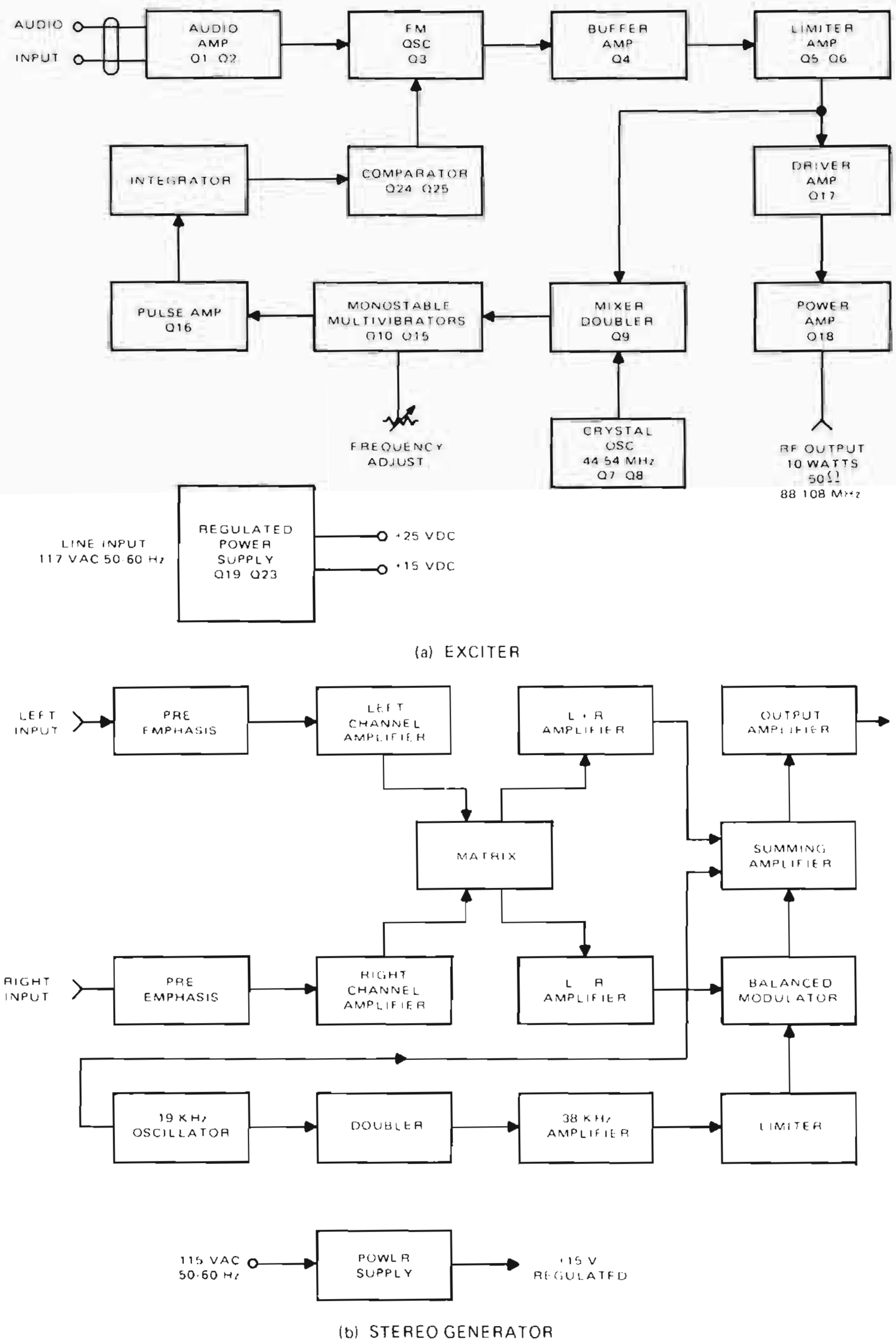


Fig. 26. Block diagrams of AEL Model 2202 Exciter and Model 2203 Stereo Generator.

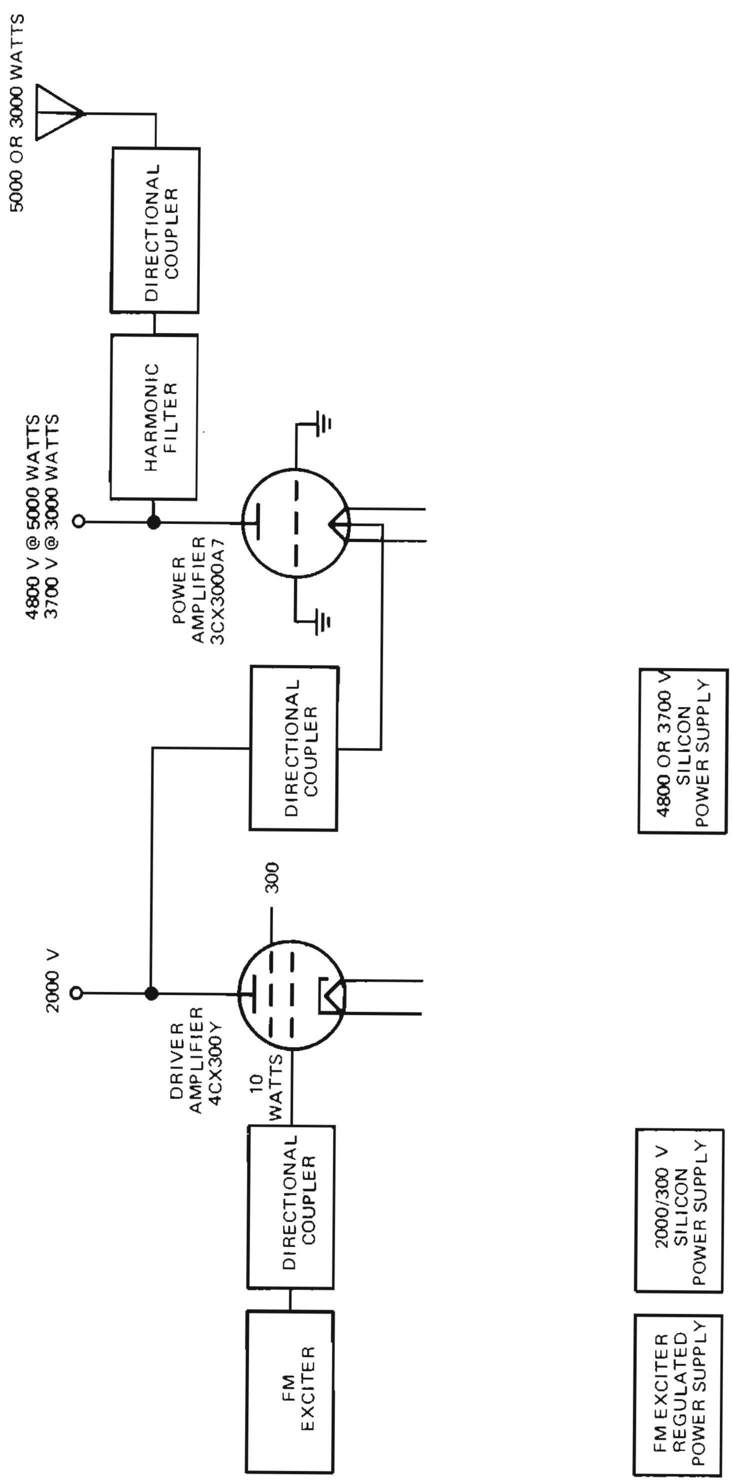


Fig. 27. Block diagram of AEL 3-kw and 5-kw transmitter.

frequency in the 5.4 to 6.6 kHz range for phase comparison and AFC control. The stereo generator uses the 38-kHz switching method of stereo signal generation.

The photograph in Fig. 32 shows the appearance of CCA 5, 10, and 20 kw transmitters manufactured by CCA Electronics Corporation. They also manufacture transmitters for the 10 watt, 250 watt, 1 kw, and 3 kw power levels. The CCA employs high-mu zero bias triodes in the final amplifier of all transmitters from 1 kw to 20 kw. A single tetrode tube provides the gain

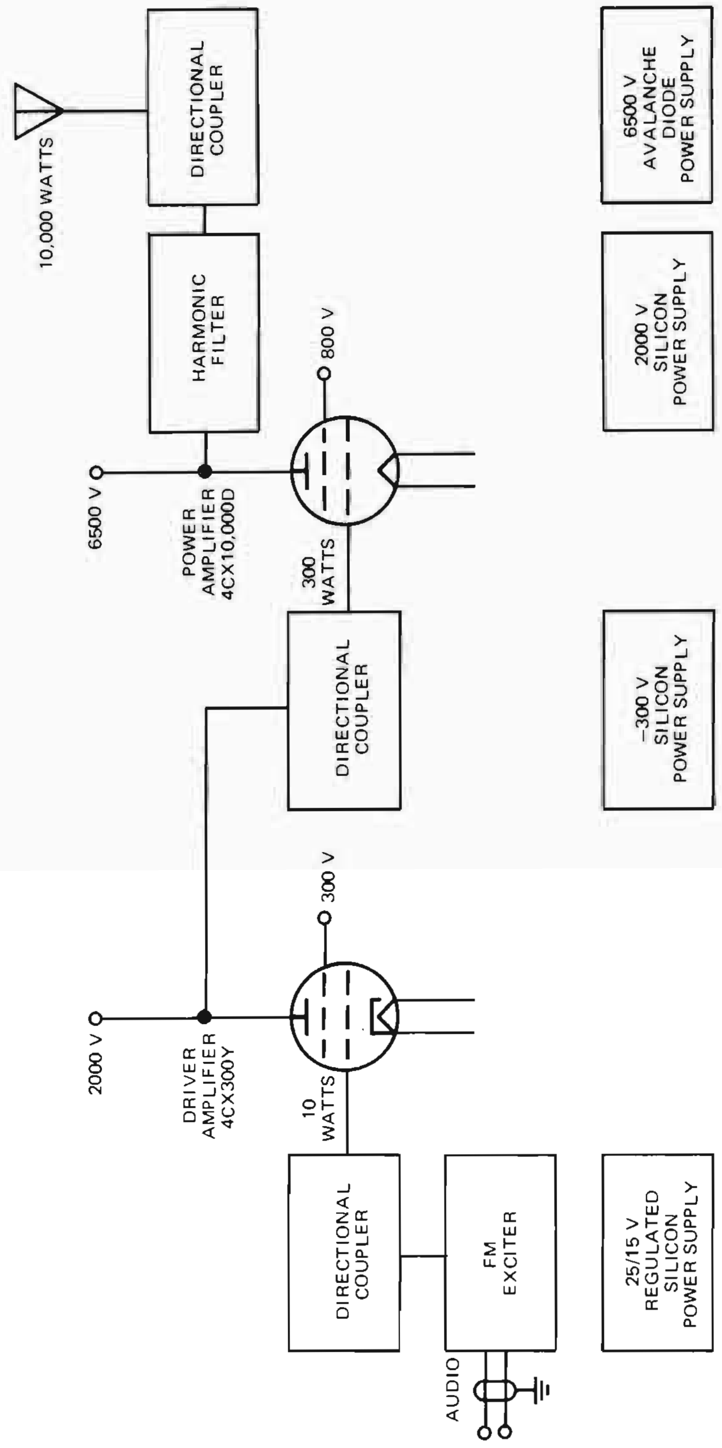


Fig. 28. Block diagram of AEL 10-kw transmitter.

necessary to drive the triode final amplifier stage in all but the 20 kw transmitter where two tetrode stages are employed. The CCA transmitters are available with either of two models of exciters. One employs phase modulation and is suitable for mono FM and SCA transmission. The other employs direct FM modulation and is required for stereo transmission.

Collins Radio Company 5, 10, and 20 kw transmitters are shown in Fig. 33. These models all employ a tetrode final amplifier and a tetrode driver stage. The rf circuitry is simplified by locating the driver stage so a common network is used to couple the driver plate to the final amplifier grid as shown in Fig. 34. An automatic rf power output control is incorporated which

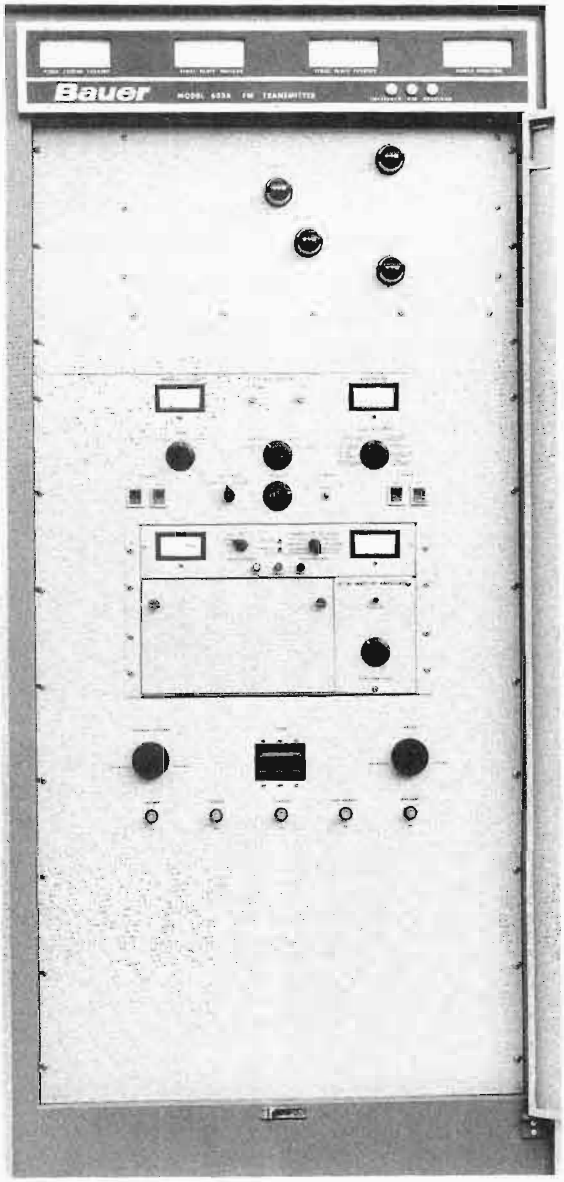


Fig. 29. Bauer Model 603 3- and 5-kw transmitter with front door open.

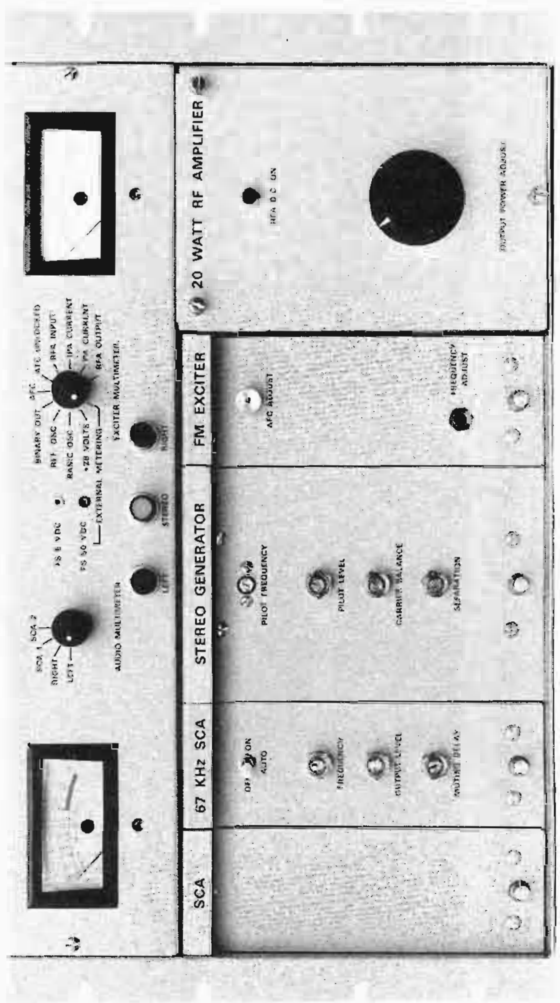


Fig. 30. Bauer Model 660 FM Exciter.

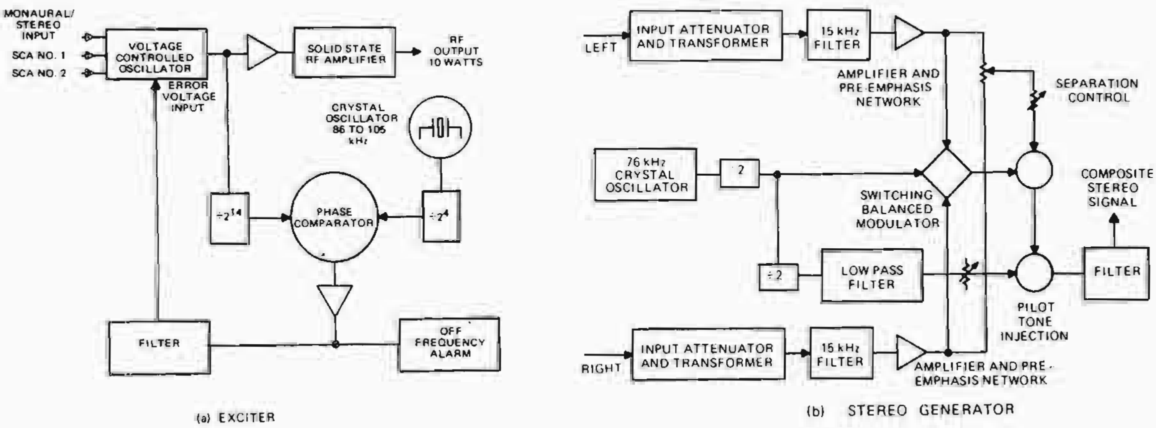


Fig. 31. Block diagrams of Bauer Model 660 FM Exciter and Stereo Generator.

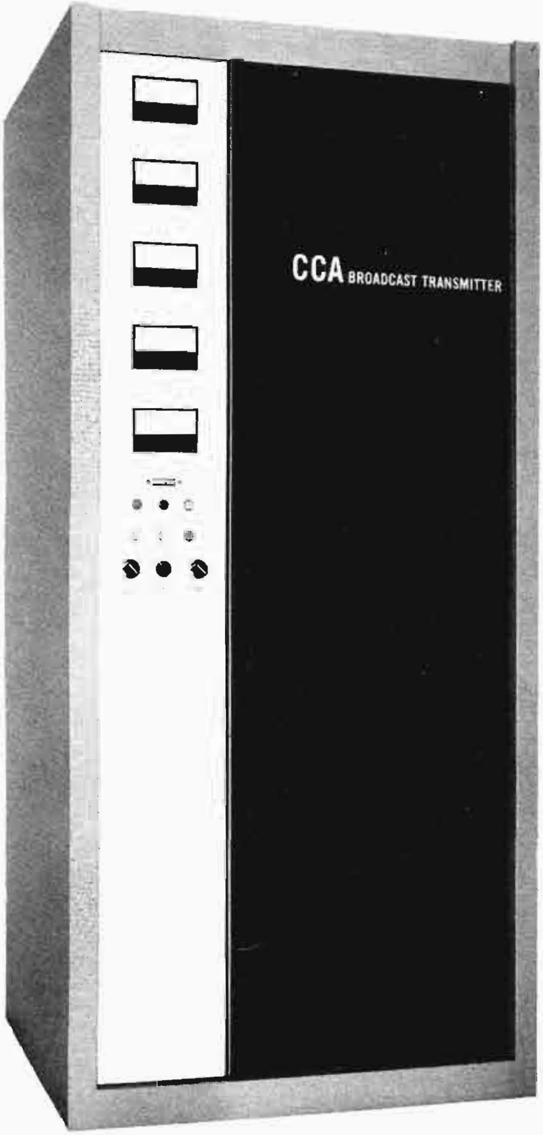


Fig. 32. View of CCA Electronics Corporation 5-, 10-, and 20-kw transmitters.

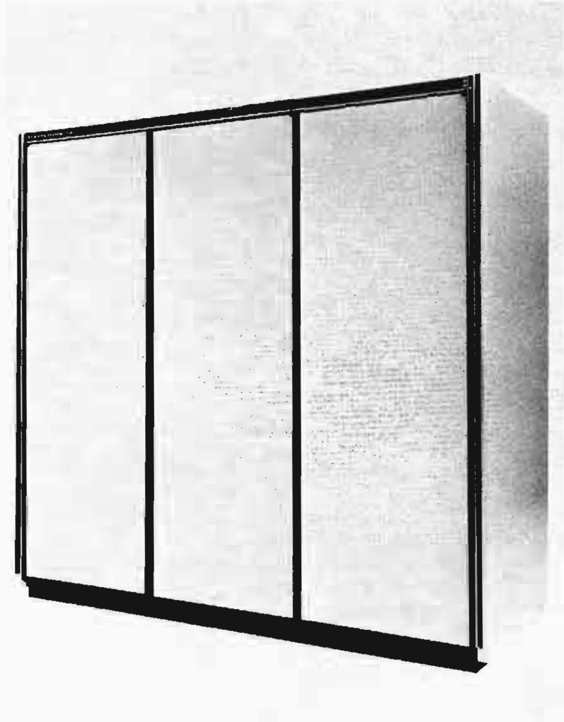


Fig. 33. Photograph of Collins, 5-, 10-, and 20-kw transmitters.

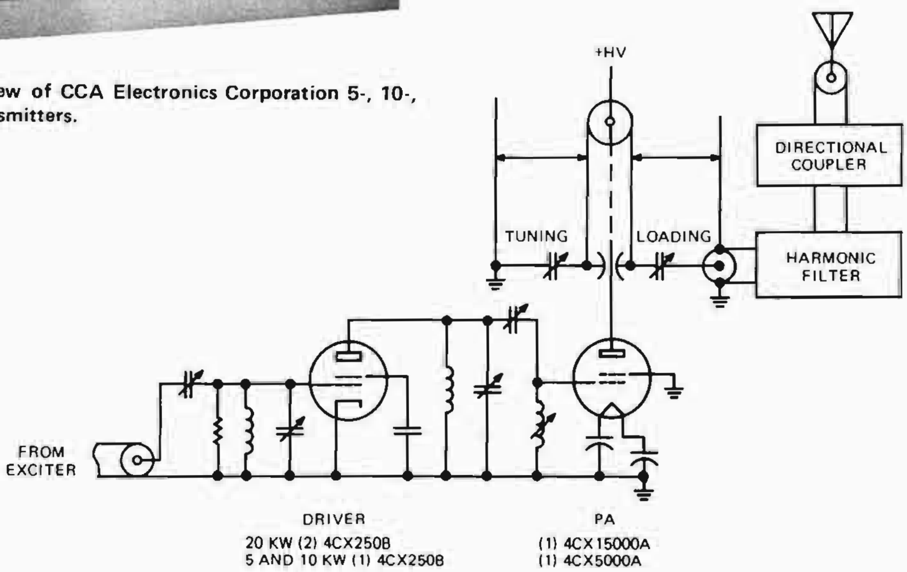


Fig. 34. Circuit diagram of Collins 5-, 10-, and 20-kw power amplifiers.

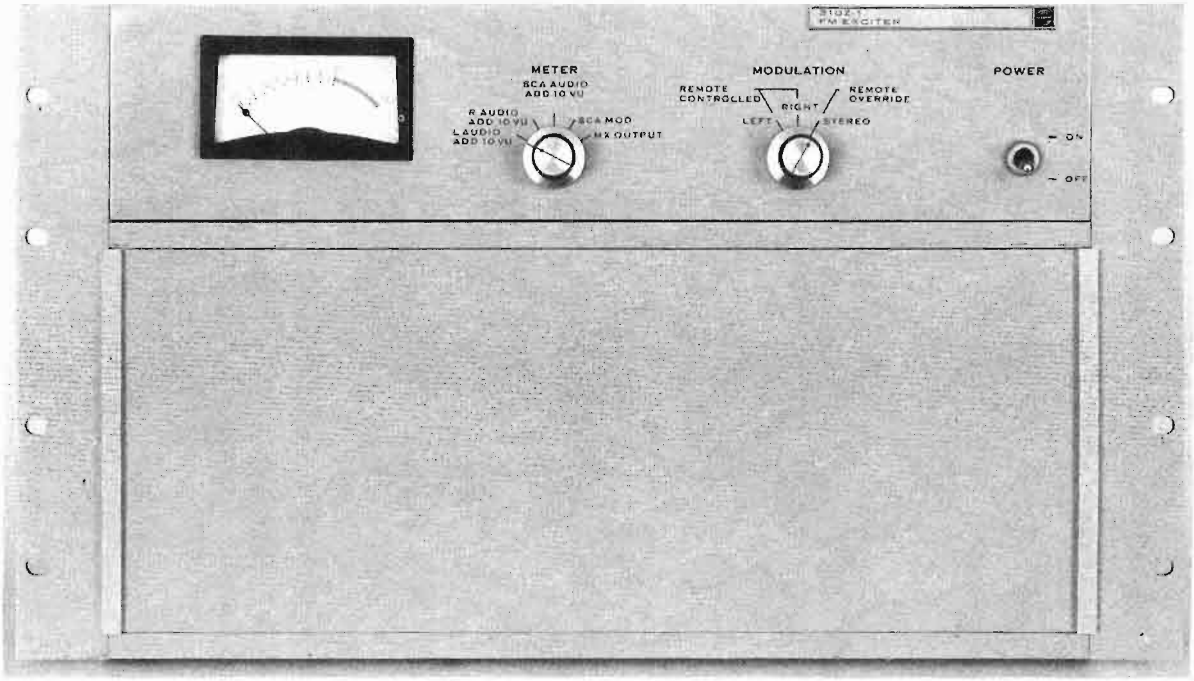


Fig. 35. Collins Model 310Z-1 Exciter.

keeps the output constant through wide variations in primary line voltage. Collins also manufactures transmitters for the 250 watt, 1 kw, and 2 kw power levels. The Collins exciter shown in Fig. 35 employs direct FM of an oscillator operating at 14 MHz. This is converted up to the desired carrier frequency as shown in Fig. 36. The AFC circuit uses a frequency comparison technique where the modulated oscillator frequency and the reference 14 MHz crystal oscillator are alternately sampled at about a 5 Hz rate. Most of the exciter circuitry is contained in six plug-in cards, each containing a major circuit function. The stereo generator employs the switching matrix method of stereo signal generation. The stereo generator and SCA generator are optional units which may be plugged into the main exciter at any time.

The Gates FM-20H transmitter and TE-1 exciter, shown in Fig. 37 and Fig. 38, are manufactured by Gates Radio Company, a subsidiary of Harris Intertype Corporation. Gates manufactures transmitters for all power requirements. The Gates exciter employs modular construction as shown in the photograph. The basic exciter is prewired to accept the SCA and Stereo units without modification. An overall block diagram of the exciter is shown in Fig. 39. Direct FM is employed. Two SCA units can be installed

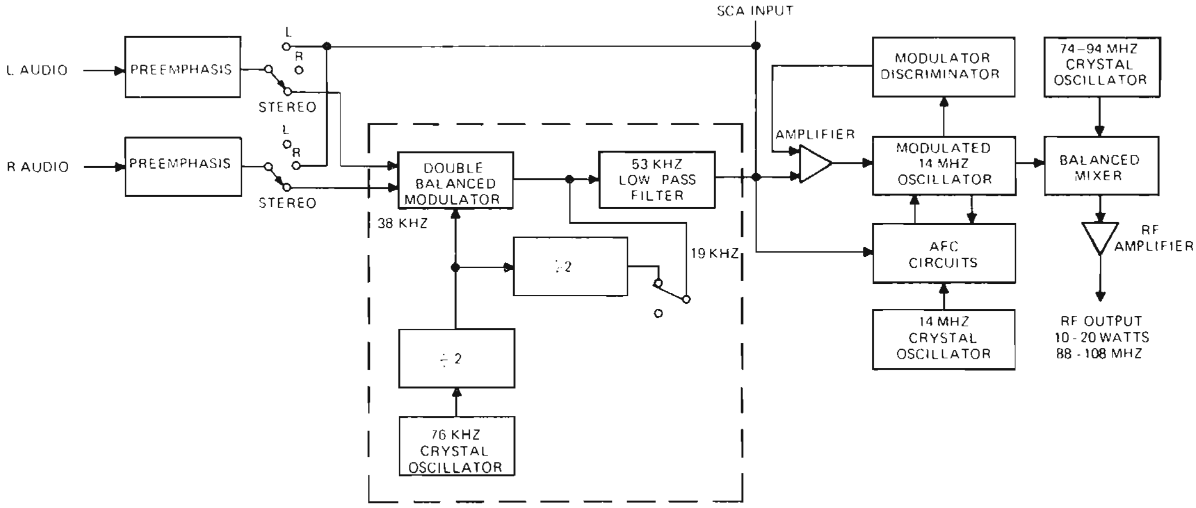


Fig. 36. Block diagram of Collins 310Z-1 Exciter.

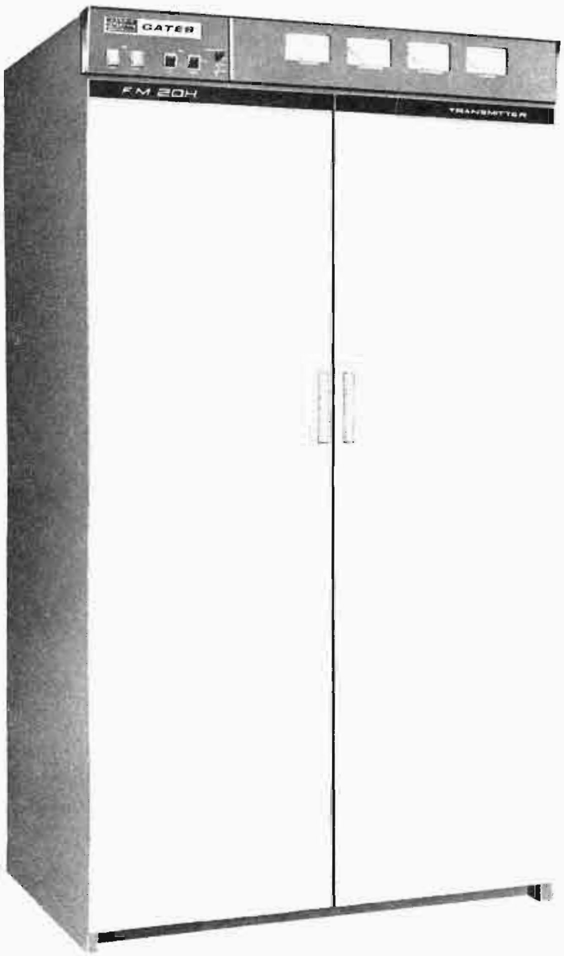


Fig. 37. Gates FM-20H Transmitter.

in addition to the stereo unit. The 41 kHz SCA unit, if installed, is automatically disabled when stereo operation is desired. More detail of the SCA generator is shown in Fig. 40. Two oscillators are used, one operating at 900 kHz and the other operating at either 941 or 967 kHz. They are modulated in opposite directions and their outputs are mixed to obtain the difference frequency. The stereo generator block diagram is shown in Fig. 41.

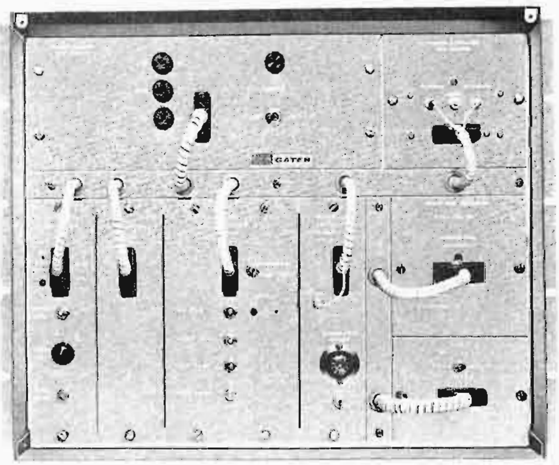


Fig. 38. Gates TE-1 Exciter.

The stereo matrix is in the main exciter so the stereo generator receives the L+R and L-R audio inputs and generates the composite stereo signal including insertion of the pilot carrier. The AFC operation is shown in Fig. 42. The output of the crystal oscillator is tripled to produce an output 200 kHz lower than carrirer frequency. This is mixed with the modulated oscillator output frequency to obtain the 200 kHz output which is processed and applied to a pulse counting type circuit to produce a ±dc voltage to control the center frequency of the modulated oscillator.

A photograph of the RCA BTF-40E 40-kw FM Transmitter is shown in Fig. 43. The output of a pair of 20 kw amplifiers is combined to produce the 40 kw. RCA also produces lower power transmitters. The BTE-15A FM Exciter is shown in Fig. 44. Block diagrams of the exciter and BTS-1B stereo generator are shown in Fig. 45 and Fig. 46. The reference crystal oscillator operates at 2^{-10} or $\frac{1}{1024}$ of the carrier frequency. Both are divided down to a common frequency in the 6 kHz region where they are compared with a phase detector. The phase detector output provides the AFC control voltage to keep the modulated oscillator on frequency. The stereo generator employs the switching type matrix for generating the composite stereo signal.

An interior view common to the Visual 10, 15, and 20 kw transmitters manufactured by Visual Electronics Corporation is shown in Fig. 47. The block diagram for these transmitters is shown in Fig. 48. Visual manufactures various models to cover any power requirement. They obtain 40 kw by combining the output of two 20 kw transmitters. All transmitters use zero bias triodes in grounded grid operation except for the 250 watt transmitter. The 1 kw model and the 3/5 kw models employ a tetrode driving a triode final power amplifier. The 5/7.5/10 kw model and 10/15/20 kw basic models employ a tetrode and two grounded-grid zero bias triode stages as shown in Fig. 48. The Visual direct FM exciter and block diagram is shown in Fig. 49 and Fig. 50. The frequency modulated oscillator operates on 21.5 MHz that is heterodyned up to the desired carrier frequency. For AFC control the output of the modulated oscillator is converted down to 400 kHz where a counter detector is employed to generate the AFC voltage.

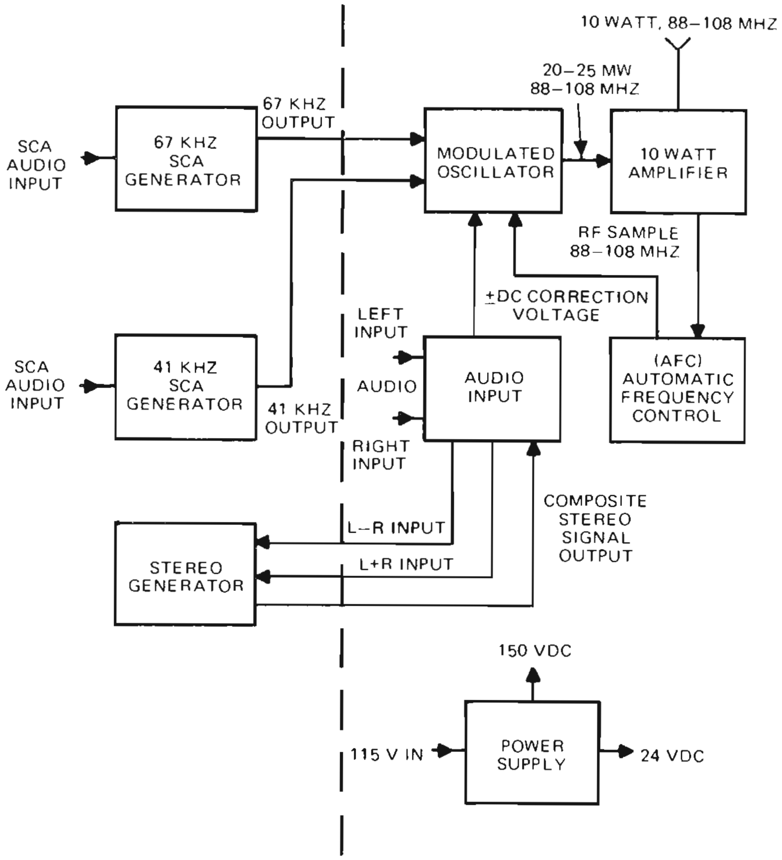


Fig. 39. Block diagram of Gates TE-1 Exciter.

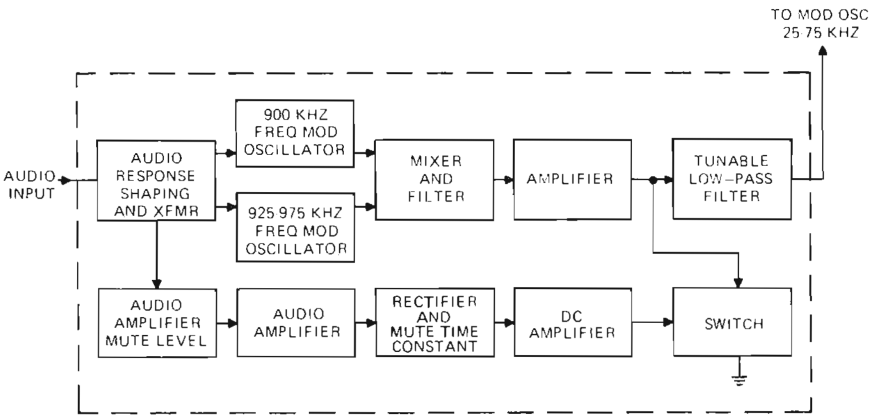


Fig. 40. Block diagram of Gates SCA generator circuit.

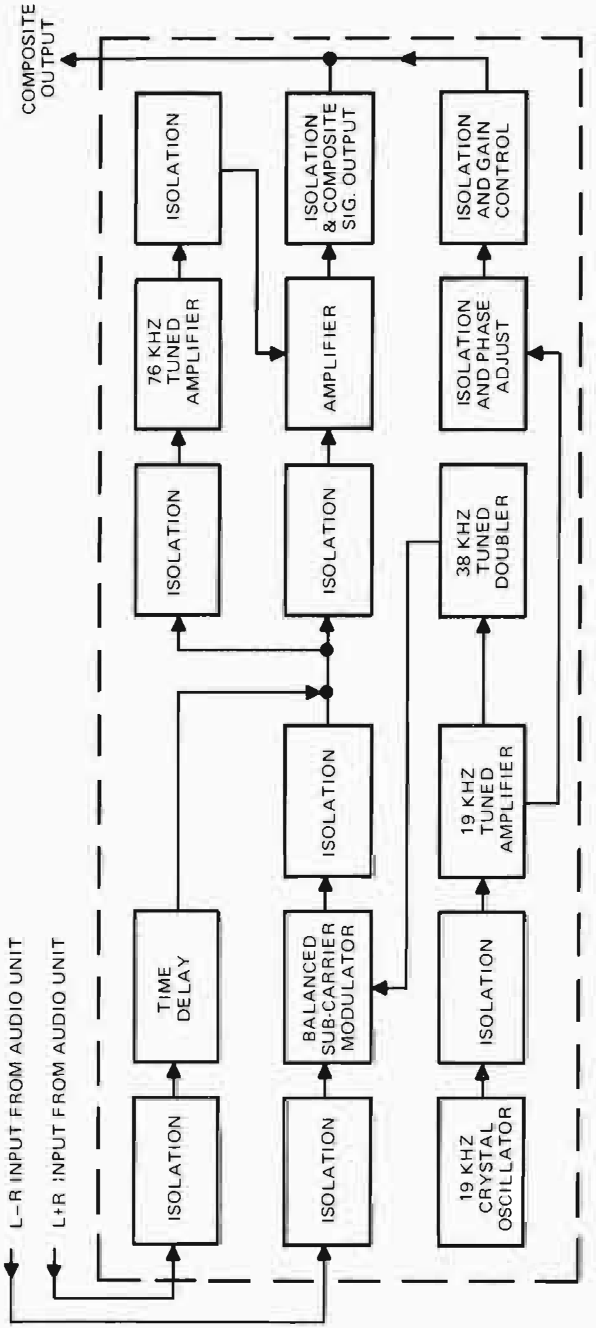


Fig. 41. Block diagram of Gates Stereo generator circuit.

PERFORMANCE MEASUREMENTS

Measurements required to insure high quality transmissions from an FM station fall into three general categories. These are:

a. Routine operational measurements required in the day-by-day operation of the station.

b. Proof-of-performance measurements required at least once each year and prior to application for license renewal;

c. Maintenance measurements.

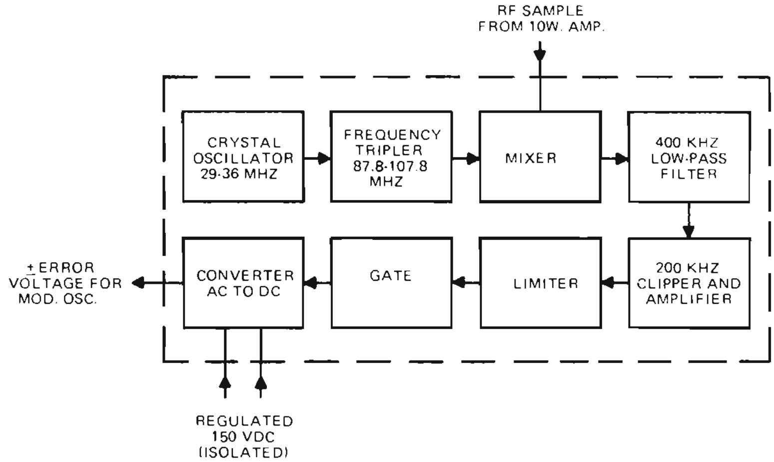


Fig. 42. Block diagram of Gates AFC circuit.

Routine Operational Measurements

Certain parameters are considered by the FCC to be important enough to justify almost continuous observation. Especially important are the modulation level, carrier frequency, and output power level. The latter two parameters, among others discussed below, must be logged at least once every 30 min.

The measurement of percentage modulation must be accomplished with a modulation monitor which has been type-approved for the applicable modulation mode or modes employed. At this writing much interest and concern has developed throughout the broadcasting industry as to the best method for the determination of modulation percentage for complex program material. The ability of meter movements to follow short-

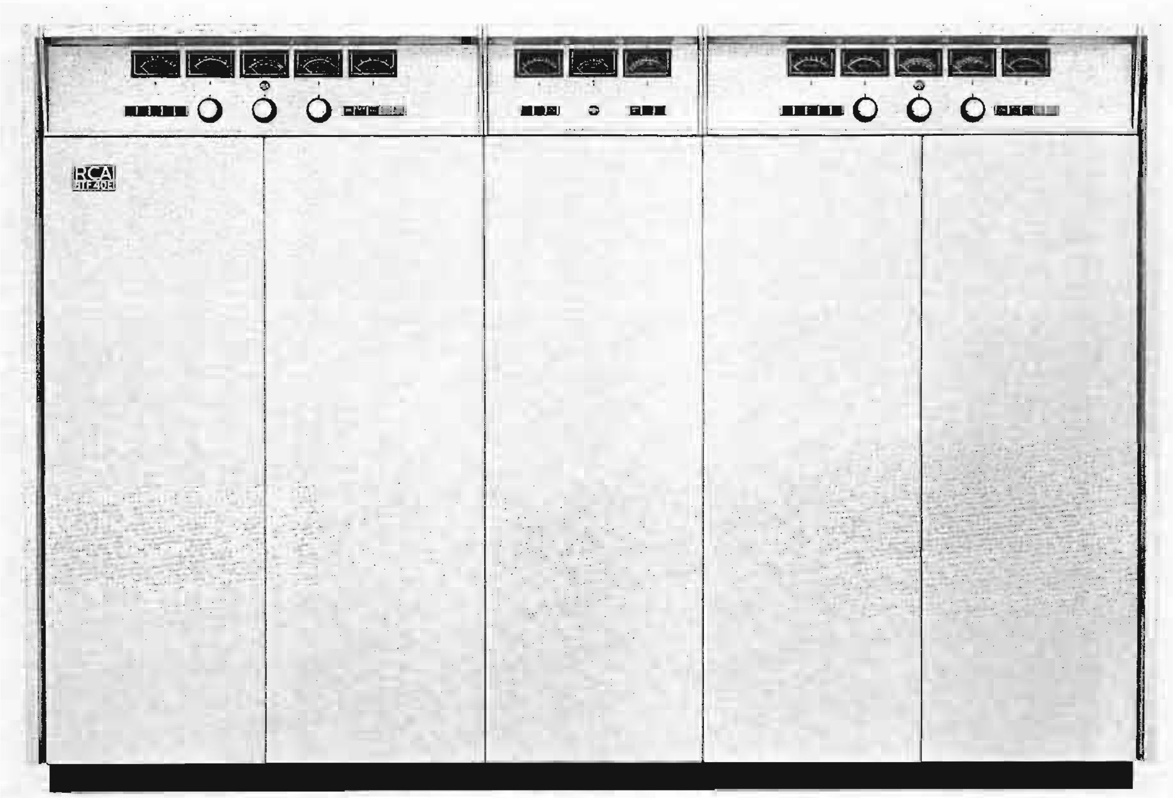


Fig. 43. RCA BTF-40E 40-kw transmitter.

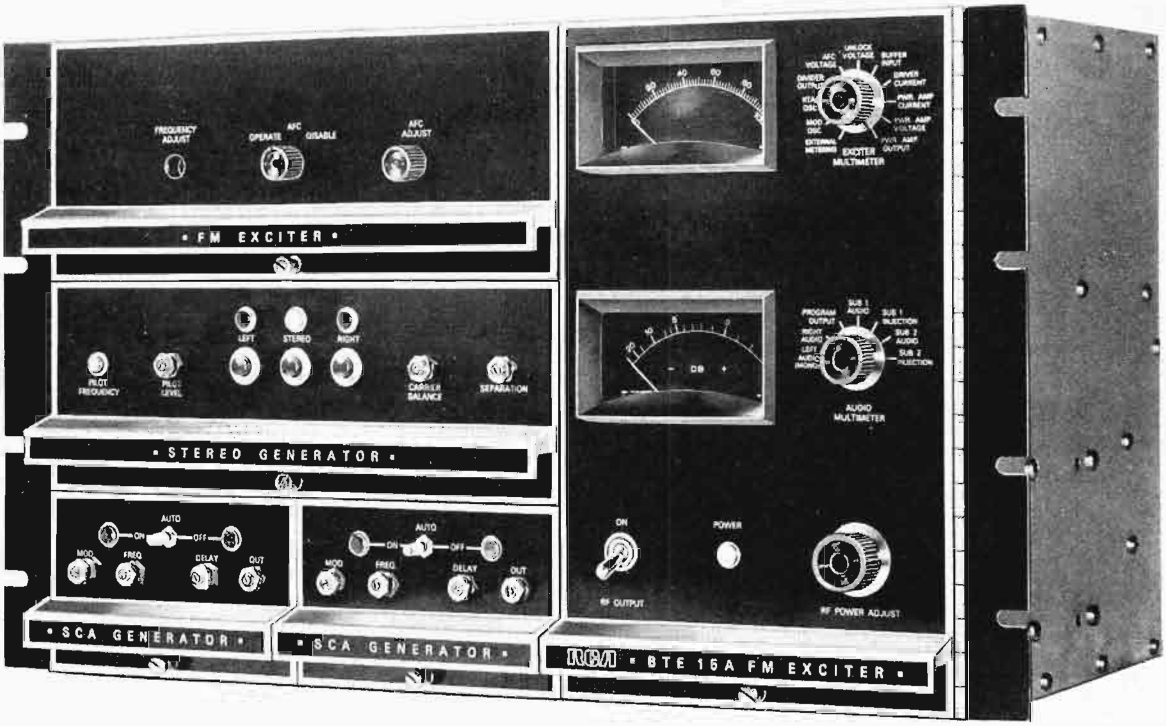


Fig. 44. RCA BTE-15A FM exciter.

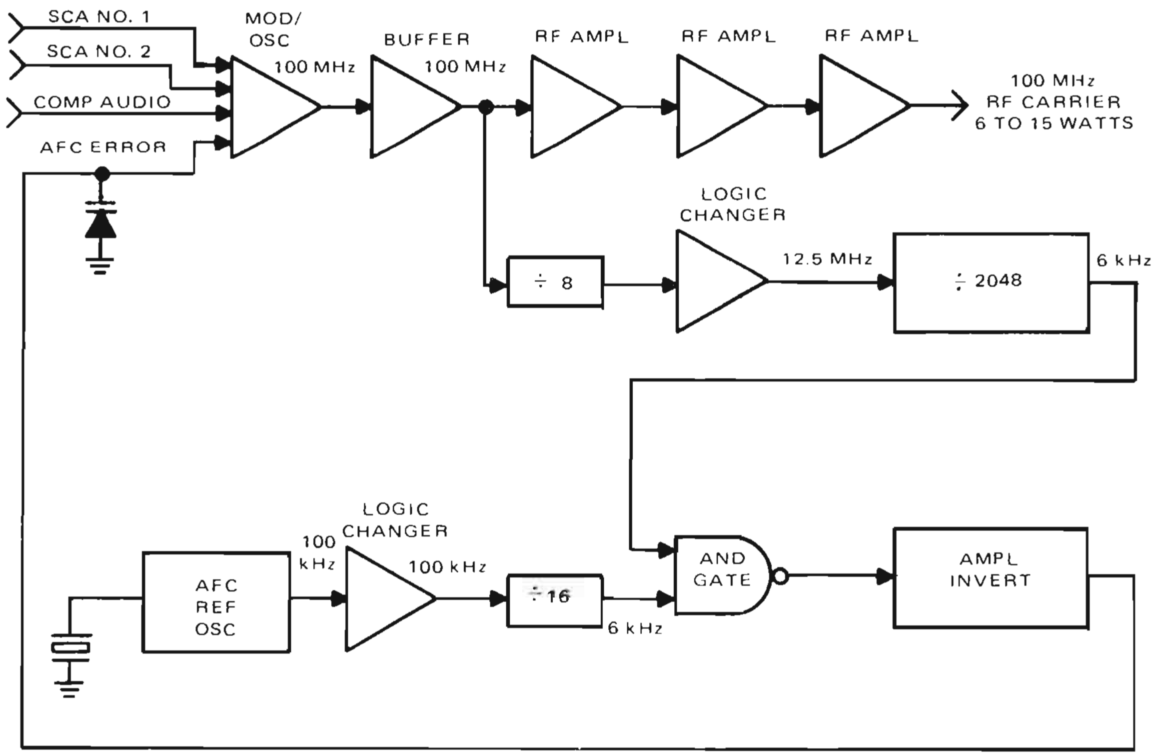


Fig. 45. Block diagram of RCA BTE-15A FM exciter.

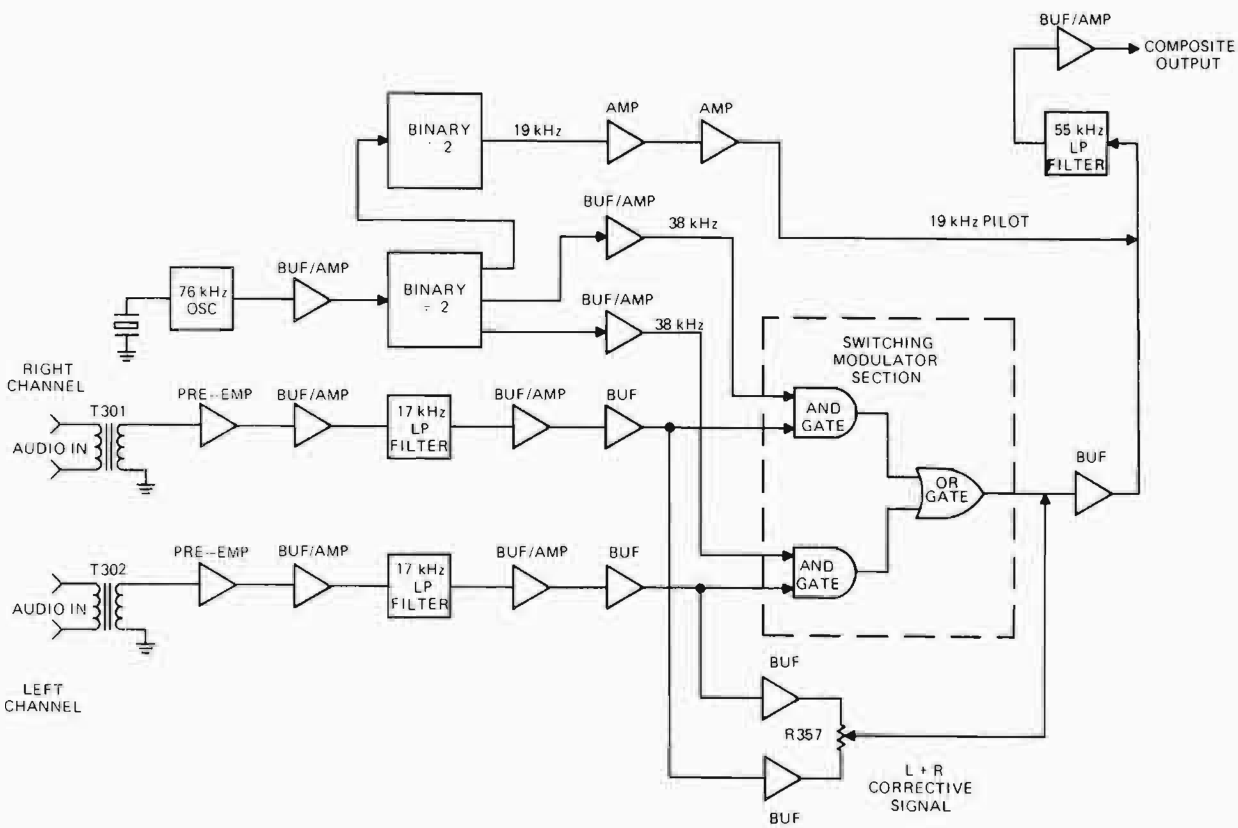


Fig. 46. Block diagram of RCA BTS-1B stereo generator.

duration, nonrepetitive peaks accurately has received special attention. The results of various tests have generally shown that meter movements

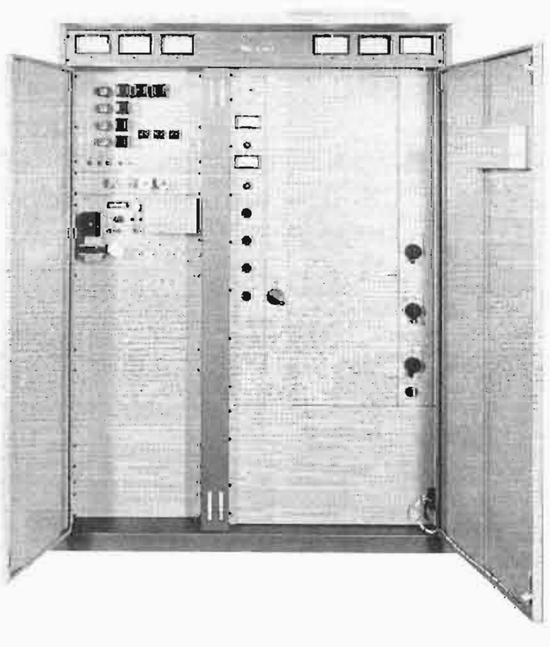


Fig. 47. Photograph of Visual Electronics Corporation, 5-, 10-, and 20-kw transmitters.

cannot follow modulation peaks with the required accuracy.

For this reason, modulation monitors are required to have, in addition to the meter, a peak-indicating device, such as a flashing light which can be preset to flash for modulating levels between 50 percent and 120 percent. This device must be used instead of the meter to determine overmodulation conditions in the transmitter.

Average carrier frequency must be measured with a type-approved frequency monitor. These monitors fall into two categories, analog and digital. The trend is toward the digital meter because of its inherent accuracy and ease of use.

The methods for determining rf output power are specified in Paragraph 73.267 of the FCC Rules and Regulations, which are reproduced in the section entitled FCC Transmission Standards. An accurately calibrated directional wattmeter provides an excellent means of making a direct measurement of rf output power. This method of operation is explained in the Directional Wattmeter section. The directional wattmeter is seldom used as the primary rf power determining method because of the requirement for recalibrating every six months. Use of the indirect method avoids this requirement. If the equipment contains a directional wattmeter, it should be used as

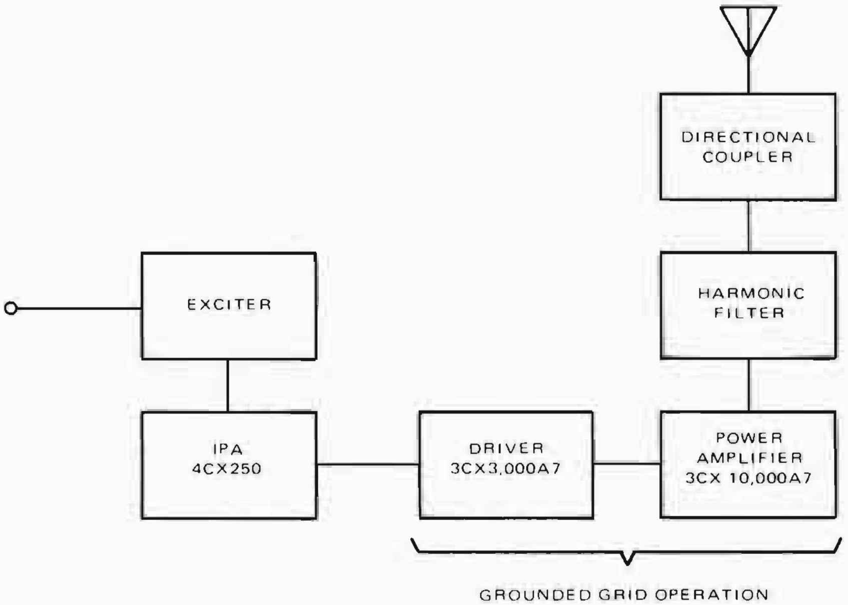


Fig. 48. Block diagram of Visual DFM-20K-B 20-kw transmitter.

a check to assure that rf output is now low, which could be caused by incorrect tuning, changing antenna conditions or a weak tube.

In the indirect method, output power is calculated from a measurement of input power multiplied by the efficiency factor of the final amplifier stage. The efficiency factor is provided by the transmitter manufacturer and must be applicable to the particular frequency and power level in use. The power input to the final amplifier stage is the product of plate voltage and plate current. These latter two parameters are read from meters provided as parts of the transmitter.

All FM stations must log certain transmitter parameters at least once every 30 min. Required entries are:

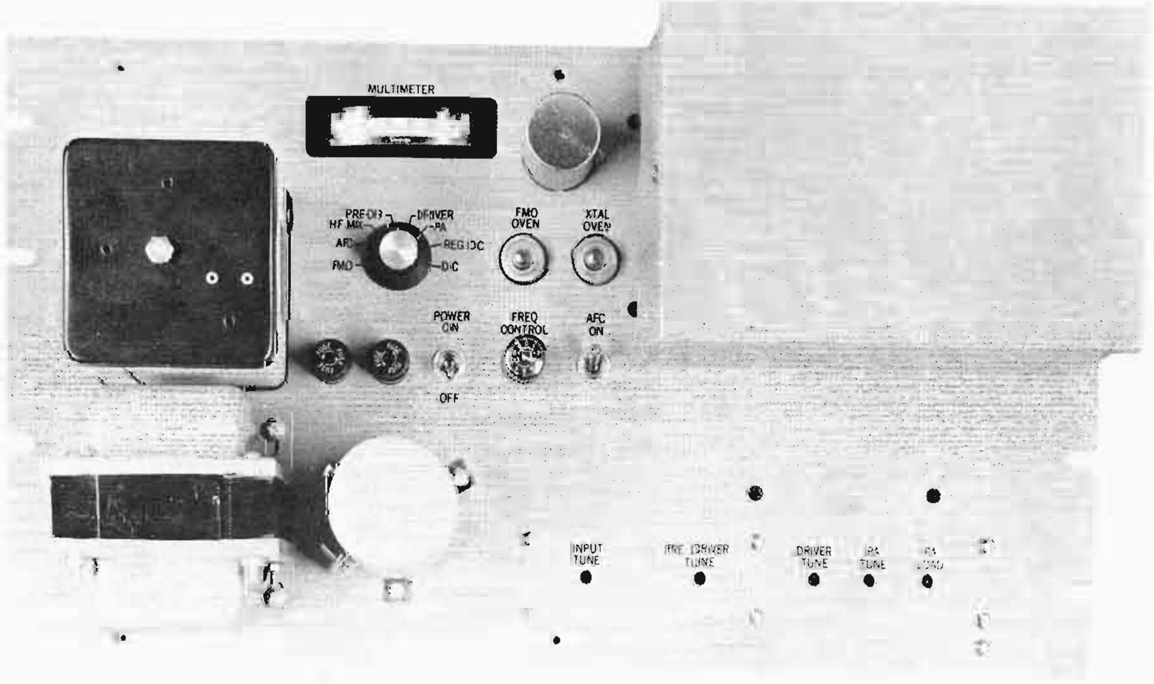


Fig. 49. Photograph of Visual direct FM exciter.

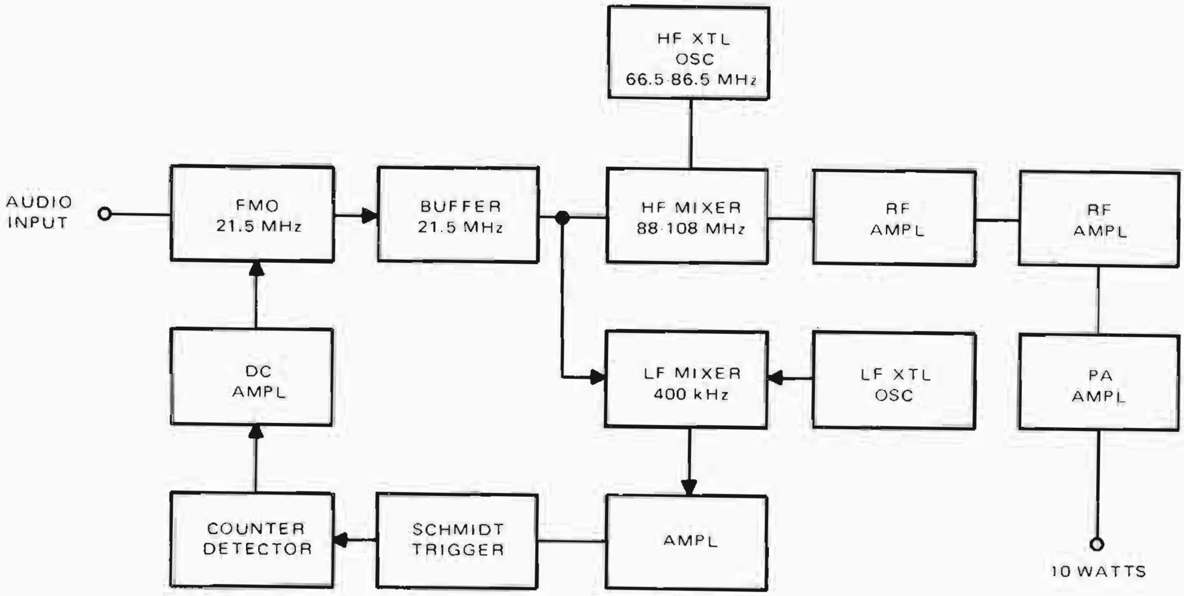


Fig. 50. Block diagram of Visual DFM-10A/B 10-watt FM broadcast exciter/transmitter.

1. Final amplifier plate voltage;
2. Final amplifier plate current;
3. Rf transmission line current, voltage, or power;
4. Average carrier frequency.

Other parameters, such as pilot subcarrier frequency and SCA subcarrier frequency, require less frequent measurement and logging. Paragraphs 73.283, 73.295, and 73.297 of the FCC Rules and Regulations should be referred to for these additional requirements. Logs must be retained by the licensee for a period of two years.

Proof of Performance Measurements

Paragraph 73.254 of the FCC Rules and Regulations defines the requirements for an FM proof-of-performance. This proof must be made at least once each year and during the four-month period preceding the date of filing application for renewal of the station license. The proof-of-performance data must be kept on file at the transmitter for a period of two years.

As of this writing, the requirements for a stereo proof-of-performance have not been defined and only monophonic measurements are required for the official proof-of-performance. Stereo stations are required to meet the requirements of Paragraphs 73.317 and 73.322 on a continuous basis, however, and it is recommended that a stereo proof-of-performance be made at least annually as a matter of good engineering practice. Stereo measurements are described later under the section that describes maintenance measurements.

The current requirements for a proof-of-performance test specify the following measurements:

1. Audio frequency response;
2. Audio frequency harmonic distortion;
3. FM signal-to-noise ratio;
4. AM noise level.

Fig. 51 is a block diagram of a typical test set-up for proof-of-performance measurements. All measurements are made on the composite system from microphone terminals of the console to the transmitter output. All normal program circuits, with the exception of limiting and compression amplifiers, must be included in the measurements. If the compression and limiting amplifiers have switches that convert them to linear, fixed-gain operation, the measurements should be made with the limiters and compression amplifiers in the linear fixed-gain mode of operation. If not, they should be removed from the circuit.

Audio frequency response measurement. Audio frequency response is measured in reverse, that is, a constant output modulating level is maintained for all modulating frequencies by adjusting the amount of attenuation between the audio generator and the microphone input terminals. This is necessary because of the rising response due to pre-emphasis. Frequency response data is taken at three levels of modulation: 25 percent, 50 percent, and 100 percent. The audio voltmeter which measures the audio generator output voltage is used to maintain constant voltage level versus frequency at the generator output terminals. The attenuator dials are adjusted for each modulating

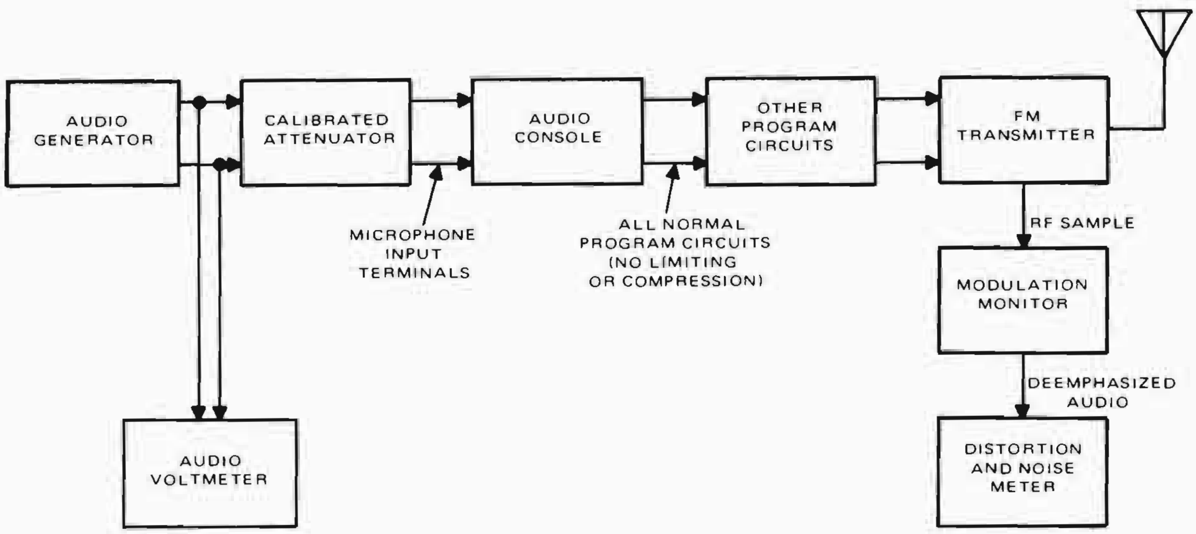


Fig. 51. Block diagram of test set-up for proof-of-performance measurements.

frequency to maintain the desired modulating level and the attenuator readings, in decibels, are recorded. Readings should be taken for the following modulating frequencies: 50, 100, 400, 1,000, 5,000, 7,500, 10,000, and 15,000 Hz. (7,500 Hz is not required by the FCC Rules and Regulations but is needed when the data is plotted within the limit curves).

When attenuation in decibels is plotted versus frequency, the 75-microsecond pre-emphasis curve is obtained if the system frequency response is perfect. Deviations from the ideal response are permitted to an extent which allows the measured curve to be fitted between the limit curves shown in Fig. 4. The procedure for doing this is to subtract or add the same number of decibels from each of the measured values. This process may be repeated until a fit is obtained. If it is impossible to obtain a fit by subtracting or adding the same value of attenuation from all measured values, the system frequency response is inadequate and adjustments must be made.

Audio frequency harmonic distortion measurement. Harmonic distortion of the system from microphone input terminals to transmitter output is measured by modulating the transmitter with sinusoidal modulating signals having low distortion and observing the harmonic content at the output of the modulation monitor. For this measurement, pre-emphasis is used in the transmitter and de-emphasis is used in the monitor. Measurement equipment must pass de-emphasized harmonics through 30 kHz.

The normal distortion meter used in this test reads not only harmonic distortion but also noise in the audio passband. If the total harmonic distortion and noise is within the harmonic distortion limits, the system is assumed to meet its harmonic distortion requirements.

Harmonic distortion must be measured under the following conditions:

1. For modulating frequencies of 50, 100, 400, 1,000, and 5,000 Hz at modulating levels of 25, 50, and 100 percent modulation;

2. For modulating frequencies of 10 kHz and 15 kHz at a modulating level of 100 percent.

The preceding measurements must show that the system harmonic distortion is less than 3.5 percent for modulating frequencies between 50 and 100 Hz, less than 2.5 percent for modulating frequencies between 100 and 7,500 Hz, and less than 3 percent for modulating frequencies between 7,500 and 15,000 Hz. If distortion levels greater than these are measured, the system requires adjustment.

FM signal-to-noise ratio measurement. FM signal-to-noise ratio of the system is measured from microphone input terminals to the transmitter output. The residual noise level at the monitor output is measured with a distortion and noise meter or with an audio voltmeter. For this measurement, pre-emphasis is employed in the transmitter and de-emphasis in the monitor. The residual audio noise level is referenced to the signal level caused by 400 Hz modulation at the 100 percent level.

The procedure for making the FM signal-to-noise ratio measurement is as follows:

1. Modulate the transmitter with a 400 Hz sine wave applied at the microphone input terminals of the console and set the level for 100 percent modulation;

2. Read and record the audio signal level appearing at the monitor monophonic output terminals. If the monitor has audio metering capability, the meter gain should be set for a 0-dB reference level according to the manufacturer's instruction;

3. Remove the modulation and terminate the console audio input terminals with a resistor equal to the normal microphone output impedance (usually 150 ohms).

4. Read and record the residual audio noise voltage in decibels below the 400 Hz signal level.

The measured signal-to-noise ratio must be at least 60 dB.

AM noise level measurement. Residual amplitude modulation of the transmitter output is measured with all audio circuits except compression amplifiers and limiters connected. For this measurement, an AM detector is required. Most FM modulation monitors include an AM detector for this purpose. The detector must include 75-microsecond de-emphasis of its output. AM noise measurements must be made directly at the transmitter output (or an accurate sample of its output). No amplifying or limiting equipment may be used between the transmitter output and the AM detector since this equipment would modify the residual AM noise level present.

The FCC Rules and Regulations require residual AM noise to be 50 dB below the level which represents 100 percent amplitude modulation of the carrier. Since the transmitter cannot be amplitude modulated, this reference must be established indirectly by a measurement of the rf carrier voltage. Refer to the instructions of the detector manufacturer to determine the reference level. Generally, the reference level is determined by setting a carrier level meter to a specified reading at which setting, the reference level is stated.

Maintenance Measurements

This section describes measurements which must be made as a matter of good engineering practice if the operation of the station is to comply fully with the FCC technical standards. At this writing, the FCC Rules and Regulations have not established a requirement for these measurements to be repeated at regular intervals, but the operating parameters concerned must be maintained within specification at all times. It is left to the station engineer to determine a schedule which will meet this requirement for his particular equipment and situation.

Several of the tests to be described apply to stereo transmission and others to SCA transmission. It is reasonable to expect that some of the tests in this section may be required in the future as a part of proof-of-performance tests for the applicable mode or modes of transmission.

Stereophonic channel separation measurement. Channel separation between the left and right audio channels is measured from microphone input terminals to transmitter output by using a type-approved stereo modulation monitor attached to the transmitter output sampling loop. Since channel separation is a very difficult parameter to measure accurately, it is recommended that rf amplifiers, which sometimes are inserted ahead of the monitor, be used with extreme care because they may have inadequate phase and amplitude characteristics for precise channel separation measurements.

The procedure for measuring channel separation is as follows:

1. Apply a sinusoidal modulating signal to the left microphone input terminals at a level sufficient to cause 100 percent total modulation (including pilot carrier);

2. Record the left signal level appearing at the left output of the monitor as the 0-dB reference level;

3. Transfer the modulating tone to the right channel, adjusting for 100 percent total modulation. Terminate the left channel in a resistance equal to the microphone output impedance;

4. Record the residual level in the left channel output of the monitor. This reading should be expressed in decibels below the previous signal level reference;

5. Repeat the above procedure for the right channel;

6. Channel separation should be measured for the following test frequencies: 50, 100, 400, 1,000, 5,000, 7,500, 10,000 and 15,000 Hz;

7. If the monitor de-emphasis can be switched out, better accuracy at the higher modulating frequencies can be obtained because the signal-to-noise ratio at the monitor output is greater (due to increased high frequency signal level).

All readings must be at least 29.7 dB to comply with stereophonic transmission standards.

Stereophonic frequency response measurement. Stereophonic frequency response should be measured from microphone input terminals to transmitter output in a manner similar to that used for monophonic measurements. Sinusoidal modulation is applied to one channel at a time. An input attenuator between the audio generator and the console is adjusted to maintain constant output levels of modulation for various modulating frequencies. When input attenuation in decibels is plotted versus modulating frequency, the pre-emphasis curve is obtained. This curve must fit between the limit curves shown in Fig. 4.

Frequency response data should be taken for both channels at modulating frequencies of 50, 100, 400, 1,000, 5,000, 7,500, 10,000 and 15,000 Hz and for total modulation levels (including pilot) of 25, 50, and 100 percent.

Stereophonic signal-to-noise ratio measurement. The FCC Rules and Regulations have not specified directly the signal-to-noise ratio required in the left and right channels, but instead have specified the signal-to-noise required in the main channel and in the stereo subchannel. The required signal-to-noise ratio in each of these channels is 60 dB.

Stereophonic modulation monitors contain filters to break the baseband spectrum into main channel and subchannel segments. The main channel noise may be measured with such a monitor but, unfortunately, subchannel noise may be impossible to measure because of the existence of the stereophonic subcarrier. The subcarrier, which falls within the passband of the subchannel filter, may be 20 dB greater than the noise level to be measured, since the FCC Rules and Regulations permit subcarrier levels as great as -40 dB.

It would appear that the only practical way to measure stereophonic signal-to-noise ratio is by the direct observation of the noise at the left and right output of the modulation monitor. This can be accomplished quite easily, but the requirements have not been defined for either the monitor or the transmitter. It is reasonable to assume that stereophonic signal-to-noise requirements should be somewhat lower than monophonic signal-to-noise requirements because of the increased noise bandwidth, slightly lower levels of signal modulation, and because of additional noise introduced in the monitor stereo demodulator. A measured value of over 50 dB signal-to-noise ratio in the left and right monitor output should be obtained for high quality FM broadcasting service.

Stereophonic distortion measurements. The procedure for measuring stereophonic is almost identical to the monophonic procedure. The audio test signals should be injected into the console microphone input terminals with one channel modulated at a time.

Measurements of each channel should be made for the following modulation conditions:

1. For modulating frequencies of 50, 100, 400, 1,000, and 5,000 Hz and total modulating levels, including pilot, of 25, 50, and 100 percent modulation;
2. For modulating frequencies of 10 kHz and 15 kHz and total modulating levels of 25, 50, and 100 percent modulation.

The measured distortion should fall within the performance specifications required for monophonic transmissions.

Stereophonic subcarrier suppression measurements. The measurement of subcarrier suppression is accomplished with the use of a stereophonic modulation monitor having a narrow 38-kHz bandpass filter included for this purpose. The FCC Rules and Regulations require residual 38-kHz subcarrier to be at least 400 dB below the 100 percent modulation level. The test procedure is to establish, first, a reference level for 100 percent modulation by modulating with either a main channel or subchannel signal (according to the monitor manufacturer's instruction). This modulation is generated by applying equal in-phase signals to the left and right inputs for main channel modulation or by applying equal but out-of-phase inputs to obtain subchannel modulation.

After the reference level is established, the monitor is switched to the stereophonic subcarrier measurement position to read residual subcarrier level with respect to the previously established reference level. The subcarrier level should be measured for various modulation conditions to insure that subcarrier holds with modulation. It is recommended that the test be made for modulating frequencies of 5,000, 10,000, and 15,000 Hz and for left only, right only, L = R and L = -R modulation.

Modulating frequencies less than 5,000 Hz may cause trouble because the subcarrier filter in the monitor may have inadequate selectivity to separate the subcarrier from the subchannel sidebands.

Stereophonic crosstalk measurements. Crosstalk between the main channel and the stereophonic subchannel is specified in Paragraph 73.322 of the FCC Rules and Regulations. The exact meaning and intent of this specification has received much discussion throughout the industry since the beginning of FM stereophonic multiplex operation. At this writing, the controversy has not been settled.

The original specification was probably written with a matrix scheme in mind wherein the transmitter had an input for accepting main channel (L+R) information and a second input for accepting subchannel (L-R) information. In a system of this type, a measurement is easily accomplished by first applying modulation to one of the inputs and then the other.

Since the FCC Rules and Regulations were written, the two-input transmitter has all but vanished. The single-input, wide-band transmitter is now commonplace. In this system, the baseband stereo signal enters the transmitter at a single input. Herein lies the basic cause of confusion in making crosstalk measurements.

In order to produce a signal in the main L = R channel with none in the stereophonic L-R channel, the separate L and R inputs must be adjusted in amplitude and phase so the signal in the L-R stereo channel is in a deep null. The residual L-R signal must be considerably more than 40 dB below 90 percent modulation in order to be able to measure crosstalk products that are required to be at least that far down. In practice, there are separate high-pass filters, low-pass filters, or 19-kHz notch filters and the pre-emphasis network in the separate L and R audio circuits ahead of the stereo matrix circuit. It is neither practical nor necessary to require that they be sufficiently well-matched (within 0.1 dB and 1°) to allow testing with L-R input signals. The normal phase difference encountered in practice can be compensated for by employing a device to shift the phase and vary the amplitude of one of the audio inputs. It is simply adjusted to null the signal in the stereo channel. The residual signal is called crosstalk.

The same situation prevails in testing for crosstalk from the stereo into the main channel. The input phases and amplitudes must be adjusted slightly from the theoretical L-R condition to null the L+R main channel signal. About all this crosstalk test does is ensure that certain distortion products generated in the circuits following the stereo matrixing circuit are kept below the levels permitted for harmonic distortion.

Crosstalk as specified in Paragraph 73.322 is defined as "crosstalk into the main channel *caused* by a signal in the stereophonic subchannel" and "crosstalk into the stereophonic subchannel *caused* by a signal in the main channel." The audio gain mismatch discussed previously causes a distribution of signal power between the main channel and subchannel which has sometimes been referred to as "crosstalk." It is not. This "apparent crosstalk" is *not caused* by the presence of a signal in the other channel but is merely the normal result of a trivial gain or phase mismatch in the audio circuits.

Crosstalk from SCA into main channel measurement. The FCC Rules and Regulations require that any component in the frequency range, 50 to 15,000 Hz, which results from SCA operation must be at least 60 dB below the 100 percent modulating level. To test for this requirement, a monitor which has a main channel filter is required. The procedure is similar to the monophonic signal-to-noise measurement except that de-emphasis is not used in the monitor and that the SCA subcarrier is turned on and modulated fully during the noise measurement. For this test, the SCA injection level should be set to the level normally used and the SCA subcarrier should be modulated with various frequencies up to and including the highest to be used.

A reference level is established for 100 percent modulation by applying a 400-Hz sine wave at a level causing 100 percent modulation of the main channel. Readings of crosstalk and noise in the main channel are then made with the main channel microphone terminals terminated in a resistance equal to the microphone output impedance.

Crosstalk from SCA into stereophonic subchannel measurement. For stereophonic and SCA operation, the FCC Rules and Regulations require that any component in the frequency range 50 Hz to 53,000 Hz which is caused by SCA operation be at least 60 dB below the 100 percent modulation level.

Most modulation monitors include filters for noise measurement of the 50- to 15,000-Hz region and for the 23- to 53-kHz region but not for the overall 50- to 53,000-Hz region. It has become standard practice to measure the noise level in the two bands which the monitor measures rather than the overall region.

The procedure for measuring crosstalk into the stereophonic subchannel is similar to the main channel measurement except that it may be necessary to deactivate the stereophonic subcarrier for the measurement in order to observe noise levels at the -60-dB level.

Crosstalk from stereo into SCA subchannel measurement. The measurement of crosstalk in the SCA subchannel from the main and stereophonic subchannels is not required by the FCC Rules and Regulations. It is a necessity, however, for stations engaged in SCA broadcasting to make periodic measurements of this parameter to ensure good SCA performance.

The measurement of crosstalk into the SCA subchannel must be accomplished with a high quality, SCA modulation monitor that has been designed for the purpose. The average SCA receiver is not capable of testing transmitter performance because it typically has a much greater level of distortion than does the transmitter to be tested. It should also be realized that the transmitter may be adequate even though all receivers in the field show an intolerably high level of crosstalk. The composite system including transmitter, antennas, transmission path, and receivers must be investigated when crosstalk is experienced.

Crosstalk into the SCA channel should be tested at the transmitter output with the main and stereophonic subchannels modulated with various modulating frequencies from 50 to 15,000 Hz. The SCA subcarrier should be on but unmodulated for the measurements. Since 100 percent SCA modulation has not been defined, the reference level to which SCA crosstalk is compared is arbitrary. It has become somewhat standard to define SCA modulation in terms of absolute frequency deviation in kilowatts rather than as a percentage of subcarrier frequency.

INSTALLATION CONSIDERATIONS

Adequate planning and care in the installation of an FM broadcast transmitter and associated equipment will help avoid many problems that may be difficult and expensive to correct later, for example, poor grounds and ground loops may cause high noise levels.

Separate conduits or troughs should be provided for the audio and the ac wiring. A third conduit should be used if computer logic levels are employed for equipment control. These conduits or wiring troughs may be either overhead or below the cabinets. The ac wiring should be well separated from the audio pairs to prevent the induction of unwanted noise into the audio circuits.

All audio shields should be grounded at only one point. This point is the one found experimentally to give the lowest noise pickup. The equipment racks should be connected together by copper straps at least 2 in. wide and tied to a good earth ground at one point. If a good ground screen is not available, a ground can be provided by driving four or five copper ground rods 8 to 10 ft. long into the ground with a spacing of about 3 ft. These ground rods should be tied together with copper strap which is at least 2 in. wide also. The wide strap connecting the equipment to the earth ground should be as short and direct as practical.

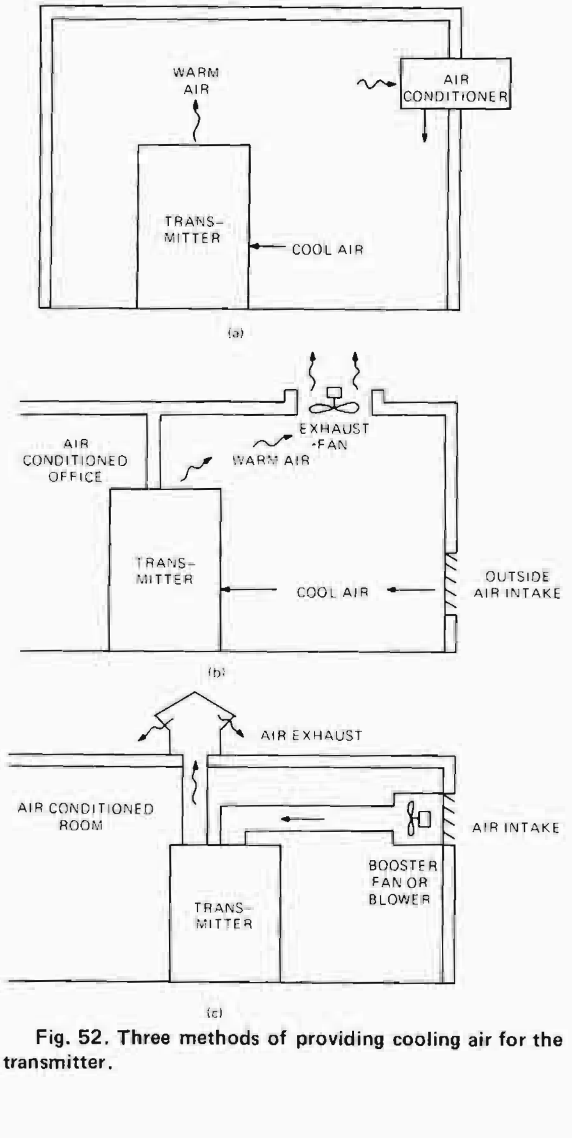


Fig. 52. Three methods of providing cooling air for the transmitter.

It is often difficult to remove rf from the equipment by grounding because at FM carrier frequencies, nearly any connection to an earth ground has an appreciable impedance. The best way to keep rf out of sensitive low level circuits is by keeping them enclosed in an rf shield and by filtering leads that enter the shielded units when necessary. Filters in the audio lines may be made up of small rf chokes and disc capacitors.

For stereo transmission, it is necessary to keep L and R audio lines phased properly. Correct phasing must be maintained throughout the station from the microphones, tape machines, and turntables through all of the audio equipment to the exciter audio input terminals.

The equipment should be located and arranged to provide sufficient room around it for easy access during servicing and maintenance.

A very important consideration in locating the transmitter is provision for cooling air. As a rough approximation, it can be assumed that the overall efficiency of the transmitter is a little less than 50 percent. In other words, it generates more kilowatts of heat than it does rf power output.

Fig. 52a shows a transmitter located in an air-conditioned room. No ducting is required and the intake air is usually much cleaner than outside air. It places a substantial heat load on the air-conditioner in the summer, but it is a source of heat in the winter. This method is used frequently with the lower power transmitters.

Fig. 52b shows a transmitter located in a wall with a non-air-conditioned room behind it. A large exhaust fan is provided in the ceiling and an adequate air intake opening is provided in an outside wall.

Fig. 52c shows a transmitter located in an air-conditioned room with intake and exhaust air ducts to the outside. An auxiliary blower or fan is normally required to overcome pressure drop in the ducting. The air intake and exhaust openings to the outside should be provided with rain shields, insect screens, and dust filters as dictated by the environment. The location of the air intake and exhaust openings should be arranged so that wind pressure will not impede the air flow.

Air filters should be periodically cleaned or replaced according to the transmitter manufacturer's instructions. This is very important because dust clogged air filters may reduce the cooling air flow enough to cause overheating of some of the components. The probability of component failure increases very rapidly when cooling is insufficient.

Dust should be cleaned from the transmitter by means of a brush and vacuum cleaner or as otherwise recommended by the transmitter manufacturer. Usually weekly cleaning is sufficient.

19

Television Transmitters

Preface

Chapter 19 is comprised of two parts—the original Chapter 19 and an addendum which, together, constitute a comprehensive discussion of current domestic television transmitters.

Television transmitters in use in the United States today can be classified, broadly, into two basic types. One type, described in the original chapter, employes modulation at an IF frequency followed by a low-level IF vestigial sideband filter, an upconverter to final frequency at very low power, and a chain of linear amplifiers on the final frequency to reach the desired power level. A different type described in the addendum, employes modulation at some moderate RF level followed by linear power amplifiers and a high-level vestigial sideband filter at the transmitter output.

The unique circuits and special characteristics of each type is discussed in approximately equal depth in the two portions of Chapter 19. The original chapter includes much general information on television transmitters that applies to either type, and this information is not repeated in the addendum.

19

Television Transmitters[1]

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The following chapter is written to provide the operating engineer with a better understanding of the functioning of his equipment. It is not the intent to provide sufficient information to design the equipment.

Emphasis and more detail is offered in areas thought to be new and not readily found in easily obtainable references. Areas which are long established, widely understood, with readily available references, are treated in less detail.

A television transmitter will accept a video signal at its input terminals and produce an amplitude modulated carrier of proper power in which the video information is contained. It also accepts an aural signal at a second input terminal and produces a frequency modulated carrier of proper level. It will generally include elements to combine visual and aural output signals into one transmission line.

Performance standards, power levels, and frequency assignments for TV transmitters are regulated by FCC Rules and Regulations (Volume III, pt. 73) which in many areas conform with recommendations made by the CCIR (International Radio Consultative Committee).

TV broadcast services operate on the following frequency bands:

54 to 88 MHz (VHF-Low Band) Channels 2-6
174 to 216 MHz (VHF-High Band) Channels 7-13
470 to 806 MHz (UHF) Channels 14-69

The channel width is 6 MHz and all VHF channels are exclusive assignments, i.e., they are not shared with other services. Some UHF channels are shared with land mobile services.

[1]Superscript numbers refer to references at the end of this chapter.

Acknowledgment. The author wishes to thank Amperex, Eimac, and RCA for furnishing the information contained in Table 1. He also wishes to give credit to the authors of the paper cited in Reference 15 for allowing the use of several figures from their paper. Mr. Fred W. Haushalter provided valuable assistance in writing about mechanical and cooling aspects of a TV Transmitter and credit is due Mrs. Madelyn S. Wade and Mr. Francis W. Wentura for their help and patience in the preparation of this manuscript.

The system in the USA (and some other countries) is designated by the CCIR as "System M."

The limited number of available channels requires assignment of the same channel to broadcasting stations in different areas. In March 1974 almost 600 VHF stations were licensed, which would indicate that on the average each VHF channel is assigned 50 times.

To reduce interference between stations, the FCC limits the effective radiated power (ERP) of every station on Channels 2-6 to 100 kw, on Channels 7-13 to 316 kw and Channels 14-69 to 5000 kw. The ERP equals transmitter output power multiplied by the antenna gain (neglecting transmission line losses for the moment) and leads to the following predominant power ranges of TV Transmitters (Visual Transmitter):

VHF, Low Band:	100 watts to 35 kw
VHF, High Band:	100 watts to 50 kw
UHF,	1 kw to 220 kw

The majority of VHF stations operate at a transmitter output of approximately 75% of the high limit shown above with lower power operations predominantly serving small, isolated communities. At UHF very few stations operate near the high limit shown, with the majority operating from 30 to 60 kw transmitter output power.

The RF output power of the aural transmitter ranges from 10% to 20% of the visual transmitter power. The output power of the visual transmitter is the peak power transmitted during the synchronizing pulse. The average output power of the visual transmitter varies with picture content from approximately 20% for a completely white picture to 60% for a totally black picture.

Transmitters for VHF service employ gridded tubes in the power stages while most UHF transmitters use klystrons in the power stages. Some UHF transmitters with output powers of 10 kw and less use gridded tubes in the power stages.

PERFORMANCE REQUIREMENTS

Visual Transmitter

The visual transmitter is offered a video signal from a 75 ohm coaxial cable at 1 volt peak-to-peak. This signal contains all synchronizing and picture information and can be expected to show significant spectral components from dc to about 6 MHz.

It is the transmitter's task to amplitude modulate this signal to a carrier of constant frequency and to shape the amplitude response of this carrier signal to fit within the available channel. Otherwise the transmitter should be a linear device as far as voltage and phase are concerned (except for the prescribed receiver delay predistortion).

The frequency of the visual carrier must, under FCC Rules, be within ±1 kHz of the assigned value. If a group of stations operate under precision offset conditions to reduce co-channel interference, only ±2 Hz departure from the correct carrier frequency is allowable to maintain this advantage.

In order to fit all video information into the available channel space only a vestige of the lower sideband is transmitted. It is designed to essentially pass all information up to 750 kHz in a double sideband fashion and attenuate all lower sideband components over 1.25 MHz by at least 20 dB, except the lower color subcarrier sideband which must be attenuated at least 42 dB.

The upper sideband should be essentially flat to 4.18 MHz, but reject components over 4.75 MHz by 20 dB or more. The requirements of the FCC Rules and Regulations for amplitude and sideband response present only a small challenge to the present-day transmitter and a more typical response tolerance pattern is shown in Fig. 1.

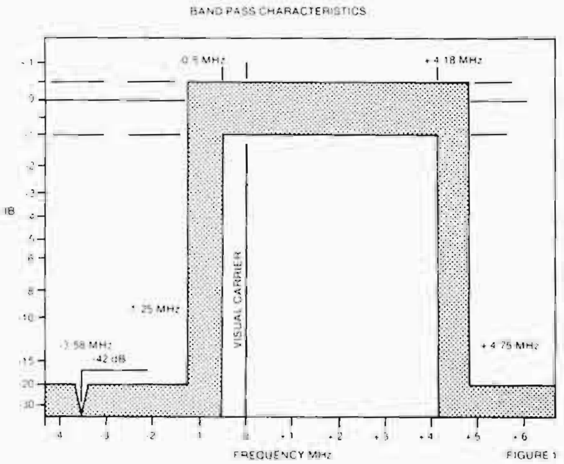


Fig. 1. Frequency response of modern TV transmitter.

Group delay through the passband from −0.75 MHz to +3 MHz of carrier should be flat. Most modern equipment exceeds the ±100 ns tolerance limit (.02 to 2.1 MHz) of the FCC Rules by a factor of 2. From 3.00 to 4.18 MHz a chroma advance is required of the transmitter with a straight line increase to place +170 ns at 3.58 MHz. The tolerance narrows from ±100 ns at 2.1 MHz to ±50 ns at 3.58 MHz and from there opens up again to reach ±100 ns at 4.18 MHz. It is highly desirable to provide a bypass switch for the circuit producing this FCC receiver predistortion in order to operate the transmitter in a "flat delay" mode for measurement purposes since no demodulators are available at this time which show a group delay behavior exactly complimentary to the one imposed upon the transmitter.

One will find, in a high power transmitter, that group delay varies with the picture level just as amplitude response varies with picture level.

If delay (or phase) of the carrier varies relative to the color sideband, we speak of differential phase. If, by chance, both vary by the same amount and direction, no differential phase could be detected even though the transmitter shows deficient performance.

Such shift, however, would readily be detectable in the aural output of an intercarrier receiver (limited of course to the rate of change which can pass the aural detector).

It is imperative, therefore, to specify allowable phase shift of the visual carrier caused by video modulation in order to preserve a minimum signal-to-noise ratio in the aural channel. No FCC limits are presently established, however, one may use the method and limits recommended by EIA or CCIR.

No further specifications, speaking in a fundamental fashion, in the frequency or time domain are required. However, it has become customary to make certain dynamic measurements which pinpoint weaknesses in the frequency or time domain under varying picture levels. Differential phase measurements using a stairstep or color bar to define phase changes of the color subcarrier over one line, and relative to burst, fall into this category. The FCC Rules allow ±10° of phase departure from the ideal (relative to the color burst) when 75% saturated primary colors are transmitted.

Since the amplitude response very close to the RF carrier cannot be properly determined using standard sweep techniques, observations in the time domain make up for this shortcoming. Improper transmitter operation in this area manifests itself by disturbances during the vertical blanking period (for very low frequency problems) and disturbances of the bar signal become visible for somewhat higher frequency imperfections.

From observations made in the time domain, changes of frequency determining elements can be made to correct for the above deficiencies. Line and/or horizontal rate squarewaves are suitable test signals by themselves or in conjunction with other test waveforms sharing a frame or line.

Other test signals, e.g., the 2t pulses and the modulated 12.5t and 20t pulses must also be viewed as measuring convenience signals since any limitations placed by them on the transmitter specifications are redundant once amplitude response, group delay, and transfer linearity are properly defined.

They also serve an educational purpose to emphasize the need to assess performance in the time domain rather than the frequency domain.

Therefore, if one is given a choice, resulting from certain system imperfections, to be only able to meet frequency response or acceptable wave shape of 2t and 20t pulses, one should choose the latter. There is no conflict in physical laws in such a possibility. The transmitter could, e.g., show a pronounced dip in response of say 2 dB at 2.8 MHz, reaching −.5 dB at 3.0 MHz and at 2.6 MHz, bringing it outside of the response shown in Fig. 1, yet allowing nearly perfect 2t and 20t signals to pass through the transmitter. An equipment designer would, of course, never rest at this point without finding the cause for the response disturbance, but an operator may be forced to place equipment with the above defect on the air and postpone the search for the cause. In such a case, pulse or transient behavior should overrule behavior in the frequency domain. Judgment is required on a case by case basis, which only a well-trained operator can provide.

It should be stressed that modern equipment generally meets the above limits irrespective of picture level (black, gray, or white picture), and over an output power range of at least 80% to 100% of rated power without the need for transmitter readjustment.

Specifications of the voltage transfer characteristic define the permissible departure from an ideal straight line for various signal conditions. Two dynamic measurements generally provide information of transfer behavior: a ramp signal for low frequency components and differential gain for one or more higher frequencies. Again, if the time or frequency domain characteristic of the transmitter were totally independent of picture level, the above requirement would be redundant. But as a practical matter, the determination is a useful one.

The FCC Rules do not define low frequency linearity, only differential gain. A tolerance of 20% from ideal is permissible. Modern equipment far exceeds this requirement.

There are several specifications controlling changes in the transfer characteristic based on changes of picture level; e.g., variation of peak power from black to white picture. The FCC Rules summarily lump many elements relating to changes in the transfer function into an overall limit of 5%, while expressing hope for a better definition in the future.

As in any communications channel, detrimental noise is generated in the system. Various methods exist to assess the detrimental effects of such noise. Some methods provide for noise weighing to take the degree of visibility into account. No such recommendations exist at this time for FCC Standards. It has, therefore, become the practice to view noise without weighing and to measure either RMS or peak voltages.

The only domestically manufactured noise measuring device measures noise by optical comparison on the waveform monitor, and, therefore, is defined as an average reading. It assumes a reference of 0 dB at 0.7 volts. In the past, transmitter noise specifications have been referred to a sine wave voltage which would modulate a transmitter from zero carrier to peak-of-sync (100% AM). Using this reference, most modern TV transmitters will meet a 50 dB requirement (RMS Measurement).

It appears that the least ambiguous approach to measure signal-to-noise in a TV transmitter would be to measure peak-to-peak noise over a defined frequency range through a suitable weighing network and refer it to the black to white transition. The same standard would be applicable to other elements of the system; for instance, demodulators, cameras, tape machines, etc.

The slight "disadvantage" of this latter method is that it produces smaller numbers than the presently employed methods, with the inherent danger of making better equipments look poorer when compared to old equipments characterized with the older method of measurement. A complete set of manufacturer's specifications are shown with typically commercially produced equipment towards the end of this chapter.

Mention should be made of the excellent tool for transmitter and system observation which is now widely available in the form of VIT and VIR signals, allowing continuous monitoring of most significant characteristics.

Only FCC Rules and Regulations are mentioned so far since the operator, by law, is only bound by them.

Yet a very useful additional standard exists: EIA, RS-240. This standard is more encompassing than FCC Rules and provides additional guidance by defining the method of measurement. Efforts are underway to revise and update both standards to bring them in line with present practices.

Aural Transmitter

The aural transmitter receives an input signal of +10 dBm from a symmetrical (balanced) 600-ohm line. It contains spectral components from 30 to 15,000 Hz. This information in turn is frequency modulated onto a carrier causing ±25 kHz carrier deviation when 400 Hz is present at +10 dBm. Seventy-five microsecond pre-emphasis is applied to the audio signal to improve system noise performance, a standard practice with FM broadcast systems.

The frequency of the aural carrier is specified to be 4.5 MHz above the visual carrier with a tolerance of ±1 kHz. Power of the aural transmitter may be between 10% and 20% of the peak-of-sync power of the visual transmitter.

The requirement for amplitude response under the FCC Rules and Regulations can be satisfied by a signal whose response can be fitted into a window 3 dB wide from 100 to 7,000 Hz with the signal allowed to drop to 4 dB at 50 Hz and 50 −5 dB at 15,000 Hz. The upper edge of this window is defined by the 75 microsecond pre-emphasis curve.

The voltage transfer characteristic is defined in terms of harmonic distortion of the input sine wave, allowing one-half of the system distortion for the transmitter proper. This will then establish limits of: 1.75% from 50 to 100 Hz, 1.25% from 50 to 7,500 Hz, and 1.5% for frequencies from 7,500 to 15,000 Hz. De-emphasis may be applied during distortion measurements, and all harmonics up to 30 kHz must be included in the measurements.

The FM signal-to-noise ratio including all spectral components from 50 to 15,000 Hz measured after de-emphasis should exceed 56 dB relative to ±25 kHz deviation by 400 Hz.

Since the FM carrier passes through selective circuits, a degree of FM to AM conversion will take place. No limits are established by FCC Rules and Regulations, but other administrations prescribe limits of −40 dBm relative to 100% AM for 25 kHz deviation and term this deficiency "synchronous AM."

If, in an FM system, the modulation transfer characteristic contains even order distortion, the mean frequency may experience one-sided shift with modulation. It is implied in the FCC Rules and Regulations that shift must not bring the mean (center) frequency outside the ±1 kHz tolerance, yet some administrations separate center frequency shift with modulation from carrier long-term drift.

The different treatment is largely brought about by traditionally different methods of controlling the center frequency of aural transmitters. In the U.S.A. where direct crystal control (e.g., serrasoid modulator or FMXO), or phaselocked loop systems are predominantly employed, center frequency shift with modulation is practically nonexistent as opposed to AFC type controls predominantly used in European countries which can show substantial center frequency shift with modulation.

It is questionable whether transfer linearity measurements presently defined in terms of harmonic distortion should be replaced by intermodulation measurements (acoustically a more meaningful quantity) as it would require every user to change his instrumentation. Once the new test equipment is available however, only a single measurement will be required to determine intermodulation distortion as opposed to a series of measurements for different frequencies with harmonic distortion. Furthermore, intermodulation measurements disregard frequency components falling outside the audible range. These components can be neglected.

Visual and Aural Transmitters

Every transmitter will produce spectral components appearing at its output terminals, or as radiation from its cabinet which are undesirable. These components become increasingly obnoxious as the density and utilization of the spectrum increases, with enormous differences in operating power of systems assigned to adjacent frequency bands.

The unwanted radiation consists largely of components harmonically related to the carrier, but sometimes may contain components not harmonically related to the carrier.

No modern transmitter should radiate signals created through parasitic oscillation of active devices. For this reason, every spurious component detected during measurements must be clearly identified for its frequency relationship (harmonic or intermixing) to the visual and aural carriers and any other primary frequency (e.g., the color subcarrier frequency).

An extremely useful practice in facilitating this identification is to modulate the primary signals (the visual and aural carrier) with identifying waveforms using extremely low modulation percentages to avoid creating additional sidebands. The detecting device must be able to produce a demodulated output from amplitude or frequency modulated signals or a combination thereof.

Industry standards generally call for unwanted signals in the output transmission line of 80 dB below carrier at peak of sync power. The FCC Rules and Regulation presently require spurious components to be attenuated at least 60 dB. Equipment can be produced without great difficulty in which spurious components are attenuated from 90-100 dB below carrier. One should remain suspect of receiving and monitoring devices since large input signals appearing in these devices may regenerate unwanted components in magnitudes considerably greater than the magnitudes appearing in the output of the transmitter.

Among emissions generated by a television transmitter one must also take into account acoustical emissions and x-rays. As a guidance, acoustical noise should be approximately 80 dB or less (remembering that in acoustics the dB is an absolute measure—not a relative one). Proof of compliance to this specification is quite difficult as measurements should be made in an anechoic chamber. Measurements made with the equipment sitting in a factory environment can only be considered for guidance purposes, as acoustical standing waves will materially change sound levels. Furthermore, a transmitter is a highly nonuniform and very directional sound source making levels highly dependent on the location of the sensing devices.

Similar reasoning applies to x-rays but in this area one must take the approach that anywhere outside the cabinet any detectable level of radiation must be comfortably within safe values.

The term "radiation" includes electromagnetic radiation as well as accelerated particles. High power transmitters, because of high anode voltage potentials, may generate gamma rays (x-rays). The presently accepted maximum level is .5 milliroentgens per hour anywhere along the outer surface of the cabinet, but it appears that further recommendations will place this level at .25 mR/hr.

It is not difficult in properly designed equipment to meet this requirement, especially in VHF transmitting equipment due to its lower anode potential as opposed to UHF klystron amplifiers which employ collector potentials up to 25 kv.

DESIGN PHILOSOPHY

The Engineering profession should accept a fundamental challenge in its design of any machine:

1. It should accomplish its assigned task with the greatest fidelity necessary.

2. It should do it with the best efficiency possible within an economic framework.

A measure of fidelity has been established under the heading "Performance Requirements" which state how well the process has to be performed without being carelessly tolerant or excessively stringent. Efficiency, in our commercial environment, is best measured by adding expenses and cost and replacement of capital.

Operating expenses include cost for operators, replacement parts, power consumption, repairs, etc. Capital cost include depreciation and interest on capital outstanding.

Engineering decisions should generally be made based on concrete information and numbers, but not on emotions and speculations. This, however, does not mean the engineer needs to be an emotionless or colorless person. Sometimes emotions will play a role in his decision, but he should be able to recognize when this is so.

One measure of efficiency, and in turn low maintenance and repair cost, is the statistic MTBF, (mean time between failure). The MTBF of complex equipment is the inverse of the sum of the failure rate of all components. Every effort must be made to find circuits requiring the least number of components consistent with stability and proper performance. One can expect that MTBF's for 50-kw TV transmitters may be around 500 hours. Therefore, the probability to get through an 18-hour broadcast day without any component failure is

$$R = e^{-t/T}$$

where R = probability of no failure (or reliability)
t = operating period
T = MTBF

$$R = e^{\frac{-18}{500}} = e^{-0.036} = 96.46\%$$

It should be remembered, however, that failure of a component does not necessarily cause a service interruption (e.g., an indicator light burning out is as much a failure, mathematically, as a short in the high voltage rectifier).

Consumption of electric power should be kept as low as possible. To aid in this direction air-cooled tubes with low-pressure anode radiators are preferable, all other things being equal over tubes showing high pressure drop across the anode radiator. It is more costly to produce high pressure air than low pressure air.

There are additional guidelines, e.g., adjustment for proper operation should, as much as possible, be done with built-in meters, components should be readily available; catalog items, component exchange should not cause undue equipment disassembly, equipment should be safe to operate, it should be self-protecting, etc.

TV TRANSMITTER FOR VHF SERVICE

Visual Exciter Modulator

The visual Exciter Modulator will generate a carrier at final frequency, modulated by video information and properly processed for sideband and delay shaping including moderate amounts of correction for linearity, differential phase and gain to make up for later stages in the transmitter. It's output power may be in the area of several Watts.

Fig. 2 shows a block diagram of a typical exciter-modulator.

In this type of exciter-modulator all signal processing is performed at video or intermediate frequencies including the modulation itself. After all processing is complete, the signal is raised to the final carrier frequency by an up converter and to the final power through suitable linear amplification.

The signal levels indicated on the block diagram are intended to show orders of magnitude only. It can be seen that most of the processing takes place around a level of 1 milliwatt, which is consistent with levels employed in most other video equipment. Only after the final frequency is reached is there gain to increase power levels.

The first task in the exciter-modulator using an IF modulation approach is the suitable selection of the intermediate frequency. The following criteria apply:

1. The frequency should be low enough to be advantageous for modulation and for processing.
2. It must not reach into the video range nor be so low as to cause image frequency or local oscillator separation problems in the required up converter.
3. The conversion process must not produce mixing products of intolerable magnitude within the final passband or mixing products outside the passband which may be unduly difficult to attenuate.

Intermediate frequencies have already been standardized for TV receivers: 45.75 MHz (in the U.S.A.), and 38.9 MHz (in Europe) for the visual carrier. The difference between the two standards is lodged in the different channel assignment for TV in the area from 50 to 90 MHz.

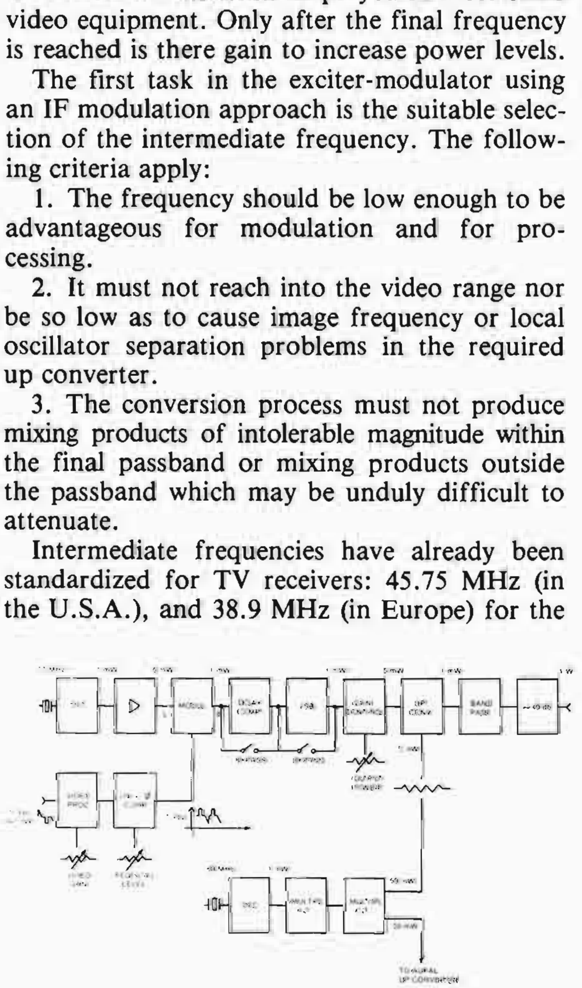


Fig. 2. Block diagram—Visual Exciter/Modulator.

For television transmitting equipment manufactured by the Broadcast Products Division of Harris Corporation an IF frequency of 37 MHz was chosen. Selection of this frequency relating to Items 1 and 2 above is largely a matter of judgment but careful analysis should prove the chosen frequency to satisfy Condition 3.

Similar conditions were encountered by designers of SSB communications equipment which uses IF Modulation processes exclusively.[1]

The mixing products investigation must first be conducted on the assumption that both input signals to the balanced mixer are inherently pure. This initial analysis quickly establishes that no in-band components exist for all UHF channels, that one in-band component exists for Channel 7$\left(\frac{4 \times f_p + f_{IF}}{5}\right)$, a fifth order component with an expected magnitude of −100 dB relative to the wanted signal: $(f_p - f_{IF})$ but several in-band components exist in Channel 4 and one each for Channels 2, 3, and 5. The magnitudes of these in-band components are expected to be more than 100 dB below the carrier level of the wanted signal, except for one component in Channel 4 $\left(\frac{f_p + f_{IF}}{2}\right)$ at −80 dB below carrier producing a 3.405 MHz beat. Actual measurements confirmed the magnitude of this signal to be better than above indicated.

It is imperative to use a mixer circuit whose long-term stability is invariant and whose performance is insensitive to normally expected variations in the amplitude of the pump source.

Reference 1 shows samples of a graphical analysis for the determination of possible in-band mixing products.

The investigation must not stop at this point but be repeated for possible unwanted harmonic or subharmonic components which may be contained in the pump and IF inputs.

These secondary checks must be performed for all bands: VHF as well as UHF. The task is considerably simplified when the pump chain is designed with the highest possible crystal oscillator frequency, e.g., 60 MHz, which will of course reduce the number of possible harmonic and subharmonic components in the multiplier chain.

Again, a graphical analysis is feasible for subharmonic and harmonic components and it becomes obvious at once that low voltage levels of those spurious components are highly desirable. Fig. 3 shows the schematic of a multiplier

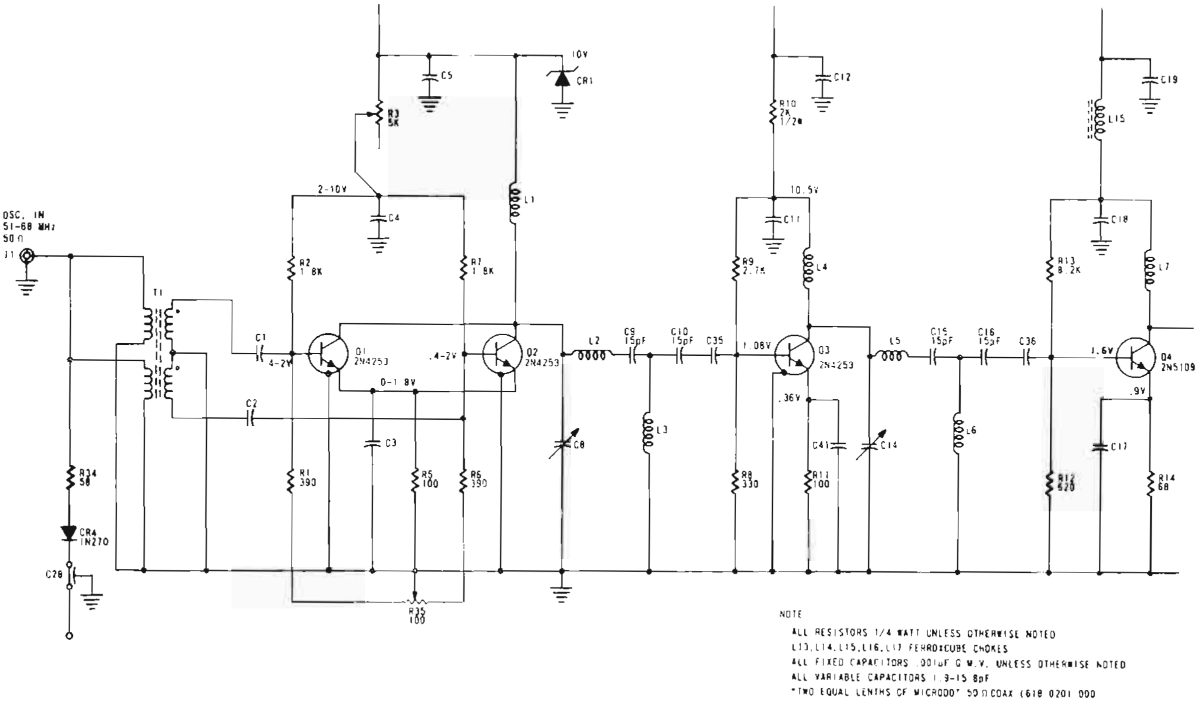


Fig. 3. Multiplier in pump chain.

chain specifically designed to maintain the level of unwanted subharmonics and harmonics at −50 dB relative to the wanted signal.

The selection of 37 MHz as IF for systems operating under FCC Rules and Regulations has one added advantage of being very close to the accepted European IF of 38.9 MHz, therefore, only one model of a visual sideband filter is required and can universally be used for any standard, any channel, and any CCIR system by allowing for a small amount of tuneability in the filter design. Fig. 4 shows a picture of this filter including a simplified schematic.

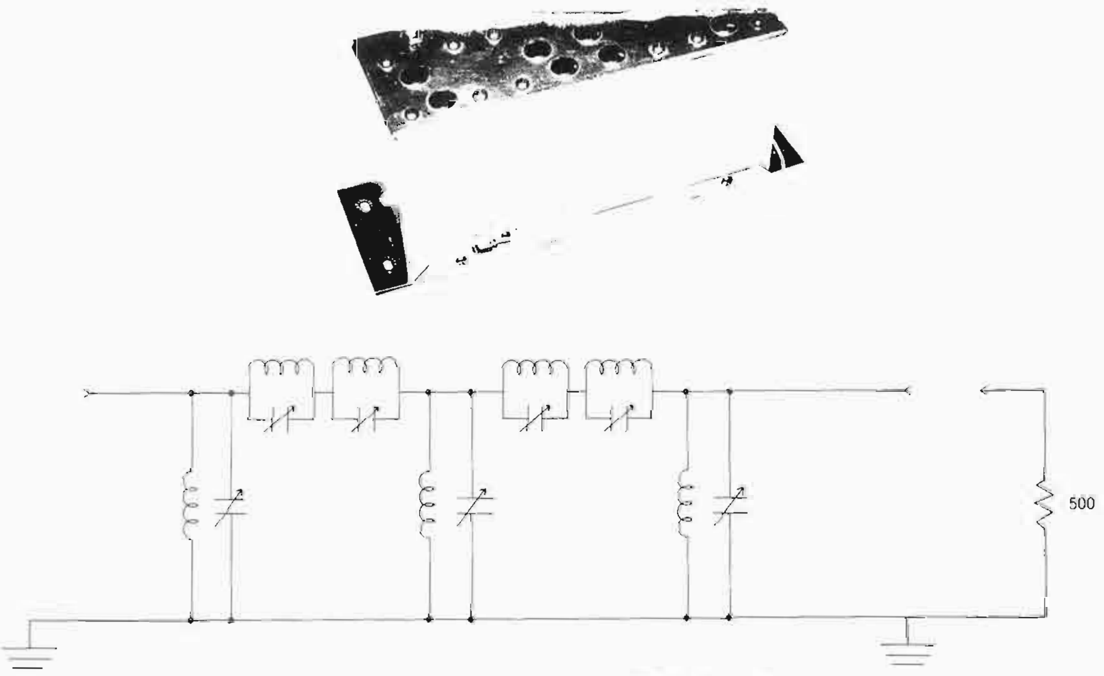


Fig. 4. VSB filter including simplified schematic.

After the choice of the frequency plan is confirmed to be without conflict, the selection of practical power level for processing must come next. Fundamentally, one should aim to work at as low a level as possible. This allows the design engineer to produce a more perfect system without paying penalties in performance by stressing active devices. The efficiency of the processing circuits, including the entire Exciter-Modulator, is of little consequence when compared to the whole transmitter. Therefore, emphasis should be placed towards attaining the most perfect signal possible with a minimum of circuit adjustments. Since the noise floor is predominantly established by active devices and cannot be altered, this level establishes the reference point upon which the choice of the signal level is based.

It was found that an operating level of 1 milliwatt (which is approximately 1 volt peak-to-peak in a 50-75 ohm system) would provide a generous margin in the signal-to-noise performance of the final processed signal and at the same time not unduly tax the requirement for voltage handling capability, linearity, etc., of transistors and integrated circuits using moderate supply voltages.

(This choice of level, it can be added, conforms to the level widely chosen for numerous types of video equipment, like recording devices, cameras, distribution amplifiers and the like.) Therefore, as can be seen from the block diagram Fig. 1, the power levels throughout the Exciter-Modulator are closely maintained around a level of 1 milliwatt.

RF Generator

The generation of the unmodulated RF frequencies (the IF carrier and the pump source) follows established principles and need not be dealt with in great detail. In both oscillators the crystals are operated at low power levels to avoid mechanical stresses which could possibly lead to destruction of the crystal. This precludes the need for built-in spares. In the past spare oscillators were often required when the crystals were operated at high power levels with a high probability of destruction.

Both oscillators are placed in ovens which are proportionately controlled for temperature and remain activated continuously. With this practice, frequency drift can be reduced to allow a UHF transmitter at the highest possible carrier frequency (the worst case) to remain well within tolerances prescribed in the FCC Rules and Regulations for at least 60 days. This means, of course, that the carrier frequency stability on Channel 2 is 10 times better than it actually needs to be.

Both unmodulated RF frequencies are available at proper levels and harmonic and subharmonic content is at least 50 dB below the level of the wanted frequency. To ascertain this level we again refer to Fig. 3.

Proper RF level is set through diode CR-4, followed by a balanced (Push-push doubler consisting of transistors Q1 and Q2 and a high pass filter to reject the fundamental frequency.) (See C9, C10, L3 and C15, C16, L6.)

Video Processing

Before going into actual circuits a policy should first be stated which may be subjected to debate but is defined as follows:

The transmitter should correct for its own problems but otherwise be transparent to the input signal. Nonstandard signals should not cause any damage to the equipment.

This policy does remove the burden of judging the correctness of the input signal from the transmitter to a processing amplifier if such judgment is required by other deficiencies in the system prior to the transmitter. Since the defects will vary with every system, correction outside the transmitter can better be tailored to individual requirements without placing the burden for the worst case on all equipments.

Following this policy, only four PC boards are required in the video portion of the Exciter-Modulator which will: (1) accept the input signal either single ended or with common mode rejection; (2) compensate moderately for the transmitter's own nonlinearity; and (3) will restore dc level of signal. A FCC receiver delay predistortion unit is provided in its own tray.

The sync negative input voltage is received by a differential amplifier offering 40 dB of common mode rejection. The main target is 60 Hz hum possibly appearing in phase on the inner and outer conductors of the coax line.

The FCC receiver delay predistortion is performed by active circuits possessing all-pass

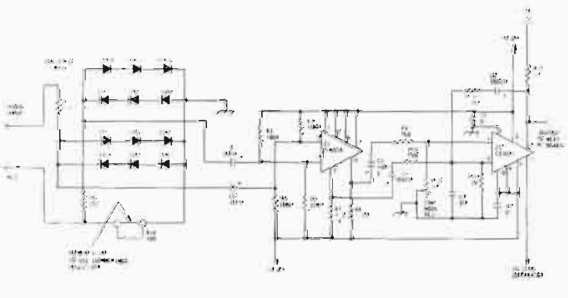


Fig. 5. Common mode rejecting and input protection.

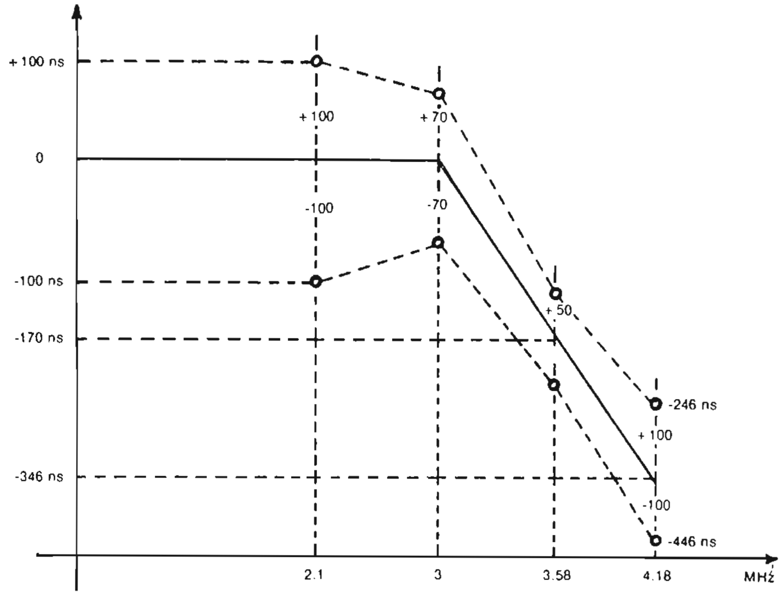


Fig. 6. Transmitter envelope delay.

characteristics. Four such all-pass networks are connected in series and will produce a variety of receiver predistortion curves under various transmission standards. The operating principle of an active all-pass will be described in more detail in the section dealing with "IF delay compensation." The common mode rejection capability is achieved by utilizing a differential amplifier in the input stage.

For protection against overvoltages of both inputs, the cable center conductor as well as the outside braid are clamped against the positive and negative supply voltages which should avoid damage to the input transistor. See Fig. 5. The allowable tolerance of overall transmitter envelope delay is shown in Fig. 6 which reflects paragraph 73.687(a)(5) of the FCC Rules and Regulations. The typical receiver should have an envelope delay characteristic complimentary to Fig. 6. However, no legal restraints have at this time been placed on receiver manufacturers due to a lack of jurisdiction of the FCC.

In the past, many delay compensators used passive devices connected as all-pass sections. Circuit configuration of the fundamental all-pass is shown in Fig. 7. The pole and zero placement of this all-pass is shown in Fig. 8 and typical delay of such an all-pass is shown in Fig. 9. The circuit shown in Fig. 7 is awkward to realize, in addition, it has no common ground connection. Under certain conditions, largely with restrictions placed on the values of com-

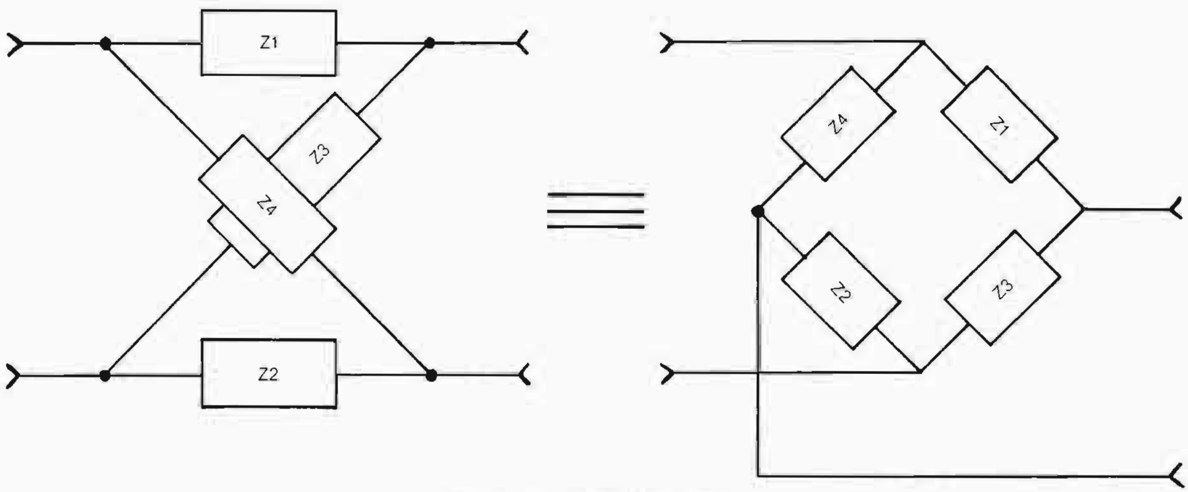
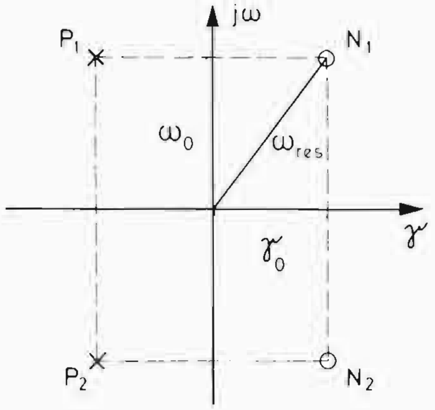


Fig. 7. Fundamental all-pass.



$$\tau(\omega) = 2\gamma_0\left[\frac{1}{\gamma_0^2+(\omega-\omega_0)^2}+\frac{1}{\gamma_0^2+(\omega+\omega_0)^2}\right]$$

$$\omega(\tau_{max}) = \omega_0\sqrt{2\sqrt{1+\left(\frac{\gamma_0}{\omega_0}\right)^2}-1-\left(\frac{\gamma_0}{\omega_0}\right)^2}$$

$$\tau_{max} = \frac{2}{\gamma_0}\cdot\frac{1}{2\frac{\omega_0}{\gamma_0}\left[\sqrt{1+\left(\frac{\omega_0}{\gamma_0}\right)^2}-\frac{\omega_0}{\gamma_0}\right]}$$

Fig. 8. Poles and zeros for all-pass network.

ponents or by introducing mutual coupling between coils, simpler all-passes are feasible are shown in Fig. 10.

No method of direct synthesis of component values from an established primary delay behavior is available and present methods of synthesis rely on analogy or cut and try approaches. Lacking a method of direct synthesis, quite elaborate methods of dc analogies have been proposed in the past.[2]

Once a passive all-pass network is adjusted for proper delay and return loss, it can not easily be readjusted without affecting its performance. Therefore, the standard method employing passive all-passes is to attain complex delay curves by suitable combination of many sections.[4] Frequently, amplitude compensation is required also since the finite Q of the all-pass components will not allow its amplitude response to be uniform. Delay compensation by video predistortion can not be provided for the double sideband region in a rigorous way.[3] However, a rigorous solution is possible in the single sideband region of the television signal, in other words, for frequencies from 1.25 MHz up if the transmitter is capable of handling leading overshoots which are placed on the signal through the predistortion process.

Returning to the video portion of the Exciter-Modulator, a second board contains a sync separator. The most significant feature of this circuit is its reliance on a critically damped tuned circuit (C4 and L1) to produce trigger pulses with the rise and fall of all sync signals. The negative trigger only is used to switch the keyed clamp in the linearity corrector and the modulator driver.

The reasons for choosing this circuit are largely twofold: (1) it is very insensitive to hum, noise, and other short-time disturbances riding on the sync signal and (2) its timing function is independent of supply voltages. The output from Z2 are one positive and one negative going pulse which will turn both clamps on during the back porch, see Fig. 11.

Modern power tubes for TV transmitter linear amplifiers require only very moderate amounts of correction for lack of linearity.

The third PC board of the video portion provides for differential gain correction of all causes which are part of the transmitter proper. Five

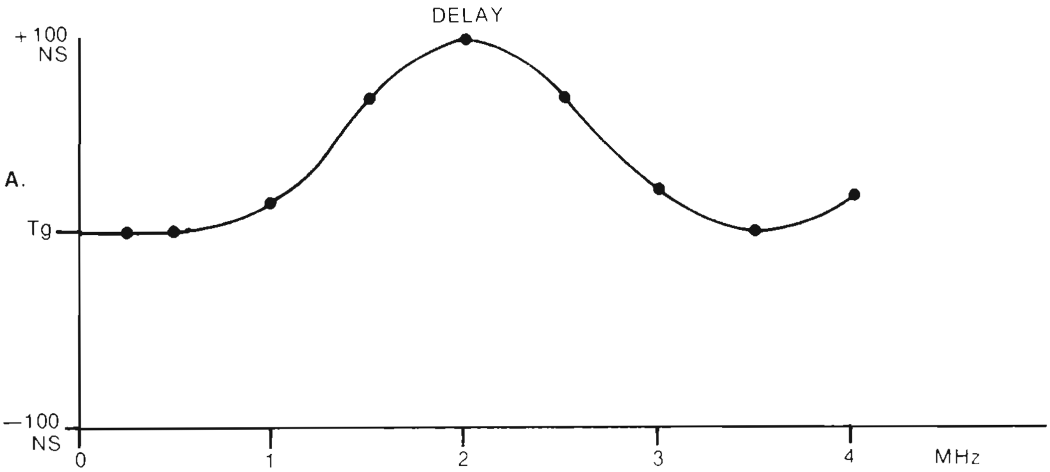
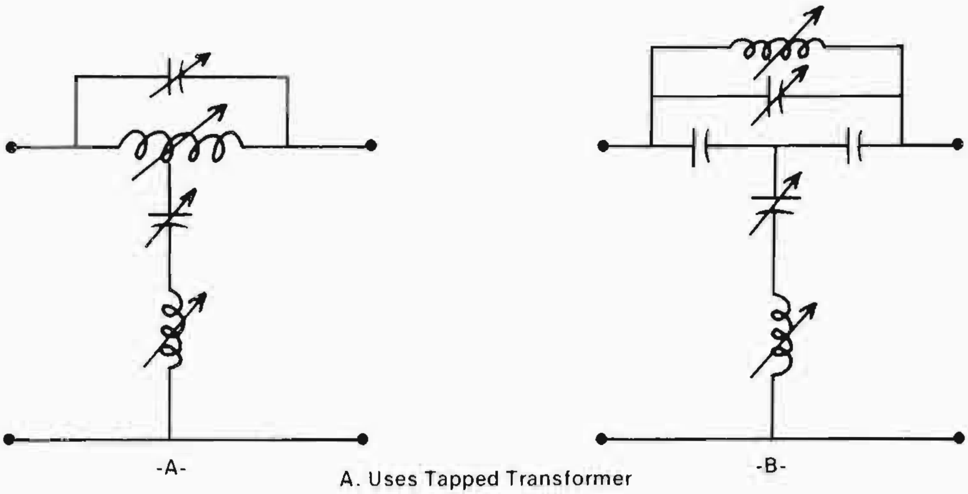


Fig. 9. Typical Delay.



A. Uses Tapped Transformer
B. Uses Split Capacitors

Fig. 10. Simplified all-pass.

steps are provided, including sync stretch. All but the sync stretch controls have potentiometers for adjustment of the cut-in level as well as the rate of correction, which will allow very precise compensation. Correction for differential phase is governed by the degree of correction applied for correcting differential gain.

The clamp circuitry, a necessary part of the linearity corrector, will not affect burst amplitude and will have only a minimal effect on the burst phase. Fig. 12 shows a simplified version of the linearity corrector, including the clamp circuit, to demonstrate the circuit's operation. The action of the linearity corrector can be defeated through a bypass switch.

The last board of the video portion of the Exciter-Modulator constitutes the modulation driver which is also clamped at the backporch level. Also included on this board is a monitor amplifier which offers a sync negative signal which is an exact replica of the signal applied to the modulator. Double sideband modulation is produced through a ring-modulator connected as a current controlled attenuator.

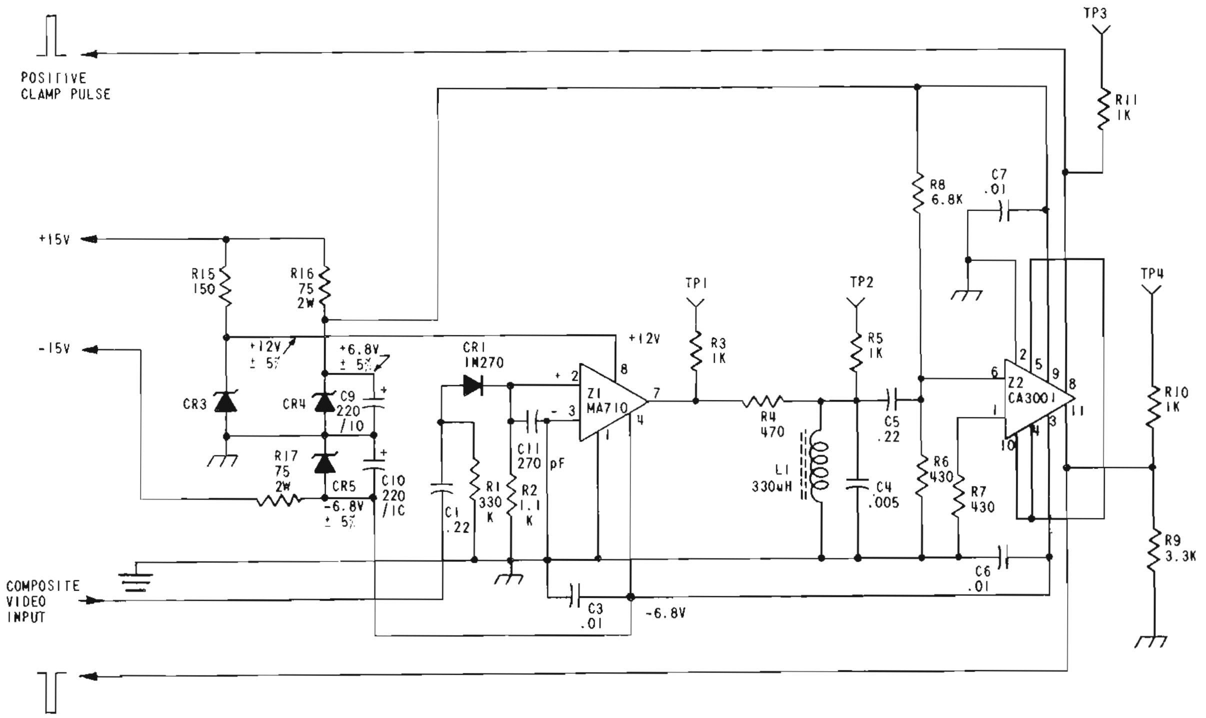


Fig. 11. Sync separator and clamp drive.

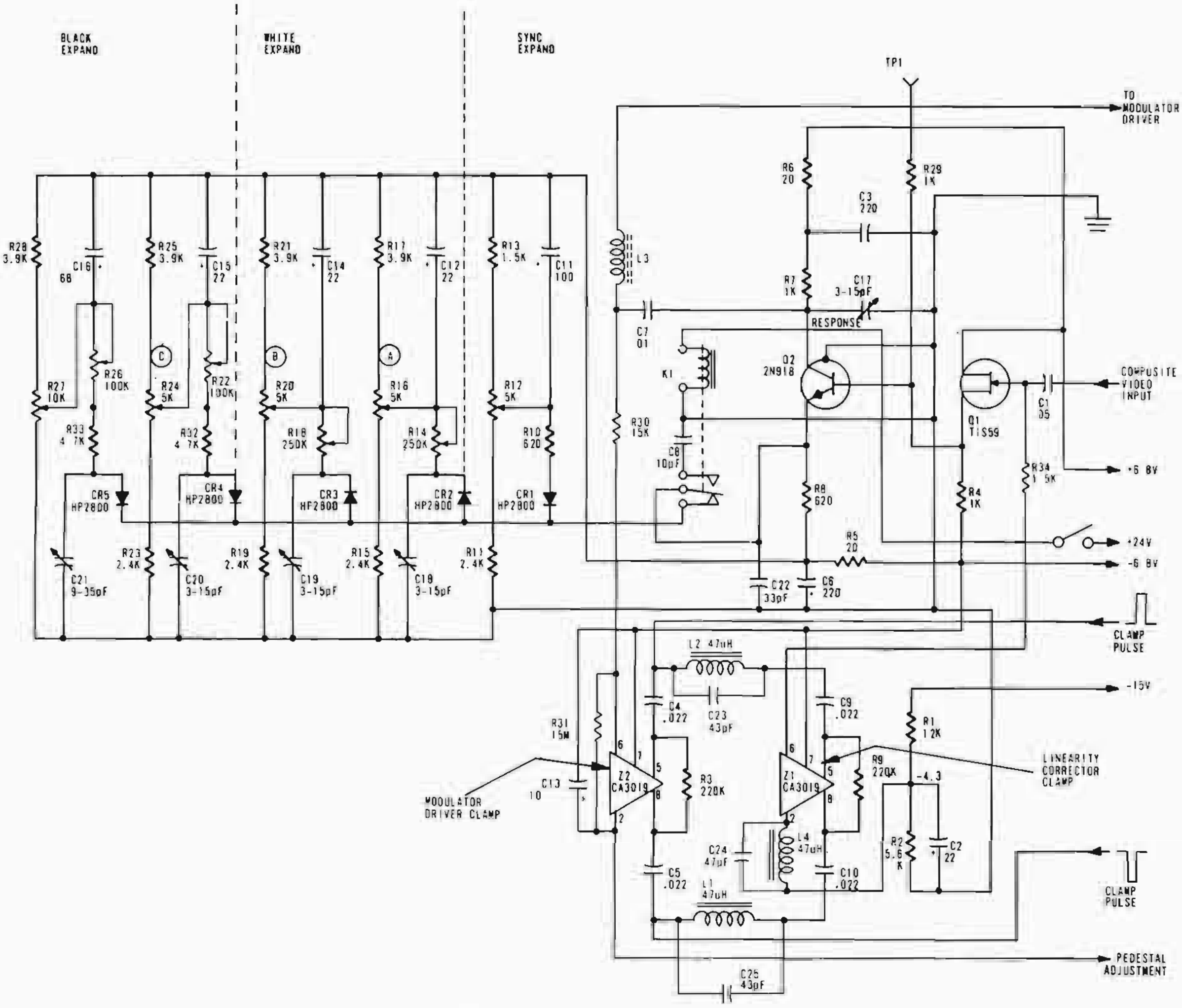


Fig. 12. Linearity corrector.

Modulator

Fig. 13 shows the transfer characteristics of a Hewlett-Packard HP10514 mixer which is typical of any ring-modulator. In the modulation circuit, peak of sync is chosen to be approximately −12 dB attenuation caused by a current of 1 ma. This is the point of maximum carrier. From this point attenuation is available through the reduction of current into the dc coupled port approximately 38 dB below the 1-ma reference, thus, allowing modulation percentages down to 2% if the peak of sync reference is chosen to be 100%. An excursion of current from 1 ma to 10 microamp will accomplish this range of modulation with good linearity.

Care must be taken to remove harmonics of the carrier frequency which consists mainly of the third, with a peak level occurring a maximum carrier approximately 15 dB below the fundamental. Proper harmonic attenuation is achieved with a 3-pole Chebycheff low-pass filter which reduces all harmonics to at least 45 dB below the fundamental, immediately following the modulator. Further harmonic reduction is afforded in all amplifier stages following as well as in the band pass VSB (vestigial sideband) filter.

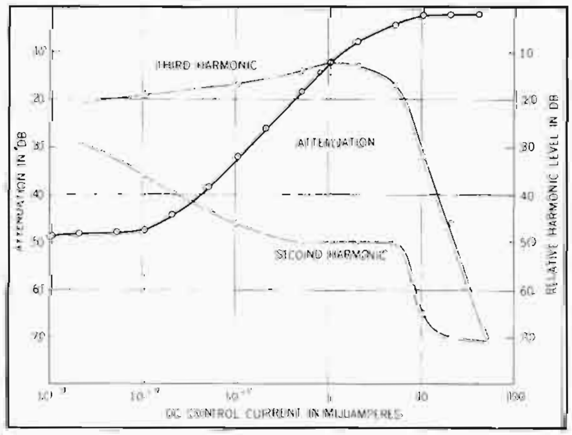


Fig. 13. Ring modulator transfer characteristic.

The modulated double sideband signal with a 37 MHz carrier appears at the R port of the ring modulator and has a level of approximately 1 mw during peak of sync. Typical performance of such a modulator is modulation linearity better than 2% relative to ideal straight line; differential phase less than 1°, and carrier phase shift (100% to 10% modulation) less than 3°.

The modulator has a distinct advantage of requiring no tuning controls. The double sideband modulated signal after passing the lowpass filter and a single stage amplifier is available at 50 ohms and will next be applied to the IF delay compensator.

IF Delay Compensator

In a television system the departure of envelope delay from a uniform curve is caused almost exclusively by the limitation of the bandwidth which is imposed by regulation. The limitation in channel bandwidth was imposed in the interest of spectrum conservation.

In a linear system delay caused anywhere in that system can be compensated anywhere else, e.g., delay in the receiver, can, in fact, be corrected by predistortion in the transmitter.

In a bandpass filter, spectrum components towards the edges of the passband are delayed more than components in the center of the passband. A steeper attenuation at the edges will cause a greater delay. The delay of a typical VSB filter is shown in Fig. 14. If the delay in the center of the passband is arbitrarily established as zero reference, Fig. 14 shows that the relative delay at carrier is approximately 80 ns, the delay at the color subcarrier is approximately 100 ns, and delays at the edges of the passband are slightly in excess of 300 ns.

The delay of a filter is an inherent characteristic (found in all minimum phase-type networks) and is directly related to its amplitude response. The delay cannot be changed without affecting response due to a relationship anchored in fundamental physical laws.

Since no circuits are available that will advance a signal in time, the only way to compen-

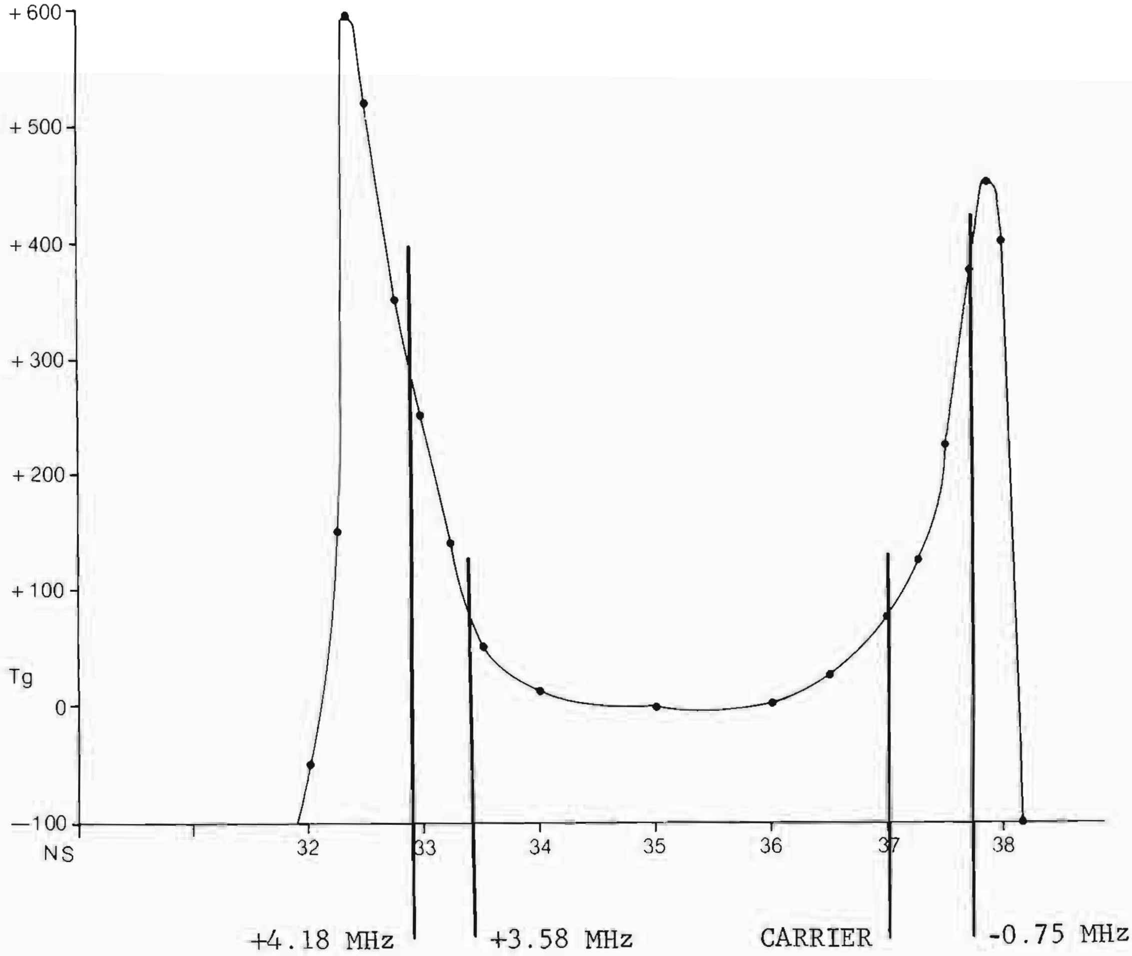


Fig. 14. Delay of typical VSB filter.

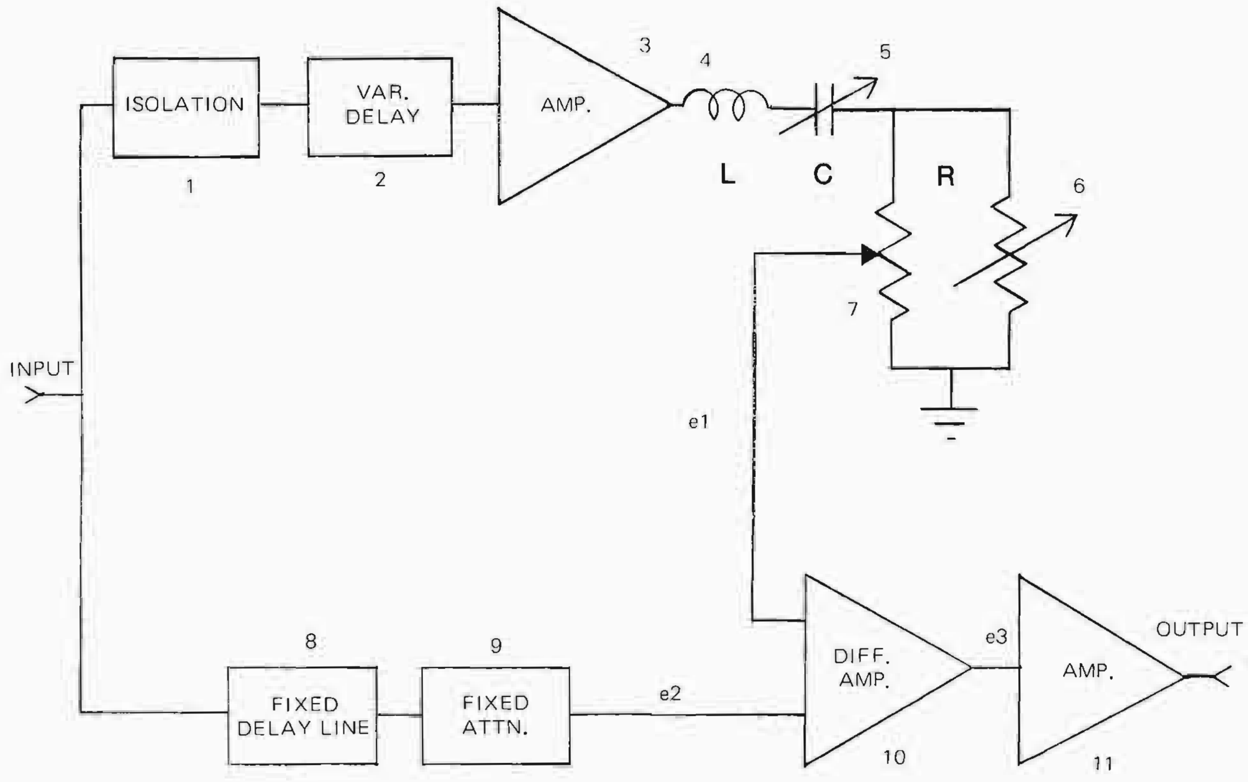


Fig. 15. Block diagram of active delay compensator.

sate nonuniform delay is by artificially delaying elements in the spectrum in order to equalize delay for all components.

This can be accomplished by using all-pass networks (which are not minimum phase type networks). An all-pass has an amplitude response which theoretically is independent of frequency and has a delay maximum at one frequency and zero or finite delay at all other frequencies. Delay compensation at IF frequencies has been accomplished using passive all-pass networks.[6] Compensation using active circuits is now feasible and practical, which provide greater flexibility and accuracy.

The concept of active all-passes is not new,[7,8] but the use at IF frequencies using solid state devices is a recent accomplishment. Fig. 16 depicts voltage relationships of an active all-pass. The phasor relationship through the upper path is shown by phasor e_1 which will vary with frequency and coincide with the real axis at resonance of the LC circuit. Its tip will travel on a complete circle from zero to infinite frequency. Phasor e_2 has a magnitude of one-half of e_1 at resonance and will be subtracted from e_1. It is, therefore, pointing to the left, parallel with the real axis, and projecting from the tip of e_2. The difference phasor of e_2 minus e_1 which is identified as e_3 has a magnitude which is independent of frequency and equal to e_2. Its phase is a function of frequency and will rotate from $-180°$ for zero frequency, to $+180°$ for infinite frequency. Envelope delay is defined as a rate of change of the phase angle of e_3 and this derivative typically is shown in Fig. 17. The point of maximum delay occurs at resonance of LC, with the magnitude controlled by R. If it were physically possible to reduce R to zero, delay would be infinite. If the area under the curve is integrated from zero to infinite frequency, one would find that it is independent of R.

Two quantities characterize the behavior of an active all-pass: ω_0 and γ_0 which are the coordinates of the poles and the zeros in the complex frequency plane as shown in Fig. 8. Envelope delay as a function of frequency is defined as:

$$\tau(\omega) = 2\gamma_0 \left[\frac{1}{\gamma_2^0 + (\omega - \omega_0)^2} + \frac{1}{\gamma_2^0 + (\omega + \omega_0)^2} \right]$$

Circuits intended for IF frequency applications are generally chosen such that γ_0 is considerably smaller than ω_0 which leads, with sufficient accuracy, to the following simplification of the frequency of maximum delay.

$$\omega(\tau_{max}) = \omega_0$$

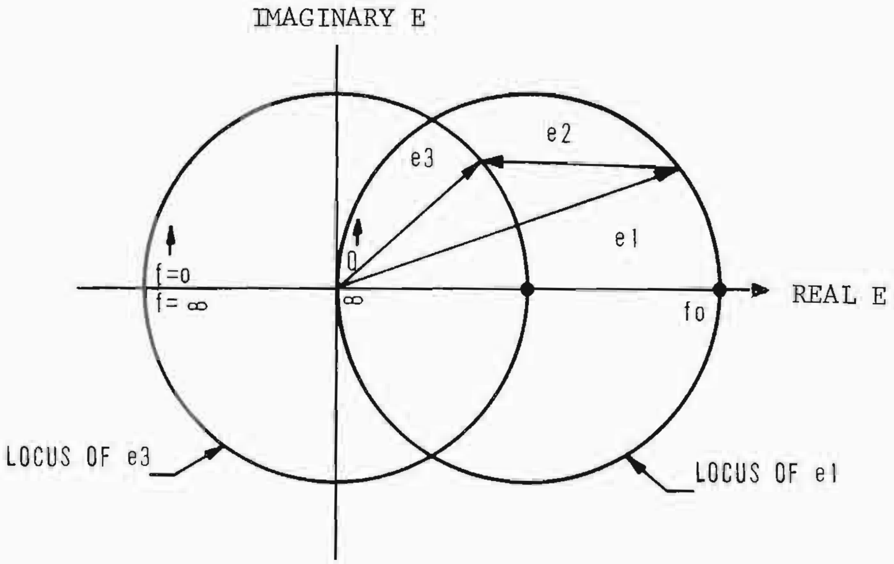


Fig. 16. Phasor relationship of active all-pass.

ω_o is the resonant frequency of LC circuit (components 4 and 5) and the equation simply states that the maximum delay occurs at the resonance frequency. (This is not true when ω_o and γ_o are nearly equal in magnitude which is analogous to the fact the resonant frequency of a tuned circuit with low Q does not coincide with the frequency of maximum impedance or equal magnitude for the reactance of L and C.)

The delay at this frequency is (still with the assumption the γ_o is substantially smaller than ω_o) $\tau_{max} = \frac{2}{\gamma_o}$.

A typical circuit with values of:

$L = 2.2$ uH
$C = 8.4$ pf
R = varies from 20-120 ohms.

Will produce

$$\gamma_o = \frac{R}{2L} = 4.545 \text{ to } 27.27 \times 10^6 \; [s^{-1}]$$

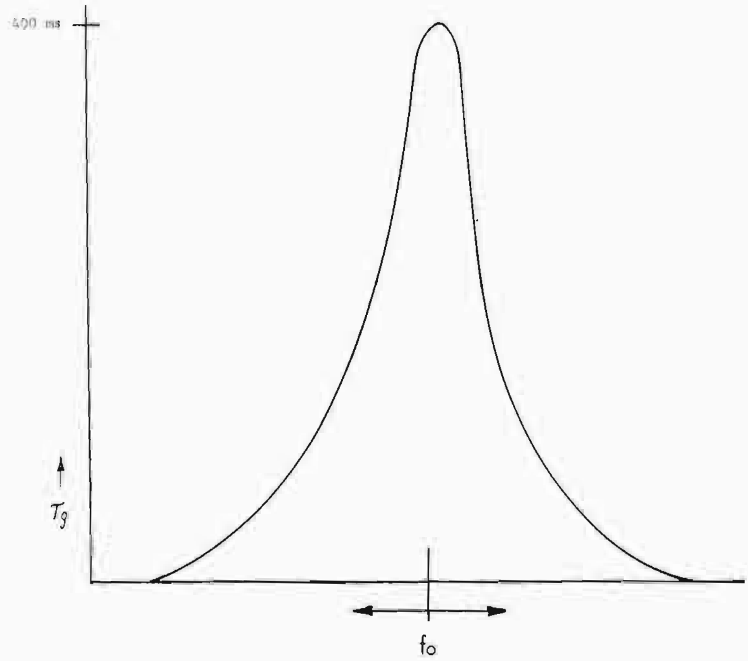


Fig. 17. Time-delay of typical active all-pass.

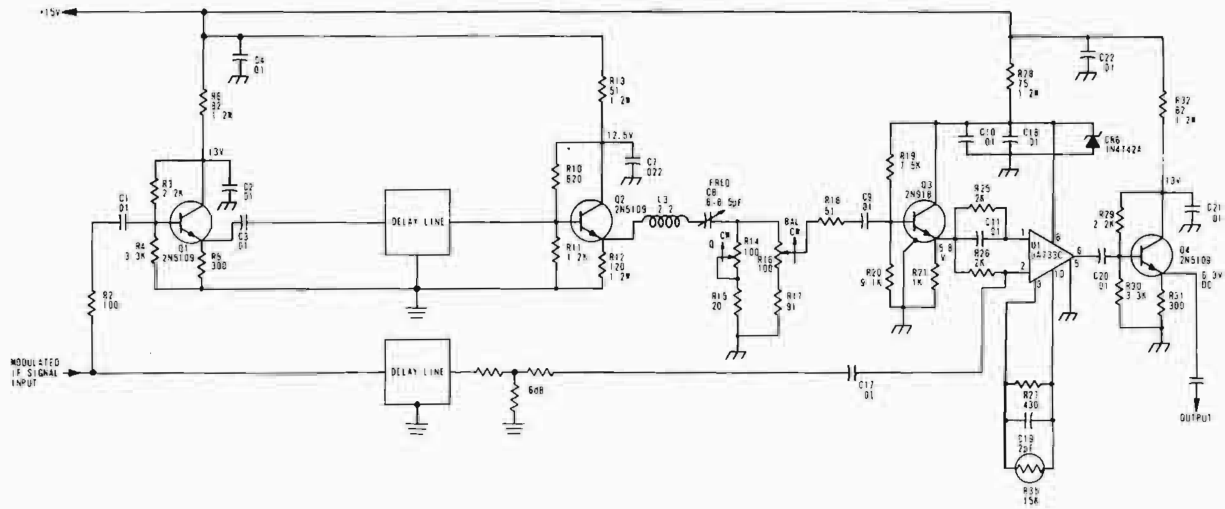


Fig. 18. Simplified schematic of active all-pass.

will have a maximum delay at 37 MHz with delay varying from 440 ns at an *R* of 20 ohms to 73 ns with an *R* of 120 ohms.

The frequency of maximum delay can be chosen anywhere within the passband without affecting the amount of maximum delay by simply tuning C. The amount of delay at any frequency can be varied by changing *R* without changing the frequency of maximum delay.

If γ_0 is chosen to produce approximately 350 ns of maximum delay, it is found that the three sections stagger-tuned over the passband of a television system satisfying the FCC Rules and Regulations will be sufficient to correct the delay of the VSB filter shown in Fig. 14, to ±30 ns. Adding more sections will improve the correction. The small number of sections needed for this correction is a further advantage of correction of envelope delay at IF frequencies as opposed to correction at video frequencies where more than 10 times the number of all-pass sections are required to attain a comparable degree of correction. Fig. 18 shows a simplified schematic of an active all-pass section. The value of the variable capacitor is chosen to allow the circuit to be tuned from 32 to 40 MHz covering the entire IF bandpass.

Adjustable, frequency-independent delay is provided to assure proper timing of the signals through the frequency-dependent and through the frequency-independent path. Such a delay section is not required for all passes designed for use in video frequency ranges, as the time delay difference through the circuit is negligible at low frequencies.

One should keep in mind when trying to understand the functions of this circuit that the tip of voltage e_2 does not travel with constant speed along the circumference of the circle but moves very slowly at first from zero to say 80% of the resonant frequency, goes rapidly through resonance, and will slow down again continuing to infinite frequency. The speed-up is more pronounced with smaller values of γ_0.

The circuit has four adjustments. Two control only amplitude response and are generally set for a flat response at one time. They are R8 and R16. R8 affects the placement of voltage e_2,

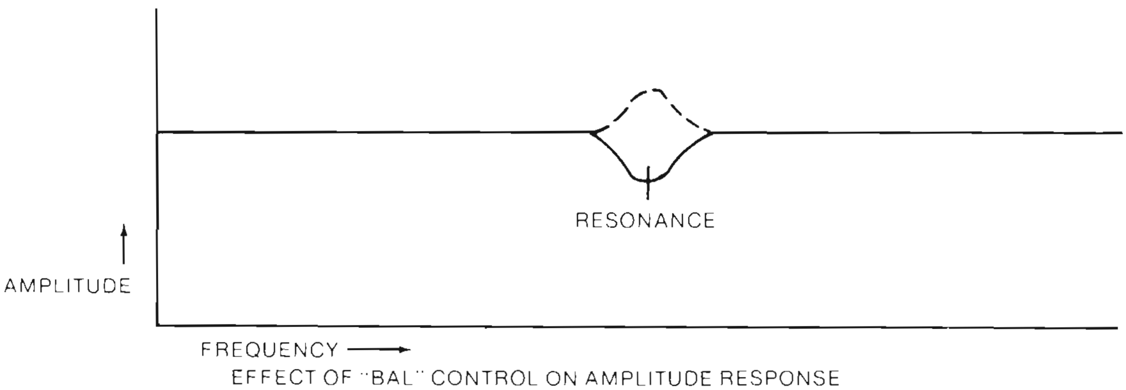


Fig. 19. Active all-pass, effective of mistiming.

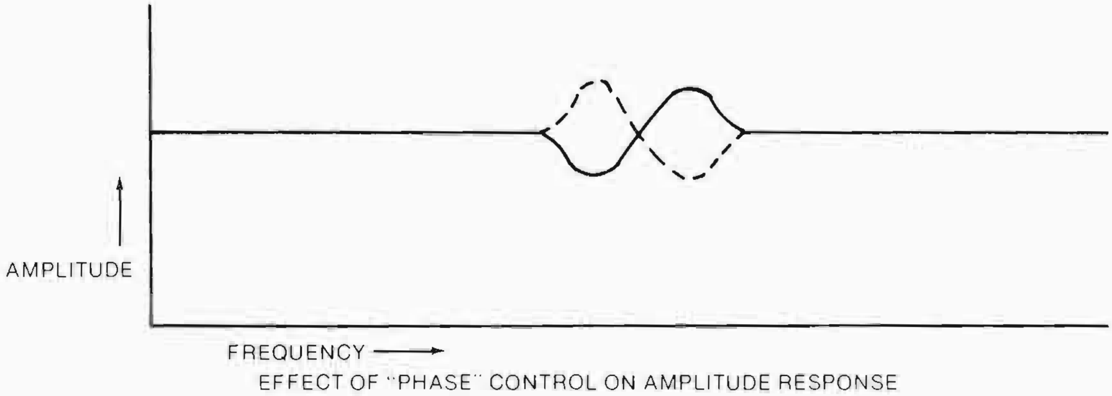


Fig. 20. Active all-pass, effect of variation in ratio of $\frac{E1}{E2}$.

which should be exactly parallel to the real axis. R16 controls the length of e_2 and, therefore, the ratio of e_2 to e_1, which should be exactly 0.5.

Misadjustment of R8 will cause amplitude variation as shown in Fig. 19. The effect of R16 is shown in Fig. 20, both adjustments only affect the amplitude response of the all-pass, they do not affect the delay. Since the disturbances shown in Figs. 19 and 20 occur at the frequency where L and C are resonant, slight adjustment away from balance of R16 serves as a ready means to find the resonant frequency of L and C.

To change the frequency of maximum delay only C needs to be adjusted. The effect of R14 which changes γ_0 is shown in Fig. 21. This control is labeled "Q" control as it somewhat resembles the effect of a series resistance on the amplitude response of a resonant circuit.

Initial adjustment begins with setting R8 and R16 for each printed circuit board for a flat response while using the above mentioned R16 to set the resonant frequency correctly for each board. To facilitate each adjustment it is beneficial to bypass all but the printed circuit board which is being adjusted. This will enable the operator to view each board independent of all other boards.

Final adjustment for proper delay is made through small changes in C and R14 while sweeping the unit for envelope delay, or by using proper test signals in the time domain.

Delay adjustment near carrier (±50 kHz) can only be performed with test signals (window) in the time domain since no sweep equipment is available which allows observation sufficiently close to carrier, irrespective of whether amplitude or time delay is swept. The importance of performance within ±50 kHz of carrier is often overlooked.

Fig. 22 shows the schematic of one section of an active all-pass compensated for video fre-

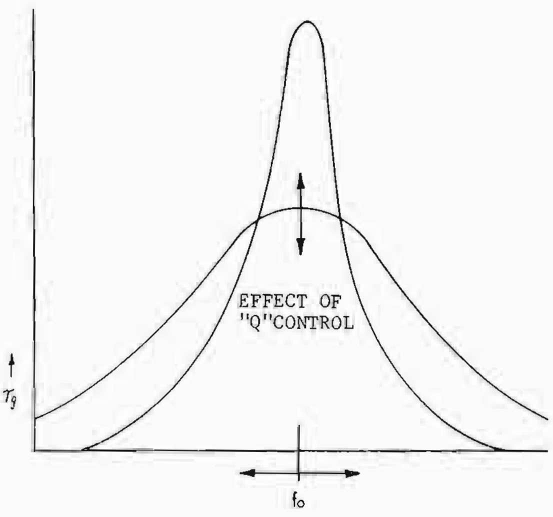


Fig. 21. Active all-pass, effect of R14 and γ_0.

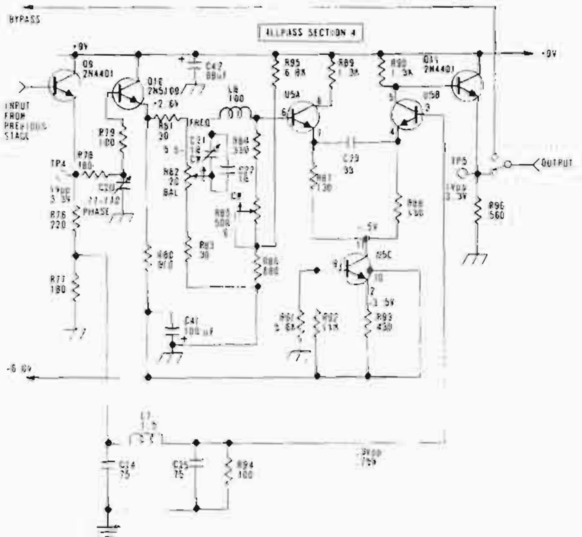


Fig. 22. Schematic of video active all-pass.

quencies. The shorter transmission delay relative to one period of the highest operating frequency of 4.2 MHz simplifies subsequent subtraction of both signals so that only one fixed time delay section is required.

Visual Sideband Filter

To conserve bandwidth, TV signals are generally required to be transmitted with part of the lower sideband removed.

Fig. 1 shows the passband response of typical equipment which will satisfy the requirements of the FCC Rules and Regulations.

If a transmitter exhibits a sufficiently linear characteristic, the shaping of the passband may be performed at the transmitter output at an intermediate stage or, in part, at video frequencies. Operating systems are in use employing all of these methods.

While there is no difference in principle between bandshaping at high or low powers, there are practical differences affecting the degree of presence of spurious frequencies, the ease of tuning, the ease of repair of failures, size, cost, and complexity of the equipment.

Passband shaping can be performed at intermediate frequencies and at low power. The design must assure that the process of frequency translation and the process of power amplification is linear in amplitude and phase over the operating range and frequency in question. A bandpass to meet the requirements of Fig. 1 can, without great difficulty, be realized at IF frequencies in the 30 to 40 MHz range.[11,12]

Such a filter is shown in Fig. 4 with a picture of its amplitude response shown in Fig. 23. The envelope delay of such a filter can be found in Fig. 14 in the previous paragraph. The designation of this type of filter is CO53357 as outlined in Reference 12.

After determination of the required number of poles from Fig. 1 in Reference 12 (five poles in this case), the design of a prototype low-pass filter can be formulated as shown in Fig. 24.

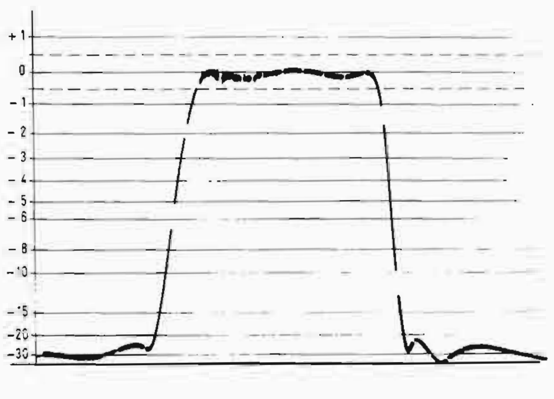


Fig. 23. Amplitude response of VSB filter.

This low-pass prototype is then transformed into its bandpass equivalent as determined by the required mean frequency. In doing this, some unrealizable circuit elements are found in the series portion of the filter which require transformation from the original configuration of the series elements as shown in Fig. 25A into a more suitable set of equivalents as shown in Fig. 25B.

The actual physical form of this filter must be chosen carefully to minimize stray capacitance and stray coupling and to assure that each reactance performs only the function for which it is provided. The success of the designer in constructing a useful filter in this particular application is not determined by his skill within the mathematical portion, but by his skill in the practical circuit realization.

This type of filter is known either as Cauer or elliptical and is generally chosen when a rapid transition from passband to stopband with a minimum number of circuit elements is desired, and a certain amount of ripple in the pass- as well as in the stopband can be tolerated.

The frequency of operation makes it possible to use air coils, air capacitors, and porcelain capacitors which produce a design of unusual stability, which is practically unaffected by changes of ambient temperature and the course of time.

The tuning range of the capacitors is chosen to allow tuning of this VSB filter over a frequency range sufficiently large to meet all the different standards of television systems around the world (with the exception of SYSTEM L, CCIR).

There is no question that any manufacturing economy achieved by using fewer components, easier assembly methods, simpler tests, larger number of similar components, or more universally useful circuits will quickly benefit the final user in lower capital costs, lower operating expenses, higher reliability, and better performance.

The output of this VSB filter is applied to an amplifier which will overcome the passband attenuation of approximately 8 dB.

The filter can be bypassed through a front panel switch without causing any change in gain at the carrier frequency and will then extend the passband of the Exciter-Modulator to ±10 MHz symmetrical to the carrier frequency.

The last stage of the IF assembly is a PIN diode attenuator with a range of approximately 13 dB. It controls total system gain and can change, therefore, the output power of the transmitter from 110% of rated power to 5% of rated power. The controlling quantity is a dc current through the PIN diode. This current is adjustable by a front panel control which is

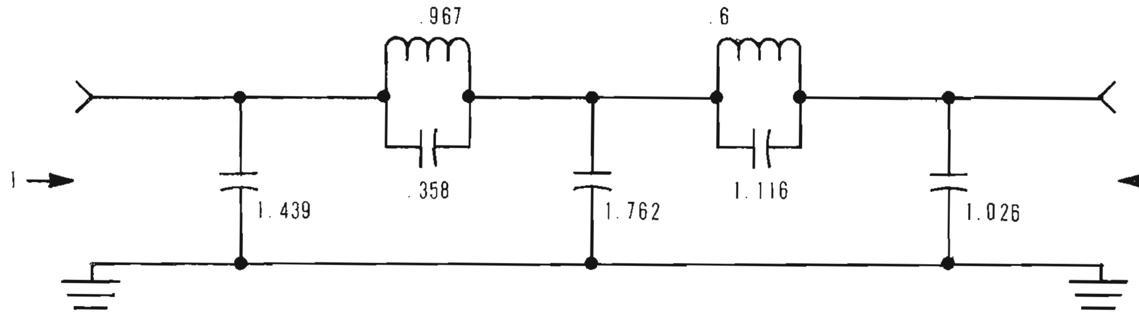


Fig. 24. Low pass prototype of VSB filter.

also motor driven for remote access. The PIN diode looks into the base of an emitter follower whose output will be connected through a suitable attenuator to the up-converter. The change in performance of the processed IF signal of the above stated range from 5 to 100% is almost unrecognizable.

The level of the IF voltage at the peak of sync is available at the front panel multimeter. This signal is applied to the up-converter to be translated to the final frequency of the station.

Up-Converter

A ring modulator, also known in this application as a double-balanced mixer performs the translation to the final operating frequency. This type of conversion has a very desirable output spectrum with both input signals as well as all even order mixing products suppressed.

The mixing products, other than the wanted frequency requiring the greatest attention are the sum frequency and the pump frequency.

The difference frequency between the pump and the IF is the wanted signal and should be available from the up-converter without any deterioration. The sum and pump frequencies are rejected by a bandpass filter. To ascertain preservation of the wanted signal a wide bandwidth of four times the actual passband is employed. A commercially available bandpass suits this application and provides 30 dB attenuation for the pump signal and 45 dB for the sum frequency. Coupled with the conversion loss and the transfer data of the mixer plus the frequency rolloff of the following amplifier and the Exciter proper, it will reduce the level of the sum frequency to a neglible value (in excess of 90 dB) and reduce the pump frequency from 30 to 35 dB below the wanted signal.

The selectivity of the following transmitter stages will finally reduce the pump frequency to below 90 dB. The characteristic of a double balanced mixer and its isolation between ports is shown in Fig. 26. Because of the inherent design, these values can be maintained with utmost certainty, and they are not influenced by time or temperature.

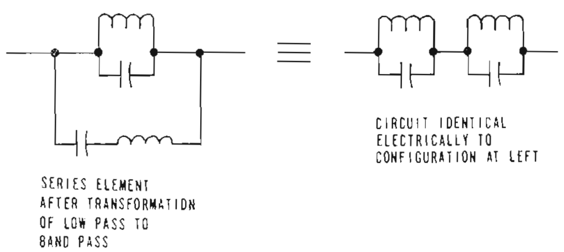


Fig. 25. Series element transformation a, b.

Power Amplifier (Exciter)

In specifying an amplifier for a television visual application the following parameters are of importance:

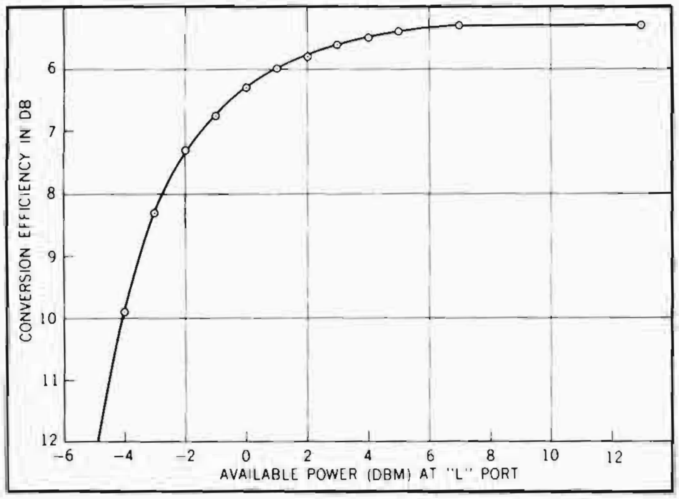
1. Linear frequency response at any power level over the frequency range in question,
2. Linear transfer characteristics, input versus output.
3. Linear phase versus frequency characteristics independent of power level.

The order stated is representative of the degree of difficulty. Item 3 is especially difficult in higher power solid state amplifiers, i.e., where more than 10 watts peak of sync power is demanded of a single device.

Fig. 27 shows the schematic of an amplifier meeting the above stringent requirements at an overall gain of 40 dB with a maximum peak of sync output of 1 watt.

Fig. 28 shows typically the frequency response of this amplifier.

The departure of the input to output phase at varying power levels can easily be measured with a Vector voltmeter and will reveal variation



Conversion Efficiency

10514A

MIXER CONVERSION LOSS (Single Sideband):

Frequency Range		Conversion Loss (dB max.)
f_L and f_R (MHz)	f_x (MHz)	
0.5 - 50	dc - 50	7
0.2 - 500	dc - 500	9

NOISE PERFORMANCE:

Frequency Range		Noise Figure (dB max.)
f_L and f_R (MHz)	f_x (MHz)	
0.5 - 60	0.05 - 60	6.5
60 - 500	0.05 - 500	9

Less than 100 nV per root cycle max. at output for f_x at 10 Hz.

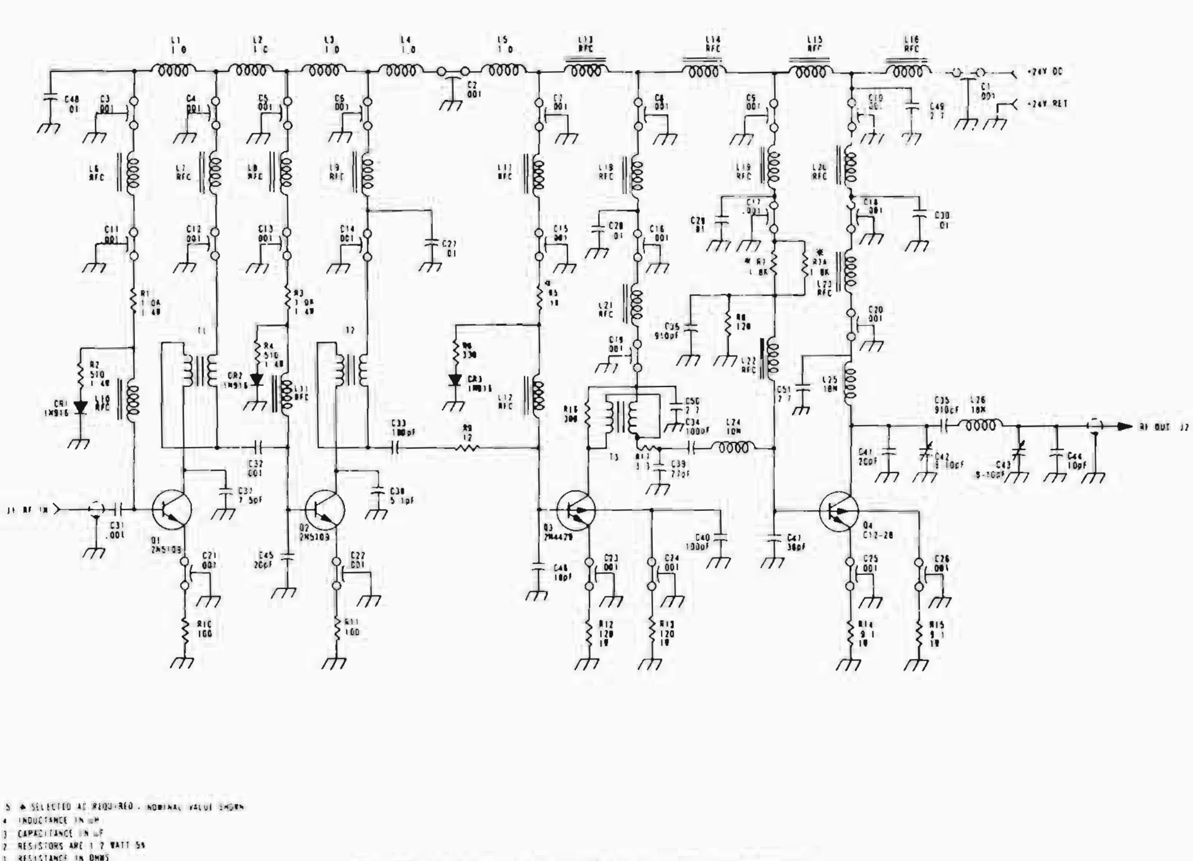
MIXER BALANCE:

Mixer Balance for	In Frequency Ranges (MHz)		Referenced to
	f_L, f_R: 0.5 - 50; f_x: dc - 50	f_L, f_R: 0.2 - 500; f_x: dc - 500	
f_L at R	40 dB	30 dB	f_L
f_L at X	40 dB	20 dB	f_L
f_R at L	45 dB	30 dB	f_R
f_R at X	25 dB	15 dB	f_R
f_x at L	35 dB	15 dB	f_x
f_x at R	25 dB	15 dB	f_x

Product	Level†	Product	Level†
$2f_L - f_R$	30 dB	$2f_R - f_L$	65 dB
$3f_L - 2f_R$	70 dB	$3f_R - 2f_L$	65 dB
$4f_L - 3f_R$	70 dB	$4f_R - 3f_L$	85 dB
$5f_L - 4f_R$	90 dB	$5f_R - 4f_L$	90 dB
$6f_L - 5f_R$	95 dB	$6f_R - 5f_L$	100 dB
$7f_L - 6f_R$	100 dB	$7f_R - 6f_L$	100 dB

† Referred to f_x level.

Fig. 26. Double balanced mixer characteristic.



5 ★ SELECTED AS REQUIRED - NOMINAL VALUE SHOWN
4 INDUCTANCE IN uH
3 CAPACITANCE IN uF
2 RESISTORS ARE 1/2 WATT 5%
1 RESISTANCE IN OHMS
UNLESS OTHERWISE NOTED

Fig. 27. Solid state amplifier, 1 watt, schematic.

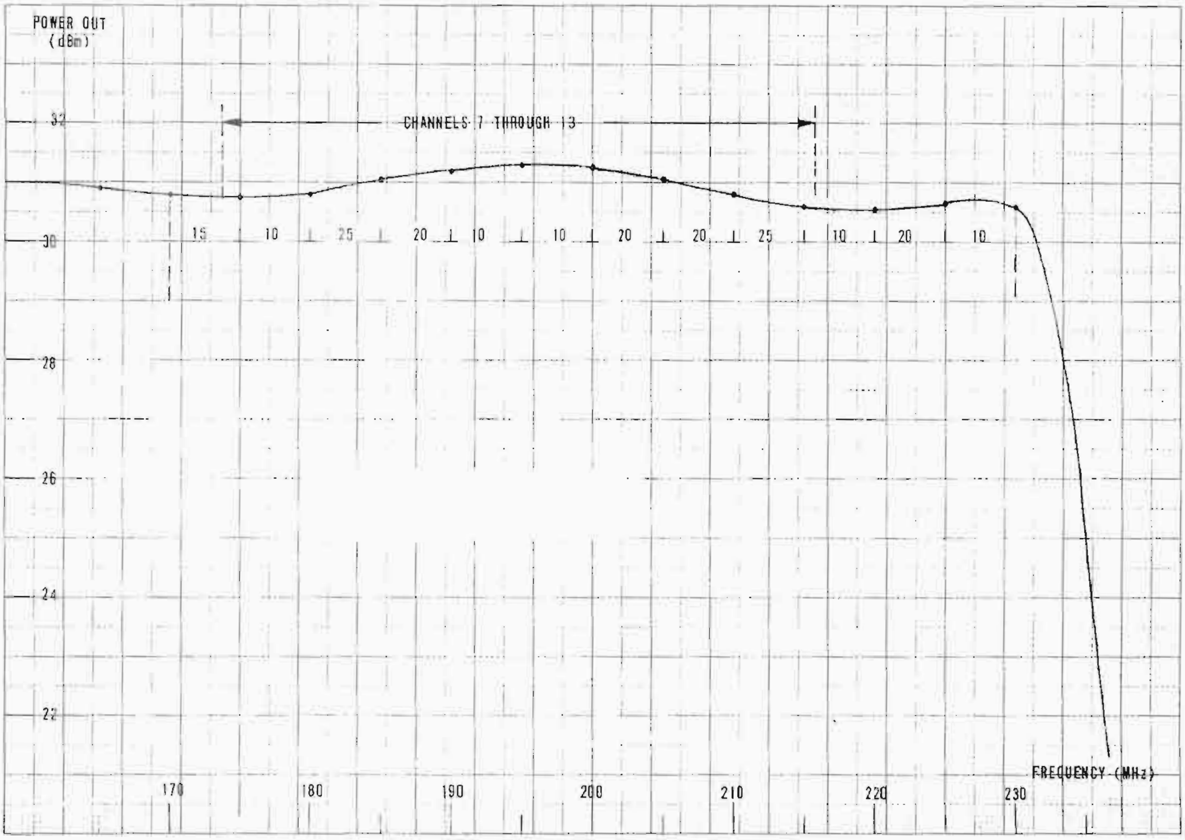


Fig. 28. Solid state amplifier, 1 watt, frequency response.

of less than 1° from 1 mw to 1-watt output power. Design of this amplifier is so arranged that it can safely be operated into any termination, including open or short circuits. Following this amplifier a directional coupler will allow sensing of the peak of sync power level leaving the Exciter as well as the power level of reflected power. Both are indicated on the front panel meter.

The circuitry described so far has produced a television visual signal at a power level of approximately 1 watt peak-of-sync, which carries the original video information with a very high degree of fidelity, proper modulation percentages, proper passband, and the proper envelope delay. This signal can, if desired, be transmitted. To obtain powers in excess of 1 watt all that is required now is amplification.

Intermediate Amplifier

There is little difference in principle between tube type amplifiers for 100 watts output or 10 kw output. The different approaches taken, however, are dictated by the physical size of components and devices and how their size relates to the frequency or wavelengths employed and, especially in higher power devices, by the need to remove large amounts of unwanted heat generated in the device.

Design of a linear amplifier using thermionic tubes for television service progresses as follows:

1. Determination of the highest load impedance which will provide the required bandwidth.
2. Establish maximum power available under conditions of 1 and determine stage gain.
3. Check that no ratings of the device are exceeded and establish safety factors.

Relative to Condition 1, Reference 13 provides a ready made design approach which comes close enough to theoretical limits to be of great practical help. See Fig. 29. C1 in Fig. 29 is the output capacity of the tube including all stray capacity. It will become quickly clear that the higher the tube's output capacity, the lower the load impedance will be for a given bandwidth. Therefore, smaller tubes will allow higher load impedances or greater bandwidth. Typical output capacities for tubes in the 10 to 100 watts power range are 1 to 10 pF.

A typical small tube, e.g., 8122, will show the following characteristics:

$$f_o = 54 \text{ MHz}$$
$$2f_1 = 6 \text{ MHz}$$

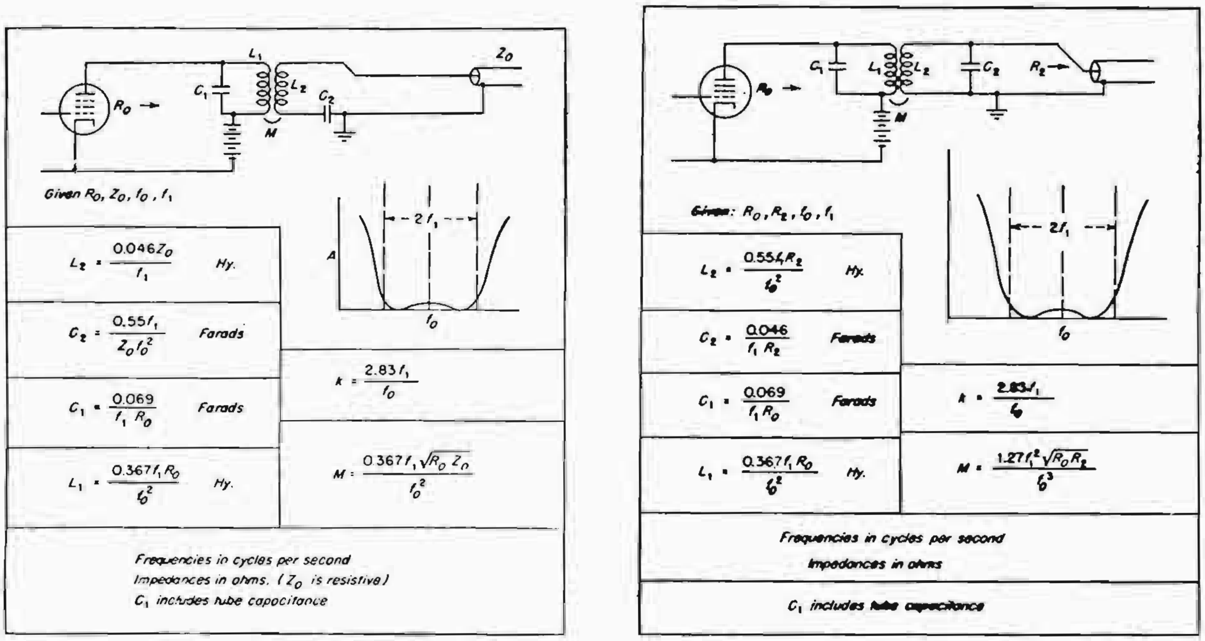


Fig. 29. Double tuned circuit.

C_1 = 15 pF
L_1 = 578 nH (for R2 = 50 ohm)
C_2 = 11.3 pF
L_2 = 766 nH
R_o = 1533 ohm.

For R_o a load line can be constructed (assuming for the moment that R_o is resistive over the entire bandwidth) to determine output power capability of the tube.

A graphical method established by Reference 14 is most convenient. Plastic overlays for this analysis are available from Eimac. To utilize Chaffee's method, constant current curves must be available which for most power tubes are part of the data sheet supplied by the tube manufacturer.

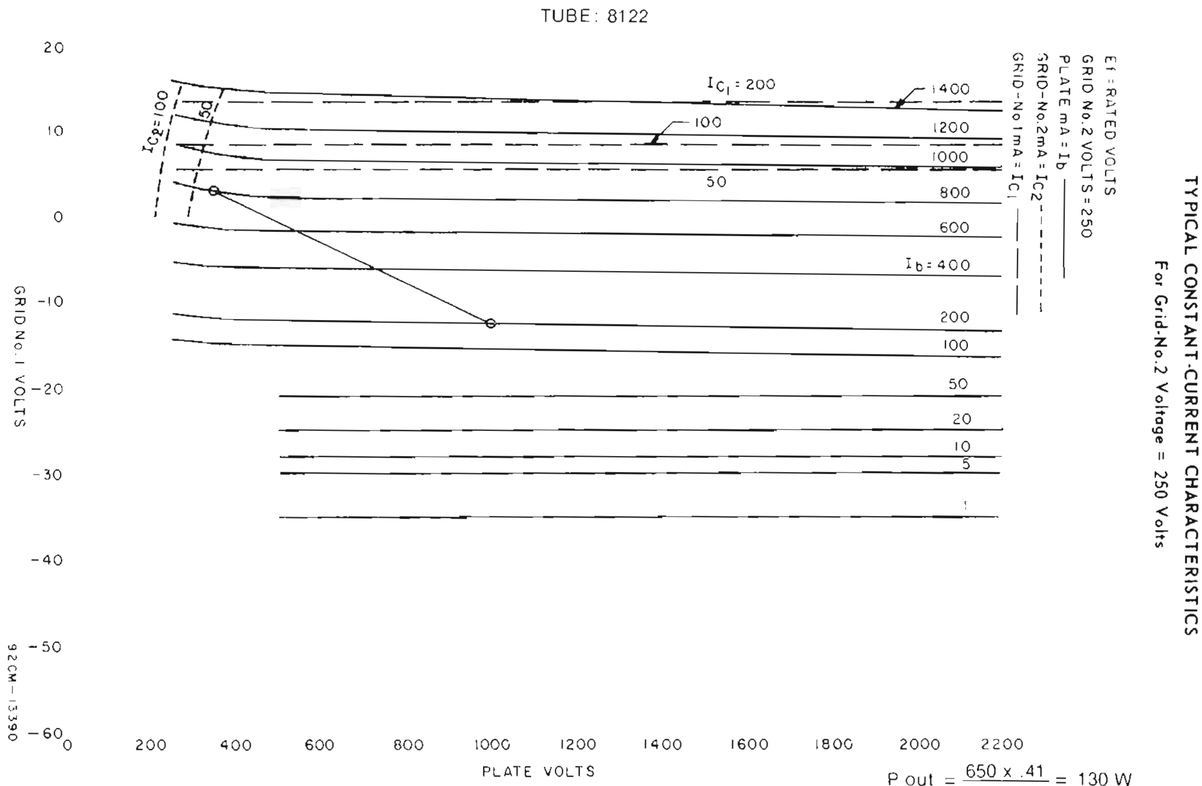
Fig. 30 shows a sample calculation using a 8122 tetrode which indicates power output, load impedance, and gain to be expected under the conditions as stated. It should be noted that the tube is driven only lightly into grid conduction.

The methods cited so far are intended to demonstrate to a television transmitter user the thinking on which the designer bases his decisions. The methods are chosen mainly because of their simplicity rather than accuracy, but it can be expected that the results obtained will be within 20% of actual performance. For example, the calculated RF anode current does not include the "negative" swing. However, if closer accuracy is desired, more elaborate versions of the tube calculator are available. Finally, checks must be made to ascertain that all circuit elements for power levels and voltages in question operate safely within their maximum ratings established by individual manufacturers, plus any safety factor the equipment designer wishes to apply to gain a greater degree of reliability. From the example chosen above, it is evident that one is in a transitional area where lumped circuit components become increasingly ill-defined and impractical, but distributed elements are still often unwieldy. The designer's choice rests largely on his personal judgment and his mechanical skills of circuit implementation. Often a softened approach is taken by only partially employing distributed devices and also, through the use of "Striplines" whose physical embodiment do not create pure distributed elements. Yet, they are extremely useful in this transitional area.

Fig. 31 is a photograph showing a typical approach in this area. The foregoing comments apply largely to VHF low band equipment. For use on high-band channels from 174 MHz up, lumped elements are practical only to levels of 10 to perhaps 100 watts, but from thereon coaxial construction is generally required. Table 1 lists a series of tubes manufactured by several companies which find application in television service. These are arranged in ascending power dissipation capability.

Power Amplifiers

Most TV transmitters over 5 kw require RF linear amplification to reach power levels up to 25 to 30 kw per tube.



$$P\,out = \frac{650 \times .41}{2} = 130\ W$$

$$Z_L = 1580\ \Omega = \frac{650}{.41}$$

$$P\ DRIVE \approx E \cdot gm \approx 5W$$

GAIN = 14 db

Fig. 30. Power output of 8122 tube.

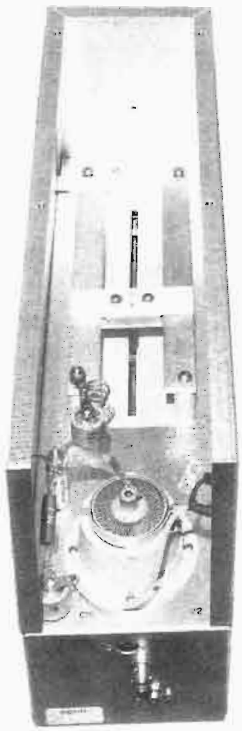


Fig. 31. Photograph of IPA anode tuning circuit.

Table 1 shows the number of different tubes available for this type of service. At first the list appears to provide a fairly wide choice of tube types. But additional requirements, e.g., cost, cooling, cathode construction, size, etc., often narrow the choice, sometimes to such a degree, that compromises are required to find even one tube type for a particular use.

The principal approach to design a high power stage is not different from the outline given in the previous section. It becomes obvious, however, that physical size works against the designer in a multifaceted way. While pseudo-distributed circuits, like striplines (in a sufficiently small enclosure) are still feasible for Low Band VHF transmitters, coaxial cavities are the only useful and practical approach for Band service. Operation at UHF frequencies using gridded tubes will not be considered here even though interesting gridded tube designs do exist. From principles mentioned in the previous Section, it can be stated qualitatively that if a tube, or other device, has zero output capacity an amplifier with infinite bandwidth could be

TABLE 1

Power Tubes for TV Linear Amplifier Service (Maximum Ratings)

Number	Manufacturer	Type	Frequency (in MHz)	Power[a] (in watts)	Output capacity (in pF)	Gain[b] (in dB)	Anode voltage (in volts)	Cathode current (in mA)	Anode dissipation (in watts)	Remarks
YD1300	AMPEREX	Triode	1,000	35[c]	3.5	20	2,000	200	300	
YDi302	AMPEREX	Triode	1,000	55[c]	3.5	19	2,000	250	325	
8814	AMPEREX	Tetrode	260	1,550	9	14	4,000	1,000	1,500	
YD1334	AMPEREX	Triode	1,000	110	8	14	3,500	550	1,800	
YD1336	AMPEREX	Triode	1,000	220	8	15	3,500	550	1,800	
YD1335	AMPEREX	Triode	1,000	550	8	14	3,800	700	1,900	
YL1540	AMPEREX	Tetrode	260	1,150	8	20[d]	4,000	1,500	2,000	
8812	AMPEREX	Tetrode	250	8,600	16.4	14	6,500	2,250	6,000	
8813	AMPEREX	Tetrode	250	18,400	18	14	9,000	3,500	12,000	
8915	AMPEREX	Tetrode	260	27,500	23	14	9,000	7,000	18,000	
8873	EIMAC	Focused triode	500		6		2,200	350	200	Conduc. cooled
4CX250B	EIMAC	Tetrode	500		4.5		2,000	250	250	
8875	EIMAC	Focused triode	500		6		2,200	250	300	Low vel. air cool
8874	EIMAC	Focused triode	500		6		2,200	350	400	
8877	EIMAC	Focused triode	250		10		4,000	1	1,500	
8938	EIMAC	Focused triode	500		13		4,000	1	1,500	
4CX1500B	EIMAC	Tetrode	110/225[e]		12		3,000	900	1,500	
3CX3000A7	EIMAC	Triode	110		24		5,000	2.5	3,000	
4CX5000A	EIMAC	Tetrode	30/225[e]		14.5		7,500	4	5,000	
3CX10000A7		Triode	160	15,000	36		8,000	5	10,000	
4CX15000A	EIMAC	Tetrode	110/225[e]	16,500	25.5	10	6,500	5	15,000	
3CX20000A7	EIMAC	Triode	110/216[e]	25,000	36	13	8,000	6	20,000	
CX20000V7	EIMAC	Focused triode	250	25,000	20	13	10,000	5	20,000	
8122	RCA	Tetrode	500	130	7	14	3,000	300	400	
8791V1	RCA	Tetrode	400	500	5	13	3,000	750	1,000	
8792V1	RCA	Tetrode	400	1,350	16	12	3,500	1.25	1,500	
4680	RCA	Tetrode	900	1,500	16	11	5,000	2	1,500	
5762	RCA	Triode	220	6,350	18.5	8	4,500	2	4,000	
8890	RCA	Tetrode	400	5,000	12	16	8,000	4	5,000	
4682	RCA	Tetrode	400	7,500	10	16	13,000	4	8,000	
8501	RCA	Tetrode	900	5,500	13	9	7,000	4	10,000	
6166A	RCA	Tetrode	220	14,000	24	9	7,500	4	12,000	
8806	RCA	Tetrode	400	10,000	13	15	8,000	4	12,500	
8807	RCA	Tetrode	400	17,600	18.5	14	9,000	6	15,000	
4681	RCA	Tetrode	400	17,600	18.5	14	7,500	6	15,000	
4683	RCA	Tetrode	400	17,600	18.5	16	9,000	6	15,000	
8891	RCA	Tetrode	400	20,000	17	14	9,000	6	17,500	
8916	RCA	Tetrode	400	27,500	17	14	13,000	6	22,000	
6448	RCA	Tetrode	890	15,000	30	14	7,000	7	26,000	
6806	RCA	Tetrode	890	28,000	30	15	9,000	8.25	35,000	

[a]Peak of Sync Power in TV linear service, 6 MHz minimum bandwidth at -1 dB points.
[b]Gain in TV linear service as grounded grid amplifiers.
[c]Sync power output in TV translator service, combined sound and vision.
[d]Grid-driven amplifier.
[e]Max. frequency for TV visual service.

built using an ideal coil and resistor as loads. If, however, distributed reactive elements, even ideal ones, are used, this is no longer true, even if the characteristic impedance of the distributed line goes to infinity. With finite impedance, one has to contend with a bandwidth shrinkage factor which has its cause in the stored energy of the distributed line.

When the cavity impedance reaches a value of about one-half the reactance of the anode capacitive reactance of the tube, the bandwidth is cut in half. A typical 15-kw tube may have the total output capacity of 30 pF, giving a reactance of 20 ohms.

A line impedance of at least 20 to 30 ohms is desirable and a typical cavity design can be found in Reference 15. Fig. 32 from Reference 15 illustrates the evolutionary steps in the realization of a cavity design, starting with a lumped equivalent through a distributed model to the

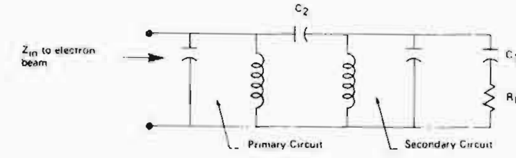


Fig. 32a. Cavity, double-tuned circuit model.

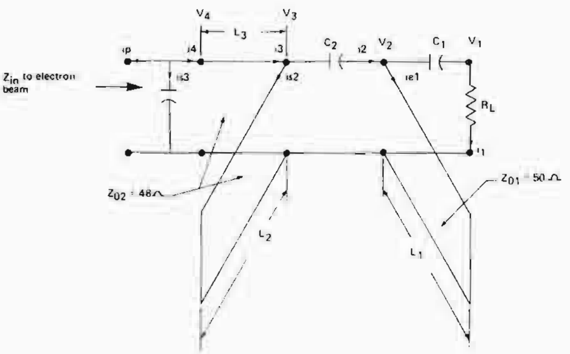
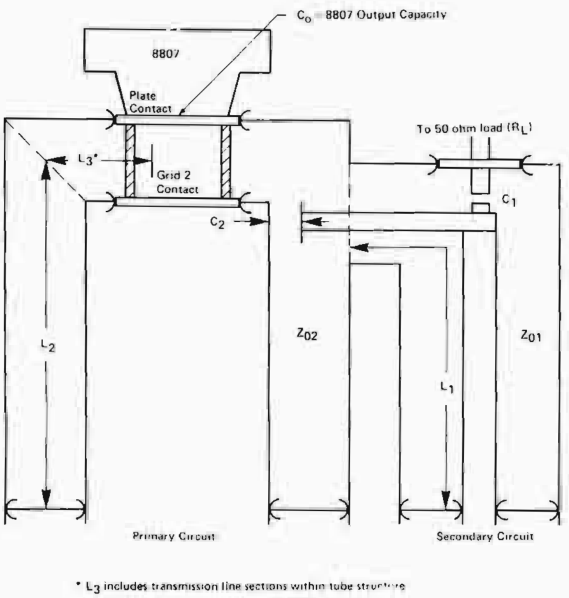


Fig. 32b. Cavity, double-tuned transmission line model.



* L3 includes transmission line sections within tube structure

Fig. 32c. Cavity, double-tuned including secondary circuit.

mechanical model. Fig. 33 depicts the final manufactured device.

The use of double-tuned circuits will increase the usable bandwidth by a factor of 1.6 over that of a single tuned circuit. The resistive component of the load presented by the above circuit is shown in Fig. 34.

Another important criteria in linear amplifier design is its transfer characteristic. This will determine gain and distortion. In a SSB, or vestigial sideband system (VSB), nonlinear distortion will not only falsify the information

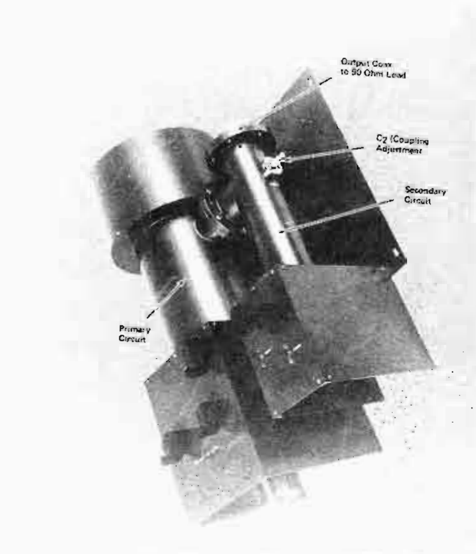


Fig. 33. 18 kw cavity for 8807 tube.

being carried, but also recreate the unwanted sideband or a portion of it.

TV systems worldwide need not meet very stringent requirements of unwanted sideband suppression as opposed to SSB or ISB (independent sideband systems). Government regulations of TV systems universally require 20 dB attenuation of the suppressed portion of the lower sideband. The remaining vestige of the lower sideband extends to 0.75 MHz below carrier. The 20 dB attenuation must be maintained from 1.25 MHz below carrier. The lower side-

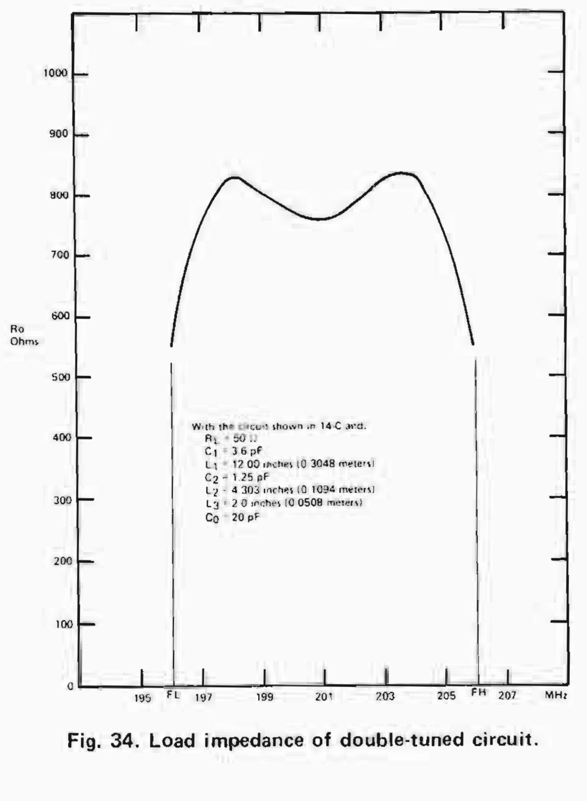


Fig. 34. Load impedance of double-tuned circuit.

band of the color subcarrier (−3.58 MHz) must be attenuated to −42 dB. Reference 15 provides much insight into the mechanism responsible for nonperfect transfer characteristics. Fig. 35 gives an indication of intermodulation performance of a typical tube.

Linearity can be measured using two-tone signals, especially in narrow band systems. Two RF carriers of equal magnitude, 1 kHz apart, are used to drive the amplifier. Third and fifth order products are measured and related to the magnitude of one of the two RF carriers as a means of linearity. If f_1 and f_2 are 1000 and 1001 kHz, the first third order product falls at 1002 kHz ($2f_1 - f_2$) and 999 kHz ($2f_2 - f_1$) while the fifth order product falls on 1003 kHz ($3f_2 - 2f_1$) and 998 kHz ($3f_1 - 2f_2$).

Tubes intended for TV translator service are rated employing a three-tone test which more closely duplicates actual operating condition in TV service. The three tones represent: the visual carrier, the aural carrier, and the upper color subcarrier sideband, with amplitude relationships of −8, −7, and −16 dB. The sum of the three signals is 0 dB and the reference normally chosen is the peak-of-sync operating power. Under the above conditions, the most visible interference is the difference frequency between the aural carrier and the color subcarrier sideband, a beat of approximately 920 kHz. Widely applied standards require this mixing product to be −52 dB or less, relative to the 0-dB reference signal.

There are a number of factors which will influence linearity of performance of an amplifier. Among those are the idling current and screen voltage (assuming the anode voltage is fixed). Fig. 35 shows that lower distortion results when higher idling currents are used. Decreased amplifier efficiency (higher input power) is the price one must pay for this improvement.

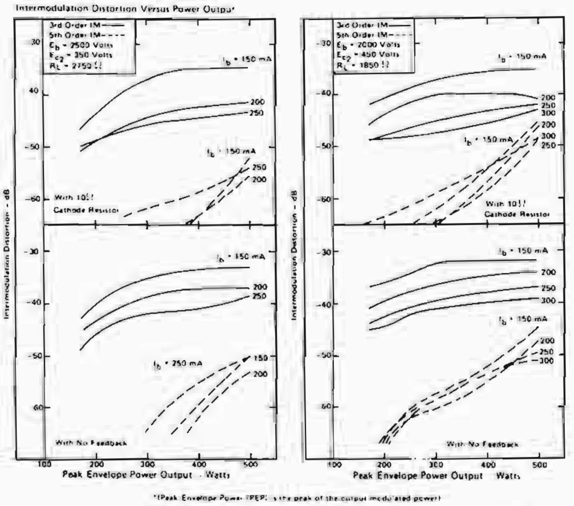


Fig. 35. Intermodulation distortion in linear amplifiers.

Fig. 36. Cermolox tubes (RCA).

Typical tubes for television service manufactured by RCA are shown in Fig. 36.

Typical 3-tone performance of power triodes suitable for translator service manufactured by Eimac are shown in Fig. 37.

To determine gain, power capability and dissipation, the same methods can be followed which were outlined in the previous paragraph dealing with intermediate power amplifiers.

Amplifiers over approximately 1kw must incorporate safety and protection circuitry not necessary for low power stages, since the destructiveness of failures is much more pronounced and costly in the higher power stages. Large power tubes are quite likely, especially during infancy to develop internal arcs (gas pings). The support circuitry (filament, bias, screen, and anode supplies) must be designed to be tolerant of such arcs and to arrest rather than maintain them.

To this end, the maximum current to be drawn from any supply should be limited to safe values. This value is different for all electrodes and varies with the internal construction of the tube. Maximum permissible values are supplied by the tube manufacturer. Often the user will find 1 to 10 ohm high wattage resistors

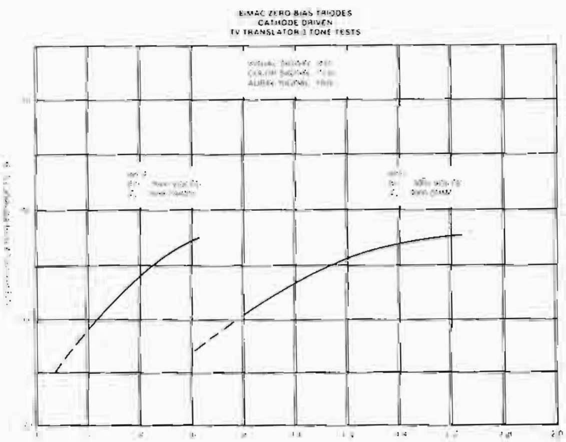


Fig. 37. Intermodulation distortion of 8877 and 8875 tubes.

(GLOBAR) in strategic places of the transmitter which perform this current, or energy limiting function. The application of supply voltages should not cause overshoots which often result from L-C type ringing in long supply leads. If the leads cannot be shortened, this L-C ringing must be damped by resistive means. Filament voltage should be applied slowly without exceeding maximum values defined by the tube manufacturer. The mechanical deformation of the tube filament between hot and cold states is a strong factor in determining the life of the cathode.

Tube life furthermore depends on operating temperature, and one should remember the rule of thumb (which incidentally, also applies to other incandescent devices operating in this general temperature range, for instance—light bulbs) that every 5% increase in supply voltage will cut life in half while each 5% decrease will double life, and so on.

Power tubes should be handled with kid-gloves (relatively speaking), especially when new and cold. The filament wires when cold are in their most brittle state. One should keep in mind that the tube elements are made from relatively soft copper and are not made of steel. (Even though they may look like steel.)

All power tubes listed on Table 1 are cooled by forced air. The final judgment of cooling effectiveness is anode core temperature. Therefore, if in doubt, one should measure anode core temperature in several places following the manufacturer's data sheet recommendation. For this purpose a temperature sensitive paint is most expedient and available from: TEMPIL, Hamilton Blvd., South Plainfield, NJ 07080. The suggested ranges are: 253°C, 226°C, 204°C, and 173°C.

Since the thermal output of a power tube under dc conditions can be measured quite accurately, a convenient method is available to measure airflow through the tube requiring only a thermometer. Assume a 8807 tube operated with 7kw anode voltage and idled at 1 amp (no RF drive applied) and the filament at 9.5 v, 145 amps. (The screen dissipation is negligible.) The tube is dissipating 8380 watts.

If the inlet temperature is 70°F, the outlet temperature (averaged over the width of the duct and measured approximately 4 to 6 feet away from the tube) is 115°F. The air flow in CFM is:

$$f_{CFM} = \frac{0.24\ w}{\rho\ \Delta T}$$

Where w = dissipated power in watts
ρ = air density (.075 lbs/f^3 at sea level and 68°F)
ΔT = Temperature in °F.

When values of the above example are inserted:

$$F = 600\ \text{CFM}.$$

Much useful information can be gathered from tube manufacturers application notes such as—AN-4869 available from RCA, Electronics Components, Harrison, NJ 07029.

AURAL TRANSMITTER

Aural Exciter/Modulator

The aural Exciter/Modulator will generate a 5-watt aural carrier, at the final frequency which carries the audio information, frequency modulated, onto the carrier. In addition a subcarrier can be frequency modulated on this carrier. This subcarrier constitutes a communications link from the transmitter back to the studio.

Fig. 38 is a block diagram of the aural Exciter.

The audio signal is available at a level of 10 dBm and will be terminated with the Exciters input impedance of 600 ohms.

The subcarrier amplitude is terminated in 2,000 ohms. A voltage of approximately 500 mv will cause ±2.5 kHz deviation of the aural carrier. The pump signal for the up-converter is provided by the visual Exciter and 5 mw are available into 50 ohms.

The aural Exciter/Modulator uses an IF approach. A modulated intermediate frequency carrier is produced at 32.5 MHz. The center frequency of this signal is controlled by a phase locked loop system.

The modulated oscillator which is placed in an oven with proportional temperature control operates directly at 32.5 MHz and employs a single varactor diode for frequency modulation. By maintaining a dc path through the diode an error voltage from the phase locked loop system will maintain the average (center frequency) within very narrow limits. The output of the modulated oscillator, after decoupling, is avail-

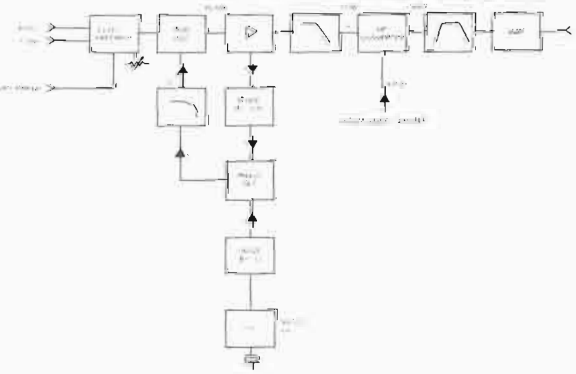


Fig. 38. Block diagram aural exciter/modulator.

able for AFC processing and up-conversion. To maintain the conversion process free of unwanted mixing products (as covered in detail in the Visual Exciter/Modulator section), a low pass filter is placed in the signal path before it is connected to the X port of the up-converter.

Again, the difference frequency is chosen and separated from the sum by a band-pass filter.[11] Amplification in a solid state amplifier is straight-forward and follows principles already explained in the visual Exciter/Modulator section. Biasing of the amplifier is chosen to operate all stages in a Class C mode as opposed to Class B for visual service.

The amplifier covers all high band VHF channels without further tuning and produces 46 dB of gain. A similar amplifier is used for all low band VHF channels. Class C operation makes it desirable to place a low-pass or band-pass filter at the output of the amplifier since higher levels of harmonic signals must be expected in a Class C amplifier. A 3-section (7-pole Chebycheff) bandpass with a bandwidth of approximately 15 MHz will assure sufficient harmonic attenuation.

Directional couplers and diodes allow to read forward and reflected power on a front panel meter.

The frequency response, FM signal-to-noise ratio and distortion are largely determined by circuit design of the modulated oscillator and can be maintained to very narrow limits. Stability of center frequency is determined by the control system chosen. Frequency control where the reference is a discriminator will always be several magnitudes poorer in stability than phase lock systems which only allow temporary departures from exact center frequency where the designer is able to choose the degree of timing of those departures freely.

The system employed in the Exciter/Modulator described here is a phase lock system. In such a system carrier deviation resulting from wanted modulation must be limited to the linear range of the phase detector or about $\pm 60°$.

The relationship between frequency and phase modulation is as follows:

$$\Delta f = \Delta\phi \times f_m$$

Where all fs are in Hz and ϕ is in radians.

If $\Delta\phi$ is limited to $\pm 60°$ or about $\pm$one radian, the Δf must be ± 50 Hz if 50 Hz is the lowest modulating frequency.

Consequently, the modulated oscillators frequency must be divided by 500 to reduce the normal ± 25 kHz deviation to ± 50 Hz or less. To allow for ± 50 kHz deviation used in other CCIR system and to provide for some margin of safety, a division ratio of 2,048 was chosen, easily obtainable with binary TTL dividers. This ratio will also place the comparison frequency just outside the aural passband (15.869 kHz). Broadcast systems require modulation capability at the low end of the audio range to 50 Hz, often to 30 Hz. The phase lock loop must leave these frequencies unimpaired and the in-loop, low-pass filter must be chosen accordingly. As a consequence, initial capture range of this system before lock up is severely restricted. Therefore, the in-loop low pass filter is automatically changed between search and lock up conditions, to allow a locking range of approximately ± 100 kHz. Once lock-up is achieved, the cutoff frequency of the loop low-pass filter is lowered so that low modulation frequencies can be handled without impairment.[16] Phase-locked loop systems have the impressive feature of very close frequency control and very small carrier shift with modulation. Accuracies of 100 Hz or less and shifts with modulation of less than 100 Hz are easily achieved in practical operation.

Phase lock systems used to suffer from difficulties with regenerative dividers. These difficulties have been totally eliminated by untuned dividers available in great variety as integrated circuits. The reference chain of the AFC system employs an oven controlled crystal oscillator whose frequency is so chosen to allow use of AT cut crystals (as opposed to NT cut crystals at lower frequencies), which exhibit much better temperature stability and ruggedness. The task of dividing this signal down to 15.869 kHz is easily accomplished in two ICs.

As the phase detector, a version was chosen which will produce zero output should one or both inputs disappear thus avoiding large center frequency shift in case of failures in one or both divider chains.

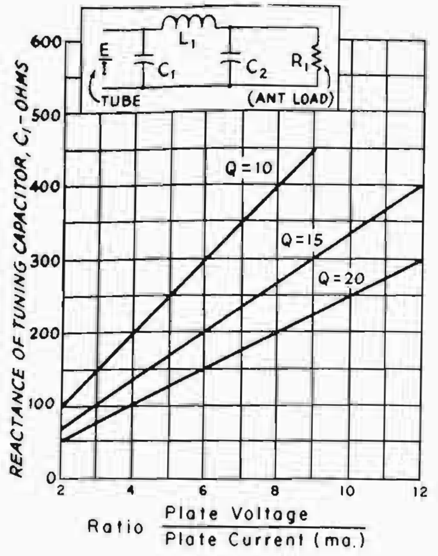
A single sensor will give a clear indication of proper lockup by comparing the phase detector input signals. Lockup is indicated by the front panel light.

Output power from the Exciter can be varied continuously by controlling the IF input voltage to the X-port of the up-converter through a motor driven attenuator.

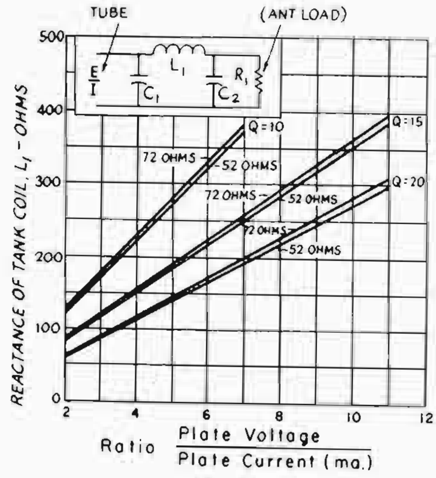
Aural Intermediate Power Amplifier

Amplification of frequency modulated, narrow band signals can follow widely accepted practices. For low power stages, e.g., up to several 100 watts, efficiency is not of primary concern and for this reason such amplifiers are often operated Class B rather than Class C since more gain is obtainable and fewer harmonics are produced.

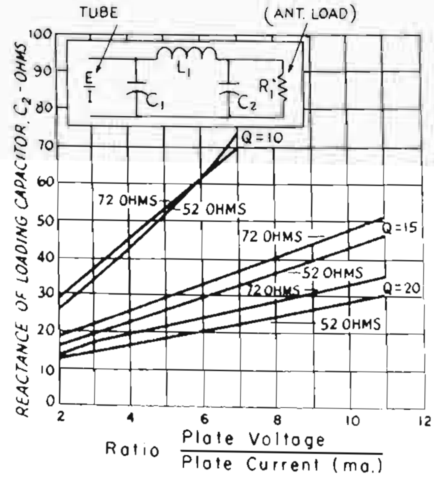
PI-NETWORK DESIGN CHARTS FOR FEEDING 52- OR 72-OHM COAXIAL TRANSMISSION LINES.



Reactance of input capacitor, C_1, as a function the ratio of plate voltage to plate current.



Reactance of tank coil, L_1, as a function of plate voltage and current, for pi networks.



Reactance of loading capacitor, C_2, as a function of plate voltage and current, for pi networks.

Fig. 39. Pi-section nomographs.

This reasoning is applied to a tube amplifier employing an 8122 tetrode to produce 250-watts output power with 5 watts drive, a gain of 17 dB. Operation as a cathode driven amplifier avoids the need for neutralization which simplifies the circuit and its operation. Input and output circuits are single tuned, using L and Pi sections.

The input capacity of the output Pi is produced by the tube. Tuning is accomplished by a parallel inductance which will tune-out a predetermined amount of the tubes output capacity.

One of the easiest to use nomographs for determining the circuit element values for Pi output sections can be found in the *ARRL Amateur Radio Handbook*. Fig. 39 is a reproduction of this nomograph.

The following example will illustrate the use of the nomograph for a tube type 4CX250B or 8122. With an anode voltage of 2 kv and a dc input of 500 watts, the anode will draw 250 ma of current leading to a voltage-to-current ratio of 8. At an assumed efficiency of 70% the output power produced will be 250 watts. The reactance values for the Pi network using Circuit Q of 15 will be as follows:

$$X_{C1} = 270 \text{ ohm}$$
$$X_{L1} = 275 \text{ ohm}$$
$$X_{C2} = 36 \text{ ohm}$$

which will lead at a frequency of 200 MHz or approximately Channel 11 to the following values.

C1 = 3.0 pf
L1 = 210 nH
C2 = 22 pf

Attention must be paid to adequate bypassing, especially of the screen grids while properly considering the higher circulating currents encountered with higher average powers for aural service and possibly higher Circuit Q as opposed to visual service which will produce an average picture power of approximately 25% of the peak-of-sync power at which the transmitter is rated.

If the Q of the tuned circuits in the aural amplifier is only 15 or 20, no noticeable degradation of the modulation content of the signal will occur, especially with the small amount of deviation employed in television service.

The only noticeable effect of a power amplifier on an FM signal is simultaneous AM caused by the frequency modulated signals (FM to AM conversion). To minimize this effect for which no FCC limits are in existence, one should tune the amplifier to maximize the second harmonic of the AM envelope. This is easily done by detecting the aural carrier in an AM detector, e.g., a diode, or a diode noise meter (used to measure AM noise), feeding the output into a distortion analyzer which is tuned to remove the fundamental frequency of the tone causing FM modulation. This leaves the second (and higher) harmonics which can now be read on the meter of the distortion analyzer.

The anode tuning of the stage being checked should now be adjusted for maximum second harmonic output which will coincide with a minimum output at the fundamental frequency. At the same time the peak-to-peak amplitude modulated envelope of the frequency modulated signal will go through a minimum.

For amplifiers up to several hundred watts output power, grid bias may conveniently be obtained through a cathode resistor or a zener diode (which should be properly protected), or a combination of both. In this way a separate bias supply can be eliminated. Higher power amplifiers make this approach, however, wasteful. All tube stages in the television transmitters produced by Harris Broadcast Products Division operate grounded grid and grounded screen, thus, avoiding any need for neutralization. Less power gain is utilized this way, but in a television transmitter the tradeoffs are favoring the approach that we choose.

Input tuning of all aural amplifiers can be single-tuned using an L section to match the 50-ohm transmission lines to the 30-40-ohm input impedance of the cathode driven amplifiers.

Aural Power Amplifiers

TV transmitters employ aural power amplifiers up to about 8 kw in a single tube configuration. From several hundred watts up the use of lumped elements becomes quickly unattractive, striplines are employed for frequencies up to 100 MHz. Higher frequencies require anode circuits in the form of coaxial cavities, some designs in circular and some in square cross-sectional configuration.

Care must be taken with the very high unloaded Q values available (up to several thousand) and the comparative ease in which cavity loading can be changed not to operate the tube in a high-loaded-Q-output circuit, e.g., a Q of 100. This would lead to unacceptably high circulating currents which could do damage to the screen contacts and possibly the tube seal. A loaded Q of 15 should be selected. This can be easily checked (since sweep equipment is generally available in a TV station) by driving the aural power amplifier from the visual exciter, with the vestigial sideband filter and delay compensator disabled. Under this condition, loading (and therefore, loaded Q) for a bandwidth of f_C/Q at the 3-dB points can be adjusted, e.g., for Channel 11 one should seek a 3-dB bandwidth of 13 MHz. This will mean, in essence, that the response of the aural power amplifier at the visual carrier is not quite −3 dB. For this test care should be exercised not to operate the amplifier in a saturated condition. The best way to assure this is to operate it at 20% to 50% of normal power. If sweep equipment is unavailable, one can first drive the aural power amplifier from the aural exciter, driving it to 50% of normal power and measuring the drive power necessary. Then the aural exciter is replaced with the visual exciter (with visual gain control counterclockwise), driving the aural power amplifier with the same power originally obtained from the aural exciter. At this point the power output from the aural power amplifier should not fall below half the power obtained when it was driven by the aural exciter. This would indicate that the response at the visual frequency is 3 dB down from the response at the aural carrier.

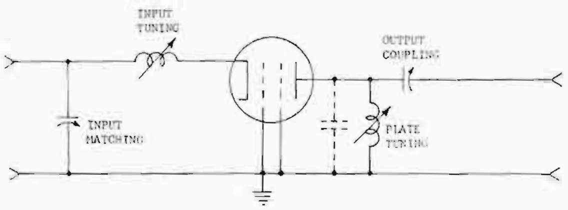


Fig. 40. Circuit equivalent, aural power amplifier.

Assessment of proper operation as far as power output, efficiency, and load impedance are concerned should follow the reasoning expounded in the previous paragraph dealing with low power stages.

The main difference in a high power stage is in the greater effort required for circuit protection against arcs and other mishaps in order to limit the destructiveness of such malfunctions. A larger resistor for limitation of short-circuit currents can be used in the aural amplifier since the constant load of this amplifier better tolerates a high impedance anode supply. Most modern TV transmitters have extensive provisions for remote control and remote reading of typical parameters. For this reason, the anode current of the aural PA is transformed to ground potential through the use of a magnetic amplifier. The equivalent circuit of an aural power amplifier is shown in Fig. 40.

Control Circuits

The control circuits of the television transmitter perform the following function:

1. Upon receipt of suitable command turn transmitter on through proper starting sequence.
2. Upon receipt of command, turn transmitter off.
3. Restart transmitter in proper sequence following short or long power line interruptions.
4. Provide status indication for various transmitter conditions.
5. Provide corrective action and indication derived from sensing an overload condition within the transmitter.
6. Cause partial or complete system shutdown in case of failure.
7. Allow system expansion, such as dual transmitter configuration.
8. Provide interface, in case of remote or unattended operation, to other functional elements of the overall system.

The traditional way to design control circuits was by using mostly telephone type relays to build up logic circuitry in accordance with established requirements. These relays provided two logic states: 0 and 1. To implement elaborate control circuits often required the use of dozens of such relays.

More elegant solutions are available now in the form of Solid State Logic building blocks, avoiding the use of electro-mechanical elements for logic functions entirely. Power switching, however, will still be performed by conventional contactors. Each cubicle of a particular transmitter contains its own control circuit and can be independently activated from switches on that cabinet. This feature was incorporated to allow easier system maintenance and tune-up. The entire transmitter may also be operated from the first cabinet.

Some of the features of each control circuit include filament warm-up time-delay, air pressure interlocks, overload cycling, automatic reactivation with ac failures and automatic high voltage removal in any power amplifier which has had three overloads.

The four basic digital logic circuit elements employed are the AND gate, the OR gate, the BINARY and the MONOSTABLE MULTIVIBRATOR. The equivalents of these circuits can be seen in Fig. 41. The two types of gates replace the usual series-wired relay contacts, or the parallel wired contacts while the binary replaces the usual latching relay. To illustrate the basic operation of these circuits, three opera-

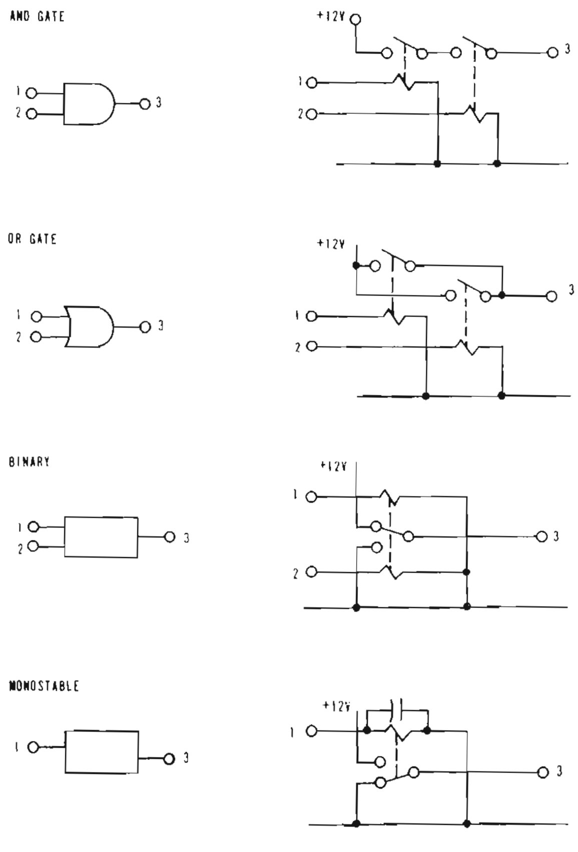


Fig. 41. Logic circuit equivalents.

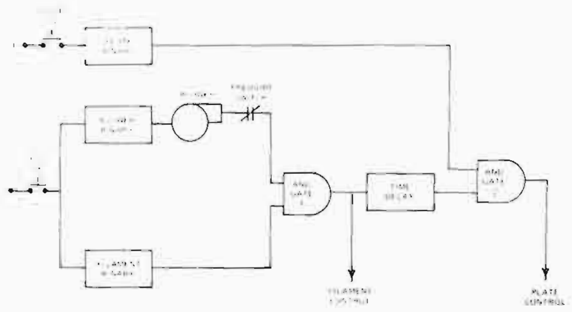


Fig. 42. Turn-on block diagram.

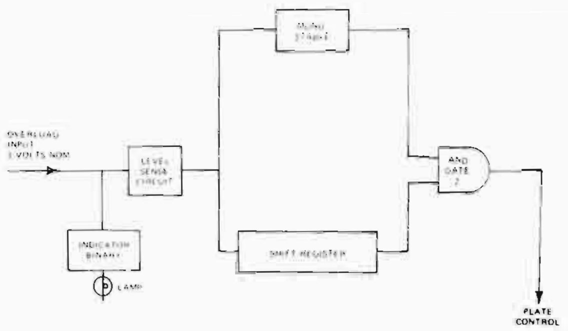


Fig. 44. Overload block diagram.

tional sequences are described in Figs. 42, 43, and 44.

Turn-on: Fig. 42 shows basic turn-on circuitry. A momentary input pulse, provided by the front panel filament ON pushbutton changes the state of the filament and blower binaries. This action starts the blower and applies the positive logic level at one input of AND Gate 1. When air pressure is adequate, a positive logic level is applied to the other input of the gate. With both inputs positive, the output of the gate goes positive, turning on the filaments and starting a time delay circuit. At anytime, the plate ON pushbutton can be depressed. The state of the plate binary changes immediately to the positive logic level. But if the time delay has not elapsed, anode voltage cannot be applied. If the plate ON pushbutton has been pushed and the time delay has elapsed, both inputs of AND Gate 2 will be in the positive state and anode voltage will be applied.

Transmitter Turn-Off: In Fig. 43 the basic turn-off circuits are illustrated. Plate control may be removed by momentarily depressing either the plate or the filament OFF pushbuttons. Again, only a momentary voltage at the plate or filament binary OFF inputs will change the state of the binary, and by reducing the input of AND Gate 2 to zero will remove plate control.

If the filament OFF button is depressed, filament control as well as plate control will be removed. In addition, a time delay circuit is activated which, after one minute, changes the state of the blower binary and removes blower control.

Transmitter Overload Features: Fig. 44 illustrates circuitry used to provide overload protection for the system. Overload inputs to the control circuits consist of dc voltages related to the system status. When an overload circuit develops a nominal 3-volt signal, the logic circuits respond. This nominal 3-volt signal is used to activate an indicator binary and a level-sensing circuit. The indicator binary changes status, driving a lamp which identifies the source of the overload. The level-sensing circuit delivers a negative-going output pulse which triggers both a monostable multivibrator and a three-stage shift register.

The monostable, when triggered, holds the input of AND Gate 2 in the zero state for one second and, thus, removes plate control for that period of time. The shift register counts the number of overload pulses and after three pulses are applied, holds the other input of AND Gate 2 at zero, and removes plate control.

The transmitter is, therefore, deactivated for a short time when an overload occurs and is disabled after three repetitive overloads. A flashing lamp on the meter panel indicates when three overloads have occurred.

Because all ON and OFF functions are achieved with the application of momentary voltage pulses, remote control is simplified. The current pulse required is small enough to permit easy interfacing with computer control devices. In addition, the voltage levels used to indicate system status can be easily sampled and computer analyzed. The use of solid-state circuits for controlling television transmitters yield numerous benefits to the user. The first is increased

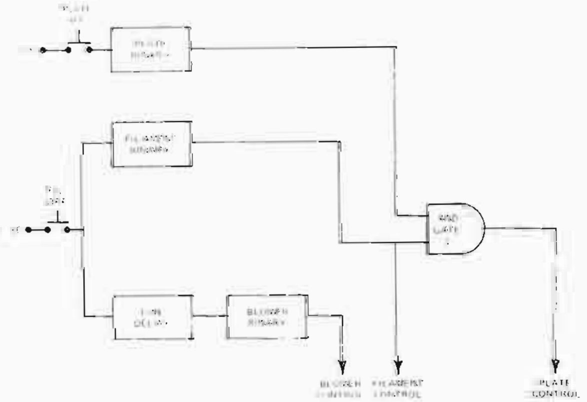


Fig. 43. Turn-off block disgram.

reliability; no relays are used to perform logic functions. Second, reduction in physical size of control circuits helps to decrease the total size of the system. Third, the simplification of intercabinet wiring makes initial system installation and, later, system maintenance much easier. Fourth, flexibility is enhanced. Fifth, remote control is easily interfaced.

Power Supply Circuits

A television transmitter requires a number of supply voltages as shown below:

1. Ac or dc filament voltages typically 5-10 volts, 1-200 Amps.
2. Bias supplies 10-250 volts, 0-300 milliamps.
3. Screen supplies 200-2,000 volts, 10-150 milliamps.
4. Anode supplies 1,000 to 8,000 volts, 100 milliamps to 15 Amps.
5. Ac or dc auxiliary supplies, e.g., for solid-state circuits and amplifiers, for logic circuits, indicator lights and power contactors, 12-28 volts and 1-5 Amps.

Filament Supplies

Filaments requiring ac voltage offer the simplest condition. Sometimes special conditions, e.g., limit in maximum current, or high voltage insulation, may lead to nonstandard designs. The ac supplied filaments are generally preferred due to their ruggedness and simplicity. If ac voltages cause undesirable effect, like 60-Hz hum modulation, dc supplies with varying degrees of ripple and regulation can be used. Care should be exercised not to overspecify the supply requirement as it leads to poor economy and reliability.

The degree of allowable ac ripple and the ripple frequency should be the determining factors for choosing half-wave or full-wave single-phase or multiple-phase circuits, since filtering by means of a low pass filter is quite impractical due to the very low load impedance encountered.

Most filament transformers used by the Harris Broadcast Products Division have input taps to allow adjustment for different input voltages from 197 volts to 251 volts in 5% steps. A typical arrangement is shown in Fig. 45. If the transformer is designed for 50-Hz operation, it will in tap position +11 and 208, accommodate the most prevalent voltage of 50 Hz systems: 220 volts.

The dc supplies should always use current limiting circuitry to avoid damage to wiring harnesses in case of a short at or near the load. Typical filament requirements for power tubes are: 10 volts at 150 amps.

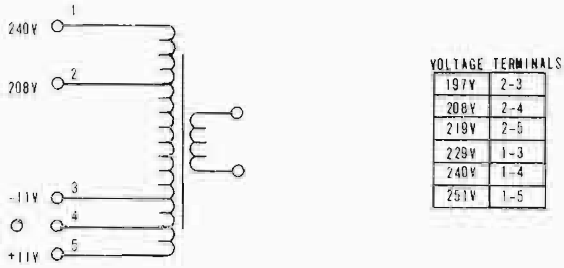


Fig. 45. Schematic of typical filament transformer.

Bias Supplies

The most important requirements for bias supplies are constant voltage with widely varying positive and negative loads. A negative load is, in essence, another supply in parallel with the existing supply whose current must be sunk into the existing supply. In a television transmitter, load variations occur at a very slow rate (camera pan or change in scene lighting), also at a frame rate (60 frames per second) and at a line rate (15,750 lines per second, or 525 lines per frame), making it necessary for the bias supply to be able to respond over a frequency range from dc to 4 MHz. Over this range the internal impedance, if not zero, should be preferably constant or change slowly and show no resonances.. Modern power tubes, fortunately, ease the requirement on the power supply by drawing only moderate amounts of grid current.

The most widely used, if somewhat wasteful, approach to accommodate grid current is to draw a steady current from the supply, about 30% higher than the maximum grid current expected, which will then "outbalance" the grid current. The bias supply will see a gradually decreasing load as grid current is increased. Grid current in excess of the maximum bleeder current will increase the bias voltage to more negative values which will tend to create a self-balancing situation if the bias supply components can stand the additional stress. However, serious waveform distortion is caused by this behavior, largely on the synchronizing pulses.

A number of triodes are available which can be operated with zero bias between grid and cathode. The lack of a separate bias supply for these tubes is one of the major advantages. Typical tubes are listed in Table 1.

Bias supplies generally range from 10 to 250 volts at currents up to several hundred milliamps. A limited adjustability of the voltage is a requirement for most supplies.

Screen Supplies

The foremost requirement of a screen supply is a constant voltage characteristic up to a defined maximum current, at which it reverts into a near constant current supply as shown in Fig. 46. During the constant voltage portion the operating voltage should be stable to ±1%, and the requirements of internal impedances outlined under Bias Supplies also apply. Voltage should be adjustable approximately ±15% from a center value.

Great care must be exercised by the designer to make the screen supply impervious to high spikes and overvoltages caused by gas pings in new power tubes. This dictates the use of thermionic devices at the interfaces with the power tube as protection necessary for solid-state devices would make it uneconomical and unreliable to use solid-state devices directly interfacing with high power tubes. The increased component count, furthermore, would decrease overall reliability. A typical simplified circuit is shown in Fig. 47. This circuit has the additional advantage of slaving the screen voltage to the (well regulated) bias supply so that a failure of the bias supply will automatically reduce the screen voltage to near zero, this way fully protecting the tube.

The function of the supply can be easily understood. If the voltage of the anode of the shunt-regulated tube tends downward, the grid voltage of the tube will get more negative, counteracting the original downward move. Amplifier A provides sufficient gain to maintain high enough loop gain for ±1% regulation on the assumption that the reference supply remains at approximately ±.2%.

Arc Gap E1 protects the amplifier tube and its screen blocker against sustained overvoltage, especially in case of failure of the shunt regulator tube.

In executing the various requirements of the screen supply, care should be exercised to keep the total energy stored in the supply below safe values. The permissible amount of energy (in Joules or Watt seconds) is obtainable from the

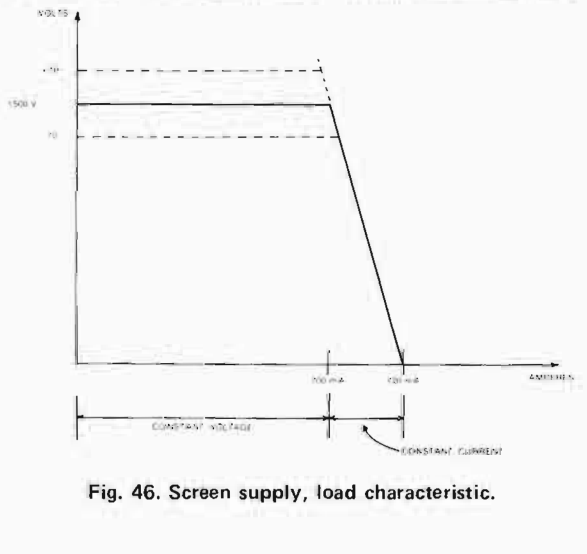


Fig. 46. Screen supply, load characteristic.

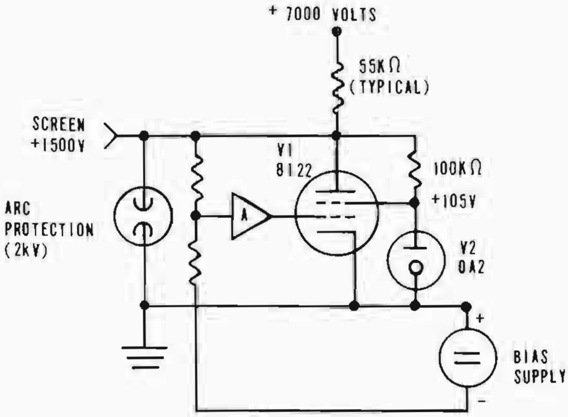


Fig. 47. Simplified schematic, screen regulator.

tube manufacturer. Any capacitors connected directly to the tube elements contains stored energy according to: $E = \frac{C \times N^2}{2}$ (Joules). In addition, energy will be supplied for a short time until the high voltage supply is disconnected from the power line (in a typical case, 50 milliseconds).

The total energy in a typical case may be:

$$E\text{total} = \frac{1.2 \times 10^{-5} \times 1.5^2 \times 10^6}{2} + .12 \times 5 \times 10^{-2} =$$

$$1.35 \times 10^1 + .6 \times 10^{-2} = 13.5\,\text{ws}$$

This is a very safe value for a power tube in the 15-kw plate dissipation category.

Anode Supplies

This supply provides the anode voltage to all power tubes. When thermionic devices were used as rectifiers, designers were forced to use choke input type supplies to limit the maximum instantaneous current to safe values for those devices. With the advent of solid-state rectifiers these limitations no longer applied as the maximum instantaneous current capabilities of silicon rectifiers were orders of magnitude higher than those of thermionic devices.[17]

Single phase capacitor input supplies require slightly larger power transformers (due to higher I^2R losses). Their main advantage for TV applications is excellent, frequency independent regulation, leading to almost total lack of amplitude disturbance during the vertical interval. Supplies of this type require very high filter capacitors, the major uncertainty relative to overall reliability. Data gathered over a five-year period on the operation are favorable, but not as yet fully conclusive.

All capacitor input supplies over approximately 1 kw should employ a starting mechanism

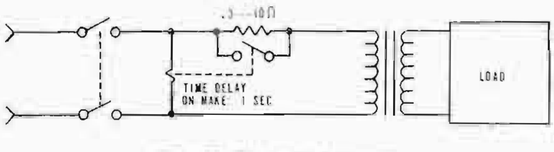


Fig. 48. Stop-start circuit.

to limit in-rush current. A scheme extensively employed is shown in Fig. 48.

The dropping resistor and time delay relay are chosen such that with a 1 second delay the output voltage under load will reach approximately 60% to 70% of the final value before the resistor is shorted out.

Supplies for power stages over approximately 1 to 2 kw are fed from three phase ac lines. For reasons stated above, capacitor input supplies are also considered. TV service with its widely and continuously varying load is demanding on power supply performance. Therefore, we choose three-phase, full-wave cascaded supplies providing 12 current "pulses" 30° apart during one cycle of the 60-Hz input period, and are therefore classified as 12-phase supplies.

From schematic Fig. 49, it becomes obvious how this is accomplished, namely, by using two full-wave three-phase supplies in a series with two secondary windings of extended delta configuration on a common transformer core.

For perfect input phase balance the ripple frequency is predominantly 720 Hz. (12 times 60 Hz). Input line phase imbalance will cause 120 Hz ripple to appear. Capacitive filtering, following the rectifier will suffice to reduce 720 Hz and its harmonics to very low levels, since without any filtering whatsoever, ripple amplitude is already at about −40 dB relative to the dc output voltage.

If serious phase imbalances of the primary feed are to be expected, line voltage regulators can be used to correct the imbalance. If this is not feasible or practical, the addition of a low pass filter to any 12-phase supply will reduce the 120-Hz component. Even with the additional filtering the 12-phase supplies still provide superior performance since very small chokes

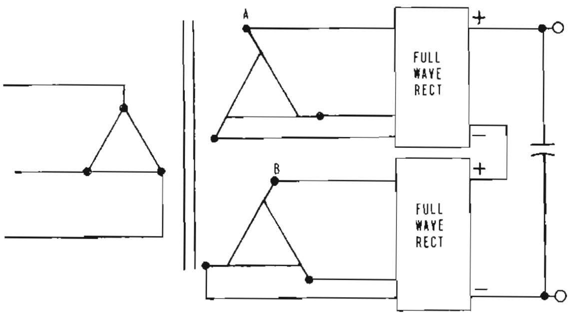


Fig. 49. Twelve-phase supply.

and capacitors are required (e.g., 1 Henry and 2 to 10 microfarads).

An extremely important element in high power anode supplies is protection of the supply itself and circuits connected to it.

The following protective elements can be found in typical supplies:

1. Circuit breaker of fast response in the input line;
2. Contactors of fast response which can turn the supply off through an external command, e.g., from within the transmitter resulting from a tube overload;
3. Arc Gaps in strategic locations to avoid overvoltages;
4. High energy resistors to limit peak currents especially of short duration to safe values; and
5. Capacitor-resistor combinations to suppress line produced and related spikes.

When properly designed, such a supply shall withstand repeated direct shorts across its output High Voltage terminals. It should also withstand line surges of at least two times normal line voltage. A typical supply is shown in Fig. 50.

Ancillary Supplies

Supplies for low voltage applications to feed, for instance, solid state RF amplifiers, discreet transistor circuits, and integrated circuits should incorporate two important parameters:

1. Fold back current limiting,
2. Overvoltage crow-bar.

Both requirements are designed to avoid destruction of delicate solid state devices. If an integrated circuit is subjected to small overvoltages, e.g., +30%, many such devices can be lost, necessitating, in large systems, very elaborate repairs.

Numerous designs for such supplies are available in the marketplace, and it makes it uneconomical, in most cases, not to use a vendor furnished power supply. Extensive design information is also available through application notes of many solid state manufacturers for IC Voltage regulators, and there is no need to elaborate on this further.

Combining Circuits

Two different types of combining circuits must be considered:

1. Combining of sources with the same frequency;
2. Combining of sources with different frequencies.

For Application 1 90° hybrid couplers have found almost universal acceptance. It is, for TV power applications, a relatively new component

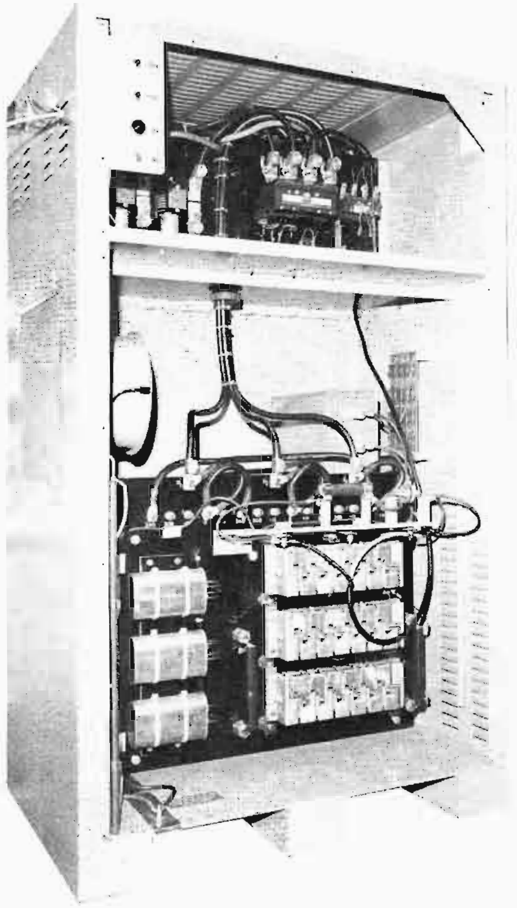


Fig. 50. Photograph power supply BT25H1.

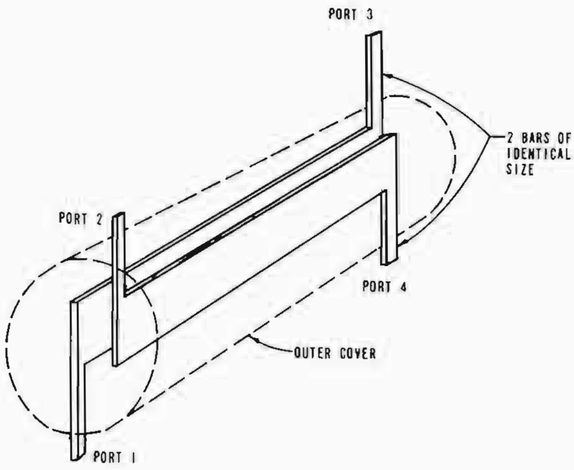


Fig. 51. Physical Model of 90° hybrid coupler.

and it's operation may not always be fully understood.

A detailed mathematical treatment with extensive other test and application data is found in Reference 18.

The following are highlights from Reference 18 which should help to visualize the elegant performance of this device. Fig. 51 shows an exploded view of a typical 90° hybrid coupler. The arrangement for Ports 3 and 4 is selected as shown for the ease of interconnecting the device. Both ports could be reversed in direction if this were more advantageous.

A 3-dB coupler consists of two identical parallel transmission lines coupled over a length "d" equal or approximately equal to $\lambda/4$ and mounted in a common outer conductor.

The construction is symmetrical, i.e., both inner conductors have the same physical dimensions and have the same capacitance per unit length with respect to the outer conductor.

The 3-dB coupler can be used as a power-splitter or as a power combiner. If the coupling attenuation at the center frequency f_0, corresponding to $4 = \lambda/4$, is exactly 3 dB, the voltage distribution as shown in Fig. 52 will be obtained. Normally 3-dB couplers are designed for a coupling attenuation slightly lower than 3 dB in order to minimize the voltage differences as measured at Ports 2 and 3 over a broad frequency range.

Compare Fig. 52 for a perfect 3-dB coupler with Figs. 53 and 54 for a coupler of 2.95- and 2.9-dB coupling, respectively.

PROPERTIES

1. The characteristic impedance Z_0 of the coupler is identical at all ports. This characteristic impedance is frequency independent and is solely determined by the geometry of the coupling region. Thus, with Z_0 connected to Ports 2, 3, and 4, the impedance as seen in Port 1 is also equal to Z_0. Furthermore, it is still equal to Z_0 at f_0—the center frequency—if the output Ports 2 and 3 are terminated in identical mismatches (phase and amplitude) as long as Port 4 remains properly terminated. Fig. 55 shows the mismatch as measured at Port 1 for the case where Ports 2 and 3 are terminated in identical mismatches of different magnitude. The worst case shown is when Ports 2 and 3 are open circuited or short circuited. It is apparent from this curve that the VSWR remains less than 1.05 for a frequency range of $\pm 14\%$ about the center frequency f_0.

2. The phase-shift between the two outputs is always 90° and is independent of frequency. If the coupler is used to combine two transmitters, then these two signals have to be fed to the 3-dB coupler in quadrature.

3. Irrespective of frequency no voltage will appear at Port 4, the isolated port, as long as

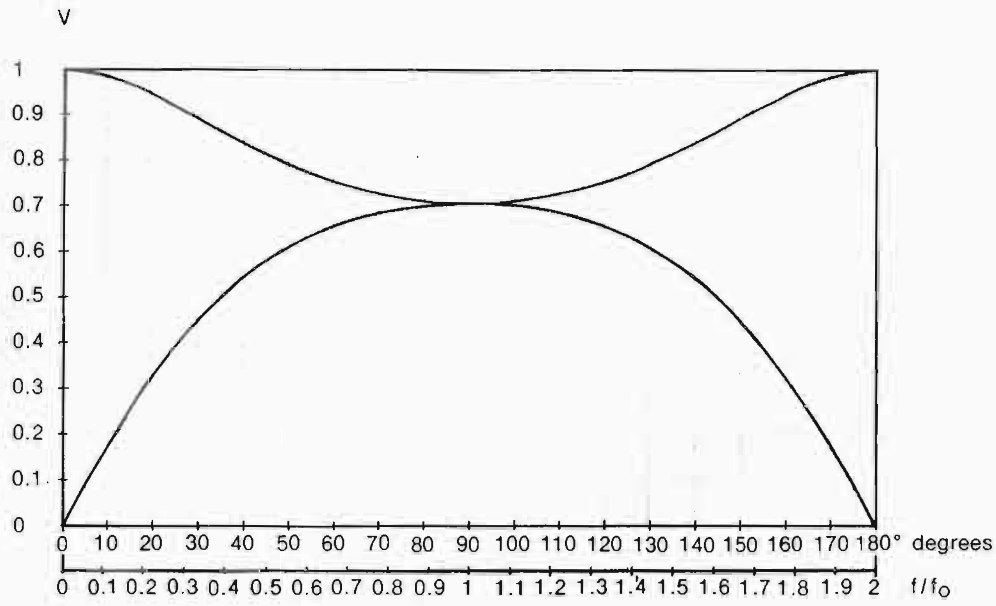


Fig. 52. Normalized voltage distribution of 3 dB hybrid coupler.

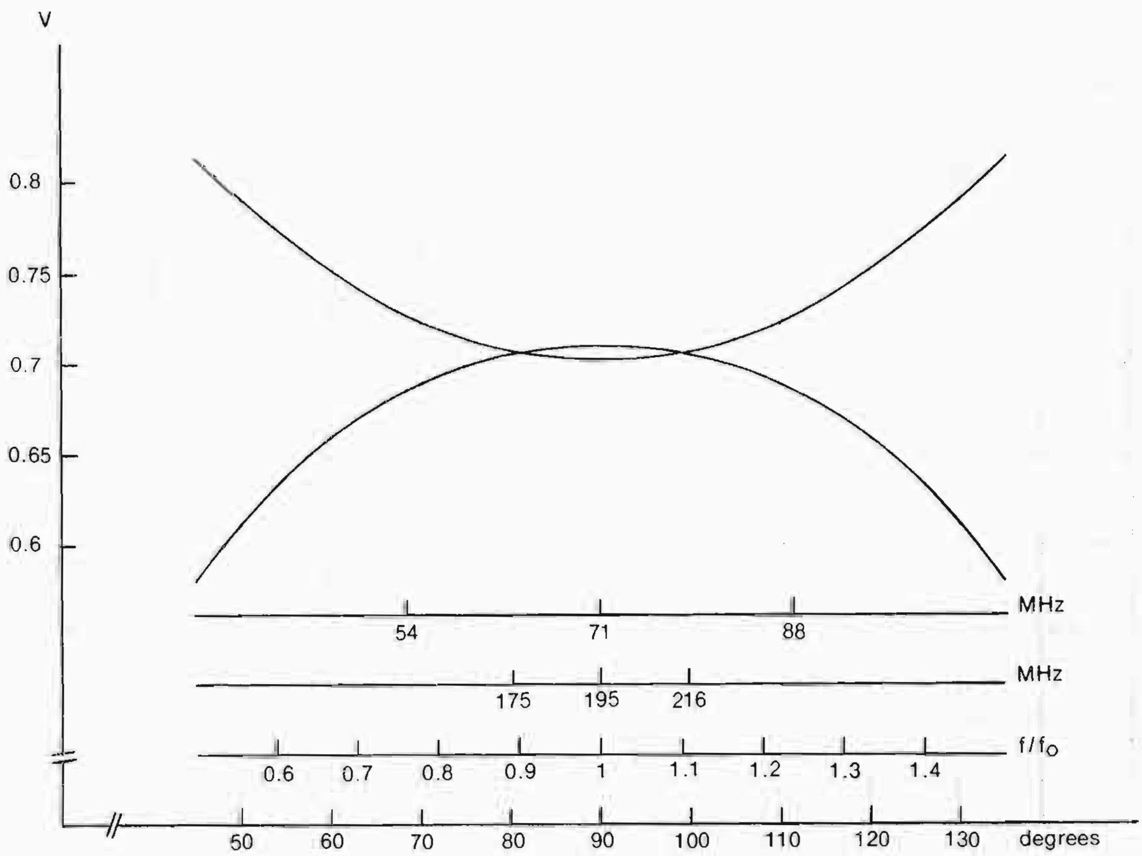


Fig. 53. 2.95 dB hybrid coupler.

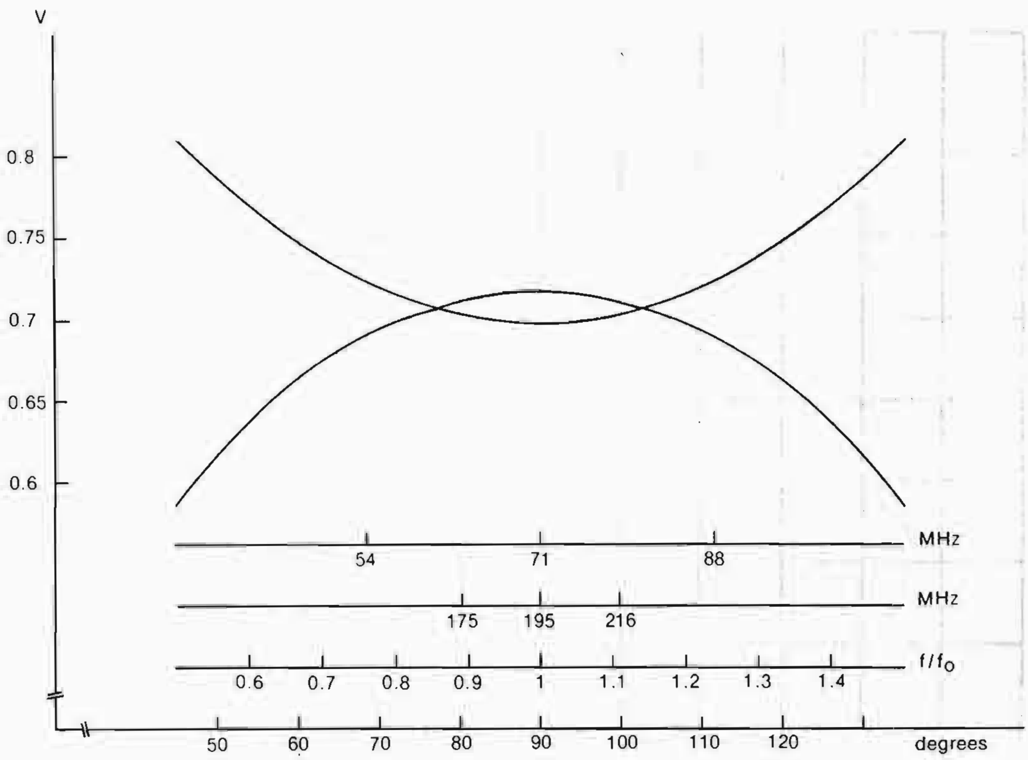


Fig. 54. 2.90 dB hybrid coupler.

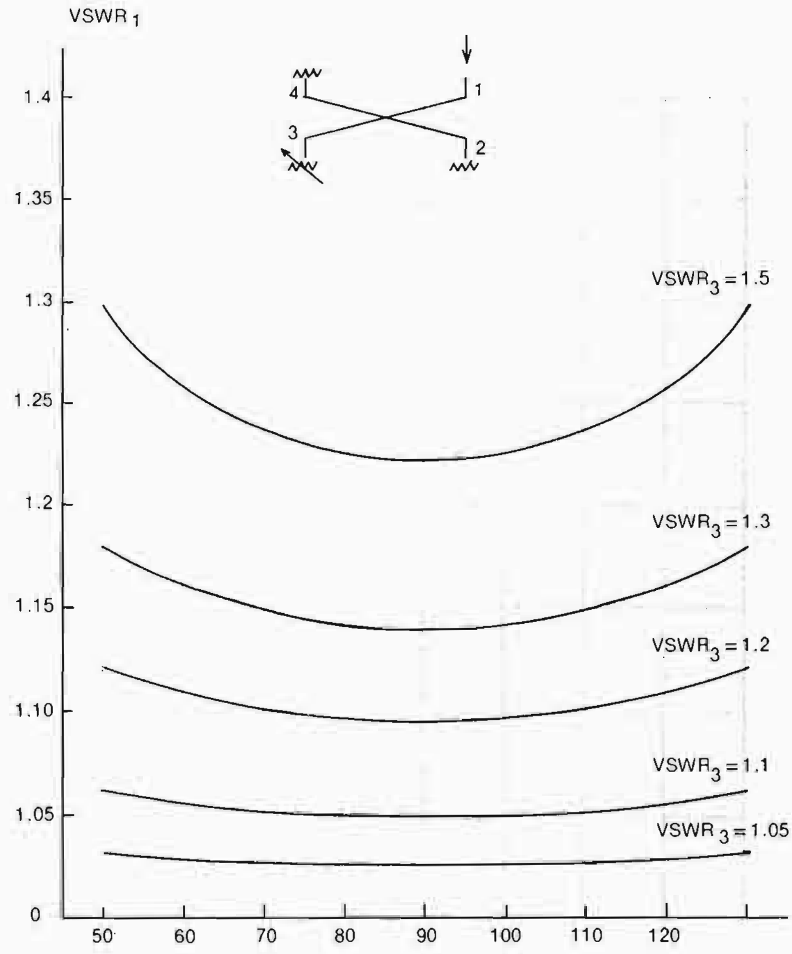


Fig. 55. VSWR of hybrid coupler.

output Ports 2 and 3 are terminated in their characteristic impedance when used as a power divider, or as long as Port 1 is properly terminated and both input Ports 2 and 3 have voltages of equal amplitude that are in quadrature.

4. The isolation between two ports, for example, Ports 1 and 4, depends heavily on the VSWR of the loads at Ports 2 and 3. If the load at Port 2 is an ideal load, the curve of Fig. 56 will then give the isolation as a function of the VSWR of the load at Port 3.

Example: If the load at Port 3 measures 1.05, then the theoretical isolation is approximately 38 dB. If the load measures 1.2, then the isolation cannot be better than 26.5 dB.

Couplers of this general mechanical form can be designed for a wide range of coupling factors and they are readily available for coupling ranges from 3 to 40 dB.

As power splitters or combiners, the 3-dB hybrid couplers are used predominantly but 4.70-dB hybrid couplers have been employed where the sum of three equal sources is combined by first summing two sources in a 3-dB hybrid and then combining the sum of the first two sources with the third source through a 4.70-dB hybrid coupler.

Fig. 57 shows the effect of two couplers connected "back-to-back." If two equal amplifiers are placed into the two connecting lines between the couplers, a nearly ideal arrangement for combining equal frequency sources is available. If, however, both amplifiers differ in phase, a reduction in output power will result, as Fig. 58 demonstrates. But, even an error of 60° (very unlikely to occur) will only cause a 25% reduction in power.

Inequality of amplifier gain, in other words different output powers, will have the effect shown in Fig. 59.

If one amplifier has only half the output power of the above, i.e., A-1 = 10 kw, A-2 = 5 kw, only 3% of the total 15 kw available is dissipated in the reject load, i.e., 450 watts. Ninety-seven percent is still transmitted to the load.

The conclusion is that hybrid splitters and combiners in the above arrangement are very tolerant of phase or power inequalities of the amplifiers operating in parallel. The second application for 90° hybrid couplers is the combining of sources of different frequency, especially where the two frequencies are not far apart and, therefore, well within the bandwidth of the coupler; e.g., in case of visual and aural transmitters of a TV transmission system.

Again, two distinct areas exist: (1) systems employing dual feed lines to the antenna, e.g., Batwing VHF antennas and (2) systems em-

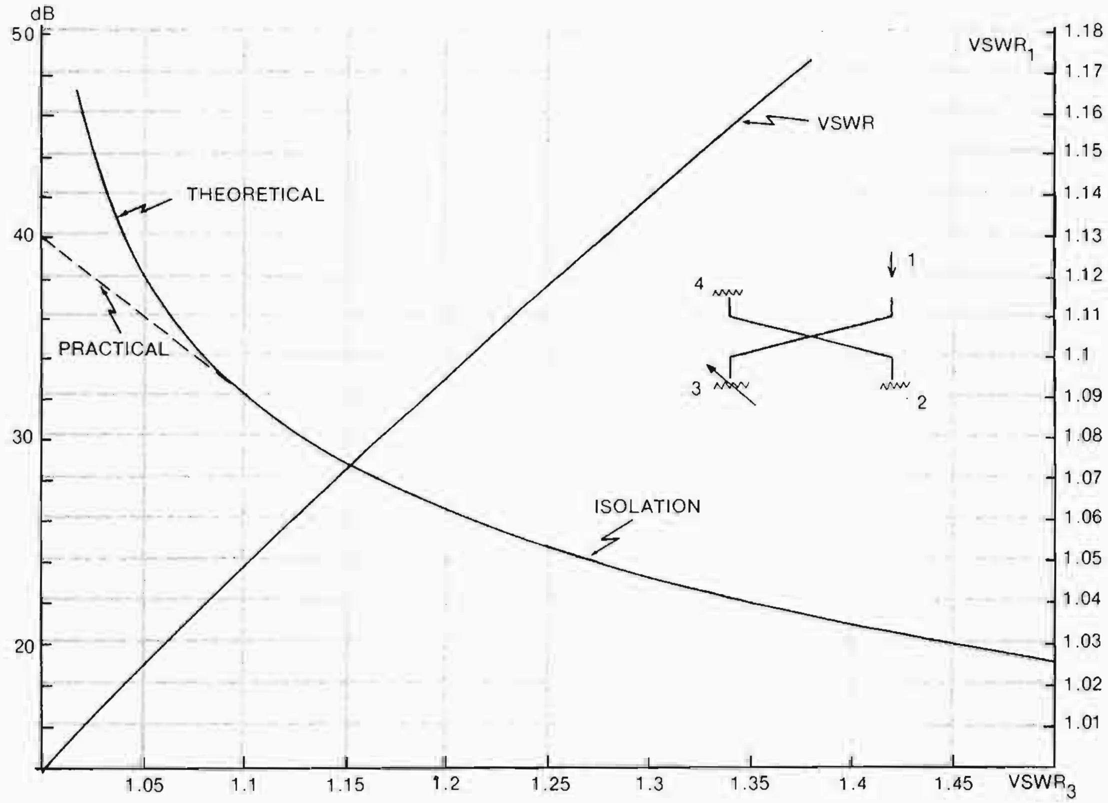


Fig. 56. Isolation of hybrid coupler.

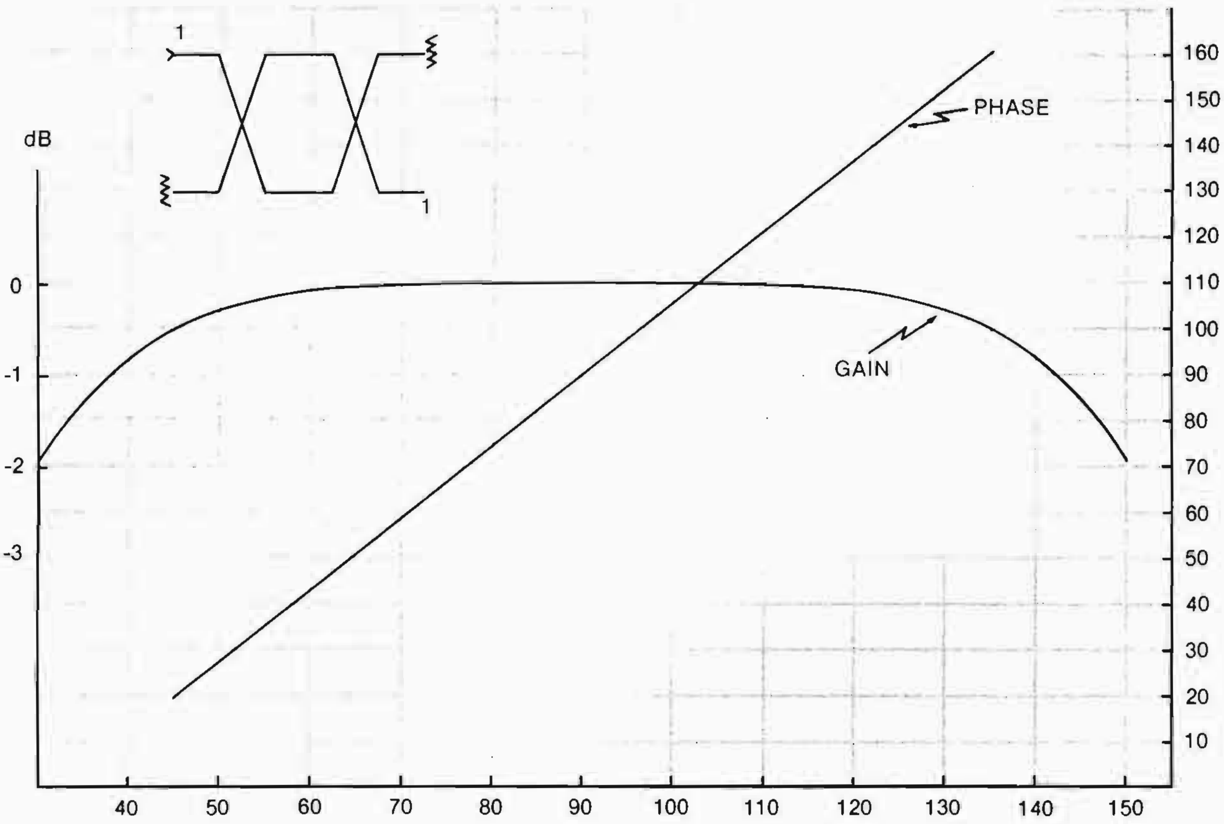


Fig. 57. 90° hybrid couplers as power splitters and combiners

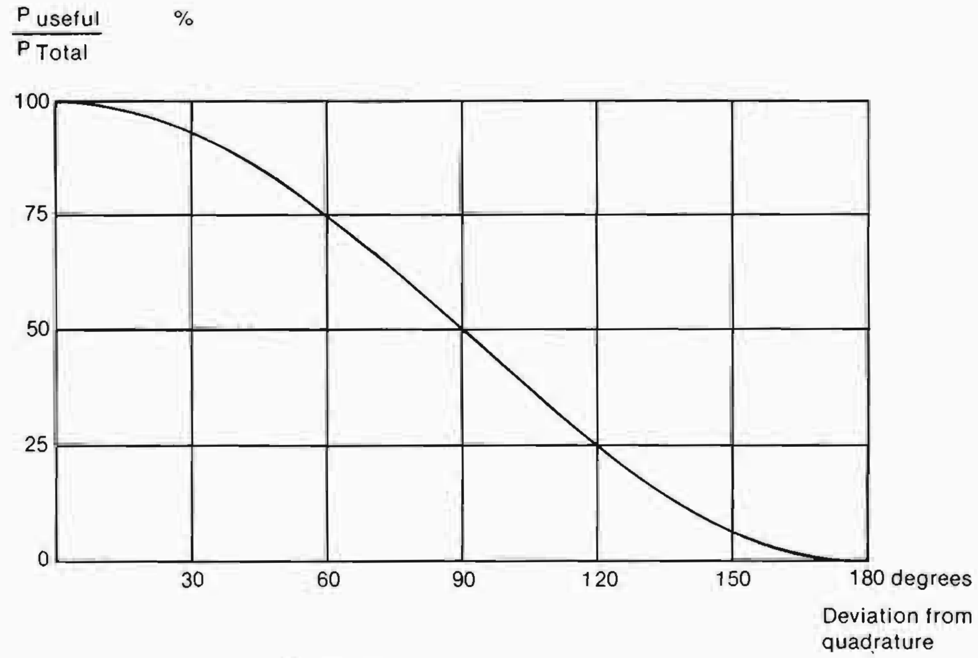


Fig. 58. Phase sensitivity, hybrid coupler.

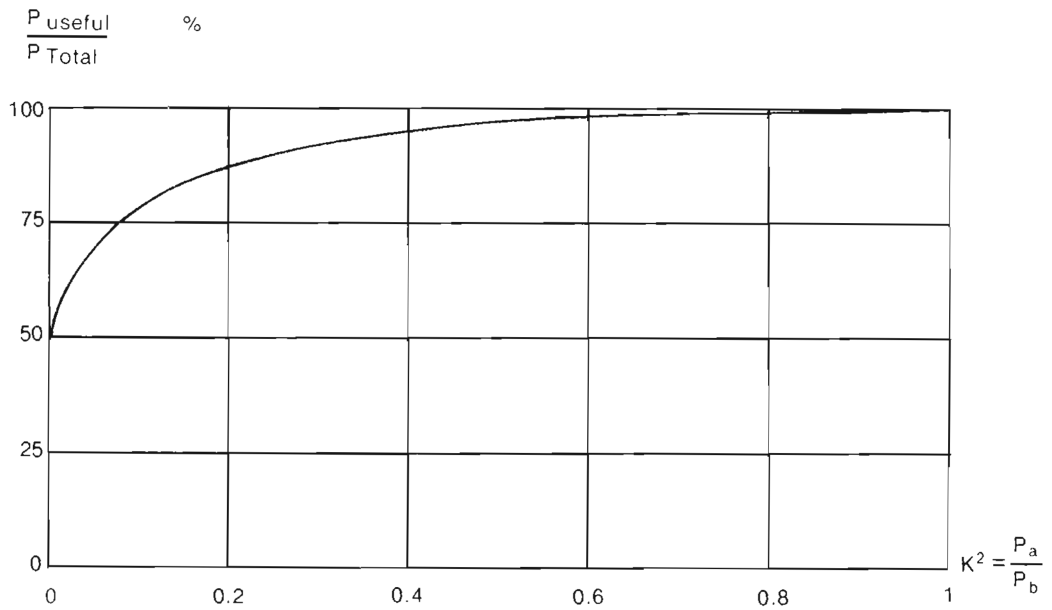


Fig. 59. Power imbalance in hybrid couplers.

ploying single antenna feed lines. The first application is very simple: Connect the visual transmitter to Port 1 of the 3-dB 90° hybrid, connect the aural transmitter to Port 4 of the same hybrid, and connect the two feed lines to the remaining Ports 2 and 3 of the coupler.

Isolation between visual and aural transmitters can be extracted from Fig. 56 if the antenna line VSWR is known, and figures of 30 dB are easily attainable, which will satisfy the requirement of any transmitting equipment. *Case 2:* "Single antenna feed line" is considerably more complicated and creates problems for which compensation must be applied elsewhere in the system.

A simplified schematic of a Visual/Aural Diplexer is shown in Fig. 60.

The aural transmitter is connected to Port 1 and the Antenna to Port 4. The Visual transmitter is connected to Port 4' and the reject load to Port 1'. Between the two 3-dB couplers, two high Q series resonant circuits are connected in parallel with the main lines. These are shown as a series circuit of L_1 and C_1. This combination is in resonance for the Aural Carrier Frequency.

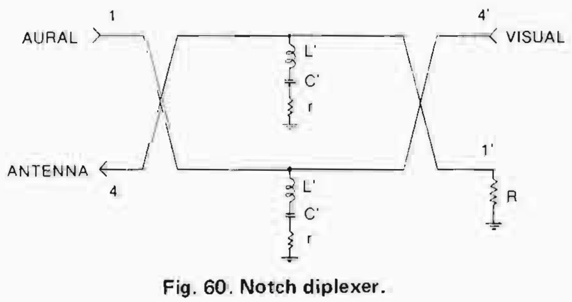


Fig. 60. Notch diplexer.

With the aural transmitter connected to Port 1, all power will be available at Port 4 since the series resonance circuits are a perfect short circuit for the Aural Carrier frequency, and no power will be transmitted to Port 1' or dissipated in the cavities.

Since a practical series resonant circuit cannot have infinite Q, the cavities can be represented with a small resistor r at aural carrier frequency. Some of the aural power will now be dissipated in this r and some will also be transmitted to Port 1'.

To have an idea how much power is dissipated in the cavities and what their equivalent resistance values are, the power at the reject port could be measured.

Suppose the Isolation between Ports 1 and 1' is 30 dB; this means that there is 1,000 times less power at Port 1' than applied at Port 1.

$$1000 \times \left(\frac{2r}{R + 2r}\right)^2 = 1$$

or:

$$r = \frac{R}{2(10\sqrt{10} - 1)}$$

since R is normally 50 ohms

$$r = \frac{25}{10\sqrt{10} - 1} = 0.81\ \Omega$$

The power dissipated in r is:

$$P_d = \frac{2rR}{(R + 2r)^2}$$

$$P_d\,\% = \frac{2 \times 0.81 \times 50}{(50 + 1.62)^2} \cong 3\%$$

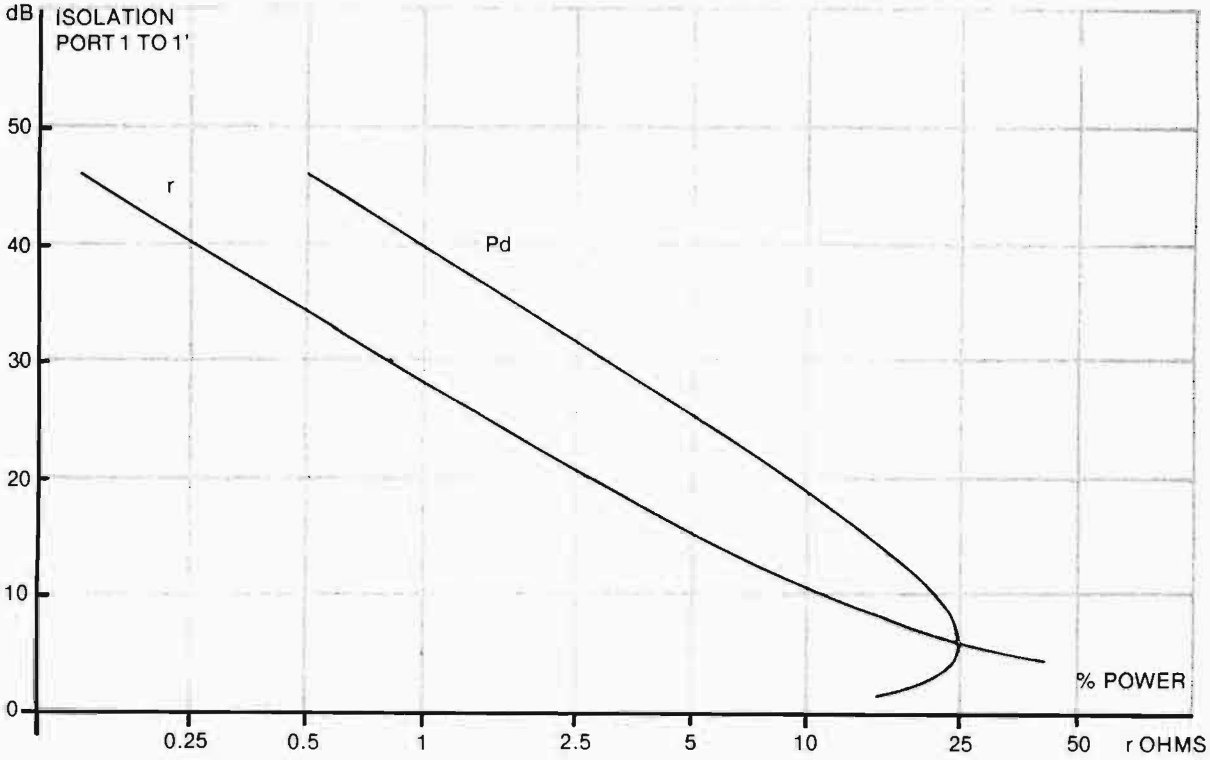


Fig. 61. Isolation of notch diplexer.

So that approximately 3% of the aural power is dissipated in each cavity.

Fig. 61 shows the power dissipated in each cavity versus the isolation of Port 1 to 1'.

The cavities have little effect for the visual carrier frequency and sidebands since they represent a high impedance (capacitive reactance) for these frequency. However, to offset whatever small effect the cavities may have, small inductances of equal, but opposite, reactances as the cavities at visual carrier frequency are installed in parallel with the cavities. To have the best possible circuit, these inductive reactances are so selected that the reactance versus frequency slope is complementary to these of the cavities.

If the ratio of voltages from Port 1 to Port 1' is compared with the notch depth, another interesting conclusion can be arrived at:

$$\frac{V_1}{V_1'} = \frac{R + 2r}{2r} \quad \text{for } \theta = 90^\circ$$

Cavity notch depth:

$$\frac{V_2}{V_2\,(1 - \epsilon)} = \frac{R + 2r}{2r} \quad \text{for } \theta = 90^\circ$$

Therefore, the notch-depth is equal to the ratio of the voltages at Port 1 and Port 1' or to the isolation of Port 1 to 1'.

The average notch diplexer will induce envelope delay for high video frequencies starting at approximately 2.5 MHz and reaching from 300 to 600 nanoseconds at 4.18 MHz, the band edge. The delay must be compensated elsewhere in the system. It can be accomplished at video frequencies, since the disturbance is restricted to the single sideband area of the television signal. For this purpose, a notch diplexer delay equalizer is generally added in, or ahead of, the visual exciter in a television transmission system.

TRANSMITTER COOLING SYSTEMS

It is the intent to provide some of the basic relationships needed to check or calculate the approximate cooling requirements for equipment of the type used in broadcast service. These relationships were simplified to make their use easy and quick. It is not intended that a major system be designed using these approximations.

Cooling by Forced Air

In broadcast equipment some of the power supplied is dissipated as heat. This requires that enough air must be passing through or over the unit to remove the heat, thereby maintaining the desired temperature. Air cooling is accomplished by pounds of air and not cubic feet per minute (CFM). The relationship between these two numbers is density (pounds per cubic foot). It is general practice to specify cooling requirements in CFM of standard air, thereby fixing the pounds per minute of air required. The density of standard air as measured at sea level and 70° F is .075 pounds per cubic foot. See Fig. 62 for correction factors to account for the specific altitude and temperature condition desired.

The basic relationship for calculating air flow requirements is:

$$CFM_{std} = \frac{3160 \times P}{\Delta T}$$

CFM is cubic feet of standard air.
P is kilowatts of power to be removed as heat.
ΔT is the temperature rise in degrees fahrenheit.
3160 is a constant.

To move this CFM from standard air to the specific condition desired divide CFM standard by the correction factor, Fig. 62.

Sample Problem: An electronic package dissipates 0.1 kw and the desired temperature rise for the air passing through the package is 15°F. The unit must operate at 100° F air inlet and an altitude of 2,000 ft. Find the CFM of air required.

$$CFM_{std} = \frac{(3160)(0.2)}{15} = 42\ CFM_{std}$$

Correction factor from Fig. 62 for 100° F and 2,000 feet altitude is .880. Dividing the CFM_{std} by the correction factor it is found that 48 CFM is required.

The air flow required is now known, but it is also necessary to know what the resistance to this flow through the unit is. This resistance must be calculated or estimated for each element of the unit, see Fig. 63. Evaluate each element.

Unity Basis = Standard Air Density of .075 lb/ft³

At sea level (29.92 in. Hg barometric pressure) this is equivalent to dry air at 70°F.

Air Temp. °F	Altitude in Feet Above Sea Level										
	0	1000	2000	3000	4000	5000	6000	7000	8000	9000	10000
	Barometric Pressure in Inches of Mercury										
	29.92	28.86	27.82	26.82	25.84	24.90	23.98	23.09	22.22	21.39	20.58
70	1.000	.964	.930	.896	.864	.832	.801	.772	.743	.714	.688
100	.946	.912	.880	.848	.818	.787	.758	.730	.703	.676	.651
150	.869	.838	.808	.770	.751	.723	.696	.671	.646	.620	.598
200	.803	.774	.747	.720	.694	.668	.643	.620	.596	.573	.552
250	.747	.720	.694	.669	.645	.622	.598	.576	.555	.533	.514
300	.697	.672	.648	.624	.604	.580	.556	.538	.518	.498	.480
350	.654	.631	.608	.586	.565	.544	.524	.505	.486	.467	.450
400	.616	.594	.573	.552	.532	.513	.493	.476	.458	.440	.424
	AIR DENSITY RATIOS										

Fig. 62. Air density ratios.

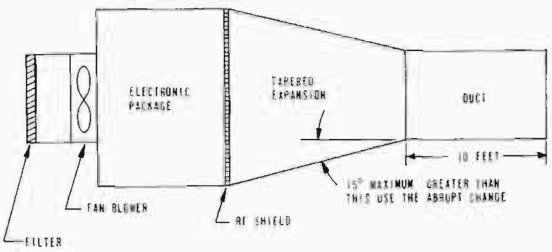


Fig. 63. Cooling system.

1. The filter is necessary to maintain a clean unit. The pressure loss across the filter may be determined by using the manufacturer's pressure loss curve. A properly designed filter will have 0.01 to 0.02 in. of water pressure loss clean and 0.1 to 0.2 in. of water pressure loss dirty.

2. The fan or blower is the driver for this system and must provide sufficient flow (CFM) and pressure (inches of water) to cool the electronics package.

3. The abrupt expansion from the fan/blower into the electronics package will cause a pressure loss. This loss is dependent on the velocity change and ranges from 0.01 to 0.02 in. of water.

4. Electronic package loss may be anything depending on construction and must be estimated or measured. For small open boxes, the pressure loss may be estimated at 0.05 to 0.10 in. of water.

5. Pressure loss across the outlet screen will depend on open area of screen. Screen wire used as RFI shield offers an average loss of 0.01 in. of water at a velocity of 300 feet per minute.

6. Tapered duct induces very low loss and unless air velocity is above 300 feet per minute may be ignored. Above 300 feet per minute allow 0.002 in. of water for each additional 100 feet per minute up to and including 600 feet per minute.

7. Duct loss should be kept to a minimum by using large, short ducts with a minimum of turns and diameter changes. A 90° turn is equal to ten (10) feet of straight duct. See Fig. 64 for approximate straight duct loss.

Pressure loss for the system is the sum of all element losses. The sample problem would appear as follows:

$$\Delta P_{total} = \Delta P_a + \Delta P_c + \Delta P_d + \Delta P_e + \Delta P_f + \Delta P_g$$

ΔP_a	- Dirty Filter	= 0.2	in. water
ΔP_c	Abrupt Expansion	= 0.02	in. water
ΔP_d	Electronic Package est	= 0.10	in. water
ΔP_e	RFI shield 300 FPi	= 0.01	in. water
ΔP_f	Taper 15° 500 FPi out	= 0.004	in. water
ΔP_g	Duct 10 ft. 5 in. @ 500 FPi	= 0.10	in. water
ΔP_t		0.434	in. water

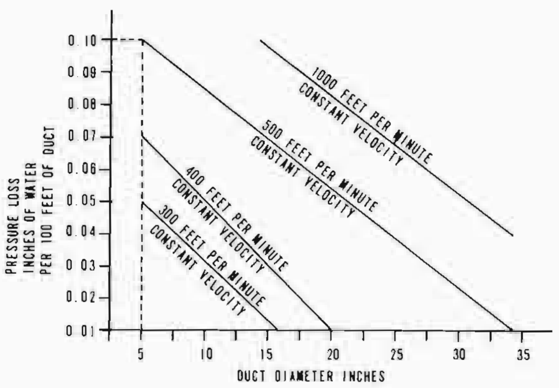


Fig. 64. Duct loss.

Correct this pressure loss for the condition of the sample problem. ΔP_t divided by correction factor equals ΔP required. $\Delta P_r = \frac{.434}{.880} = .493$ in. water. The fan or blower to cool this electronic package must move 48 CFM @ 0.5 in. of water. This is a good application for a muffin fan.

Broadcast equipment may be supplied with the blower or fan for cooling installed in the unit or the equipment may require the installation of the blower or fan external to the broadcast equipment. When the blower or fan is installed in the equipment, an auxiliary blower or fan will be required to provide for air losses in ducting if the hot air is to be ducted out of the building. The calculation for a transmitter exhaust duct system would be the same as the sample problem. To design the fan or blower the following information must be known:

a. CFM_{std} flowing,
b. Temperature of air @ outlet of equipment,
c. Altitude of site,
d. Pressure loss of exhaust duct system,
e. Negative pressure if required in exhaust duct,
f. Pressure loss of input duct system and filters.

Items a, b and e must be obtained from the equipment manufacturer while Items c, d and f must be evaluated for the case in point. More accurate data for duct losses may be obtained from heating and ventilating contractors.

Broadcast equipment using external air systems require a layout typical to the one in Fig. 65.

Air flow measurement outside a laboratory is very difficult if a high degree of accuracy is required. The basic tools required are: U-tube manometer, thermometer and some pressure drop curves for known system elements. Using the U-tube manometer, the static pressure across a known element such as a power tube may be measured. Comparison of this measured value with that same value of pressure loss on the curve gives a flow rate of air. Note here care must be taken to correct for temperature and altitude of incoming air to agree with the curves being used. A second check for air flow is to

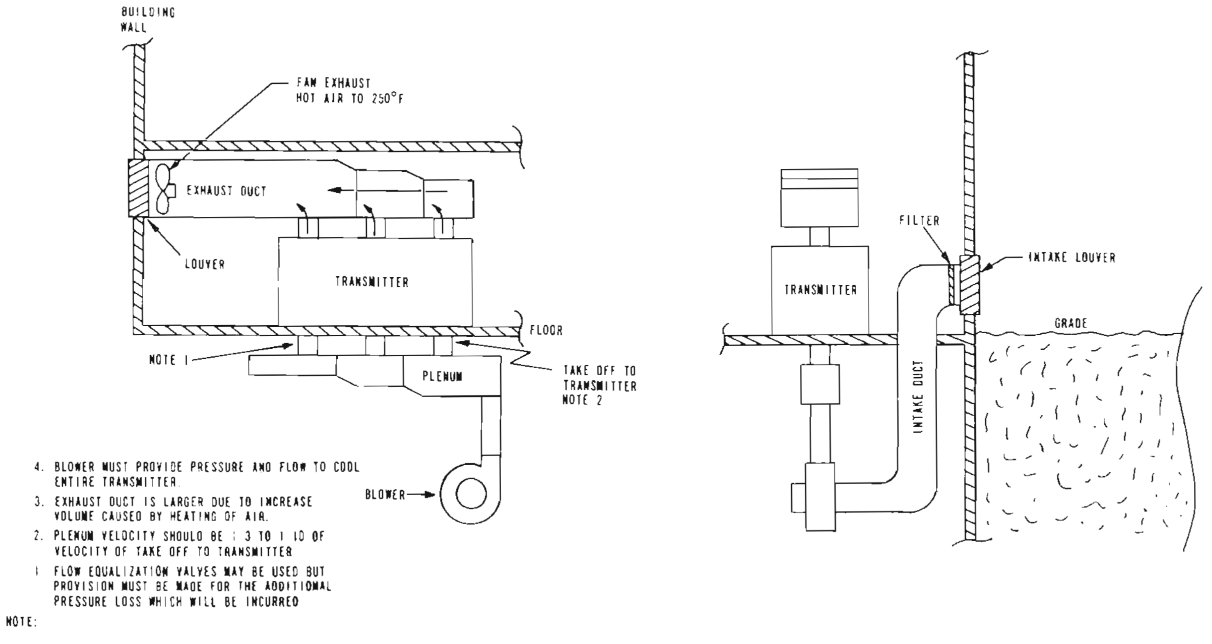


Fig. 65. Typical cooling system.

measure input and outgoing air temperatures across a known element and at the same time measure power dissipated in kilowatts. Knowing ΔT and P (in kilowatts) and using $CFM_{std} = \frac{3160 \times P}{\Delta T}$, the standard CFM can be arrived at. Comparison of this number with the one obtained by the manometer method provides a check. These numbers will not agree exactly, due to the many inaccuracies, but $\pm 15\%$ can be expected.

UHF TRANSMITTERS

Visual Exciter/Modulator

The Exciter/Modulator for UHF transmitters in principle departs little from the concept delineated in the VHF section. Other than the different treatment of the on-channel amplifier caused by the higher operating frequency and its up-converter, only two areas are modified to better serve requirements peculiar to a UHF transmitter employing klystron tubes as power amplifiers: In VHF which uses very linear tubes for power amplification, PC board No. 2 of the video portion provides for moderate correction of differential gain with a small ($\pm 3°$) capability for the differential phase correction.

With the substantially greater need for correction for both differential gain and differential phase in a klystron, this function is now performed by two different circuits. PC board No. 2 in the video portion will only correct for differential phase up to $\pm 10°$.

The need for much larger control range with steeper changes in rate make it desirable, if not mandatory, to place the corrector after the VSB filter in order to provide a wider bandwidth for the predistorted signal. Therefore, the linearity corrector is placed in the IF portion just ahead of the up-converter. With this approach four step correctors will allow a klystron to operate with a sync peak power of 10% below its saturated power.

Fig. 66 shows the schematic of the differential phase corrector. The correction is accomplished by phasor addition of in and out of phase voltages of the original video signal through an inductance (L2) and a resistor (R3), the latter being varied depending on the instantaneous video level. While this phase shift

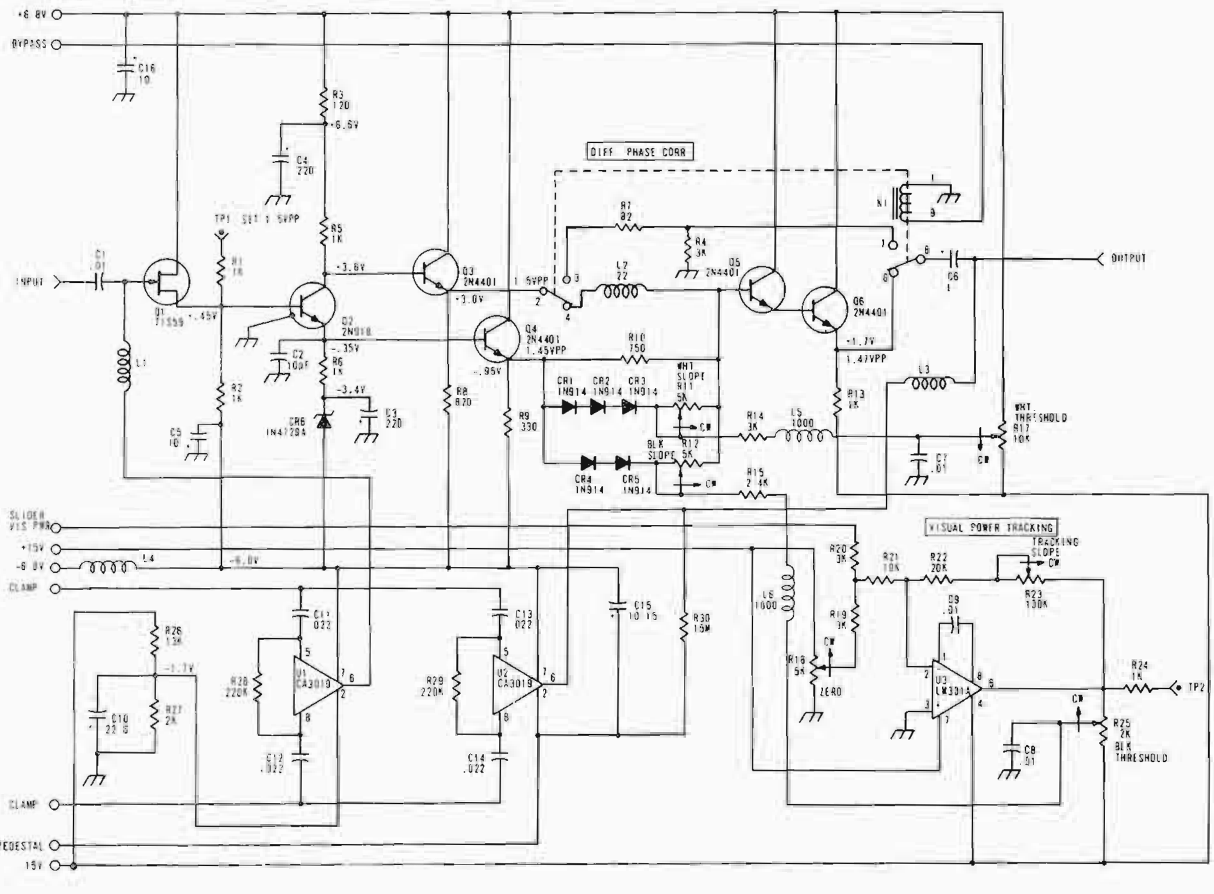


Fig. 66. Schematic of the differential phase corrector.

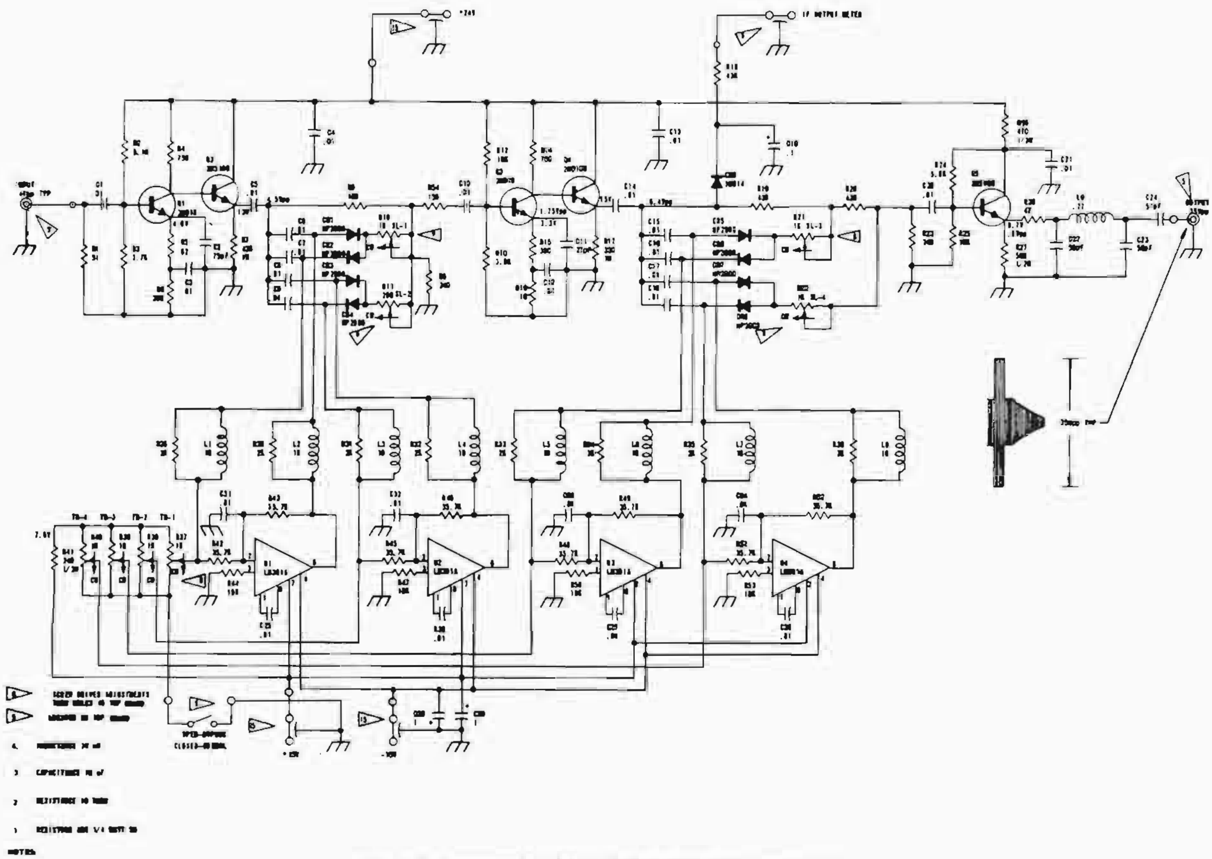


Fig. 67. Schematic of the differential gain corrector.

takes place no change in the video signal level occurs.

The circuit allows for a two step correction with adjustable slope and point of attack which has proved completely satisfactory in a practical system. A bypass switch allows the differential phase corrector to be switched in, or out.

Fig. 67 is a schematic of the differential gain corrector. It provides four control steps with the rate of change and point of attack adjustable for an optimum match. The circuit will work on the positive and the negative cycle of the IF waveform with a single adjustment, a feature that makes this adjustment easier and more straightforward.

Controls TH-4 and SL-4 set point of attack and slope for sync expansion. Controls TA-3 and Sl-3 perform the same function in the black area and TH-2 and SL-2, as well as TH-1 and SL-1 compensate for errors in the gray to white area. The circuit can also be bypassed by switch activation on the module. The operation of this unit can readily be understood from the schematic. Correction is supplied by voltage dependent control of two voltage dividers, R-8 and R-9 for white-gray and R-19, R-20, and R-23 for black and sync areas.

The generator for the pump frequency serves both mixers. The signal, which in the VHF Exciter/Modulator is obtained by multiplication by 2 for low band, or 4 for high band of the crystal oscillator, follows a totally different approach in the UHF Exciter/Modulator. This new approach is designed to accommodate the higher frequency of the carrier as well as the large number of individual channels.

The circuit centers around a step-recovery diode (SRD).[19] The advantage of this diode in this application is twofold: Every integral multiple of the drive frequency appears in the output and virtually no tuning of the device is required.

About 500 mw of drive is required which is obtained from the crystal oscillator through a conventional 60-MHz amplifier with approximately 10-MHz bandwidth.

The availability of every integral multiple of the input frequency allows design of the system with a crystal oscillator frequency variation of only 6 MHz and, therefore, the drive amplifier can be a nontuned broadband amplifier which drives the SRD diode. The tuning of the exciter to the selected channel involves merely the selection of the proper pump oscillator crystal and the tuning of two bandpass filters to the proper multiplier frequency and to the difference frequency of the up-converter. About 20 mw is available from the multiplier over a range from the 9th to the 14th harmonic when

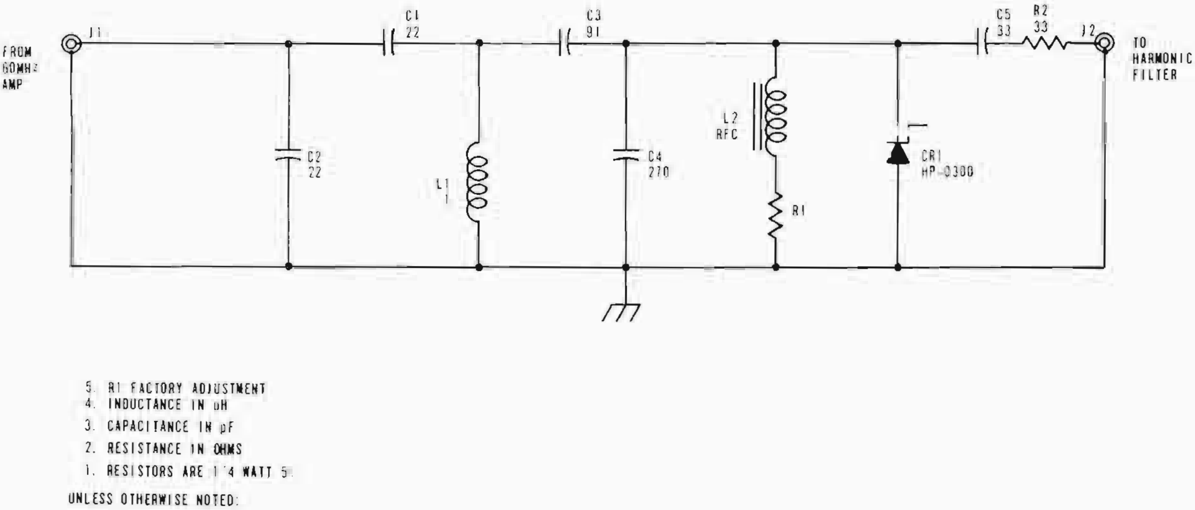


Fig. 68. Harmonic generator, schematic.

driven with approximately 500 mw. Channel 14, for instance, with a carrier frequency of 471.25 MHz, the pump is placed at 471.25 MHz plus 37 MHz equals 508.25 MHz. This is the 9th harmonic of the crystal frequency of 56.472222 MHz. The multiplier of 9 can be employed up to Channel 22, a 519.25 MHz carrier frequency leading to a crystal frequency of 61.8055 MHz. From Channel 23 on, a multiplier of 10 is used, leading to a crystal frequency of 56.225 MHz and so on.

It becomes evident that, if each integer in a multiplier is available, the crystal frequency variation, and consequently, the bandwidth of the drive amplifier is determined by the spacing of the TV channels.

Fig. 68, the schematic of the SRD harmonic generator shows that no variable, or tunable elements are present. The output is connected to a 7-pole bandpass filter which selects the wanted harmonic frequency and sufficiently rejects all other multiples of the drive frequency. This filter is adjusted for each channel selected and is identical to another bandpass which will be selected and adjusted to the difference frequency from the double-balance up-converter. However, the latter filter is tuned 37 MHz lower in frequency than the former.

A 3-dB 90° hybrid following the harmonic selector bandpass will split the signal in equal mounts for the up-converters in the visual exciter and in the aural exciter.

The SRD multiplier is often referred to as a comb generator since the display on the spectrum analyzer of its output spectrum into a resistive load resembles a comb.

Amplification of the output frequency from the up-converter is performed by a 43 dB gain, five-stage solid-state amplifier, similar to the one in the VHF exciter. The physical implementation of the circuit, however, differs greatly from the lumped circuit VHF model. Construction is in the form of a stripline which provides circuit elements in transmission line, or distributed form. A number of capacitors for tuning and bypassing are retained in lumped form. Fig. 69 is a photograph of a typical stripline amplifier. The aural exciter's IF portion,

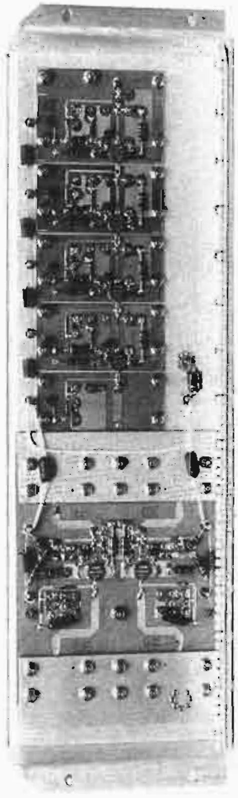


Fig. 69. Photograph of a typical stripline amplifier.

is identical to the VHF model. Only the up-converter and stripline amplifier are different, but are almost identical, except for biasing to comparable elements in the UHF visual exciter.

The visual and aural Exciter/Modulator produce 1 and 3 watts, respectively, sufficient to drive a power amplifier.

Power Amplifiers

Klystrons have found very widespread application in high power UHF TV transmitters. Excellent descriptions of their operation in broadcast service are available from several manufacturers. See References 20, 21, 22, 23, and Fig. 70.

In view of the many references available, only a short characterization of the klystron amplifier will be presented here. For visual service a five-cavity klystron resembles a stagger tuned, five-stage Class A amplifier. Its power gain is just under 10 dB per stage and, therefore, approaches 50 dB for five cascaded stages. Its bandwidth is attained by stagger tuning with the last cavity tuned to the carrier which contains, so to speak, the largest percentage of the total power.

The klystron has an input-output transfer characteristic defined by J_1 of the first order Bessel function which is very close to the first 90° of a sine wave. It will reach a point of maximum power, and if drive is increased beyond this point, the output will decline again.

In addition, when drive is varied from zero to a point reaching the selected output power, the input versus output phase varies greatly and in a nonlinear fashion, with delay rapidly rising when approaching saturated power.

To utilize a klystron for TV service both imperfections must be compensated by signal predistortion which at present is the only practical way to make the entire system linear in amplitude and phase.

While amplitude compensation is an absolute necessity, phase compensation is not required if the rest of the system has phase errors which are very small, and the klystron is not operated up to the saturated power level but only to a level of, 15 to 25% below saturated power. It becomes extremely important to devise methods

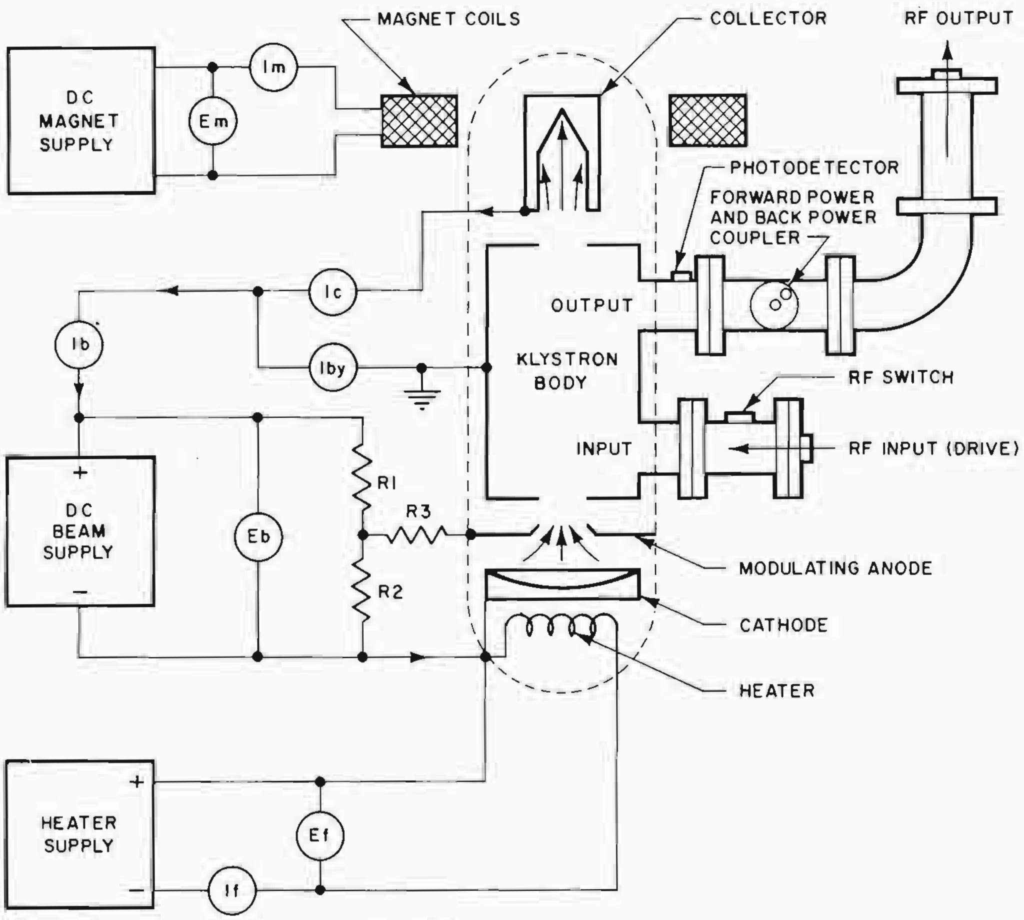


Fig. 70. Klystron amplifier.

of RF power measurements of great accuracy since a small error in power measurement in the wrong direction will force the klystron amplifier to operate closer to saturation, costing the user a loss in performance totally out of proportion with the small increase in power over that for which the station is licensed.

UHF TV stations should, therefore, pay strict attention to the accuracy and reliability of their output power measuring system. This is much less important for VHF transmitters which suffer little deterioration in performance if they are inadvertently (due to measurement inaccuracies) operated 10% to 20% above (true) rated power. From a practical point of view RF power can only be measured to an accuracy of about ±5% under field conditions and often ±10% uncertainty must be expected. Even under laboratory conditions, it becomes very difficult to be more certain than ±3%.

The beam current of a klystron is a function of collector voltage or the modulating anode—body voltage if the klystron is so equipped.

$$I = K \times V^{3/2}$$

Where: I = collector current
V = collector voltage
K = perveance

K has the dimension of $A/V^{3/2}$ power (in the nature of a conductance) and is determined by the physical dimension of the beam generating system of the tube.

By adding a modulating anode in the tube, the collector current can be varied to adapt the tube to different operating conditions, e.g., use as visual or aural amplifier.

Practical values for K lie between 0.1 and $10 \times 10^{-6}\ A/V^{3/2}$.

We can assume that for small changes in beam current the klystron efficiency will remain unchanged. Therefore, for small changes in the supply voltage, we see a 2.5 fold change in output power resulting from:

$$I = K \times V^{3/2}$$
$$P = K \times V^{5/2}$$
$$\Delta P \propto \sqrt[2]{V^5}$$

An increase of 1% of the supply voltage will increase output power by 2.5%. A klystron transmitter's power output (or any other power variation, e.g., hum) is very sensitive to supply voltage variation, and it is often necessary to regulate a supply line which for VHF applications would not require regulation.

Many klystrons are now equipped with a modulating anode which also follows the $K \times V^{3/2}$ law (allowing reduced beam current) or in effect, the tube perveance, so that like tubes can be operated in visual and aural amplifiers running at reduced beam current in the aural socket. This way better efficiency for the transmitter can be obtained.

Klystron amplifiers require a considerable amount of supportive elements.

To focus the electron beam and define its path through the drift space to the collector, a magnetic field must be established through the tube. Electro magnets and permanent magnets can be used for this purpose.

Electro magnets are predominantly employed even though there is a finite resistance of the coil and additional dc power is used and must be removed by cooling. Typically, a 55-kw TV transmitter requires 3 kw of dc power for the magnet of each amplifier.

Two supplies provide the magnet current which must be carefully controlled therefore interlock protection is required since loss of the magnetic field (without immediately removing the beam voltage) will destroy the drift tube in a matter of a few seconds. No other source of electric power, except for perhaps 200 watts for filament are required.

Cooling, however, requires an elaborate mechanical system as three different methods are employed. The magnet and klystron body are cooled by running water. Filament seals are cooled by forced air. The collector is cooled by boiling away water (vapor phase cooling). This is done by providing water to the anode or the collector of the tube and allowing the water to boil away. Water removes large amounts of heat with low flow in this mode. The relationship is:

Kw dissipated =

$$.14644\,[(GPM_w)(212 - T_{in}) + 970\,(GPM_s)]$$

Kw dissipated is the amount of power in kilowatts. GPM_w is the gallon per minute of water flowing. T_{in} is the inlet water temperature in degrees Fahrenheit. GPM_s is the gallon per minute of water changed to steam.

Sample Problem: What will the GPM_s be in a system dissipating 182 kw with GPM_w equal 3 and T_{in} equal 120 °F?

$$182 = .14644\,[3(212 - 120) + 970\,(GPM_s)]$$

$$\frac{\frac{182}{.14644} - (3)(92)}{970} = GPM_s = .996\,GPM.$$

The boil-off rate is .996 gallon of water per minute.

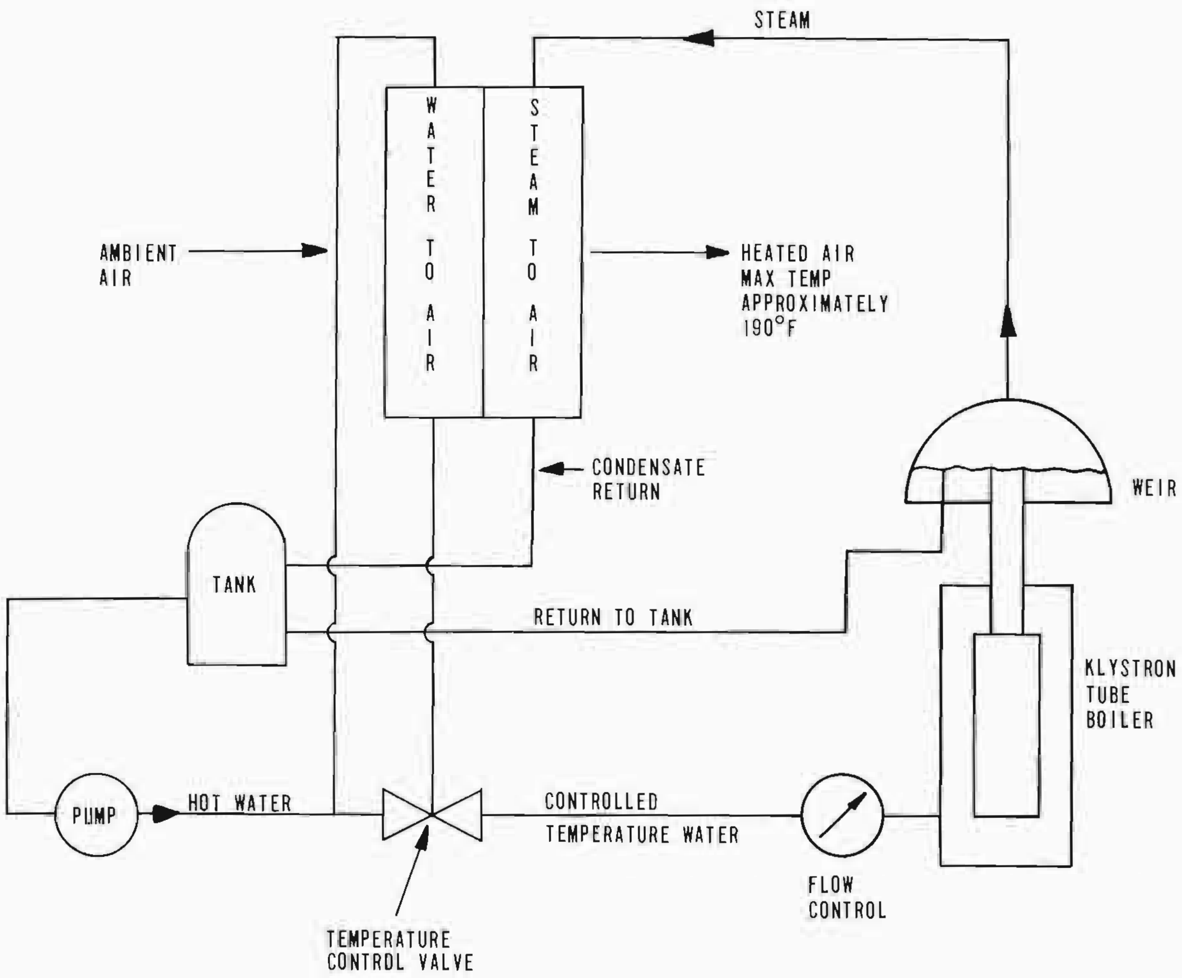


Fig. 71. Vapor phase cooling system.

The sample problem demonstrates how small the water flow required to remove large amounts of power, now a subsystem to supply water to the cooling system must be provided. This system generally consists of a blower, steam to air-condensing coil, water to air-cooling coil, a pump, and a temperature control valve to control the water temperature returning to the transmitter. See Fig. 71.

Major efforts in the design of a klystron amplifier goes into protective circuitry which will protect the expensive tube against damage from any possible malfunction. These protective circuits sense all supply voltages and some currents, they sense the RF load condition, a number of selected temperatures and coolant flow. These circuits, while not-correcting the fault, will, however, remove the transmitter from service if certain limits of the sense quantities are exceeded in order to avoid destruction of the klystron. Additional protective devices are required for operator safety.

Fig. 72. Harris BT25H1 TV transmitter.

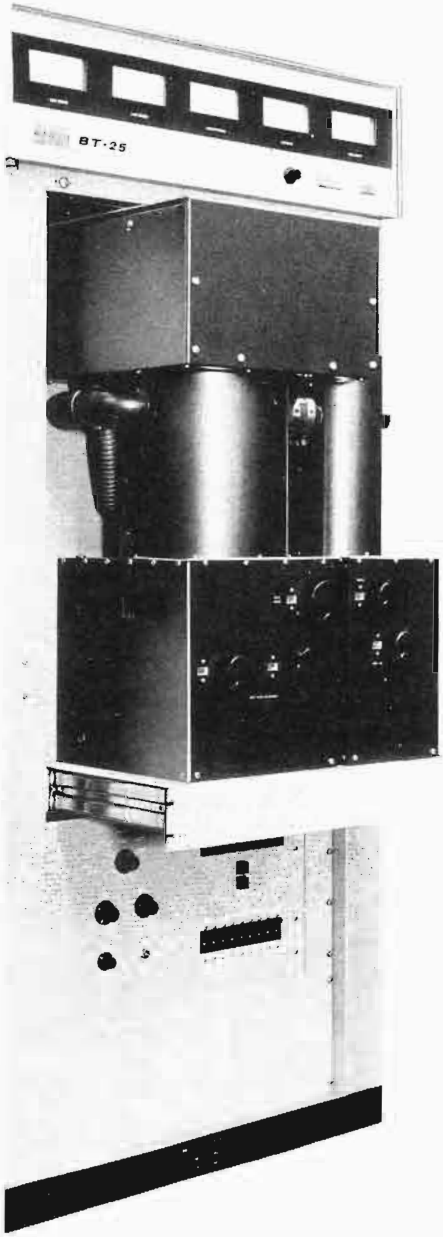


Fig. 73. 25 Kw VHF high band cavity.

TYPICAL TV TRANSMITTERS

Harris BT25H1 VHF TV Transmitter

Model BT-25H1 (25 kilowatts) high band VHF television transmitter features IF Modulation. The BT-25H1 consists of 3 cabinets: a 1.3 kilowatt exciter/driver, an aural power amplifier, and a visual power amplifier—plus an external power supply. The BT25H1 is FCC type accepted, and meets or exceeds CCIR specifications. Visual and aural exciters generate fully modulated low-level IF signals. The output of a common crystal controlled reference oscillator is used to raise the individual IF signals to the desired "on-channel" output frequency.

IF Modulation requires less circuitry to produce a fully processed visual signal. The ring modulator, with excellent linearity, permits modulation percentages to approximately 2% without compromising transmitter performance and eliminates most predistortion circuitry. This results in exceptional color performance and nearly perfect signal linearity. Even such colors as highly saturated yellow and cyan are faithfully reproduced with IF Modulation. Envelope delay compensation for the VSB filter is performed at the IF frequency. Continuously variable controls allow a precise delay correction not possible with conventional fixed-step systems.

Also, visual sideband shaping is performed on the IF frequency at milliwatt power levels, and provides precise shaping of both lower and upper sidebands.

The sideband filter used is a small removable module housed in the visual exciter.

Signal Flow (Visual): The visual exciter signal passes through two IPA stages: a Type 7289 planar triode and a Type 8122 tetrode, giving an output of approximately 100 watts. From the IPA, the signal goes to a power amplifier, an 8792 coaxial tetrode that delivers up to 1,300 watts drive through a circulator to the 8916

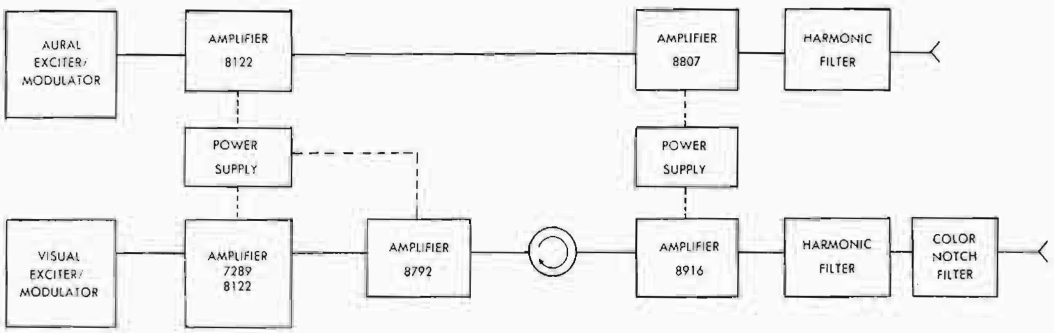


Fig. 74. Harris BT25H1, block diagram.

final visual amplifier. Harmonic filters and color subcarrier filters are externally mounted.

Signal Flow (Aural): The 10-watt output of the aural exciter drives an 8122 IPA. The IPA drives an 8807 aural final amplifier, which delivers up to 5 kilowatts average power output.

Control Logic: Complete and fool-proof control of all transmitter functions is achieved through the use of solid-state memory, timing, and logic circuits. A self-charging emergency power source is provided to maintain control logic memory during periods of power line failure.

The solid-state control logic and protective circuitry, in addition to commanding normal ac control functions, is also used to visually indicate, through pilot lights, the operating status of the transmitter system. The indicator lights allow easy isolation of circuit faults.

All control, metering and monitoring circuits have been designed specifically for remote control operation. The power controls are motor driven and all remote control and sample points are available at one common access point.

Accessibility: Total transmitter component accessibility is provided, front and back. Visual and aural exciters slide out and can operate independently from the transmitter outside the main cabinet. Various exciter circuits, such as oscillators, modulators, and processing circuitry, are of modular construction and can be removed for maintenance or replacement.

Easy-to-read, eye-level, 4-in. meters are used to monitor required transmitter functions. The meter panel is of double-hinged construction for convenient fold-down access during maintenance.

All components of the BT-25H1—including visual and aural exciters, intermediate power amplifiers, final power amplifiers, sideband filters and power supplies—are designed for ease of maintenance.

SPECIFICATIONS

Visual Performance

Power Output: BT-25H1: 25 kilowatts. (Measured at the output of the notch diplexer, if used.)

Output Impedance: 50 ohms. Output connector: (BT-25H1) 3-1/8" EIA standard.

Frequency Range: 174 to 216 MHz (Channels 7 through 13).

Carrier Stability: ±250 Hz (maximum variation over 30 days).

Regulation of RF Output Power: Better than 3%. (Black to White Picture.)

Amplitude Variation of Output: Over one picture frame: less than 2%. (Measured at blanking level.)

Visual Sideband Response:

+4.75 MHz and higher	−20 dB or better
Carrier to +4.18 MHz	+0.5, −1 dB
Carrier	0 dB reference
Carrier to −0.5 MHz	+0.5, −1 dB
−1.25 MHz and lower	−20 dB or better
−3.58 MHz	−42 dB or better

Frequency Response versus Brightness: ±0.75 dB (measured at 65% and 15% of modulation. Reference 100% = peak of sync).

Visual Modulation Capability: 3% or better.

Differential Gain: 0.5 dB or better (maximum variation of subcarrier amplitude from 75 to 10% of modulation. Sub-carrier modulation percentage: 10% peak-to-peak).

Linearity (Low Frequency): 0.5 dB or better.

Differential Phase: ±3° or better (maximum variation of sub-carrier phase with respect to burst for modulation percentage from 75 to 10%. Sub-carrier modulation percentage: 10% peak-to-peak).

Signal-to-Noise Ratio: −50 dB or better (RMS) below sync level.

Envelope Delay:

.05 to 2.1 MHz	±40 ns	Referenced to
at 3.58 MHz	±30 ns	standard
at 4.18 MHz	±70 ns	FCC curve

k Factor (2t): 2%.

Pulse Response (12.5t): 10% or less peak-to-peak disturbance of Baseline referenced to height of 12.5t pulse.

Video Input: Bridging loop through input with 33 dB or better return loss up to 5.5 MHz, 75 ohms impedance.

Harmonic and Spurious Radiation: −80 dB.

Aural Performance

Power Output: BT-25H1: 5 kilowatts. (Measured at the output of the notch diplexer, if used.)

Audio Input: +10 dBm, ±2 dB into 600 ohms.

Input Impedance: 600/150 ohms.

Pre-emphasis: 75 microseconds.

Frequency Response: ±0.5 dB relative to pre-emphasis (30-15,000 Hz).

Distortion: 0.5% or less after 75 microseconds de-emphasis with ±25 kHz deviation, 0.7% after 50 microseconds de-emphasis with ±50 kHz deviation.

FM Signal-to-Noise Ratio: −60 dB relative to ±25 kHz deviation.

AM Signal-to-Noise Ratio: −50 dB relative to 100% modulation (measured after de-emphasis).

Output Impedance: 50 ohms, output connector: 3-1/8" EIA standard.

Frequency Stability: ±250 Hz (maximum over 30 days).

Service Conditions:

Ambient Temperature: −20° to +50° C.
Ambient Humidity Range: 0 to 100% relative humidity.
Altitude: Sea level to 7,500 feet.
Physical and Mechanical Dimensions: BT-25H1: Transmitter size, 94-1/2" wide, 31-1/2" deep, 72" high. Power supply: 36" wide, 24' deep, 60' high.
Weight: BT-25H1: 3,235 lbs. Power supply: 950 lbs.
Electrical Requirements: 208/240 volts (±11 volts) 3 phase, 50/60 Hz. (Special voltages available.)
Power Factor: 100% nominal.
Regulation: 3%.
Phase Unbalance: 2%.

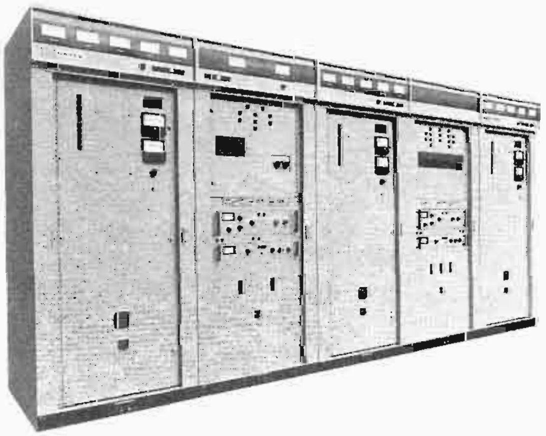


Fig. 75. Harris BT60U TV transmitter.

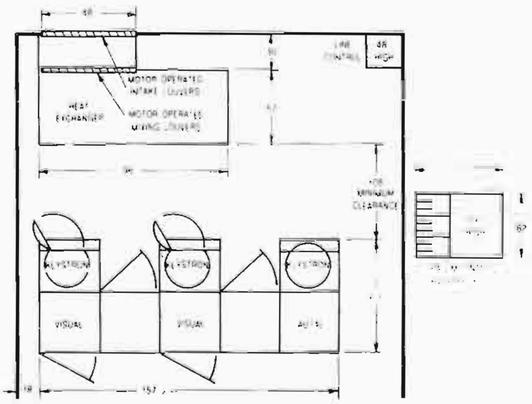


Fig. 76. Floor plan, BT60U.

Power Consumption: BT-25H1.
Average picture: 44 kw.
Black picture: 55 kw.

TYPICAL TV TRANSMITTER

Harris-Model BT-60U

Employing IF Modulation, Harris' FCC type accepted BT-60U provides redundancy of the visual amplifiers for on-the-air protection.

Each of the visual amplifiers operates at a 30-kw power level, and the outputs are added together in a hybrid combiner to produce a total output of 60 kw. If one visual stage should fail, output power will automatically drop to 25% of total output power, with no carrier interruption. The defective stage may be bypassed through an optional patching system so that power may be increased to 50% during service time. In case of an aural amplifier failure an optional kit allows a visual stage to be substituted.

The BT-60U includes two visual klystron cabinets, one aural klystron cabinet, two control cabinets, one high-voltage power supply, and one unitized heat exchanger.

The high power visual and aural amplifiers use identical klystrons. The visual amplifiers operate at 30 kw each, and the aural klystron is capable of producing up to 12 kw at the output of the diplexer. The BT-60U is completely factory tested at full-rated power to assure performance to specifications.

Standby visual and aural exciter/modulators, plus an automatic switcher, are available as options for additional protection.

Low-Level Vestigial Sideband Filtering: The VSB filter consists of lumped tuned circuits and operates at the 37 MHz IF frequency, which affords temperature stability far exceeding any type of on-channel VSB.

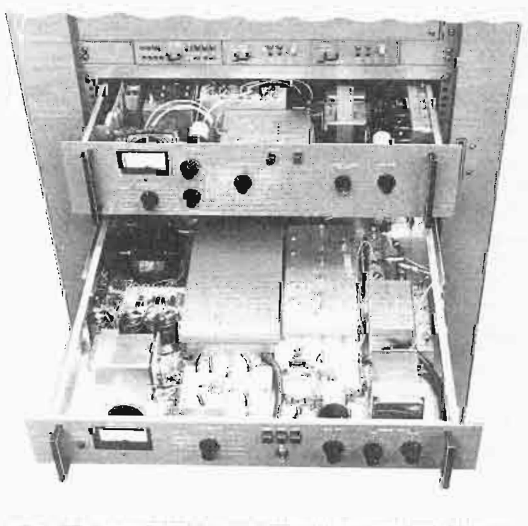


Fig. 77. Harris BT60U transmitter exciter/modulator.

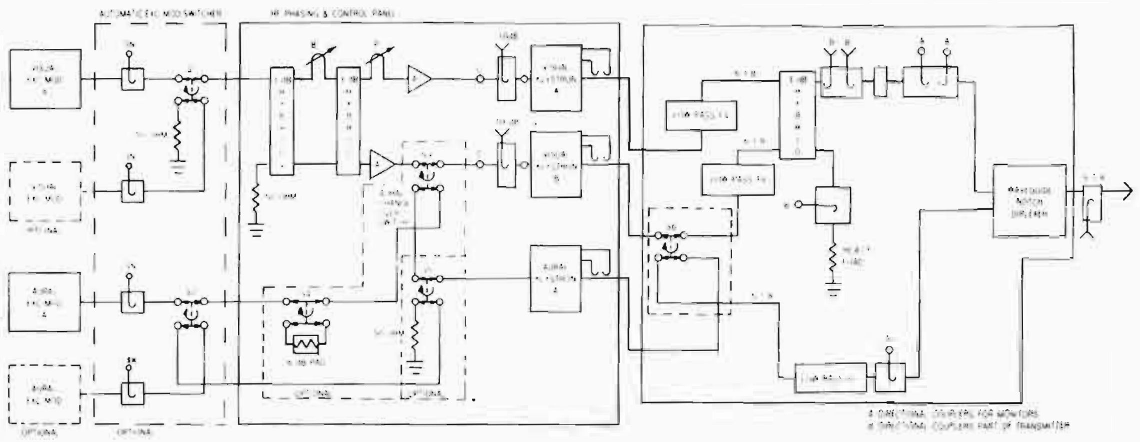


Fig. 78. Harris BT60U transmitter block diagram.

Complete color correction of VSB envelope delay is provided by stable, active filter circuits operating on the IF frequency. This allows asymmetrical correction to be made on either side of carrier to completely compensate for the VSB's nonsymmetrical delay characteristics. Direct on-carrier modulation systems can only provide symmetrical delay compensation and cannot equal the IF color performance.

Klystrons: New high gain klystrons offer substantially higher efficiency over older models. The klystrons contain five internal cavities and amplify the exciter outputs to the proper power levels. Vapor cooling is employed, with one unitized, completely self-contained heat exchanger provided. The klystrons are mounted in special mechanical assemblies which pivot to allow easy installation.

Remote Control: Control circuit functions, metering, and monitoring are designed specifically for remote control operation.

Simplified Assembly, Installation: Harris "building block" concept, in which major components are housed in functional modules, greatly simplifies transmitter assembly and installation, and allows later power increases if desired.

SPECIFICATIONS
(CCIR Specifications Available)

Visual Performance

Power Output: 60 kw, peak of sync (FCC and CCIR systems M, N).

Output Impedance: 50 ohms. Output connector: 6-1/8" EIA Standard.

Frequency Range: 470-890 MHz (Channels 14 to 83; CCIR bands IV/V).

Carrier Stability: ±250 Hz (maximum variation over 30 days).

Regulation of RF Output Power: (Black to white picture): 3% or less.

Variation of Output: Over one frame: less than 2%.

Visual Sideband Response: (exclusive of diplexer)

+4.75 MHz and higher .... −20 dB or better
Carrier to +4.18 MHz........ +0.5, −1 dB
Carrier..................... 0 dB reference
Carrier to −0.5 MHz......... +0.5, −1 dB
−1.25 MHz and lower .... −20 dB or better
−3.58 MHz.............. −42 dB or better
Corner frequencies scaled to meet CCIR standards.

Frequency Response versus Brightness: ±0.75 dB (measured at 65% and 15% of modulation. Reference 100% = peak of sync).

Visual Modulation Capability: 3% or less.

Differential Gain: 0.5 dB or better (maximum variation of sub-carrier amplitude from 75% to 10% of modulation. Sub-carrier modulation percentage: 10% peak-to-peak).

Linearity (Low Frequency): 0.5 dB or better.

Differential Phase: ±4° or better (maximum variation of sub-carrier phase with respect to burst for modulation percentage from 75% to 10%. Sub-carrier modulation percentage: 10% peak-to-peak).

Signal-to-Noise Ratio: −50 dB or better (RMS) below sync level.

K Factors: 2t 2%, 12.5t less than 10% baseline disturbance, 20t 3%.

Envelope Delay:

.05 to 2.1 MHz	... ±40 ns	Referenced to standard FCC curve
at 3.58 MHz	...... ±30 ns	
at 4.18 MHz	...... ±70 ns	

Video Input: Bridging, loop through input with −30 dB or better return loss up to 5.5 MHz, 75 ohm system.

Video Input Level: 1.0 Volt peak to peak ±3 dB, sync negative.
Harmonic Radiation: −80 dB.

Aural Performance

Power Output: 6 kw to 12 kw, at diplexer output.
Output Impedance: 50 ohms. Output connector: 6-1/8" EIA standard.
Audio Input: +10 dBm, ±2 dB into 600 ohms.
Input Impedance: 600/150 ohms.
Pre-emphasis: 75 microseconds.
Frequency Response: ±0.5 dB relative to pre-emphasis (30-15,000 Hz).
Distortion: 0.5% or less after 75 microseconds de-emphasis with ±25 kHz deviation.
FM Noise: −59 dB relative to ±25 kHz deviation.
AM Noise: −52 dB relative to 100% modulation (measured after de-emphasis).
Frequency Stability: ±250 Hz (maximum variation over 30 days).

Service Conditions

Ambient Temperature: +2° to +50°C. (36° to 122°F).
Ambient Humidity Range: 0 to 95% relative humidity.
Altitude: Sea level to 7500 feet.
Physical and Mechanical Dimensions: Transmitter: 157-1/2" W X 63" D X 72" H.
Weight: 6550 lbs. Power Supply: 72" W X 62" D X 59" H. Weight, 9200 lbs. Heat Exchanger: 96" W X 52" D X 80" H. Weight: 4000 lbs.
Electrical Requirements: Power input: 440/460/480 Volts, 3 phase, 60 Hz, 4 wire (380 Volts 50 Hz available on special order). Power consumption: 20% aural, 290 kw. 10% aural, 263 kw. Regulation 3%. Phase unbalance: 2%. Power Factor: 100%.

Klystrons

Types:
Low Band (Channels 14-29, 470-566 MHz), VA 946H.
Mid Band (Channels 30-51, 566-698 MHz), VA 947H.
High Band (Channels 52-83, 698-890 MHz), VA 948H.

PRECISE FREQUENCY CONTROL

The limited number of available channels for TV Broadcasting makes it necessary to assign the same carrier frequencies to many stations. To avoid interference between stations operating on the same frequency (cochannel interference) geographical separation and radiated powers are carefully selected.

Nevertheless, considerable cochannel interference was encountered in many locations and investigation showed that additional means were available to reduce cochannel interference by making use of optical or perceptive elements in the system. In other words, steps were taken not to alter the strength of the interferring carrier but to choose operating parameters to reduce the visibility of the interference.

Considerable investigative work was done to lay the scientific and physiological basis and to define the parameters which need to be controlled to reduce the visibility.[24,25,26,27,28]

It turned out, with horizontal and vertical sweep ratios fixed, the Visual carrier frequencies of the interferring stations was the parameter which had to be controlled.

Cochannel interference between television stations appears to viewers as a horizontal pattern of alternating light and dark bars on the viewing screen—very much like the shadows cast by venetian blinds. It has been demonstrated for many years that the visibility of these bars varies cyclicly as a function of the difference in frequency of the interfering carriers (Fig. 79). The interference is most visible when the carriers were offset by multiples of the line frequency (15,734 kHz) and least visible when the carriers are offset by odd multiples of one-half the line frequency. In addition to the gross maxima and minima, fine grain maxima and minima occur when the frequency offset is a multiple of the frame frequency (29.97 Hz). Ideally, stations would be offset by odd multiples of one-half the line frequency to provide minimum interference visibility. However, a third station in the same area would be offset from one of the other stations by an even multiple of the line frequency. Hence, maximum visibility of the interference. The 10 kHz offsets were chosen to provide approxi-

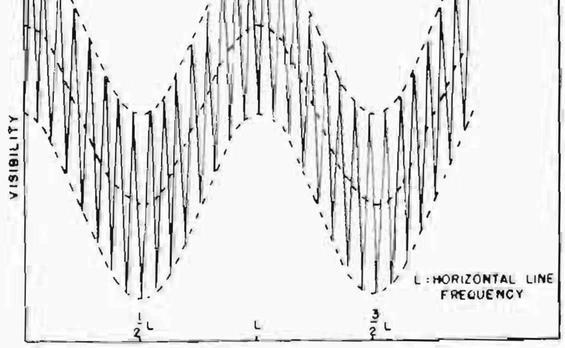


Fig. 79. Cochannel interference.

mately equal reduction of the interference patterns for any number of stations in geographical proximity, see Figs. 80 and 81.

Although it is not practical to utilize the gross minima occurring at odd multiples of one-half the line frequency, it was determined experimentally that utilizing the fine grain minima, occurring at even multiples of the frame frequency, would be very advantageous in reducing the visibility of co-channel interference.

The nearest even multiple (334th) of the frame frequency to the 10 kHz offset is 10,010 Hz. Since the carrier frequency tolerance is ±1,000 Hz, the precision offset is compatible with existing regulations. In a three station arrangement, the stations will be offset by 10,010 Hz and 20,020 Hz. Experiments indicated that changes in the frequency differences of ±5 Hz had a negligible effect on the reduction of the interference visibility.

To maintain the precision offset within ±5 Hz requires maintaining each visual carrier frequency within ±2 or 3 Hz.

Maintaining a television transmitter to such tight frequency tolerances requires some type of control system using an extremely stable frequency source.

In IF Modulation transmitters, the modulated carrier is obtained by up-converting the modulated IF signal. Gates transmitters employ two crystal-controlled oscillators—one to generate the IF and one to generate the Master Oscillator frequency. After multiplication, the Master Oscil-

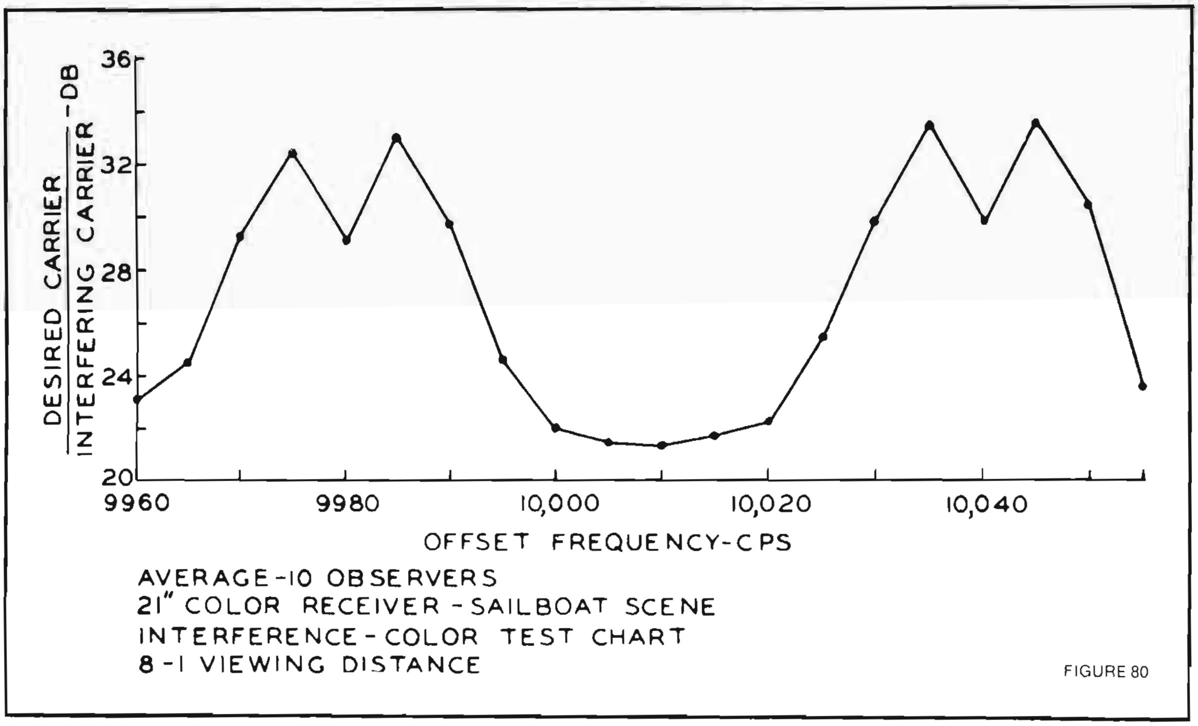


Fig. 80. 10 kHz offset pattern.

lator signal is mixed with the modulated IF signal. The difference frequency is then the visual carrier frequency. The multiplication factors are X2 for VHF Low Band and X4 for VHF High Band.

$$f_{VCAR} = J X f_{MO} - f_{IF} \quad \begin{matrix} J = 2 \text{ VHF Low Band} \\ J = 4 \text{ VHF High Band} \end{matrix}$$

Since the carrier frequency is derived from two independent oscillators, precise control of the carrier frequency must allow for frequency drift in both oscillators. One possible way to achieve control is to phase-lock each oscillator to an extremely stable oscillator. Another method, which requires less circuitry, is to sample the carrier frequency and correct only one of the oscillators to maintain the correct frequency, see Fig. 82.

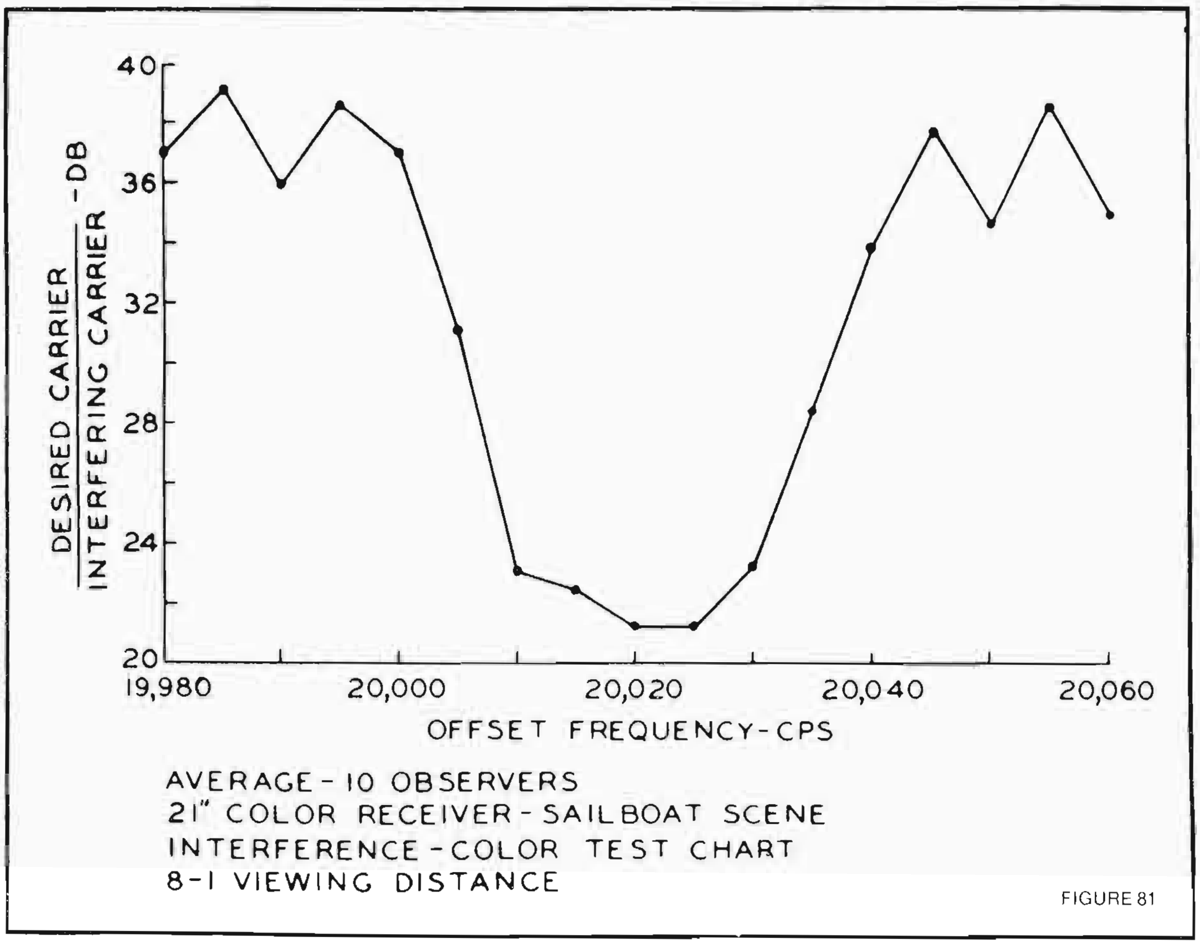


Fig. 81. 20 kHz offset pattern.

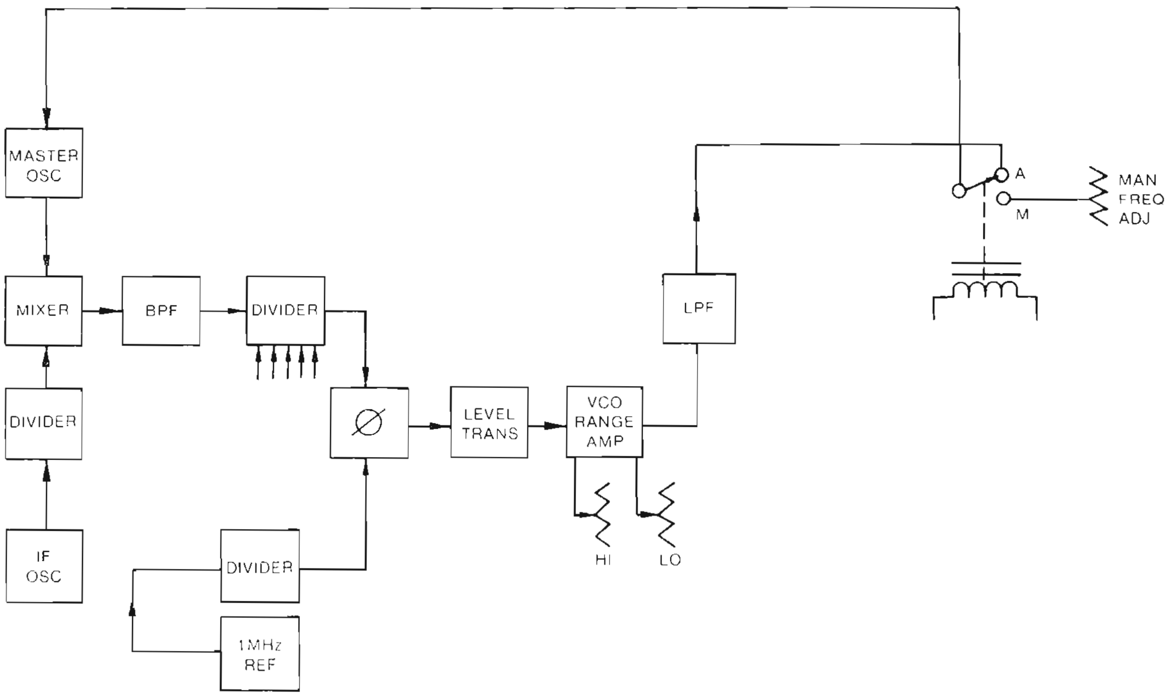


Fig. 82. Precision frequency control block diagram.

The Precise Frequency Control uses the latter method. The Master Oscillator is used as the variable frequency oscillator (VFO) in a phase-locked loop. Although the oscillator is crystal-controlled, its frequency can be pulled slightly by a varactor diode. A sample of the carrier frequency is compared with the signal from an extremely stable oscillator in a frequency/phase comparator. The output of the frequency/phase comparator is the error signal applied to the varactor diode in the Master Oscillator.

To obtain an unmodulated sample of the visual carrier, both the IF Oscillator and Master Oscillators are sampled. For FCC Channels 2-13 the Master Oscillator frequency ranges from 46 MHz to 62 MHz. The IF Oscillator is fixed at 37 MHz. Using digital devices the IF sample is divided by exactly 2 for VHF Low Band and by 4 for VHF High Band. After division, this subharmonic of the IF is mixed with the Master Oscillator sample. A bandpass filter at the mixer output port selects the signal whose frequency is the difference between the Master Oscillator and the subharmonic of the IF Oscillator. The difference frequency is then an exact subharmonic of the visual carrier frequency.

$$f_{\mathrm{d}} = f_{\mathrm{mo}} - \frac{f_{\mathrm{IF}}}{J} = \frac{f_{\mathrm{vcar}}}{J} \quad J = 2,4$$

The carrier sample is frequency divided by a six-stage decade counter. The decade counters are programmable so that any integral division ratio up to 10^6 can be obtained. The programming can be easily changed to provide the correct division ratio for each channel of operation. This way precision control equipment can be manufactured completely before its channel application is known, leading to a considerably more economic method of production. Furthermore, it becomes possible to use a readily available 1 MHz precision reference for practically all possible VHF and UHF channels without the need to procure precision oscillators for uncommon frequencies. Similarly the output of an extremely stable reference oscillator is digitally divided and compared with the carrier sample in a phase frequency comparator. After filtering, the dc error voltage is applied to the varactor diode in the Master Oscillator. To prevent excessive frequency pulling before lockup, the error voltage is limited to a preset range.

Sensors are employed to disable the loop in the event of any malfunctions. When the loop is broken, the Master Oscillator returns to its normal crystal-controlled operation. Although precision control may be lost because of some malfunction, the transmitter carrier frequency will still remain under crystal control and within FCC limits.

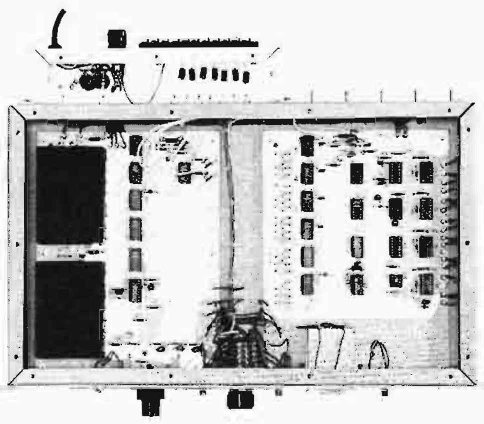


Fig. 83. Precision frequency control, top view.

By phase-locking the Master Oscillator to a stable reference oscillator, the Master Oscillator acquires the stability of the reference source. Crystal-controlled oscillators today can achieve stabilities of less than a few parts in 10 billion (10^{10}) per day. Stabilities of this magnitude mean that a transmitter can be maintained within a few Hertz of a desired frequency for several months. Experimental results have indicated that frequency differences between transmitters can vary as much as ± 5 Hz from the precision offset before cochannel interference becomes noticeably worse. This means that two television stations can minimize their cochannel interference without the requirement to frequently adjust the transmitter frequency. When adjustments are required for the system described in this paper, the transmitter frequency can be changed by adjusting the frequency vernier controls on the reference oscillator. See Figs. 83-84.

Determining when transmitter adjustments are necessary is not an easy task. Measuring transmitter frequencies as high as 200 MHz with 1 or 2 Hz precision is very difficult.

To ascertain the carrier frequency of a station operating under precision control, assuming a

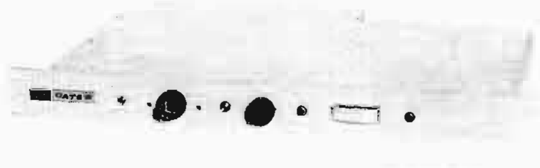


Fig. 84. Precision frequency control, front view.

measuring accuracy 10 times better than the quantity to be measured, leads to the following accuracy requirements:

VHF Low Band	$\pm 2.5 \times 10^{-9}$
VHF High Band	$\pm 1 \times 10^{-9}$
UHF	$\pm 3 \times 10^{-10}$

No frequency counter presently on the market will fulfill these requirements directly.

Standard frequency transmissions from station WWVB, located at Fort Collins, Colorado, can be used as primary reference. Transmissions from WWVB run 24 hours a day without interruption at 60 kHz with 16 kw radiated power, vertically polarized and can be received in the entire continental U.S.A.[28]

The transmitted signal is modulated in amplitude by a digital code transmitting at 16 kw for the high logic state and 1.6 kw during the low logic state. This time code is irrelevant for our purpose here.

We are only interested in the carrier itself. This carrier is advanced in phase by 45° at 10 minutes after the hour and returned to 0° phase at 15 minutes after the hour which serves as identification for the station.

The accuracy of WWVB's carrier is a few parts of 10^{-12}.

The signal from WWVB is available 24 hours in the entire U.S.

However, measurements with high accuracy should only be made during periods when the entire path from Fort Collins to the measuring site is in daylight. Figs. 85 and 86 illustrate the effects of transmission irregularities during nondaylight hours. They show the rate of change in phase of a signal received from WWVB versus a local precision reference. It can be assumed that the local

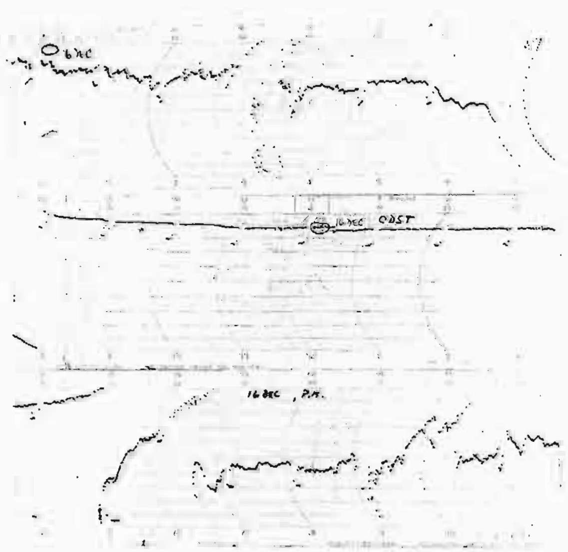


Fig. 85. WWBV phase recording 16-DEC-1974.

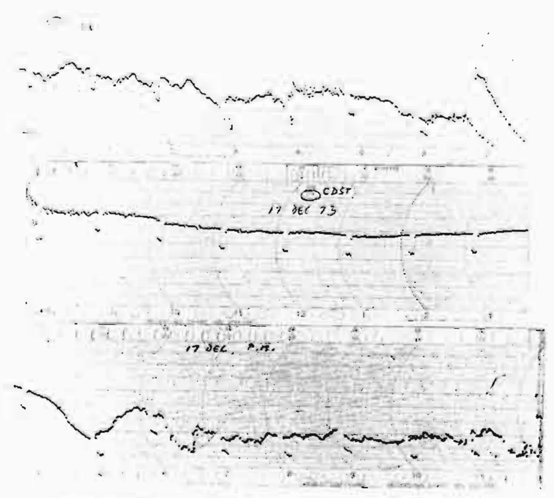


Fig. 86. WWVB phase recording 17-DEC-1974.

source did operate in a consistent manner, day or night, and that a phase departure during nighttime conditions is a result of path disturbance from the WWVB carrier. These disturbances are not always present, but best results are obtained during daylight hours. Note the phase advance from 10 to 15 minutes after the hour which serves as identification of the station.

Two approaches to measure the carrier frequency of a television station operating under precision control will now be described. The first method requires that modulation be removed from the visual carrier and that the aural transmitter be disabled sometime during daylight hours. If this is undesirable, a second method is shown which avoids the above service interruption (leaving, however, a small element of uncertainty).

The first method requires an HP-117A VLF comparator with modification HO1-117A and a HP5245L/5253B Frequency Counter. With the VLF comparator installed and operating (following the instructions provided with this unit), the 1 MHz output from the HP-117A, which is now phase-locked against WWVB, is utilized as an external time base reference for the HP5245/5253 Frequency Counter. With the counter in the frequency measuring mode and using a 10-sec. sampling period, the carrier frequency of the TV transmitter can now be measured, see Fig. 87.

With the aural transmitter turned off and the visual modulation removed, the transmission line sample of the visual transmitter should be fed to the input of the counter. At least ten "10-sec. periods" should be measured, sampled, and recorded for comparison. One should not see more variation in frequency (now displayed to 0.1 Hz resolution) than approximately 1 Hz, plus the usual 1 county ambiguity of the frequency counter. If the frequency indicated is not within ±2.5 Hz,

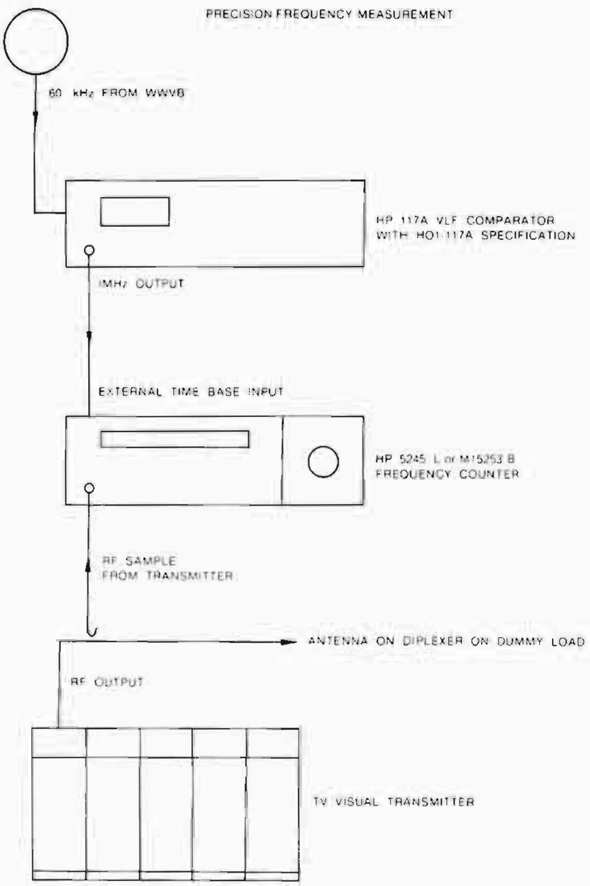


Fig. 87. Measuring system, precise frequency.

the reference standard of the transmitter's precision control equipment should be adjusted. One should keep in mind that any adjustment of the reference standard of the precision control equipment sees a considerable time lag in the phase-lock loop system such that adjustment in the reference standard should be made only in very small frequency increments. Most precision reference standards have calibrated incremental adjustment capability. After an adjustment sufficient time must be allowed for the precision control Equipment of the transmitter to place the transmitter in exact phase-lock to the reference source which may take up to 30 min. Therefore, if adjustment of the carrier frequency of the transmitter is required several measurements should be made at 30-min. intervals to bring the transmitter frequency to within 2.5 Hz of the assigned frequency.

A second method can be used when a service interruption during daylight hours cannot be tolerated. In this case the HP5245M/5253B frequency counter is recommended which has a time base with a lower aging rate.

Preparatory to the frequency measurement of the TV transmitter initial measurements of the carrier frequency (during nonservice hours) should be made using the counter's internal standard to establish proper frequency control, lockup and consistent frequency indication. Next, during daylight hours the exact frequency and drift-rate of the HP counter should be established against WWVB, again utilizing the VHF comparator by recording the phase difference between the 1 MHz phase-locked reference of the VLF comparator against the 1 MHz external output of the frequency counter (which is 1/5 of the internal 5 MHz standard. A recording over several hours should clearly establish the exact frequency of the reference standard as well as it's drift rate. Once the error is established the frequency measurement of the previous night can be recomputed or the internal reference standard of the counter can be adjusted to be within one times 10^{-9} of the wanted frequency and then measurements can be repeated the next night. During the 12-hour waiting period from the daylight measurement of the reference standard to the nighttime measurement of the transmitter's carrier frequency, the precision reference of the HP counter may drift two or three parts of 10^{-10} which will leave the system accuracy well within the limits stated above.

It becomes obvious that the above approaches can be varied in several ways. One should, however, always remember to let precision crystal oscillators operate without any interruption. Any interruption, no matter how short, will (within our frame of reference, speaking in units of 10^{-10}) radically change frequency of any crystal oscillator.

It has been shown that the considerable reduction of areas of cochannel interference between two or three stations operating on the same assigned channel can be utilized in modern television transmitters employing precision control equipment. This advantage can be utilized and maintained without undue efforts and expenditure of funds by employing a low frequency comparator and a standard frequency counter which will allow the user to trace the accuracy of the frequency of his visual carrier to the primary standard of the United States at the National Bureau of Standards in Boulder, Colorado.

AUTOMATIC POWER CONTROL

The output power of visual and aural TV Transmitters may change, resulting from variations of the supply voltage, changes in ambient temperature and for other reasons. Operators are used to adjust the transmitters' output power from time to time to maintain it constant within certain limits, but definitely within the +10, −20% limit established in the FCC Rules and Regulations.

It seems logical to relieve the operator of this tedious task by maintaining output power of both transmitters automatically. In a transmitting system which produces fully processed RF signals at

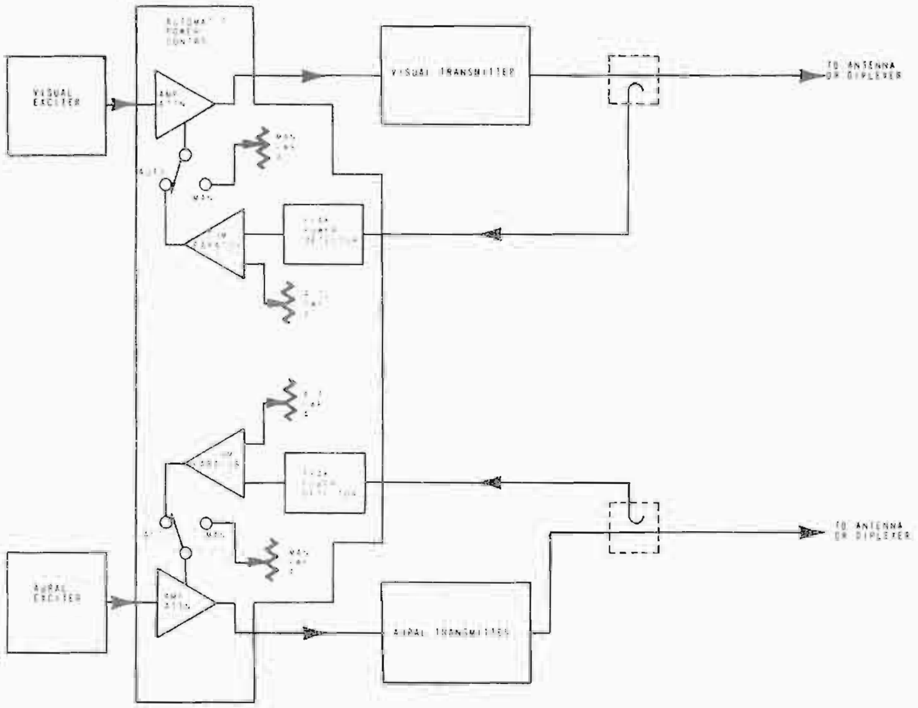


Fig. 88. Block diagram of an automatic power control.

low power levels, a straightforward method offers itself and has since found application as a standard product. Fundamentally, a controllable attenuator is inserted in the transmitter chain at approximately 1-watt power level which will be so adjusted to make the output power constant. The Block Diagram of such a unit is shown in Fig. 88. Three distinct elements are found: an output sensing device, a comparator producing a control signal, and a pin diode attenuator.

The sensing device in the case of the visual transmitter samples the output power during the peak-of-sync period and produces a dc voltage analogous to the power output. In similar fashion, the aural transmitter output is sampled and a dc voltage proportional to it's average output power is produced. In the comparator the dc analog voltages in each case are compared with a stable (but settable) dc reference. The dc output voltage from the comparator, which is proportional to the difference between the sampled dc and the reference voltage, will now steer an electrically controllable attenuator changing system gain to adjust the output power to the desired 100% output.

The control loop can be broken if it is desired to control output power of the transmitter manually.

Automatic power control units employing the above principles can maintain the output power of a visual or aural transmitter to within ±2% of a wanted level with system variations (open loop) of up to ±20%. Over this control range no noticeable change in the control signal can be detected, including maintenance of all modulation levels in the visual signal. In part, this is due to a unique type of hybrid attenuator employing dual diodes. This type of attenuator maintains input return loss to narrow limits over its entire control range. Fig. 89 shows a simplified schematic of this type of current controlled attenuator. The automatic power control unit presently manufactured by Harris Corporation contains a pair of control units in a single rack-mounted chassis and is so arranged that it controls either the visual and the aural transmitter of a single television transmitter, or both visual transmitters when they are operated in parallel.

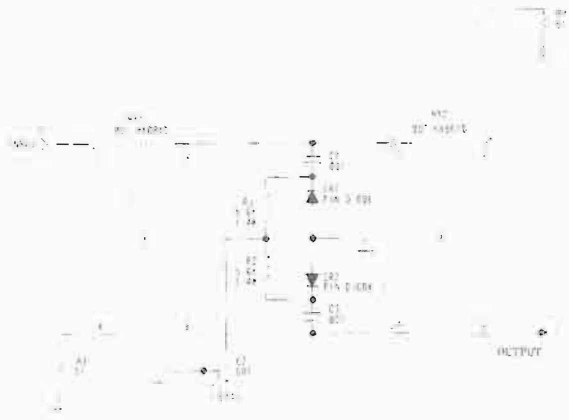


Fig. 89. Schematic of a pin diode attenuator.

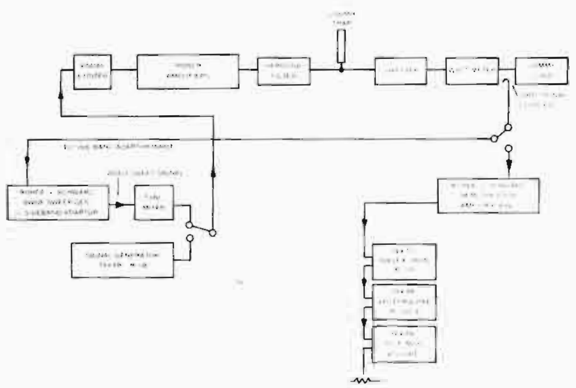


Fig. 90. Test set-up, performance measurements.

PERFORMANCE MEASUREMENTS

Measurements of system performance are generally required after completion of the construction of a new station. When filing a license application with the FCC these measurement data are required in addition to a list of statistical and numerical information related to the transmitter, the station and the antenna system (Proof of Performance). The visual transmitter and its test equipment is arranged as shown in Fig. 90. The following measurements were made on a 220-kw UHF TV transmitter, the first transmitter of this power level ever to be placed in service. Frequency response measured with a double-sideband diode is shown in Fig. 91, while the same response plotted from the scope display of a Rohde & Schwarz SWOF Sideband Analyzer is shown in Fig. 92. In both cases the RF was sampled after the diplexer.

Further measurements were made to show compliance with applicable specifications related to differential gain, differential phase, low frequency response and signal-to-noise ratio. Fig. 93 shows differential phase and gain, Fig. 94 characterizes the transmitter's behavior at low frequencies by showing the vertical interval which occurs at a field rate of 60 Hertz. Visual signal-to-noise ratio through a flat system was −57 dB RMS (referenced to the peak of sync Voltage).

Performance of the aural transmitter is shown in Fig. 95 which indicates frequency response and Fig. 96 showing harmonic distortion. FM noise of the system is −64 dB and AM noise is −58 dB.[29]

The above performance data are generally sufficient for FCC filings in connection with a license application.

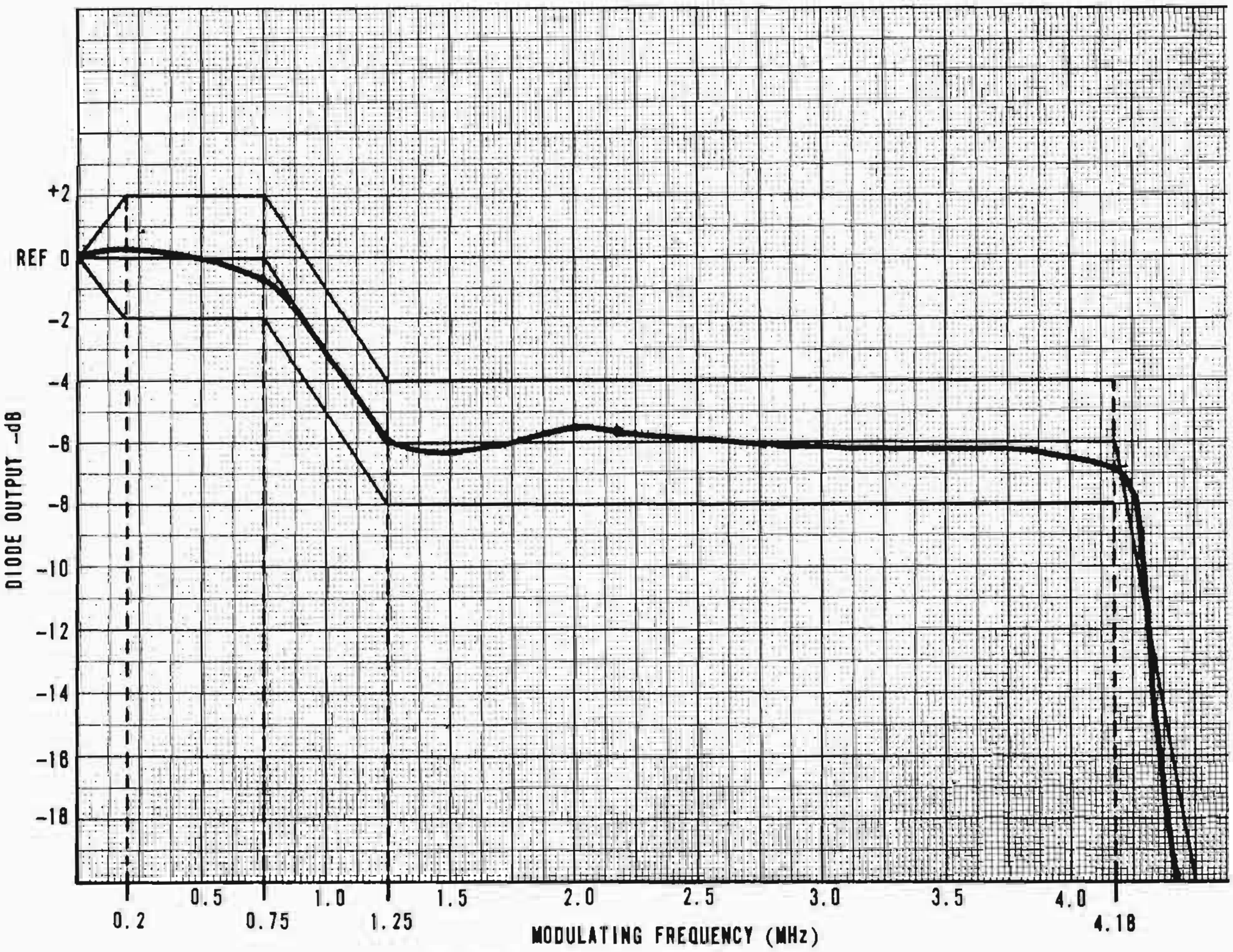


Fig. 91. Double sideband response diode.

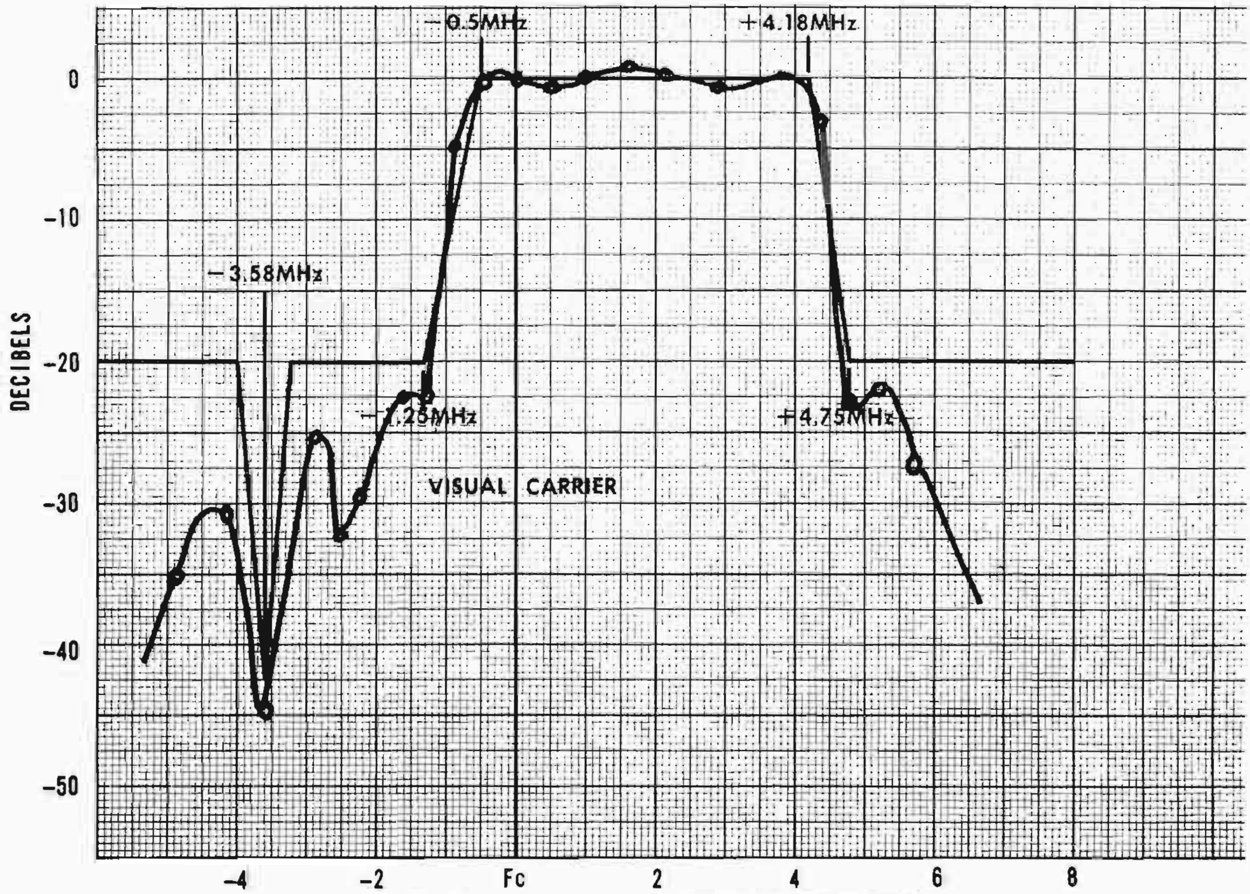
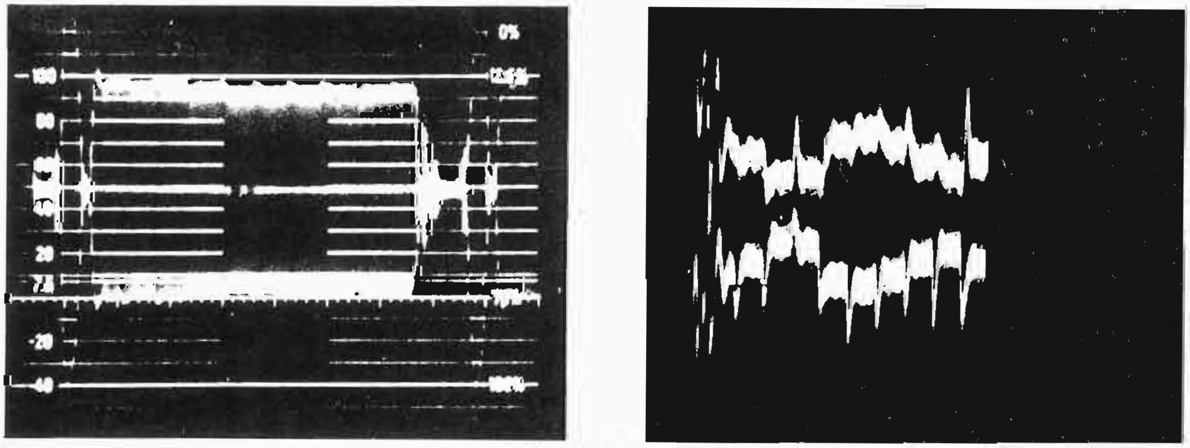


Fig. 92 Frequency response thru Rohde & Schwarz SWOF.



3.5% Fig. 93. Differential gain and phase 2.3%

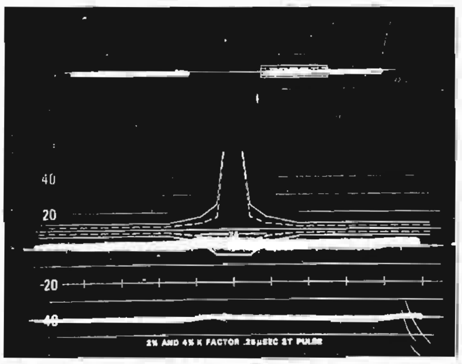


Fig. 94. Low frequency response (vertical interval).

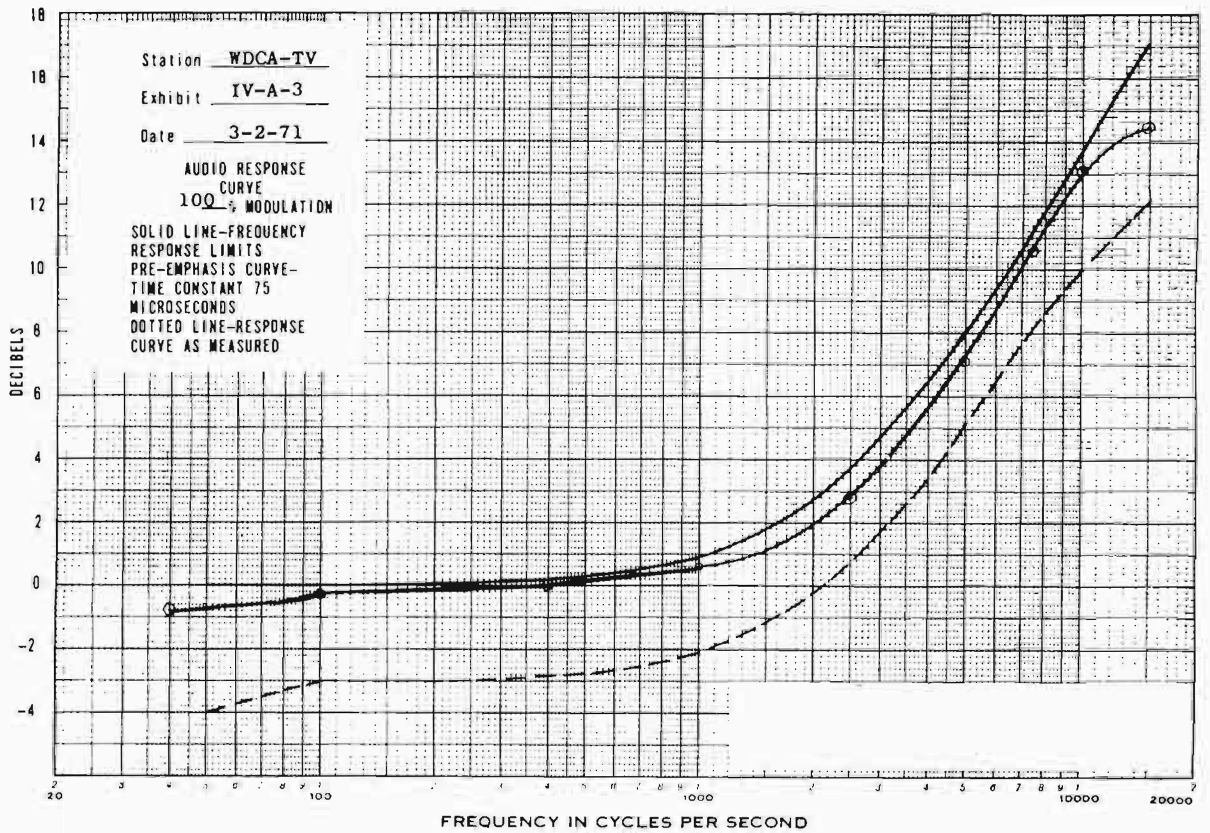


Fig. 95. Frequency response, aural transmitter.

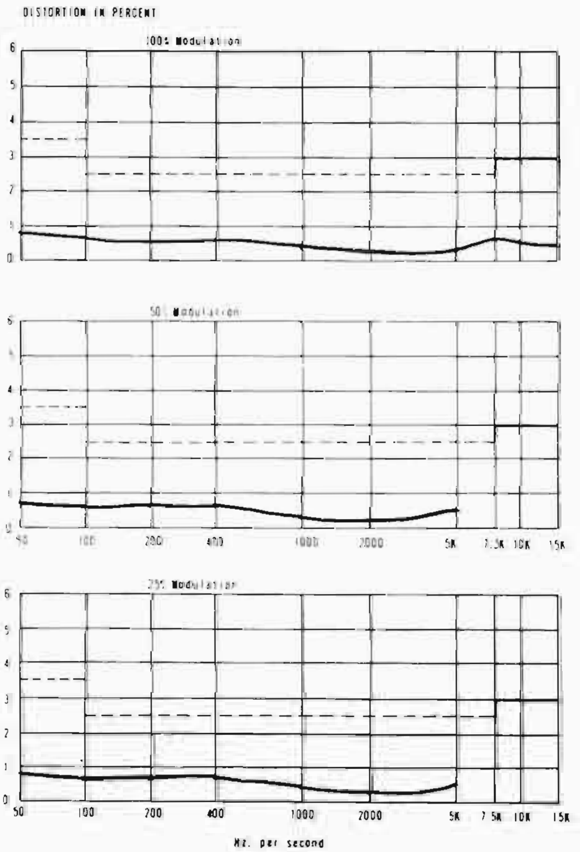


Fig. 96. Harmonic distortion, aural transmitter.

Further information, however, is needed to ascertain optimum performance in a color system. Most importantly, time coincidence between luminance and chrominance information must be shown by measuring envelope delay typically as shown in Fig. 97.

Very similar answers can be obtained from a test signal according to FCC Rules and Regulations Paragraph 73,699, Fig. 15. Typical results (employing a signal very similar to the above mentioned FCC composite test signal) are displayed in Fig. 98.

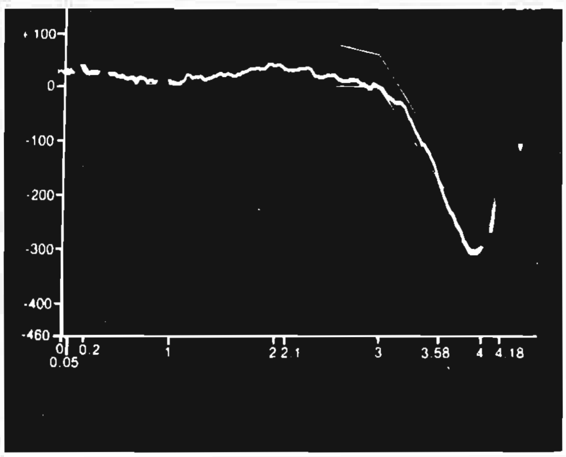


Fig. 97. Swept envelope delay.

One must keep in mind that many performance characteristics of a transmitter, for instance, frequency response and envelope delay, can vary with picture level; in other words, they are slightly different when measured at black as compared to white. To assess this deficiency many other test signals can be varied to produce high or low average picture levels. This is often accomplished by transmitting the test signal on one line to be followed by four lines which are either black or white.

An alternate very useful approach is to view the various test signals during the vertical interval, which allows the remainder of the available time to be operated at predetermined picture levels with transitions either at line or field rates.

Numerous excellent descriptions of the various techniques are available from test equipment manufacturers and many excellent papers have been published in the various journals, which can be consulted for Reference 30.

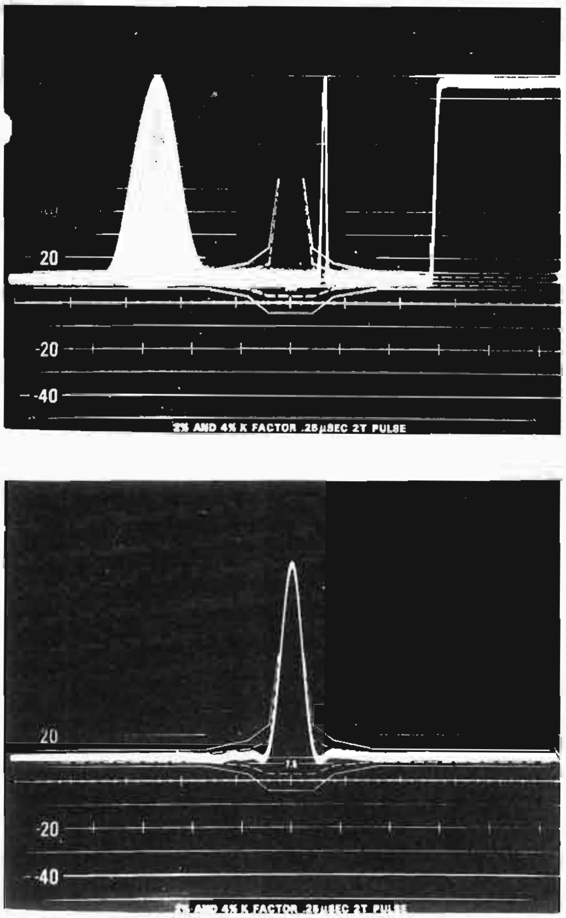


Fig. 98. Composite test signal response (2t, 20t).

REFERENCES

1. Pappenfus, Bruene, and Schoenike, "Single Sideband Principles and Circuits," McGraw-Hill (91-98).
2. Bernath, K., B. Binz, and E. Salvetti, Dimensionierung von Laufzeitentzerrern, nach dem Analogieverfahren, Tech. Mitt. PTT, Vol. 37 (1959), No. 1o, pp. 445-452.
3. Fredendall, G.L., Delay Equalization in Color Television, *Proc. IRE* 42 (1954) pp. 258-262.
4. Davies, M.W., Phase Adjusting All-pass Networks, *Proc. of IRE,* Australia, Nov. 1962, pp. 637-646.
5. White Electromagnetics, Inc., *A Handbook of Electrical Filters,* White Electromagnetics, Rockville, Md.
6. Kiefer, Dieter, Gruppenlaufzeitentzerrung im Bereiche der Fernseh-Zwischenfrequenz. Rundfunktechnische Mitteilungen., Vol. 8 (1964), No. 4, pp. 200-211.
7. Kiefer, Dieter, Ein aktives Allpassnetzwerk mit kontinuierlich einstellbarer Gruppenlaufzeit im Videobereich, Rundfunktechnische Mitteilungen, Vol. 10 (1966), No. 2, pp. 67-74.
8. Kiefer, Dieter, Entzerrersucher zur experimentellen Bestimmung von Allpassnetzwerken, Rundfunktechnische Mitteilungen. Vol. 13 (1969) No. 2, pp. 64-72.
9. Bott, A.H., et al., IF Modulation of VHF Television Transmitters, *IEEE Transactions on Broadcasting,* Vol. BC-16, No. 3 (Sept. 1970), pp. 65-74.
10. Stanger, L.J., Active IF Group Delay Correction of TV Transmitter, Internal Publication by Harris, Broadcast Products Div., Quincy, Ill. 62301.
11. Geffe, Philip R., *Simplified Modern Filter Design,* Haydon Book Co., New York, N.Y.
12. Saal, R., Der Entwurf von Filtern mit Hilfe des Katalogs normierter Tiefpaesse, Frequenz, Vol. 15 (1961), No. 4, pp. 111-121.
13. Dome, R.B., *Television Principles,* McGraw-Hill, New York, N.Y.
14. *Eimac Application*—Bulletin #5, Eimac, Div. of Varian—301 Industrial Way, San Carlos, Ca. 94070.
15. Yingst, T.E., Carter, D.R., Eshleman, J.A., and Pawlikowski, J.M., "High Power Gridded Tubes—1972," *Proc. of IEEE,* March 1973, pp. 357-381.
16. Gardner, F.M., *Phaselock Techniques,* New York, Wiley, 1966.
17. RCA Application Note AN-3659, "Application of RCA Silicon Rectifiers to Capacitive Loads," Coran, B.J. and Neilson, J.M.S., RCA Electronic Components, Harrison, N.J.

18. Uyttendaele, A.G., *Design Requirements and Operational Features of the Gates Dualtran RF Switching System.* Broadcast Products Div. of Harris Corp., Quincy, Ill.
19. *Harmonic Generator Using Step Recovery Diodes,* Application Note 920, Hewlett-Packard, 620 Page Mill Road, Palo Alto, Ca.
20. Brookshier, John, *Training Manual on Integral Cavity Klystrons for UHF TV Transmitters,* Varian, Palo Alto Tube Div., 611 Hansen Way, Palo Alto, Ca.
21. Nelson, Bruce E., *Introduction to Klystron Amplifiers,* Varian, Palo Alto Tube Div., 611 Hansen Way, Palo Alto, Ca.
22. Technical Services Dept., *Integral Cavity Klystrons for UHF TV Transmitters,* Varian, Palo Alto Tube Div., 611 Hansen Way, Palo Alto, Ca.
23. Chalk, C.O. and C.N. O'Loughlin, "Klystron Amplifiers for Television," *Electr. Equipment News,* Feb. 1968.
24. "Reduction of Co-Channel Television Interference by Precise Frequency Control of Television Picture Carriers," W.L. Behrend, February, 1957, *IRE Transactions on Broadcast Transmission Systems,* PGBTS-7.
25. "Co-Channel Television Interference and It's Reduction." Chapin, E.W., Middlekamp, L.C., and Roberts, W.K., June, 1958, *IRE Transactions on Broadcast Transmission Systems,* PGBTS-10.
26. Reduction of Co-Channel Television Interference by Very Precise Offset Carrier Frequency, Middlekamp, L.C., December, 1958, *IRE Transactions on Broadcast Transmission Systems,* PGBTS-12.
27. FCC Laboratory Observations of Precision Frequency Control of TV Stations, E.W. Chapin, August 1961, *IRE Transactions on Broadcasting,* PGBC-7.
28. *NBS Frequency and Time Broadcast Services,* NBS Special Publication 236, U.S. Dept. of Commerce, National Bureau of Standard.
29. Gates Engineering Report, *The World's Highest Power UHF Television Transmitter,* Harris Corp., Broadcast Products Div., 123 Hampshire, Quincy, Ill.
30. Rhodes, Charles W., *Measuring Distortions in the Television Signal,* (A-2495), Tektronix Inc., Beaverton, Or.

Television Transmitters Addendum

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RCA Broadcast Systems

Television transmitters in use in the United States today can be classified, broadly, into two basic types. One employes modulation at some moderate RF power level followed by linear power amplifiers and a high-level vestigial sideband filter at the transmitter output. A block diagram of such a transmitter is shown in Fig. 1.

The second type employes modulation at an IF frequency followed by a low-level IF vestigial sideband filter, an upconverter to final frequency at low power, and a chain of linear amplifiers on the final frequency to reach the desired power level. A block diagram of a system of this type is shown in Fig. 2. Signal levels shown in Figs. 1 and 2 are illustrative of common practice, but levels in specific designs may vary from these values significantly.

There is a third type which is a mixture of the first two. It employes modulation at IF frequency, an upconverter to final frequency but at comparatively high power (4 w), followed by final frequency linear amplifiers to the desired output power. The main difference between this variant and the basic system shown in Fig. 2 is that a low-level IF VSBF is not employed. Instead, a high-level final-frequency filter is used. A block diagram and a more complete description of a transmitter of this type will be covered later as part of a discussion of UHF-TV transmitters.

There are, as might be expected, variations of each basic type and many different circuit arrangements are possible for each major block of the diagrams. Some of these variations will be described and compared in later paragraphs.

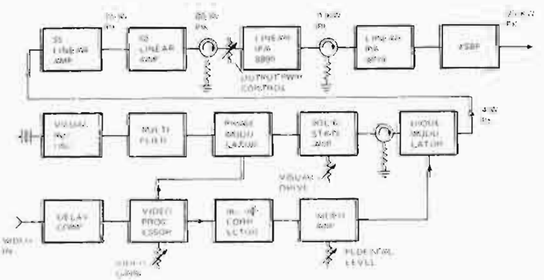

Fig. 1. Visual transmitter with modulation and VSBF at final frequency. Block diagram.

The basic Chapter 19, preceding this addendum, described fundamental principles and performance requirements of television transmitters in general. It provided a fairly complete description and many circuit details of television transmitters employing modulation at IF frequency. The design philosophy of these transmitters was stated and reasons were advanced for selecting the concepts and circuits chosen.

Similarly, in this addendum to Chapter 19, circuits will be described which are used in transmitters with final frequency modulation and high-level sideband filtering.

DESIGN CONSIDERATIONS

The prime considerations in design of a television transmitter are good technical performance and performance stability, reliability, maintainability and low cost—both capital cost and operating cost. The equipment designer must make some tradeoffs to achieve a proper balance among these and other factors, based upon personal or corporate judgment. Finally, equipment performance, reliability, operating cost, etc., depend not only upon the choice of circuit and packaging concepts made by the designer but also upon excellence in design details, product quality, and the operating and maintenance skills of the broadcaster.

Certain block diagrams or circuit choices do offer fundamental possibilities of improved per-

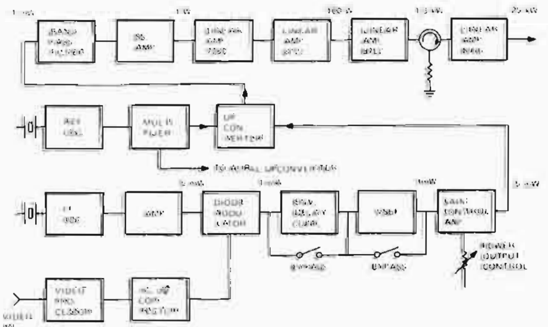

Fig. 2. Visual transmitter with modulation and VSBF at IF. Block diagram.

formance of one characteristics or another, but often at the expense of other desirable factors as illustrated in the following examples.

Modulation Levels

It is possible, and less expensive, to achieve better modulation linearity in a 1-milliwatt diode ring modulator at IF frequency than in a higher power diode modulator or grid bias modulator at final carrier frequency. On the other hand, low-level modulation requires a greater number of wideband linear amplifiers and, in general, more numerous tuning controls and adjustments.

When modulating at a higher level, linear amplifiers after the modulator are exchanged for cw amplifiers preceding the modulator. These need not be wideband and can be operated at nearly saturated output power for improved power output stability. An arrangement of this type was selected by RCA for the design of transmitters to be described in later sections of this addendum.

The following table lists modulation levels and associated linear amplifier gains required to reach a power of 25 kw for each of the three modulation methods in common use in VHF-TV transmitters. The ring modulator is followed by a small IF linear amplifier, an upconverter and, as for the other modulators, a succession of wideband final-frequency linear amplifiers. The 80 dB gain figure listed in the table for the ring modulator system makes allowance for a 6 dB upconverter loss.

Modulation method	*Mod. output power*	*Linear amp. gain required to reach 25 kw*
Ring modulator	0.001 w	80 dB
Switching mode diode modulator	2 w	40 dB
Grid bias modulator	1000 w	14 dB

Low Level versus High Level VSBF

It is believed to be less expensive to use a low-level (IF) vestigial sideband filter, and it is possible to design a more compact system than when using a high-level VSBF. However, the size advantage is minimal when a high-level notch-type aural-visual combiner is required, and there are some advantages to consider in favor of a high level filter.

Among these advantages are that it permits reduced transmitter power consumption, simultaneous good luminance and chrominance linearities, and a reduction of out-of-channel intermodulation products when a VSBF and other bandwidth limiting circuits are not included between the linearity corrector and the visual PA.

A linearity correction circuit generates distortion products that are out of phase with those generated in nonlinear modulators and imperfect "linear" amplifiers. Ideally, all the distortion products cancel out before reaching the PA output, thereby eliminating intermodulation products and restoring signal linearity at all modulating frequencies. This cannot happen as effectively if some of the distortion products are lost between the correction circuit and transmitter output in a low-level VSBF or cascaded linear amplifiers of limited bandwidth.

A lower power consumption with high-level filtering (or IF filtering followed by linearity correctors) is possible by operating the PA in Class B, with idling current near cutoff. Improved plate efficiency is achieved by accepting some PA nonlinearity and compensating for this in video linearity correction circuits.

Fig. 3 is a set of spectrum analyzer photographs that illustrate the advantage of carrying the distortion products of the linearity corrector through the system to the PA input. In-channel intermodulation products cannot be seen as they are masked by useful sidebands but out-of-channel components can be seen. Second harmonic distortion of the 3.58 MHz color envelope (or third order intermodulation of main carrier and color subcarrier) gives rise to out-of-channel signals displaced 7.16 MHz from visual carrier. Fig. 3a is the output of the IPA (in this case a grid bias modulated stage) with linearity correction (differential gain correction) applied. Fig. 3b is the output of the PA ahead of the VSBF and Fig. 3c is the output after a high-level VSBF.

Without linearity correction for the PA, the 7.16 MHz components of Fig. 3b would be nearly as large as those of Fig. 3a. The indicated improvement is 12 dB and 15 dB for the upper and lower 7.16 MHz components. Of this amount, the PA circuit selectivity accounts for 3 dB and 6 dB, respectively. Even greater improvement would occur except for some bandwidth limitation of the IPA/PA interstage coupling network.

Another argument for a high-level filter at the transmitter output is that it is less apt to depart from specified attenuation limits through component aging or manipulation of adjustments than is an IF filter comprised of coils and capacitors.

Video versus IF Delay Equalizer

The design choice between video and IF (or RF) delay equalizers involves both theoretical and practical considerations.

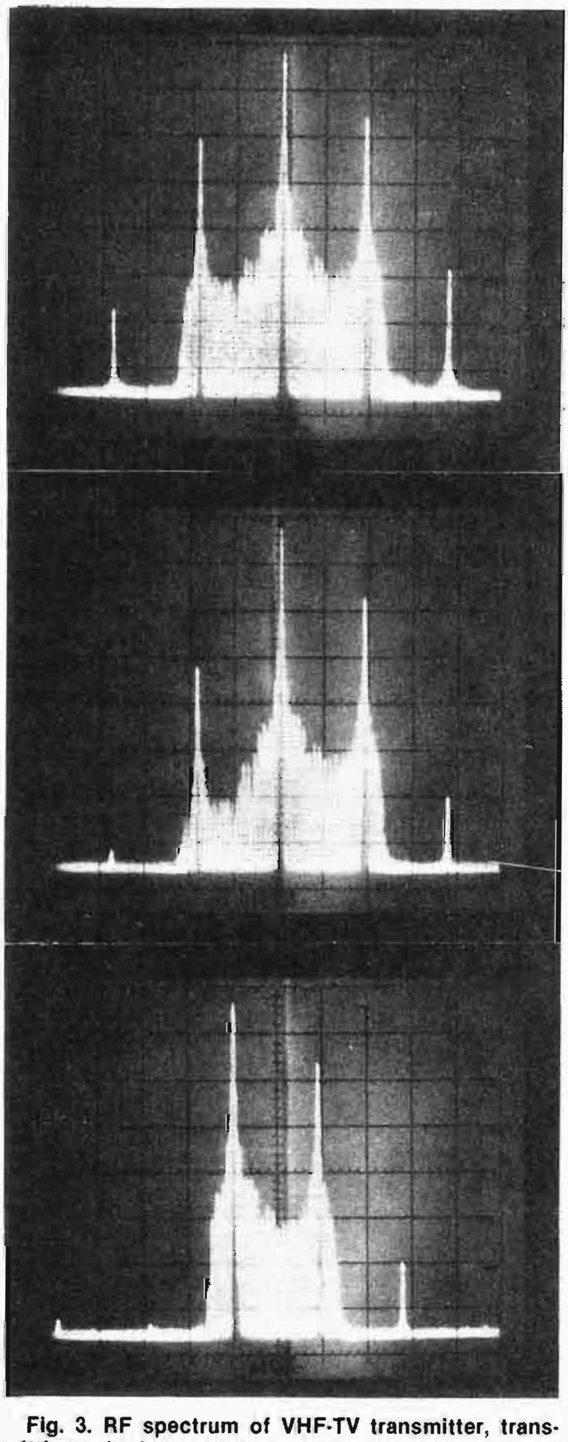

Fig. 3. RF spectrum of VHF-TV transmitter, transmitting color bars.
a. IPA (grid bias modulated amp.) output.
b. PA output ahead of vestigial sideband filter.
c. PA output after vestigial sideband filter.

For frequencies in the region of 1 to 4.18 MHz, since only one sideband is transmitted, there is no theoretical difference in system performance whether envelope-delay correction is carried out at video frequency or at IF frequency and both methods are in common use. The choice depends on the frequency range that permits the best practical design for a specific overall system.

For video frequencies in the region of 0.01 to 1.0 MHz (visual carrier ±1 MHz) both sidebands are transmitted and the delays of upper and lower sidebands relative to carrier are different. A rigorous solution to delay correction in this frequency band would require that correction take place at IF (or RF) so that upper and lower sidebands could be equalized separately. In practice it makes little difference whether equalization is at baseband (video) or at IF. The system envelope delay of transmitter plus demodulator, for any one demodulator, can be equalized exactly by transmitter video delay equalization. The delay equalization may not be quite correct for other demodulators or receivers, but the residual delay error will be quite small. (See References 1 and 2).

Video delay equalizers have the advantage that required coil Qs are lower and more practical to attain, and the adverse effect of stray couplings (parasitic elements) is less than at IF.

One video equalizer, to be described later, employs multiple, switchable, delay sections with specific settings and corresponding delay characteristics defined by graphs or tables in an instruction manual.

Solid-State versus Vacuum Tube Linear Amplifiers

Solid-state circuits have, by degrees, replaced vacuum tube circuits in sequential transmitter designs until only the higher power RF amplifier stages still employ vacuum tubes.

In most designs, when transistors have replaced tubes in RF circuits, the circuits have been made wideband and/or fixed tuned. Consequently, solid state transmitters not only are more reliable but also require a minimal number of adjustments.

Reliability is not assured by the mere utilization of transistors since many things can, and have, caused transistor failures, especially in first-generation transistor circuits and in high-power applications. However, there can be little doubt that a properly designed solid-state circuit is more reliable than its vacuum tube counterpart when only a moderate number of transistors are required to take the place of each tube.

VHF-TV TRANSMITTER CHANNELS 2-6

Transmitters described in general terms in the introduction were of two basic types. Following is a more detailed description of the first type employing modulation at some moderate RF power, followed by linear amplifiers and a high-level VSBF at the transmitter output. Examples of this transmitter type are the RCA low-band model (Ch. 2-6) employing grid bias modulation at a

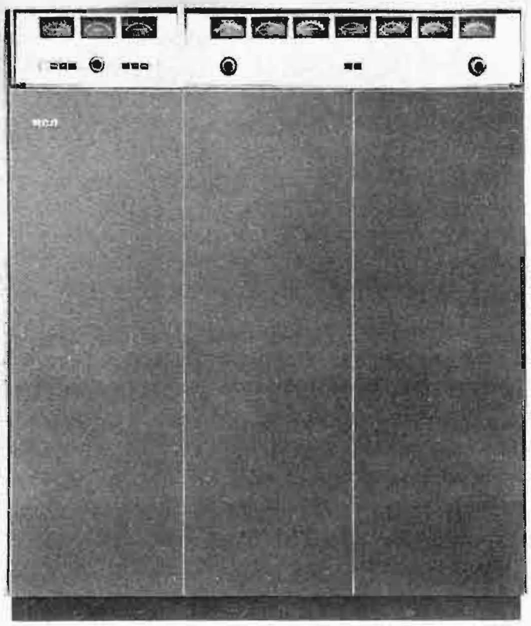

Fig. 4. RCA TT-25FL lowband VHF TV transmitter.

level of approximately 1 kw and the high-band model (Ch. 7-13) employing diode modulation at a level of approximately 2 w. The low-band design will be described first. Some elements of the low-band design also apply to the high-band design, to be described later.

A photograph of an RCA TT-25FL low-band transmitter appears in Fig. 4. It is a 25 kw transmitter for Channels 2-6. The photograph shows only the front line cabinets and not the complete transmitter which also includes a power supply cabinet and a vestigial sideband filter. All these assemblies are drawn to scale in the floor plan, Fig. 5. The power supply is approximately the size of the amplifier cabinet. It can be placed alongside the front line cabinets, but more often it is placed elsewhere as illustrated in the typical floor plan. An internal view of the power supply cabinet is shown in Fig. 6. Elements of the power supply unique enough to warrant description will be covered in later paragraphs.

A block diagram of the transmitter is shown in Fig. 7. The transmitter circuit is all solid-state except for the visual modulated stage and PA, and the aural IPA and PA. A total of five tubes are employed: quantity-3 8791-V1, quantity-1 3CX3000A7 and quantity-1 3CX20,000A7.

Circuits performing the functions titled in the block diagram will be described, with emphasis on the functions that are performed differently than in IF modulated transmitters which were described in the basic Chapter 19.

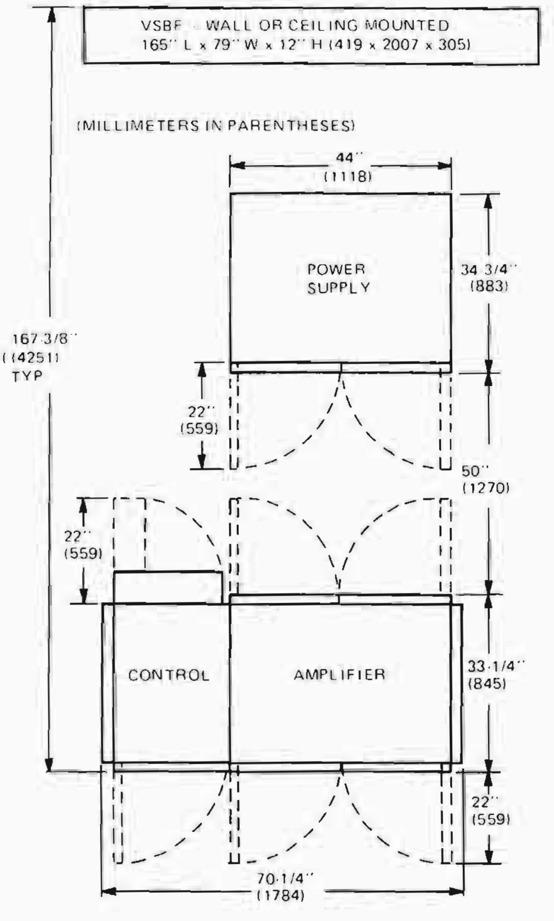

Fig. 5. Typical floor plan, TT-25FL transmitter.

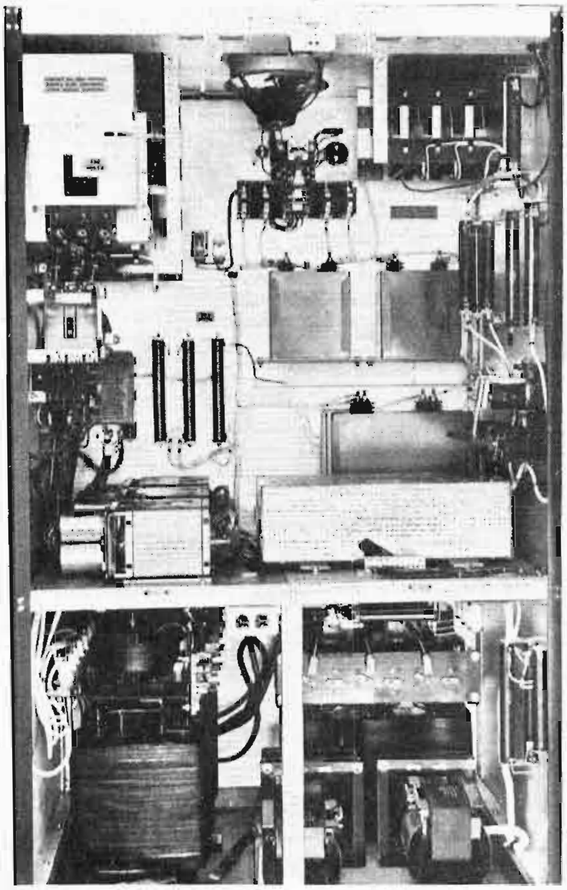

Fig. 6. Power supply cabinet, doors removed.

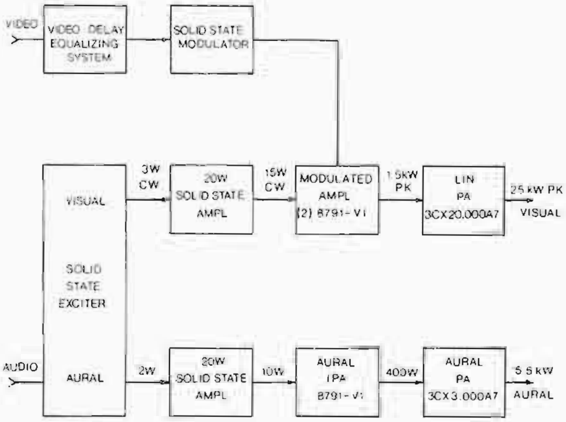

Fig. 7. TT-25FL transmitter, functional diagram.

Video Envelope-Delay Equalizer

With reference to Fig. 7, the video signal enters the transmitting system at the video envelope delay equalizer which is divided into the functional segments shown in the block diagram, Fig. 8. Each section of the equalizer can be switched out, as shown, for test purposes, but all are connected for normal programming. The envelope-delay equalized low-pass filter limits the maximum video frequency response to -20 dB at 4.75 MHz and above to meet the FCC rules for transmitter amplitude versus frequency response.

The low-frequency equalizer corrects mainly for the envelope delay distortion introduced by the vestigial sideband filter plus a lesser amount introduced by the transmitter bandpass coupling circuits. It is adjustable to any of 72 preset curves by combined operation of two switches—a 4-position switch and an 18-position switch. These curves, tabulated in the instruction manual, have different slopes and curve break points and are designed to match the delay of a variety of transmitter systems and different transmitter adjustments to within approximately 25ns.

The high-frequency equalizer corrects for the relatively small (approx. 50ns) high-frequency delay distortion introduced by the bandpass coupling circuits of the transmitter. However, for the many transmitting systems where an aural-visual notch diplexer is employed, introducing rapid visual signal cutoff between 4.18 MHz and 4.5 MHz, several hundred ns of additional high-frequency envelope-delay error are introduced. The delay equalizer allows for these extremes by providing delay correction ranging from 0 ns to 1,000 ns at 4.18 MHz. A choice of 39 curves is provided by combined operation of two switches—a 3-position switch and a 13-position switch.

The receiver equalizer provides -170 ns envelope-delay predistortion at 3.58 MHz for "typical" receivers as required by par. 73.687(a)(5) of the FCC rules. It must be kept "on" for normal transmission but should be switched "off" when the demodulator sound trap is turned "off" for transmitter performance measurements.

Video Circuits (Solid-State Modulator)

The video circuits of the transmitter connect after the video envelope-delay equalizer. Fig. 9 is a simplified block diagram of the video circuits.

Video input amplifier. A combination of a differential input amplifier and a fast-acting clamp circuit eliminate hum and low-frequency noise from the video input signal. The differential amplifier rejects any common mode noise on the input signal rising from possible ground loop problems in the coaxial cable connection between terminal equipment racks and the transmitter proper.

The first clamp circuit not only reduces input signal hum and noise but it also reinserts the dc component of the video signal as required ahead of the differential phase and gain correctors. This makes the applied corrections fall at specific brightness levels on the video amplifier transfer characteristic independent of picture signal APL.

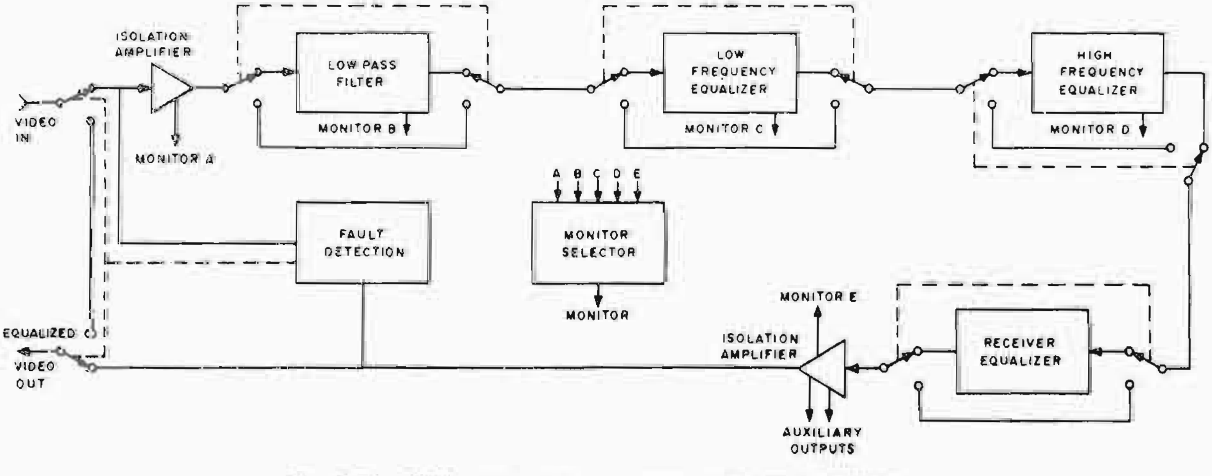

Fig. 8. Type TTS-1 video delay equalizer, functional diagram.

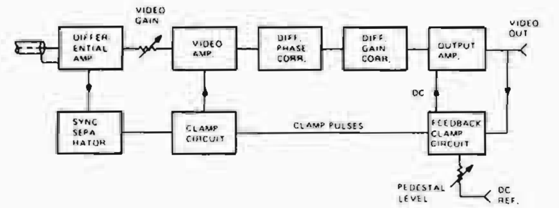

Fig. 9. Video amplifier and processor, simplified block diagram.

Differential phase and gain corrector circuits are connected in tandem in RCA VHF-TV transmitters, and can be adjusted with negligible interaction between the two. A wide range of control is available, but a generous number of controls permits precise correction (complementary matching) of any ordinary differential phase or gain error likely to be encountered.

A separate but similar circuit controls sync stretch.

Output amplifier. With reference to Fig. 9, the dc component is removed (AC coupled) in the output amplifier and then promptly reinserted by a feedback clamp circuit referenced to the video output signal. This holds the pedestal level constant at the amplifier output, independent of any long-term drift accumulated in the cascaded video amplifiers.

The output stage is a complementary symmetry video amplifier capable of delivering up to 70 Vpp to the grid bias modulated RF amplifier. Approximately 40 Vpp normally is required for 25 kw at the transmitter output.

The bandwidth of the video amplifier, including the output amplifier, exceeds 8 MHz. Consequently, video harmonics generated in the nonlinear differential gain correction circuits are carried through to the grid bias modulated amplifier, as required for proper correction of modulated amplifier and "linear" amplifier nonlinearities.

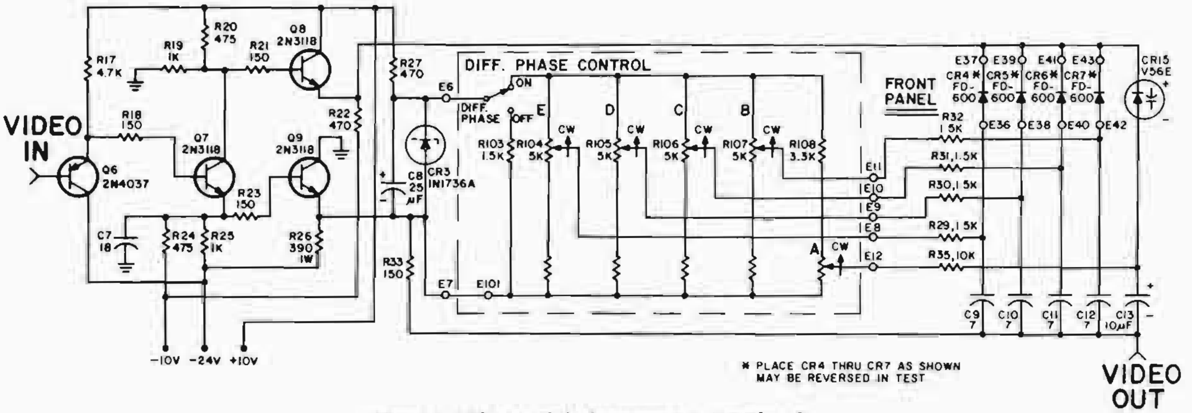

Fig. 10. Differential phase corrector circuit.

The differential phase corrector circuit, shown in Fig. 10, operates in the following manner. Video output is extracted from a pair of push-pull emitter followers. The principal output is from one emitter through resistor R33. To this is added a small capacitive-coupled output from the opposite emitter through any or all of four gated capacitors C9-12 and a varicap CR-15. The added capacitive coupled signal shifts the color subcarrier phase by up to ±2° for each gated capacitor and + 8° maximum for the varicap. The brightness level at which the capacitors are electronically connected is determined by controls B through E and the effectiveness of the varicap is controlled by A.

The differential gain control, or more properly "linearity control" circuit modifies the video amplifier gain as a function of instantaneous picture brightness. This is accomplished by gating a succession of five resistors across the coupling circuit between two transistors. The resistors have different values and each can be gated at any desired brightness level, thereby achieving a variety of smoothly changing transfer functions.

Grid Bias Modulated RF Amplifier

The output of the video amplifier (solid state modulator) is connected to the grid bias modulated RF amplifier as shown in the simplified schematic, Fig. 11. The push-pull arrangement provides a way of introducing the video at an RF

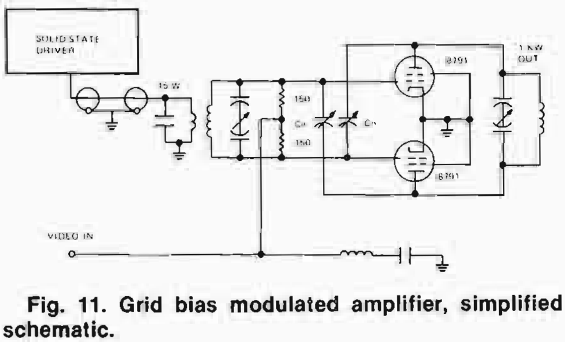

Fig. 11. Grid bias modulated amplifier, simplified schematic.

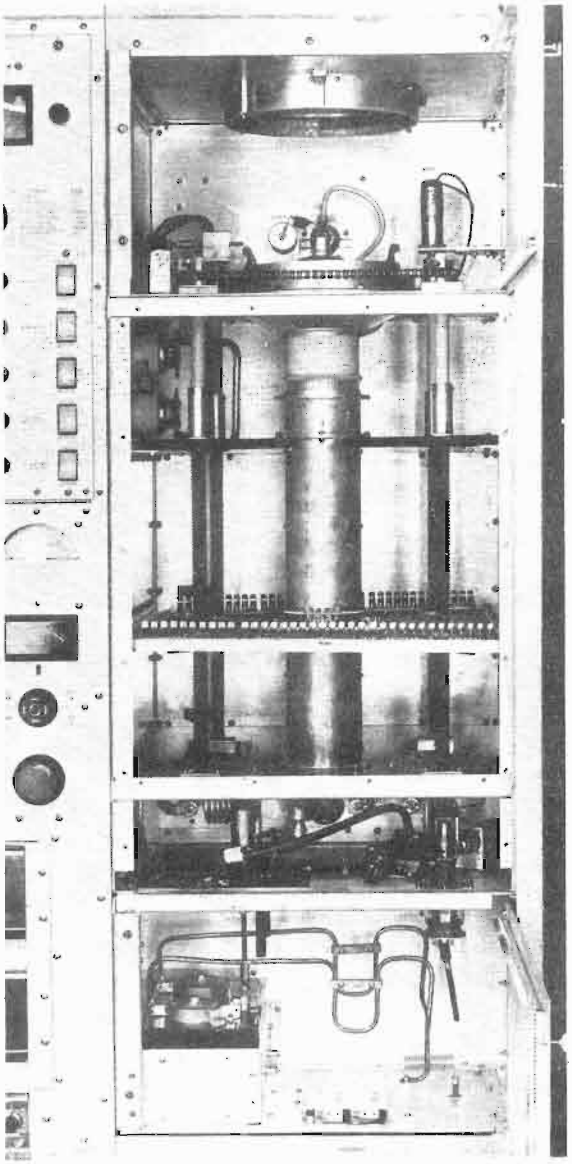

Fig. 12. Visual modulated amplifier and PA.

null point and avoids burdening the video system with the added capacitance of an RF bypassing and filtering scheme. It also enables wideband neutralization by virtue of the simple capacitance bridge neutralization circuit.

A very special point is that the input circuit, although carrying only a cw signal, nevertheless is a wideband circuit just as if the stage were operated as a visual linear amplifier. As a result, any residual feedback or load modulation caused by varying input impedance of the modulated stage, is independent of modulating frequency and does not produce waveform distortion. Residual modulation, if any, is very small because of improved neutralization, better tubes with lower input circuit loading, and the tubes are not driven into grid current, even at sync peak level. These circuits do not exhibit the waveform distortions sometimes encountered in older designs.

Visual Power Amplifier

The visual PA is a hi-mu zero-bias grounded-grid triode linear amplifier. The use of a triode has notable advantages—and like most engineering choices, some disadvantages. In this case, the advantages strongly outweigh the disadvantages.

The zero-bias triode eliminates the requirement for: a regulated bias supply; a regulated screen grid supply; associated metering, control, and protection circuits; and screen grid bypassing and tube contact pieces in the cavity. These eliminations result in a simple and reliable circuit.

The disadvantages of a triode as compared with a tetrode are: somewhat higher output capacitance and therefore a lower gain-times-bandwidth product; higher feedback capacitance (not troublesome on Ch. 2-6); and higher grid current.

Fig. 12 is a photograph of the visual modulated amplifier and visual PA. The front panel of the PA cavity has been removed to make the interior visible. The PA anode is bypassed to the top of the cavity to eliminate the anode radiator-to-ground capacitance from loading the circuit and consequently reducing the bandwidth.

It may be hard to interpret the cavity circuit of Fig. 12 as a grounded-grid circuit. Clearly, the grid terminal is not physically grounded as it can be seen where the spring fingers connect at the bottom of the anode-to-grid ceramic insulator. If the circuit is renamed a "common-grid" amplifier instead of a "grounded-grid" amplifier, the circuit operation should become clear. The terminology parallels that of a transistor amplifier which may be called a grounded base amplifier or a common base amplifier, interchangeably.

The PA input circuit (cathode-to-grid) is inside the copper pipe in the center of the cavity. The PA output circuit primary (anode-to-grid) is in the space inside the box and outside the pipe. Just as in a conventional grounded-grid circuit, there is no electromagnetic coupling between input and output circuits.

Aural Exciter

Fig. 13 is a functional diagram of the aural exciter and low power solid-state amplifiers.

The varicap controlled FM oscillator is in a temperature controlled oven. It operates at

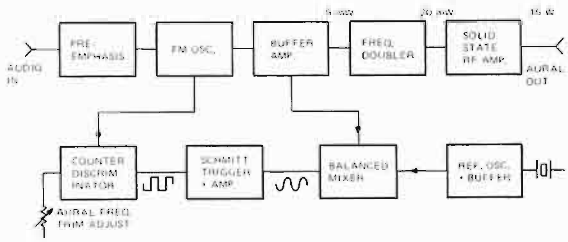

Fig. 13. Aural exciter and low power amplifiers, functional diagram.

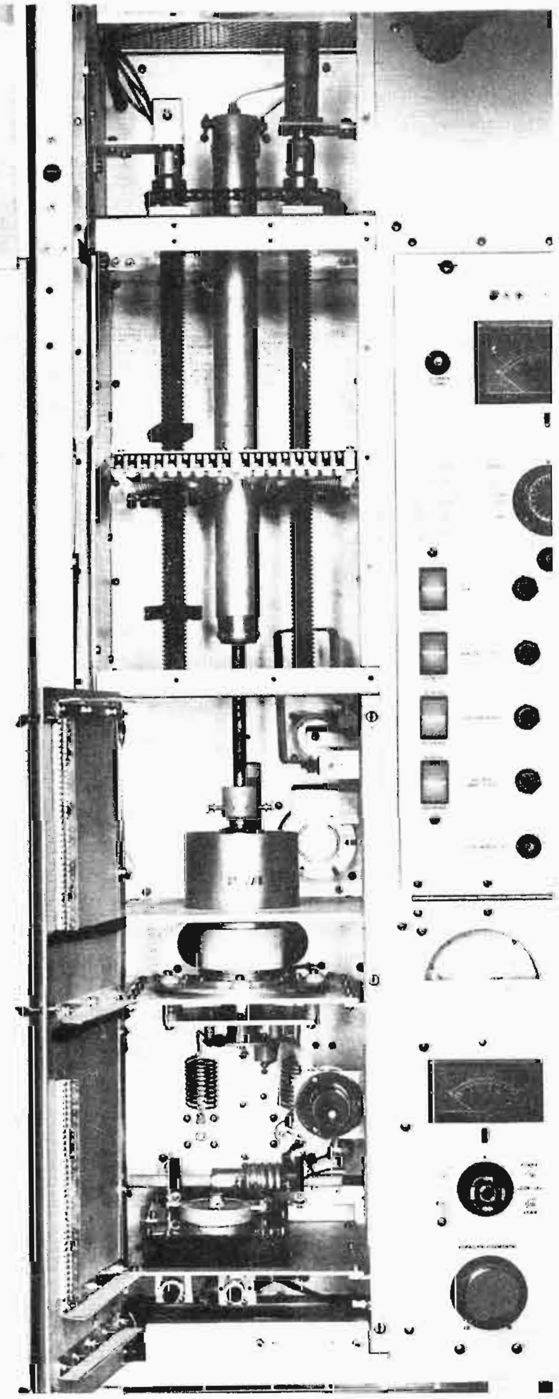

Fig. 14. Aural IPA and PA assembly.

one-half carrier frequency. One varicap controls the aural frequency deviation and a second controls the center frequency through an AFC loop.

A crystal controlled reference oscillator is offset from the FM oscillator by a convenient counting frequency of 150 kHz. The 150 kHz difference frequency is obtained in a balanced mixer then changed to a square wave and applied to a counter type discriminator. The discriminator develops a dc output voltage directly proportional to frequency. The developed voltage is offset by a highly stabilized dc reference so that the net output is zero when the counting frequency is exactly 150 kHz. The control voltage swings plus or minus if the FM oscillator should tend to drift above or below the assigned frequency.

The loop gain of the AFC system is 48 dB which ensures that the FM oscillator center frequency is closely held with respect to the temperature controlled crystal reference oscillator.

A succession of broad-band solid-state amplifier stages raises the aural signal to a level of approximately 15 w to drive the two tubes in the aural transmitter—the IPA and PA tubes.

Aural IPA and PA

A photograph of the aural IPA and PA enclosure with the doors open is shown in Fig. 14. The Type 8791 V1 IPA tube operates grounded cathode employing lumped constant input and output circuits.

The PA, employing a 3CX3000A7 triode, operates grounded-grid with a coaxial cavity output circuit. Unlike the visual PA, the aural grid is directly bypassed to the cabinet, forming a ground plane to isolate input and output circuits. This is practical because, in the case of the aural PA, the capacitance of the tube anode radiator to ground is of no concern. Consequently, the aural cavity is simpler in construction than the visual cavity.

Power Supply

The power supply cabinet (Fig. 6) contains a high voltage supply for the visual PA and an intermediate high voltage supply for aural PA, visual IPA and visual PA stages. Both power supplies employ three-phase full-wave silicon rectifier circuits.

A distribution transformer and three constant voltage transformers rest on the shelf above the high voltage transformers. Another transformer, in the transmitter control cabinet, isolates the control circuit ladder from the incoming 230 v, 3 Ø power line for safety and provides 117 v ac to circuits requiring the lower voltage.

The constant voltage transformers regulate the filament voltage to all vacuum tubes to a stability of 1 percent for extended tube life. This is an important feature. In the absence of the many other things that cause catastrophic tube failure or premature performance degradation, wearout in a tube with thoriated tungsten filament is caused by loss of emission through depletion of the carbide layer. It has been calculated that the theoretical tube life is reduced 2/1 by a 3 percent excess of filament voltage over the life span of the tube.

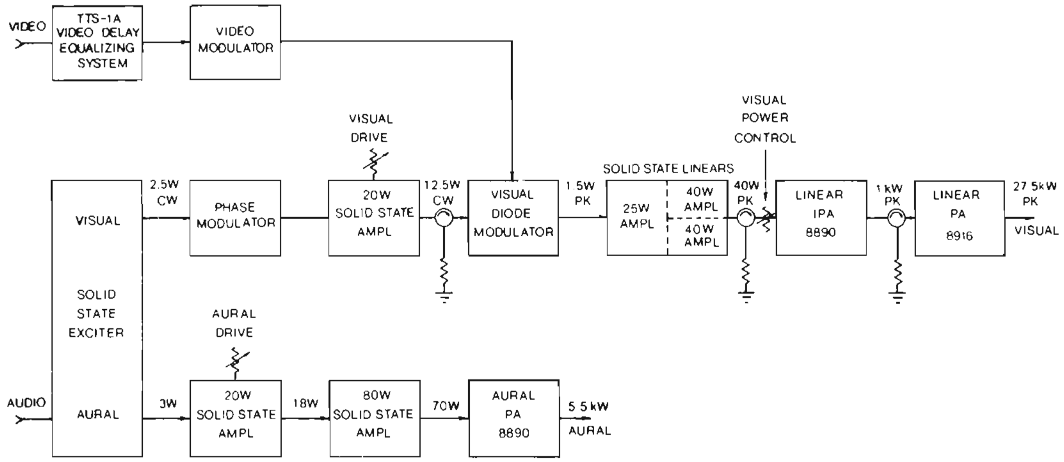

Fig. 15. TT-25FH transmitter, functional diagram.

Filament power supplies for tubes with directly heated cathodes are dc to minimize hum which can originate, in part, from magnetic deflection of the electron stream within the tube. The hum has high harmonic content and the magnitude is not stable with time. Consequently, hum bucking circuits are less effective than eliminating hum at the source through the use of 3-phase full-wave dc filament supply.

VHF-TV TRANSMITTER CHANNELS 7-13

In overall size and external appearance, the RCA highband transmitter (Ch. 7-13) is nearly identical to the lowband transmitter (Ch. 2-6) previously illustrated (Fig. 4).

The left-hand rack contains control circuit logic, exciter, modulator, solid-state aural amplifiers, solid-state visual linear amplifiers, and the solid-state power supplies. In brief, solid-state circuits are located in the left-hand rack and power tube circuits are located in the right-hand rack.

The right-hand rack contains the three cavities for the only three tubes in the transmitter, motor-driven cavity tuning controls and dc power supplies (located in the air plenum) for the power tube filaments.

A block diagram of the transmitter is shown in Fig. 15.

The envelope delay equalizer, video circuits and solid-state exciter are similar to the corresponding blocks in the lowband transmitter which have been described.

Visual Diode Modulator

A simplified schematic of the visual modulator is shown in Fig. 16. Two diode bridge modulators are employed, connected in quadrature, and they are operated at comparatively high power—not in the square law region.

The diodes are biased by the video signal and pass more or less of the RF cycle, depending upon the instantaneous video potential. The capacitance of the diode assembly is neutralized by coil Ln so that negligible signal is passed when the diodes are biased off. The diode modulator operates with an insertion loss of approximately 5 dB at sync peak.

The tuned circuits L1C1, L2C2 are tuned to visual carrier frequency to suppress harmonics generated in the modulation process.

The input impedance of each diode assembly varies widely over the brightness range (instan-

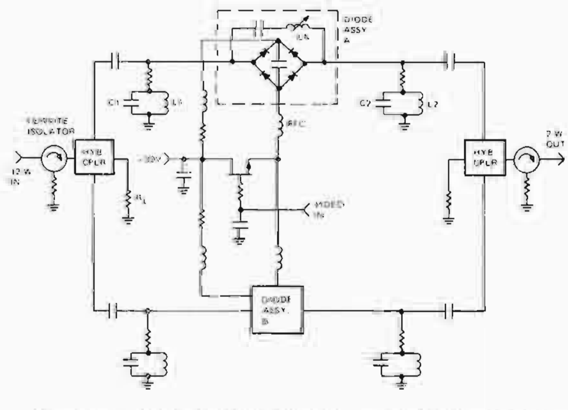

Fig. 16. Video diode modulator, simplified schematic.

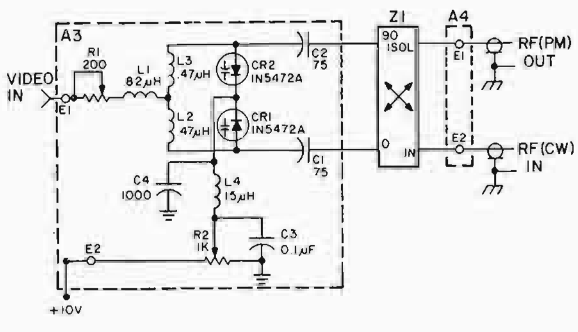

Fig. 17. Phase modulator, simplified schematic.

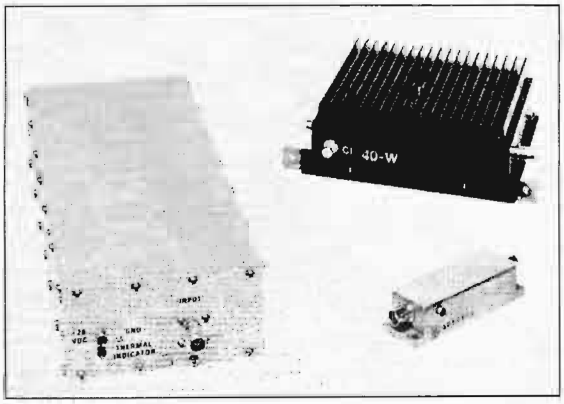

Fig. 18. Solid-state amplifiers: 20 w, 40 w, 80 w.

taneous video signal) and this would cause an undesired modulation of the input signal, except for the hybrid coupler. If the two diode assemblies are identical, and the hybrid is well balanced, the varying reflections from the diodes end up in the reject load R_L. Therefore, the input impedance to the coupler remains a constant good match to the 20-watt solid-state carrier source. The ferrite isolator removes residual reflections due to imperfections in the hybrid coupler or minor differences between the diode assemblies.

Phase Modulator

The purpose of the phase modulator is to correct for transmitter incidental phase modulation. It accomplishes this by introducing phase modulation into the visual carrier (cw) path, ahead of the visual modulator, of the correct amplitude and polarity to cancel unwanted phase modulation occurring elsewhere in the transmitter. The result is a transmitted signal essentially free of any incidental phase modulation at all modulating frequencies.

Adverse effects of uncorrected incidental phase modulation, which are avoided by the design of this transmitter, are:

- Noise ("buzz") in the aural output of intercarrier sound receivers. However, incidental phase modulation is only one of several possible causes of this problem.
- When differential phase has been corrected using a demodulator with envelope detection, it is then incorrect for synchronous detection.
- Envelope-delay correction required is different at different brightness levels. One result is that "sync spikes" may be excessive.

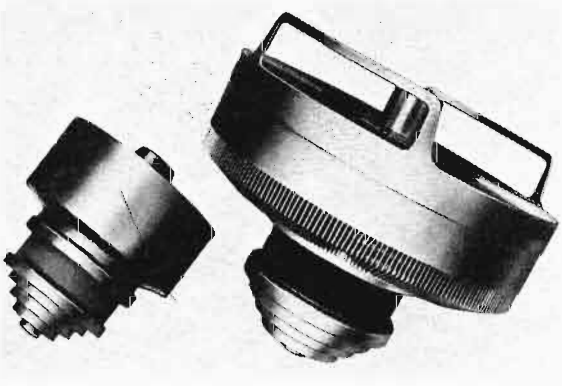

Fig. 19. Power tubes employed in TT-25FH, tube types 8890 and 8916.

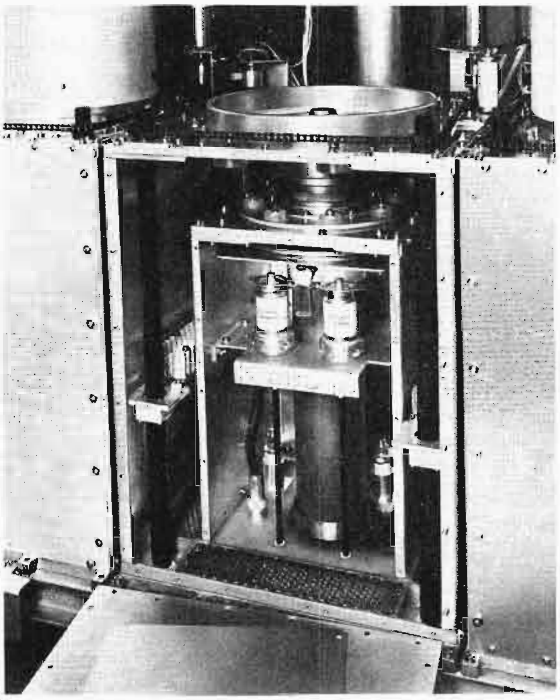

Fig. 20. View inside RF amplifier cavity.

Fig. 17 is a simplified schematic of the phase modulator which operates as follows. A cw signal at visual carrier frequency is applied to the input port of a 3 dB hybrid. The normal output ports are connected to varicaps. Since these present nearly identical reactive loads, the signals at the output ports are reflected and combine in the "isol." port; and this becomes the phase-modulated RF output signal.

The phase shift through the 3 dB hybrid depends upon the magnitude of the two reactive loads which in turn is controlled by the instantaneous value of the video signal applied to the varicap. The video input signal is shaped in circuits similar to a differential gain corrector to control the degree of phase modulation versus brightness level.

Solid-State Amplifiers

Both aural and visual solid-state amplifier stages have approximately 80 w capability, but the designs are different. The visual linear amplifier stage is, in fact, two separate 40 w linear amplifiers operated in parallel and combined by means of input and output 3 dB quadrature phase hybrids. Each 40 w amplifier uses a pair of transistors, operated in push-pull.

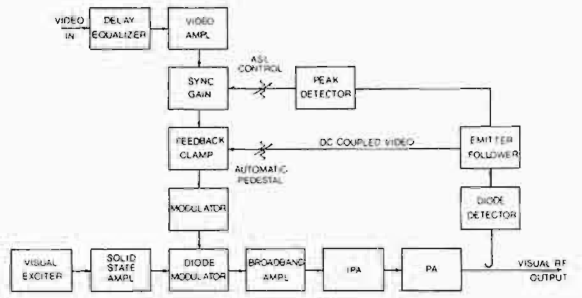

Fig. 21. Automatic power control functional diagram.

Fig. 18 is a picture of the 20 w (cw or aural), 40 w visual linear, and 80 w aural solid-state amplifiers employed in the transmitter. They are essentially "black-box" devices with no adjustments and need not be accessible in the transmitter except to facilitate removal if required for replacement or bench repair.

IPA and PA Power Tube Stages

There are only three tubes in the transmitter. They perform the following functions: visual IPA, visual PA, and aural PA. The visual IPA and aural PA employ the same tube type so only two tube types are required—an 8890 and 8916, shown in Fig. 19. Both are tetrodes. Unlike the case of the lowband transmitter, no triode tube is available for operation on Channel 7-13 with adequate power, gain, low feedback and good tuning characteristics in a practical Channel 7-13 cavity. Modern tetrodes permit wideband operation with the high gain necessary for compatible operation with the moderate-power solid-state amplifiers already described.

All three tubes are used in the same basic RF cavity, one of which can be seen in Fig. 20. The front plates of the inner and outer boxes of the cavity have been removed to provide a view of the internal construction and also to illustrate that disassembly for maintenance or repair is not especially difficult.

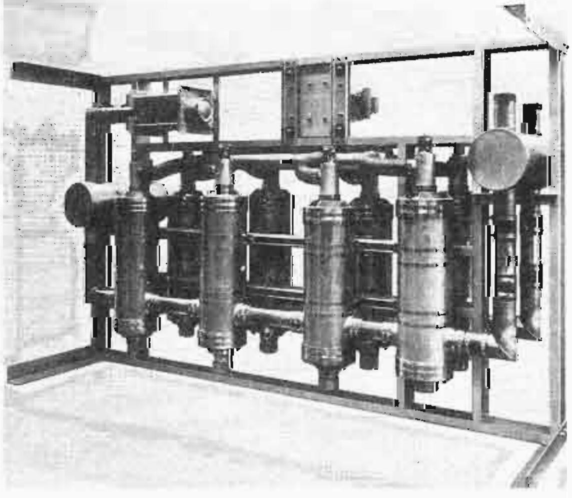

Fig. 22. A 50 kw high-band VHF filterplexer.

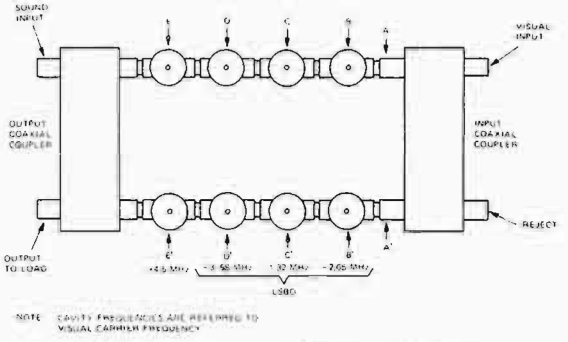

Fig. 23. Filterplexer functional diagram.

An assembly change is made to adapt the cavity to one tube type or the other, using interchangeable anode contact assemblies. A further variation is that the secondary plate circuit of all three cavities are different. This does not show in the photograph because the secondary circuits are comprised of assemblies of coaxial line sections mounted on the rear side of the cavities.

The cathode driven input circuit is a pi network, coupling between a 50-ohm RF drive source and the somewhat lower input impedance of the power amplifiers.

The pi network is adjusted by two vacuum variable capacitors that can be seen in the photograph. They are simply adjusted for minimum reflected power under normal operating conditions.

Automatic Power Control

The transmitter includes automatic power control circuits which operate as shown in the block diagram, Fig. 21.

A sample of the visual output signal is detected and the sync peak and pedestal levels are compared to reference levels. The error voltages from

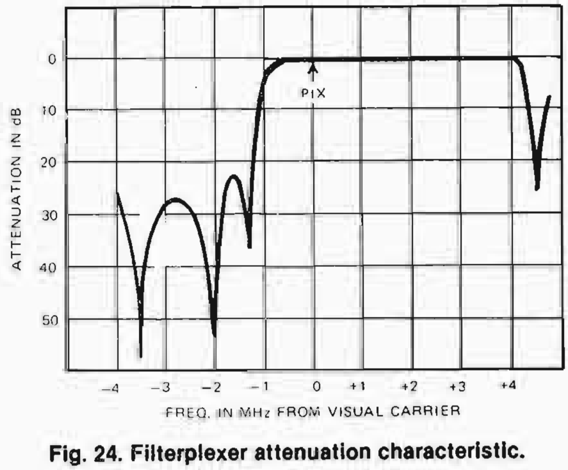

Fig. 24. Filterplexer attenuation characteristic.

the comparators are applied to sync gain control and feedback clamp circuits to control visual peak power and pedestal level, respectively. Thus the transmitter licensed power and the correct sync-to-picture ratio are automatically regulated. This capability is especially useful in contemporary remote control operation and will be useful in future automatic transmission systems.

Switches are included for turning off either or both automatic control circuits as an aid in initial setup of transmitter operating levels.

VSBF or Filterplexer

A harmonic filter is connected at the output of the aural PA; and a harmonic filter plus a vestigial sideband filter are connected at the output of the visual PA. Then aural and visual signals are combined.

If a turnstile antenna is employed with a two-transmission line feed system, then aural and visual transmitters can be combined in a broadband bridge diplexer and there is no need for a 4.5 MHz notch filter in the visual output system. On the other hand, if an antenna is selected with a single transmission line feed system, then aural and visual signals must be combined in a notch diplexer following the visual VSBF.

An alternate arrangement that takes less space, is less expensive, and often results in better performance is to combine the functions of VSBF, and notch diplexer in one assembly called a filterplexer. Fig. 22 is a picture, Fig. 23 is a functional diagram, and Fig. 24 is the attenuation characteristic of a high-band 50 kw filterplexer.

In the functional diagram (Fig. 23), observe that there are four pairs of resonant cavities connected between an input and an output 3 dB coaxial coupler. The resonant frequencies of the four pairs of cavities correspond to the four notch frequencies in the attenuation curve, Fig. 24.

With reference to Fig. 23, the visual signal splits in the 3 dB coupler into two equal signals, one delayed from the other by 90°. When the signals encounter a pair of cavities, the signal frequencies corresponding to the cavity resonant frequencies are reflected. The signal delay in one path is increased by an additional 90° in the return trip through the coupler. Consequently the reflected frequencies are routed to the reject load and dissipated. Signals which are not reflected combine in the output coaxial coupler and arrive at the output port.

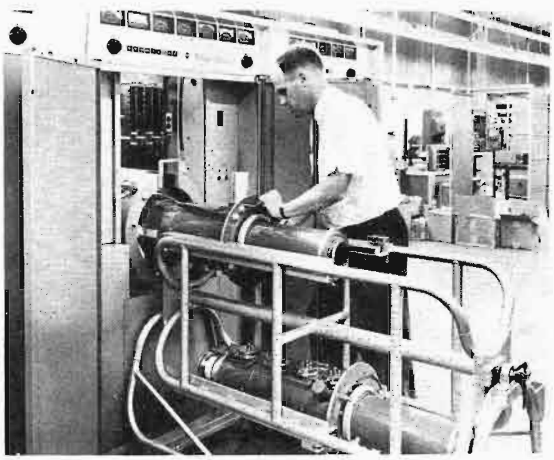

Fig. 26. Replacing a 30 kw 4-cavity klystron.

The aural signal, applied to one port of the output coupler, is reflected by a pair of cavities. The reflected signals combine and also arrive at the output port where both visual and aural signals are combined and routed to the antenna or to a test load.

UHF-TV TRANSMITTER

The vast majority of modern UHF-TV transmitters in service in the United States employ internal cavity klystrons manufactured by Varian Associates. The usual power output ratings of these klystrons for visual service are either 30 kw or 55 kw per klystron. Transmitter power output ratings are in multiples of these values with power outputs ranging from 30 kw to 220 kw. Except for power supply and cooling components, there is little difference in transmitter configuration, size,

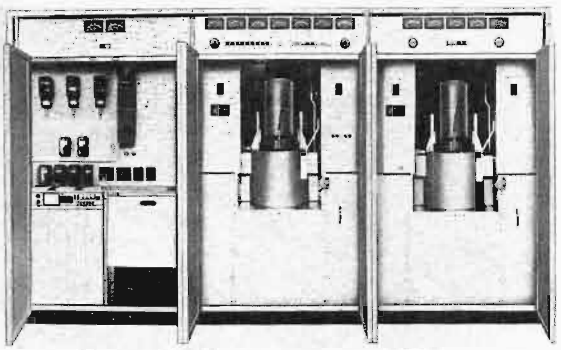

Fig. 25. RCA TTU-30C, 30 kw UHF TV transmitter, front line cabinets.

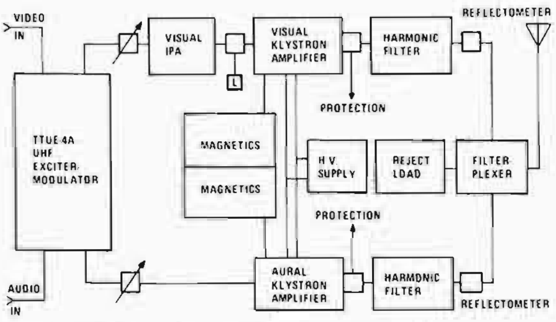

Fig. 27. Type TTU—30C, 34 kw UHF TV transmitter, functional diagram.

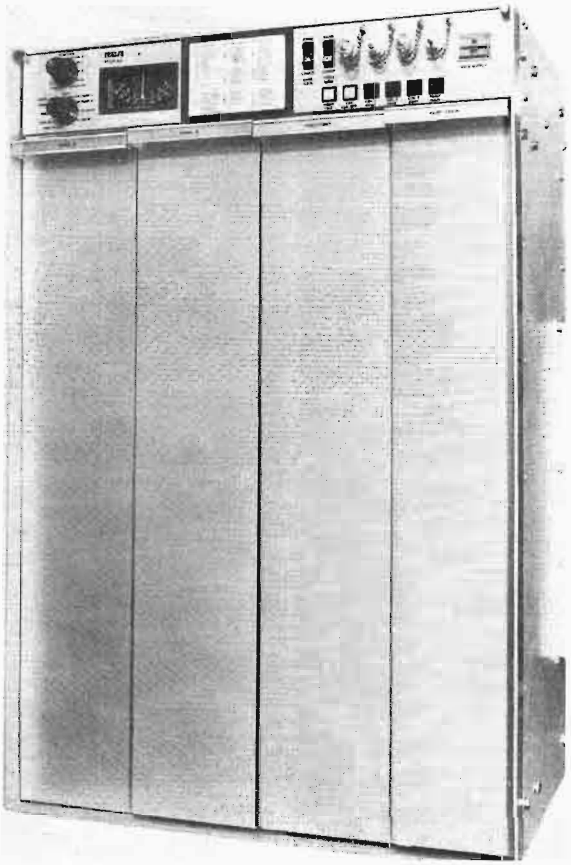

Fig. 28. UHF TV solid-state exciter-modulator.

or appearance whether 30 kw or 55 kw klystrons are employed.

A further classification of klystrons that can be made is into 4-cavity and 5-cavity types. The klystron power gain is just under 10 dB per cavity or roughly 40 dB and 50 dB for 4-cavity and 5-cavity klystrons, respectively.

RCA UHF-TV transmitters use 4-cavity 30 kw klystrons in some models and 5-cavity 55 kw klystrons in others. Five-cavity klystrons eliminate the need for a 10 w solid-state linear amplifier preceding the klystron, shown in one of the diagrams to follow. However, four-cavity klystrons are less expensive to replace and consequently permit slightly lower operating cost. A short discussion of power costs, which is a more significant element of operating cost, may be found in a subsequent paragraph.

Fig. 25 is a picture of the front line cabinets of an RCA TTU-30C, 30 kw UHF-TV transmitter with the cabinet front doors open to provide an internal view. The all-solid-state exciter is in the lower left corner of the left-hand cabinet. In each of the other two cabinets can be seen a 30 kw vapor cooled klystron, mounted in its magnet assembly. This may be pivoted forward for easy removal of the klystron as shown in Fig. 26.

A block diagram of a 30 kw transmitter is shown in Fig. 27. The transmitter is comprised of an exciter, a visual solid-state IPA, two klystrons, power supplies, a filterplexer, and some lesser subsystems and components.

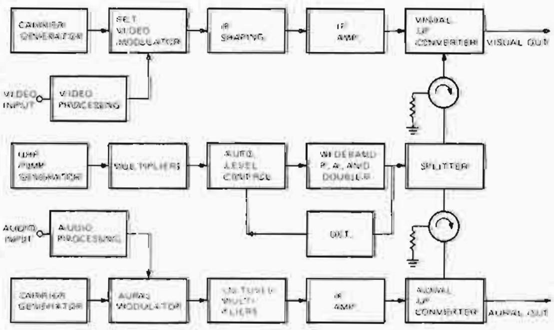

Fig. 29. Exciter-modulator, functional diagram.

Solid-State Exciter Modulator

An external view of the exciter modulator is shown in Fig. 28 and the related block diagram is shown in Fig. 29. There are four vertical slide-out drawers organized into the following basic functions: aural IF, visual IF, video processor, and pump chain. Each drawer houses a number of plug-in modules and insofar as practical, each module performs one basic function. The module performance can be metered on a multi-meter by combined operation of a nine-position switch and a ten-position switch. The concept is to minimize downtime if a fault should occur by rapid location and replacement of the defective module.

Visual and aural modulation occur at IF. The IF visual carrier frequency is 45.75 MHz and the aural frequency is 50.25 MHz. The aural frequency is higher than the visual frequency as a result of operating the pump circuit below the frequency of the UHF TV output signal—a desirable condition for maximum stability of the upconverter.

Video processing. The video processing circuits perform the same functions as those carried out in the VHF circuits, previously described. The circuits are similar. However, the quantitative linearity correction requirements are different for a UHF klystron transmitter, and the video signal level required to operate the FET modulator is

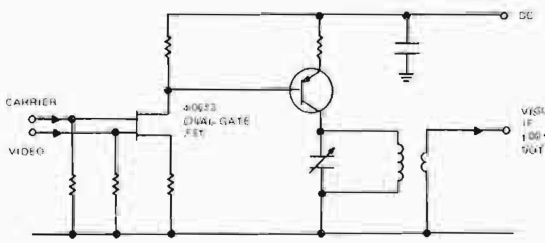

Fig. 30. FET visual modulator, simplified schematic.

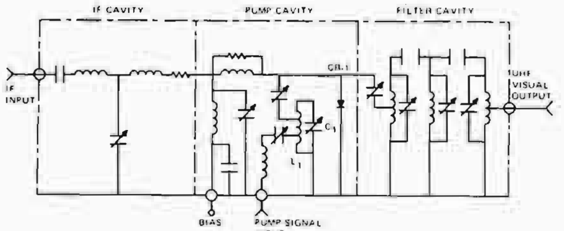

Fig. 31. Upconverter, simplified schematic.

less than required for VHF grid bias or diode modulators.

The UHF processor linearity correction requirements are for small or negligible white level differential gain correction, moderate black level correction and approximately 100 percent sync stretch. Klystrons are purposely operated close to saturated power for best efficiency. This produces substantial sync compression to be overcome by operation of the sync stretch circuits.

FET visual modulator. Fig. 30 is a simplified schematic of the IF visual modulator employing a dual-gate field-effect transistor. The operation is extremely simple. Video is applied to one gate and IF visual carrier to the other. The drain output is a double-sideband amplitude-modulated IF visual signal with a nearly linear modulation characteristic.

Active IF filter. An IF shaping filter follows the visual modulator. It serves two functions. First, it restricts the bandwidth and establishes the initial vestigial sideband response characteristic. The final steep cutoff at the edge of the channel is established by a high-level filterplexer following the klystron.

The second function of the active filter is to provide a trim adjustment for the exciter or overall transmitter frequency response. The exciter normally is adjusted for flat frequency response within a tolerance of 0.25 dB across the channel.

The active filter has overall unity gain and 50 ohm input and output impedances.

Following the active filter, the signal is amplified to a level of 2 w, then padded to 1 w at the input to the visual upconverter.

Visual and aural upconverters. A parametric upconverter employing a microwave varactor diode was selected to convert from IF to final frequency because it is extremely linear over a wide range of power output, and it has a power gain of approximately 6 dB. This compares to a typical loss of 5 or 6 dB for a conventional diode mixer. Consequently, the desired final frequency visual output power of 4 w is achieved with an IF power of only 1 w.

No final frequency linear amplifiers are required to drive a 110 kw transmitter employing a pair of 5-cavity visual klystrons.

A simplified schematic of the upconverter is shown in Fig. 31. CR-1 is the mixer varactor diode. L_1 C_1 is the pump frequency tank circuit. The other circuit elements in the "IF cavity" and "pump cavity" blocks are required for: isolation between pump frequency and IF frequency; impedance match between the upconverter diode and the IF and Pump circuits; and control of intermodulation products.

Residual harmonics, or intermodulation products substantially removed from the desired output frequency, are eliminated by the three-pole bandpass filter in the "filter cavity" block of the diagram.

Another identical parametric upconverter handles the aural signal at an output level of 0.8 w. A common pump chain drives both upconverters.

Pump chain. Three temperature compensated crystal oscillators (TCXO) are employed, one each for: visual IF carrier generator, aural IF carrier generator; and UHF pump generator. Temperature compensation is precise from 0 degrees to +45 degrees C. No ovens or crystal heaters are required.

Of the three crystals, the stability requirement is most severe for the pump generator. The pump chain TCXO unit operates with a power output of 5 milliwatt on a frequency between 11 and 18 MHz, depending upon the channel assignment. Then, through a succession of wideband amplifiers and diode frequency multipliers, a power in excess of 20 watts is developed at the output of the pump chain.

The pump chain output is sampled, detected, and the resulting dc is used in an automatic level control circuit to maintain constant pump power at the splitter input.

The splitter is a 6 dB coupler which delivers 15 w pump power to the visual upconverter and 5 w pump power to the aural upconverter.

Solid-State IPA

The solid-state IPA is a 10-watt broadband fixed-tuned linear amplifier with a bandwidth approximately equal to the tuning range of a klystron. It is the "black box" device in the upper right-hand corner of the left cabinet in Fig. 25.

The output of the visual IPA connects to the klystron input through a ferrite circulator to isolate the IPA from load changes when tuning the klystron input circuit. No aural IPA is required.

Klystron Efficiency and the Anode Pulser

Power costs of operating UHF TV transmitters is substantial and there is strong incentive to reduce it.

In the first place, very high power transmitters are required to provide equivalent service to that provided by typical VHF-TV transmitters.

A second factor contributing to high power costs for UHF transmitters is the mediocre beam power efficiency of klystrons compared to the plate efficiency of VHF PA power tubes. The former have, until recently, operated at a sync peak level efficiency of approximately 35 percent compared to approximately 55 percent for VHF power tubes. Recently, high efficiency 30 kw klystrons have gone into service and this ameliorates the problem somewhat. These have a typical saturated efficiency of approximately 43.5 percent, corresponding to 40.5 percent sync level efficiency.

A third factor, more important than the second, is that the klystron input power is independent of average picture level (APL) whereas the tube input power is essentially directly proportional to signal output level. At mid-characteristic (average power = 1/4 sync power) a VHF tube would be twice as efficient as a UHF klystron on the basis of this factor alone.

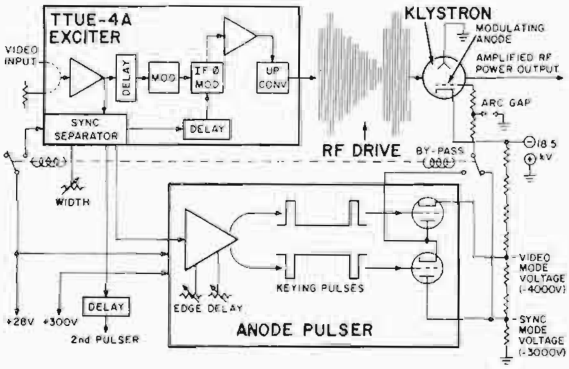

Fig. 32. Anode pulser system, functional diagram.

A system has been described (See Reference 3) for reducing the average power requirement of visual klystrons. In the new system, the klystrons are operated with increased RF drive and lower modulating anode voltage during all but the synchronizing interval. Then the modulating anode is pulsed to a higher voltage during the sync interval. A functional diagram of the anode pulser system to accomplish this is shown in Fig. 32.

The mod. anode pulser system produced an improvement in klystron beam power efficiency of 20 percent—further closing the gap between VHF power tube and klystron operating efficiencies.

REFERENCES

1. Gluyas, T.M., TV Transmitter Luminance Transient Response, IEEE Transactions on Broadcasting Vol. BC-20, No. 1, March 1974.
2. D'Amato, P., Distortion of the ITS Waveform in the Diplexer and the Vestigial-Sideband Filter of a Television Transmitter, *EBU Review*—Technical Part No. 154, Dec. 1975, pp 274-285.
3. Bullock, J.B., & Schmidt, R.C., A System for Reducing the Power Required by UHF TV Transmitters, *Proceedings 30th Annual Broadcast Engineering Conference,* NAB, March 21-24, 1976.

20

Network Facilities for Radio and Television Transmission[1]

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GENERAL CONSIDERATIONS

Network Requirements

Multiple-Channel Requirements

Whenever it is desired to broadcast the same program material, either audio or video, simultaneously from two or more broadcasting stations, or when it is desired to record a program at a point remote from its origin for retransmission at a later time, it is necessary to provide a transmission channel of suitable grade from the point of origin to the remote point or points. The combinations of transmission facilities which make up such channels are known as networks. They are further distinguished as radio or television networks, the latter consisting of a "package" which includes video channels and associated TV-audio channels.

If such channels were required only to connect a few fixed points to a single program source, the operation would be relatively simple. In the United States, however, there are several principals who operate networks to provide program material to associated stations. Programs on each of these networks may be originating at different points, and at various times the points of origin on each network may change. In addition, in many population centers, there are several broadcasting stations, each associated with a different network and operating competitively for the available audience. Thus, while the networks are independent of one another, they largely serve the same geographical locations and duplicate facilities are required on essentially the same routes.

Reliability and Protection

Reliability of service and satisfactory transmission are essential requirements. Any transmission channel, however, is subject to complete interruption by the failure, in service, of any one of the thousands of individual components of which it is composed. Since there is no known way of completely avoiding such failures, the reasonable approach is to provide similar facilities which can be rapidly interchanged for the defective parts with a minimum of lost service time. This adds a further requirement for duplicating facilities.

Flexibility

The variation in time across the United States is another factor which enters into network operations. A program which originates in the East at a time when the greatest audience attention would be expected would not, if broadcast simultaneously in the West, encounter the same favorable time period. Regional shifts to day-

[1]The material in this section has largely been abstracted from technical papers and operating information published by the American Telephone and Telegraph Company. The contributions of the anonymous authors of this material are hereby acknowledged.

Most of the mileage of facilities used for radio and TV network program transmission in the United States is provided by the Bell System operating companies. However, there are many segments of the overall distribution network which are served by miscellaneous common carriers and by private systems. The basic techniques used by the other carriers are essentially similar to those used by the Bell System. Also, Bell makes use of both the baseband and radio systems produced by manufacturers other than the Western Electric Company. The material in this section while based entirely on Bell applications of Western Electric systems, may be considered as being typical of general practice.

light saving time further complicate the time factor. It has, therefore, become standard practice to record a program at some strategic point from a regional network on which it is being carried "live" and then to retransmit it later on another regional or sub-network. At any given time, therefore, a station associated with a network may be:

1. Broadcasting a local program;
2. Broadcasting a network program simultaneously with all other stations on the network;
3. Broadcasting and recording one program from a network while retransmitting to another network a program previously recorded;
4. Broadcasting and feeding to the entire network a local program of national interest; and
5. Other possible combinations of these conditions.

From the foregoing, it is fairly obvious that if each network principal were to establish his own network facilities with the requisite distribution, reliability, and flexibility, the economic burden would be considerable. If, however, the channels could be provided on a cooperative basis, avoiding duplicate construction maintenance costs, and if backup facilities and equipment could be provided for groups of channels rather than for each individual channel, a considerable saving could be effected. If these costs could be further shared through the combination of network facilities with other communication channels which also serve the same geographical areas, further economy is apparent.

Common-Carrier Operation

It is primarily for these economic reasons that the provision and maintenance of audio and video network facilities, for the most part, have become the responsibility of communications common carriers. It is the function of such carriers to provide channels for the transmission of electrical communications of every type between any points where it is economically justified to provide them.

The Bell Telephone System

Functions of Major Corporate Units

The Bell System includes the American Telephone and Telegraph Company, the parent organization; the Bell Telephone Laboratories, the research and development organization; the Western Electric Company, the manufacturing and supply organization; and 23 associated operating companies, such as the Northwestern Bell Telephone Company, the New York Telephone Company, The Bell Telephone Company of Pennsylvania and the others, and the Long Lines Department of the American Company. The areas served by the associated companies are shown in Fig. 1.

The American Telephone and Telegraph Company, with headquarters in New York, as the parent company, coordinates the various Bell Companies into a system having a common policy. With respect to network service particularly, this includes basic research and development work, planning and coordination of manufacturing and construction activities, assistance in financial matters, and expert assistance in all phases of operation and maintenance.

The development and research function is carried on by the Bell Telephone Laboratories, which is owned jointly by the American Company and the Western Electric Company. For the American Company, the Laboratories carries

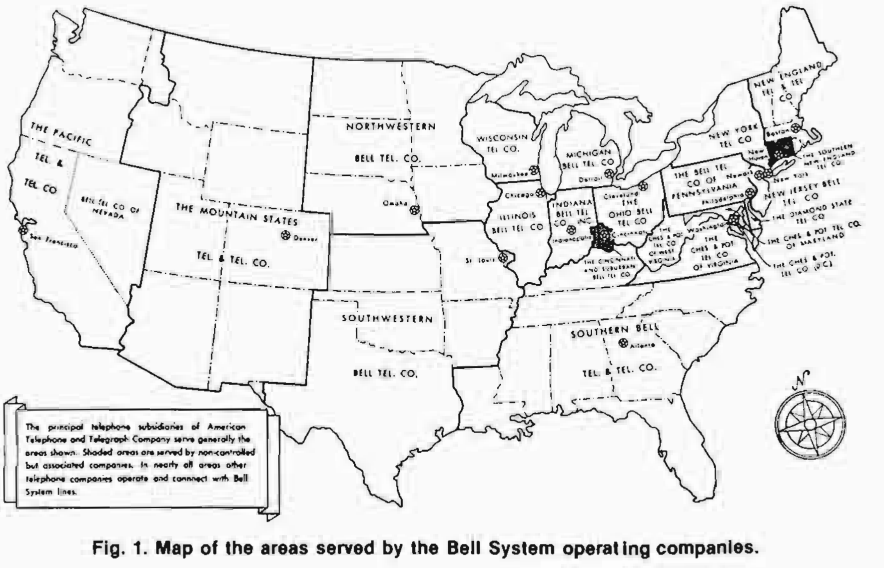

Fig. 1. Map of the areas served by the Bell System operating companies.

out the necessary fundamental research in all branches of communication; for the Western Electric Company it prepares manufacturing designs and specifications based on these researches. In the field of broadcasting, both the American Company and the Laboratories maintain active contacts with broadcasting principals and the engineering societies to keep abreast of progress and requirements in the art.

The Western Electric Company, which is owned wholly by the American Company, manufactures most of the equipment, cable, and wiring used in the construction of communications facilities; arranges for the acquisition of the remaining supplies; and installs all central office equipment. It also maintains stockpiles of material at strategic points for use in emergencies. Through this source, a supply of standard, uniformly high-quality equipment is available at reasonable cost to all the associated companies. This standardization also makes possible emergency assignments of maintenance personnel in any area, since the equipment and arrangements are uniform and standard regardless of location.

The associated companies engineer, install, maintain, and operate all the local communications facilities in their respective territories and also the short-haul (primarily intrastate) intercity services. In carrying out this function they have arrangements with the independent companies in their areas for extending services and providing intercommunications. In certain cases they may offer engineering assistance or other similar services.

The Long Lines Department

The Long Lines Department is the operating department of the American Company. Broadly, its function is to provide, maintain, and operate the long-haul facilities which interconnect the facilities of the associated companies.

Within the Long Lines Department, the Marketing Department is responsible for conducting the business relations of the Company with the network principals. The Service Costs and Rates Department is responsible for establishing the regulations and rates under which service is furnished, and for filing this material with the proper governmental regulatory bodies. In the conduct of the business relations one of the functions of the Long Lines Marketing Department is to be continually aware of new customer requirements in both the immediate and more distant future. If the new requirements are for plant expansion of facilities similar to those already in use, routine channels are followed to provide them when required. If advances in the art are in prospect which require capabilities beyond those of existing facilities, the full cooperation and facilities of the Bell Laboratories, the American Company, and the Long Lines Engineering Department are enlisted. The Laboratories normally would provide the design of the new systems to meet the requirements, the American Company would coordinate the activities of all companies, the Long Lines Engineering Department would plan and coordinate the installation and construction of the interexchange facilities, and the associated companies would do likewise for local connecting facilities. Using information provided by all the engineering and manufacturing groups, the Marketing Department would coordinate all matters pertaining to a contract for a new type of service.

The Long Lines Engineering Department is, in general, responsible for the planning and construction of the overall network facilities, basing layouts on standard components developed by the Bell Laboratories. It is responsible for determining the most propitious time for introducing new types of equipment or systems into the plant. The new facilities need not be for the purpose of handling a new service. It is a natural outcome of Bell Laboratories continuing fundamental research to develop systems and equipment which will perform the same functions as existing equipment more reliably, more efficiently, and more economically. These new systems are introduced into the plant under existing rate structures at the time and in the location decided by the engineer after consideration of all related factors.

Network Operation

Operation of network facilities is the function of the Operations Departments of the associated companies and the Long Lines Department in their respective areas. Maintenance personnel carefully check all components of every system and test and line up overall channels before they are put into service. Subsequently, they perform regularly scheduled routine tests on components and systems, set up and execute network changes, and handle reports of trouble. Reported troubles are verified, network reroutes are established, the source of trouble determined, and men dispatched to clear the trouble.

In connection with the development and maintenance of network services, mention of two special committees is of interest, the Video Transmission Engineering Advisory Committee (VITEAC) and the Network Transmission Committee (NTC). The VITEAC is composed of the engineering and operating heads of the major networks and the American Telephone and Telegraph Company, both Headquarters and Long Lines Department, and the New York Telephone Company. It is the function of this committee to promote the common understanding of the various factors of an engineering and policy nature related to network service. Special emphasis is placed on avoiding consideration of day-to-day operating conditions.

The Network Transmission Committee is the working subcommittee of the VITEAC. This group is composed of broadcasting and telephone engineering personnel who are normally concerned with network operation. It is the function of this group to collect data for the VITEAC, to check the overall performance of the networks by periodic surveys, to investigate those network operating difficulties which require engineering attention, and to devise standard testing procedures and transmission objectives.

Routes of the Bell System

Message Service Routes

It is the function of the Bell System and the independent telephone companies to provide channels for the transmission of electrical communications among any points in the United States and, by interconnection with the facilities of other agencies, from points in the United States to points anywhere in the world. Within this country, as pointed out previously, local communication channels are provided by associated companies and independent companies in their areas and long-haul interconnecting channels are provided by the Long Lines Department of the American Telephone and Telegraph Company. Since the major requirement for long-haul channels exists among major population centers or cities, it is natural that a series of "routes" has been developed, linking groups of these cities in tandem. The wire or radio facilities on these routes are equipped at all intermediate points with through or terminal types of equipment to provide groups of channels between any two cities on the route and, from them, to any connecting channels in their areas. At the terminals of the routes, interconnecting facilities are provided between routes to extend connections to any part of the country. Through the normal growth of the system, new routes have been developed and added, so it is now possible to interconnect many points by any of several routes. This provides protection against a major failure on any route.

It is fortunate that the broadcasting stations which desire network service also are close to or in the cities through which the major long-distance routes extend, although some television stations are notable exceptions. This makes it possible to provide for network-transmission channels along with channels for other communication services and thereby to derive the economies previously pointed out.

Network Facilities

Since the inception of network service it has therefore been Bell System policy to include in all new construction, facilities which are suitable for various grades of network transmission. The number and types of such facilities provided in any section are determined by long-range forecasts, based on the best available customer and company estimates, to be adequate for a considerable time. It, therefore, is possible that wire facilities would be constructed in advance of actual requirements to secure the construction economy, but that central office equipment would not be added until some later time when service was actually ordered.

In the development of network service over the years, it has frequently been necessary to make temporary modifications of existing communications channels in order to adapt them to meet an early service date for network service. These short-term arrangements have been superseded as soon as possible by standard arrangements developed and installed particularly to meet specified service requirements. This article will not refer to any of the temporary arrangements but will discuss only the standard facilities now provided for network service.

Fig. 2 shows the major routes along which facilities have been provided for full-time television network service. Radio-network facilities are available on these routes and to many other points not included on the map. The facilities provide for all present full-time radio- and television-network requirements, including adequate facilities for protection and for occasional services.

Facilities are also available for occasional and recurring services on short notice, and facilities can be provided, as for remote pickups, to points not on existing routes by special inquiry. In most cases these pickups require special temporary construction.

Channels are also available for audio-program service from all the principal cities in the world. Normally these are not considered as part of a network. Rather they are provided for short periods in the form of "mike leads" as for news commentators. The mike lead may be fed live to a network, or a recording may be made

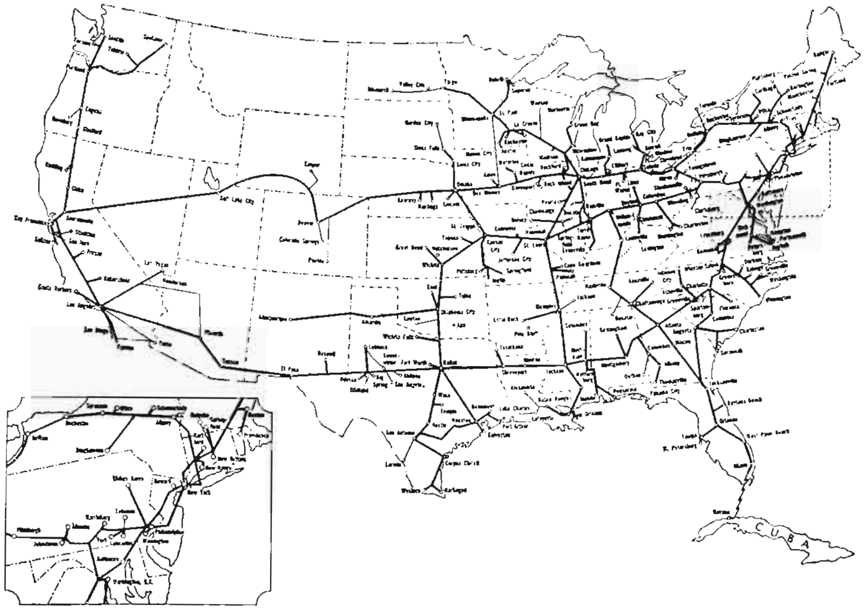

Fig. 2. Routes of the Bell System television network as of September 1974.

for later broadcast. Most of the overseas channels are derived from satellite or cable message circuits suitable for voice transmission only. The undersea cables to London and Hawaii, however, are equipped to provide wideband (Schedule A or B) audio-program channels and from those terminals, service may be extended to Europe and to Australia and to Japan. Arrangements for these channels are handled through normal Marketing Department contacts.

Network Facility Arrangements

Network Sections

The facilities which are provided for network services are normally established in sections. For audio networks they are designated as PNNTs, a computer code which indicates the type of program circuit units, and for video networks they are designated as VURs or VUCs, or video units, radio or cable. The various units are further identified by number and letter codes which indicate the type of facility, the direction of transmission, the terminal cities, and, in some cases, additional information.

The units are combined to form network sections. Audio network sections which are operated as units by the broadcasters are designated by letter codes assigned mutually by the broadcaster and the telephone company. Combinations of units, which are not specifically assigned to a network, are designated OCCL, or occasional program circuits. Television units are combined to form TVSs, or television sections, which are identified by number and letter codes. Combinations of TVSs are used to provide complete networks which are designated by the same procedure as the audio networks.

Units and sections of the same type are identical with one another at their terminals and in their component parts so that such sections are interchangeable in whole or in any part. Units and sections on different types of facilities are identical with respect to levels and equalization at their terminals, through the use of appropriate terminating arrangements so that different types of facilities can be either interconnected or substituted at these terminals. This provides a layout which is completely flexible in relatively large units. These units may be permanently connected into a fixed network, or switching arrangements may be included to permit rapid switching to convert the overall network into several regional networks. Some combinations of facilities have remained in relatively fixed arrangement with respect to routing and connections for long periods and thereby have tended to become identified with a particular network principal. Despite such identification, networks are provided, not as physical entities, but as transmission or channel services at charges based on distance and period of use.

Since network facilities are provided in sections along major communications routes, the most economical method of reaching all points which desire network service is to establish a channel by the interconnection of sections which pass successively through each service point. This leads to some long and circuitous routings for some service points, but with the present transmission performance of network facilities, the transmission penalty is small in comparison with the operating economies derived.

Reversible Operation

It has been pointed out that programs may be originated at different points on any network or that it may be desired to operate several regional networks over the same facilities that normally comprise a larger network. Two features are available which facilitate network operations in these situations, namely, reversible channels and round robins. Reversible operation is limited to audio channels, but round-robin operation is applicable to both audio and video channels.

Program units assigned to carrier systems on cable or radio are normally assigned in pairs for opposite directions of transmission.

Switching is normally accomplished at the ends of a channel where remotely controlled switches are operated to select the desired direction of transmission. Reversible operation is normally furnished on a nominal 15-sec. basis in order to allow time for the sequential operation of all the circuit features. The remote-control features may be operated by the telephone company on orders from the broadcasters which will specify either a time cue or an audible cue, or the control may be extended to a studio location on the network. Reversible channels normally will result in shorter mileages between pickup points and service points than will be obtained by round-robin operation. This results in an automatic improvement in those transmission parameters which are directly related to length.

Round-Robin Operation

Round-robin operation consists of connecting facilities in tandem through the points desiring service in a manner to form a closed loop back to the originating point. Transmission over such a network is always in the same direction, either clockwise or counterclockwise as required by the broadcaster. Stations may be bridged onto the main line by local channels, or the network may be routed "in and out" of the local studio. With the latter arrangement programs or inserts can be originated and fed to all stations on the round robin. It is important that the previous originating studio close through the in-and-out connections for continuity, but the closing must be delayed sufficiently after the cue to permit opening the loop at the succeeding originating studio. This will avoid setting up a closed loop which, in the case of audio networks, would produce an audible oscillation and, in the case of video networks, would produce bright flashes on video monitors or receiving sets. At any point on the round robin, side legs of varying lengths can be connected which, for audio, are usually reversible.

While round-robin operation has many operating advantages, it does result in long, circuitous routings for many points. An audio round robin, for example, might start at New York, go to Boston and then back via Albany to Buffalo, Cleveland, Chicago, St. Louis, Pittsburgh, Washington, and other intervening points to New York, for a total distance of about 3,000 miles. Thus, Philadelphia, about 90 airline miles from New York, is fed at the end of the 3,000-mile channel.

Network Layouts

The basic, or backbone, layout of a particular network as regards routing and stations connected is normally a relatively long-term condition which is provided in accordance with orders for service by the network principal. Thus, as previously mentioned, some combinations of facilities have come to be identified as permanent networks. The regional shifts to and from daylight saving time are the principal factors which influence recurring major revisions. These layouts are established by the Operations Departments involved on the basis of permanent circuit orders which are prepared by the Engineering Departments. The broadcaster knows that this basic layout, equipped with the necessary switching equipment, is at his disposal during all service periods contracted for.

Operation Orders

Directions and cues for the daily switching and temporary rearrangements of the network are transmitted to the Operations Department either in service orders or operation orders. These orders are received at the Operations General Control Office two days in advance and are transmitted to every point on the network where a change is to be made one day in advance of the requirement. At all such points, on all networks, program and Serving Television Operating Centers (STOC), or Television Facility Test Positions (TFTP) have been established. In some cities, for example, New York, where large local networks are also maintained, the associated company provides locations where testing and facility rearrangements are concentrated. At all these locations specially trained personnel execute network operations, conduct and direct routine local and overall channel tests, and take action to sectionalize and clear any troubles noted or reported.

Separation of Audio and Video Networks

In the discussions thus far, reference is made to network service in general and three classes of networks have been mentioned, audio, TV-audio, and video, indicating that the audio and video portions of television programs are carried on separate networks. In this country this is usually so.

As far as technical considerations are concerned, the two networks could be derived from the same basic facilities and travel together throughout. Tests have been conducted using various types of diplexers for deriving the TV-audio channel from the video facility in an effort to determine the feasibility of connecting the diplexers into the network at the broadcasting location. At this time, the test results are inconclusive, but preliminary results indicate diplexers could become the method of obtaining the TV-audio channel in the future. The diplexer is discussed further in the section on Audio Network Facilities. Since sound broadcasting preceded television by many years, however, substantial quantities of audio facilities had been built up about the country and could be added to in kind, readily, when the television sound requirements began to materialize. As a result, video and associated sound networks are completely independent, often not even traveling over the same route among the cities in which they serve broadcasting stations. This has no important disadvantage, since the sound channels used are from pools of such channels existing on all routes to the extent required to care for established needs for all types of broadcasting. On the contrary, this independence usually has the advantage of making the sound channels largely immune to failures affecting video channels.

The method of charging for broadcasting channels is based, in general, on airline distance between service points, so charges are not affected by the fact that the video and accompanying sound channels may travel different routes between television service points unless intermediate service points are provided for the broadcaster on the sound channel.

Although video and associated audio networks thus remain independent in operation, a "package" audio-video service was made available in 1954 at some saving in cost, based on a limited service period per day.

Differential Audio Delay

Although the television sound and picture channels are physically independent, they function essentially as though they were derived from the same basic facility. The only special consideration involved is that the picture and sound signals travel nearly enough at the same speed so that sounds heard will appear to be properly in step with the action on the screen from which they seem to emanate. This does not require absolute synchronism. Human perception normally experiences considerable delay in sound accompanying action seen. For example, a sound coming from action observed only about 100 ft. away will arrive at the ears of an observer nearly 1/10 sec. delayed without his being conscious of anything unusual. This is contributed to somewhat by the fact that the exact instant that the sound is produced is not so readily discerned at even a 100-ft. distance as at a shorter distance, a conclusion supported by the fact that a comparable delay from action observed as a close-up on a television screen a few feet away will be less tolerable. The nature of the action plays an important part in this.

A sharply defined impulse type of sound where the action is such that the eye can easily detect the exact instant the sound is produced, such as that of a hammer striking a nail, is most susceptible to differential delay effects. Lip sounds coming from a clearly enunciating speaker observed in a close-up also are particularly revealing of differential delay, if present. In both of these instances observation is aided by unconscious ability of average human perception to recognize rhythm or rate of development of a motion and to anticipate the exact instant of its completion whether it actually occurs or not.

A series of tests conducted by the Long Lines Department with different types of program material and different amounts of sound delay over loops of regular network facilities showed that a differential delay of the sound up to about 0.06 sec. (60 msec.) was not detectable on any of a number of representative commercial programs observed by a group of average observers under conditions comparable to those in the average home. The tests also showed that in much of the action a differential delay of 100 msec. or more would pass unnoticed. Beyond about 100 msec.

the effect became observable more frequently when looked for specifically.

Tests have also been made with "leading" sound (in advance of visible action), which showed considerably less tolerance for this condition. This is consistent with the fact that it is a condition not encountered in nature. It is also a condition not encountered in the networks with current routing practices, since most long sound channels usually have a number of sets of carrier terminal equipment in tandem, all of which introduce more delay than encountered in the video channels. A typical transcontinental audio channel of this type about 3,500 miles long (New York to Los Angeles) before television affected the situation might have had about 150-msec. total delay. A video channel on microwave over the same distance, on the other hand, would probably have only about 20-msec. delay. The differential of 130 msec. would be considerably more than desirable. Special measures are applied in the circuit layout engineering of channels to be used for television sound to minimize the transmission time of the sound. In particular, carrier program channels are so arranged or routed that they will make the longest practicable jumps between terminals where the carrier channels have to be brought down to voice frequency. By such measures differential delay on transcontinental hauls can be kept within acceptable limits.

While it would be possible technically to delay the video signal by the use of delay networks to accomplish the same purpose, it has not been necessary to attack the problem in this way.

Grades of Service—Audio

Facilities for both program and TV-audio network services are offered in a number of grades and for different time intervals, including the following high-quality services:

TABLE 1

Grades of Audio Services

Designation	Approximate frequency range, Hz	Notes
Schedule AAA	50 – 15,000	Full time 24-hr. day
Schedule AA	50 – 8,000	Full time 24-hr. day
Schedule A	100 – 5,000	Full time 24-hr. day
Schedule B	100 – 5,000	Part time by hour or fraction

Note: As of September 1974, there were roughly 304,000 miles of Schedule A service in operation about the United States under Long Lines contract alone, not counting a substantial mileage under associated company contract. Of those 304,000 miles, about 145,000 miles were used for TV-audio.

In addition to the high-grade channel services listed, several lower grade services, Schedules C, D, and E are also available. Aside from bandwidth, there is an important difference between the lower and the higher grade channels. The high-quality channels are amplitude- and delay-equalized to provide satisfactory transmission over the longest distances between originating and delivery points that should be encountered normally within the continental limits of the United States, and with something to spare. The lower quality services, on the other hand, make use of channels designed and constructed primarily for telephone purposes, which are equipped with telephone-type repeaters (amplifiers), repeating coils (transformers) and other equipment. Some modifications in the adjusting of this equipment are made to secure small increases in effective bandwidth or improvement in signal-to-noise conditions. These changes are possible because the channel need transmit in one direction only, thereby eliminating balance requirements involved in normal two-way telephone service. While the improvements thus obtained are beneficial for program-transmission purposes, transmission impairments accumulate to objectionable magnitudes for program purposes at relatively short distances with the lower grade circuits. The controlling factor in this is usually delay distortion which increases with distances and with bandwidth. Delay distortion is much more objectionable in broadcast reception than in speech over a regular telephone instrument. For these reasons the Telephone Company usually places some limitation on the distance over which the lower quality services should be used, particularly where transmission of music is a requirement. Despite these limitations, however, there is an extensive demand for the lower quality services, particularly for baseball and similar sports reporting, because of the saving in cost afforded.

Service Preferences

At the present time the preponderance of full-time sound network service is of the 5,000 Hz type. The nearest approach to this is a 3,500 Hz medium-quality service of which about 151,000 miles were in use in 1974. The 5,000 Hz service appears to represent a balance point between cost and quality, including consideration of such things as limitations in response of the average radio receiver, indifference of a large segment of the listening public to wider band quality, and the fact that a 100- to 5,000-Hz band can provide pleasing results. The weighting of these various factors is, of course, established by the broadcasters who pay for the service.

The same preference for 5,000 Hz audio service has been extended to television, as will be noted from Table 1. The television picture tends to divert critical attention from the sound quality. Relative cost to the broadcaster is also a controlling consideration.

Grades of Service—Video

In the early years of television network service, two grades of facilities were offered, one suitable for the transmission of monochrome signals and one suitable for the transmission of color signals. Today, only one grade of facility is offered that is suitable for monochrome or color signals.

Since color transmission requires close attention to the control of frequency response and differential phase and gain in the region of the color subcarrier, this high grade facility necessitates the provision of additional equipment and greater maintenance effort. This service is available on a time and distance basis.

Special Services

Special services, for example, 15-kHz audio service or 8- or 10-MHz video service can also be provided. The demand for such services at this time is not sufficient to justify the maintenance of permanent facilities of these grades. They are provided therefore only on special inquiry and with a time interval to permit engineering and, when necessary, special construction and installation or modification of central office equipment at the points involved.

Service of standard quality to points not located on existing routes normally is also provided only on special inquiry as previously mentioned.

VIDEO-NETWORK FACILITIES

Local Channels—The A2A System

General

Local video service is that service which includes such channels as remote studio to master control, studio to transmitter and master control to and from the telephone company intercity network connecting office. This service normally does not involve a multiplicity of channels between any two points and the distances are usually quite short. For these reasons carrier-type facilities are not economically justified and, while some channels are established on single-channel radio links, the majority of them are established on wire facilities which transmit the video base band. The channels are usually required in urban areas in which other communications services are provided in exchange-type cables. The usual wire facilities in these cables, however, have very high losses at the higher video frequencies and are unsatisfactory for a number of other reasons. Because of these factors the Bell Telephone Laboratories designed a wire facility particularly for short-haul video service and developed a complete transmission system based on the use of this cable. This system is known as the A2A System. A newer solid state version of the basic A2A System designated the A2AT System has largely superseded the A2A for local video service.

An overall system includes, in addition to the wire facilities, transmitting and receiving terminals with associated amplifiers and equalizers and intermediate amplifiers and equalizers as required by the length of the channel. All of these units are provided in equipment blocks which may be combined as required to meet the overall requirement. The maximum length channel in current use is about 13 miles long and the median length is about 1.5 miles.

Video-Cable Facilities

Three types of video cable pairs are now in use in the plant. These are illustrated in Fig. 3.

The 16 PSV-S pairs are polyethylene-string-insulated 16-gauge wires covered with two copper wrappings, spirally wound in opposite directions.

The 16 PSV-L pairs are similar to the 16 PSV-S pairs except that the inner copper tape is applied longitudinally instead of spirally. This construction results in improved crosstalk performance and a small reduction in attenuation.

The 16 PEV-L pairs are also 16 gauge but the conductors are individually insulated with expanded (foamed) polyethylene and the fillers are the same material. Longitudinal and spiral copper tapes are applied as for 16 PSV-L. This construction results in a cable whose impedance can be held to closer tolerances and one with reduced internal echoes due to manufacturing irregularities.

A number of video pairs may be enclosed in a sheath to provide a cable exclusively for video service or a number of these pairs may be enclosed in the same sheath with the paper-insulated pairs used for local service. Both arrangements are in use and, by virtue of the inclusion of video pairs in many exchange area

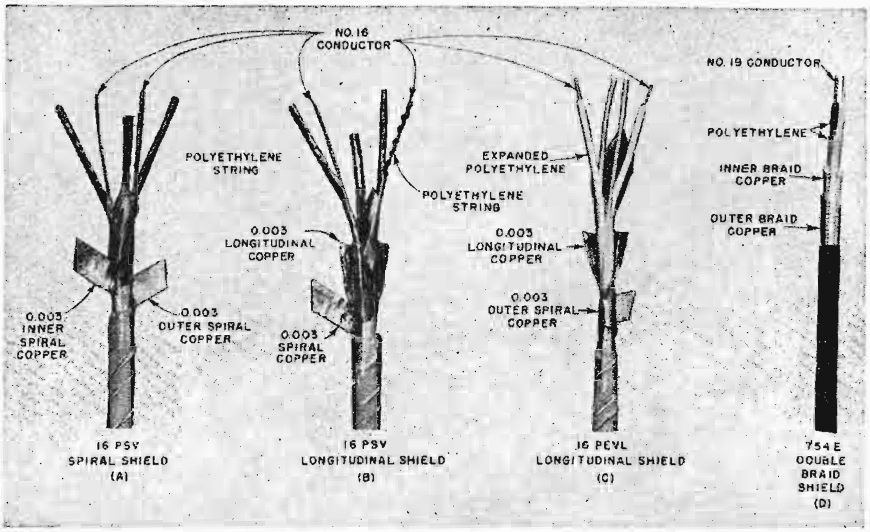

Fig. 3. Video-cable pairs and balanced office cable.

cables in the larger metropolitan areas, where the need is anticipated, a local network of channels is readily made available by adding the necessary amplifier equipment.

Because of the effective shielding in this type of video cable, there is no limitation on the direction of transmission or the number of pairs which may be operated in a single sheath, either with respect to interchannel interference or interference to or from the paper-insulated pairs in the cable. Freedom from such interference is important since impulse noise from relay contacts, switch-hook operation and other sources is high in local cables.

The transmission loss of the heavy-gauge copper pairs is not excessive at high video frequencies so that reasonable repeater spacings may be achieved. Normal repeater spacing may be as much as 3.5 miles but, with the use of network amplifiers, this may be extended to 4.5 miles. The actual transmission losses of video cable pairs are given in Table 2.

Variations in attenuation due to temperature changes in 16-gauge video cable are about 1/10

TABLE 2

Attenuation of Video Line Facilities

Type	Shielding	Loss per 1,000 ft., dB at 75°F		Loss per mile, dB at 75°F	
		0[a]	4.5 MHz	0[a]	4.5 MHz
Shielded video pairs:					
16 PSV-S	Spiral inner tape	0	3.65	0	19.3
16 PSV-L	Longitudinal inner tape	0	3.52	0	18.6
16 PEV-L	Longitudinal inner tape, expanded polyethylene	0	3.52	0	18.6
Office cabling:					
Paired:		at 70°F			
720	Single braid	0	10.0		
754A	Single braid	0	5.3		
754B	Single braid	0	5.3		
754D	Double braid	0	5.2		
754E	Double braid	0	5.2		
760A	Double braid	0	7.2		
KT51	Double braid	0	6.6		
KT52	Double braid	0	5.3		
Coaxial:					
KS-8086	Double braid	0	11.0		
724	Double braid	0	5.2		
728A	Double braid	0	5.2		

[a]It can be assumed that for the lengths of cable employed in A2A repeater sections the loss at essentially zero frequency is 0 dB.

of 1 percent per degree Fahrenheit, expressed in decibels. For all practical purposes it may be assumed that this change is a change of slope equal to one-tenth of 1 percent per degree Fahrenheit of the normal 4.5-MHz loss of the cable at 75°. Thus the primary effect of seasonal temperature variations is to change the effective length of the cable. This may be compensated by a change in the variable equalizers that are provided.

The characteristic impedance (Z_0) of 16 PSV and 16 PEV cable is almost a pure resistance of 124 ohms at the higher video frequencies. Below about 500 kHz the resistance component increases to a value of about 1,000 ohms at 60 Hertz and the reactive component, which is essentially zero at the higher frequencies, increases to about the same value as the resistance at 60 Hertz. The characteristic impedance approaches infinity as the frequency approaches zero. Certain of the characteristics of 16 PSV and 16 PEV pairs are given in Table 2.

In the design of equipment components which are associated with the video cable plant in the A2A system, particular attention was paid to matching the characteristic impedance in the range below 500 kHz. This results in a smooth overall frequency-response characteristic and decreases the need for field-designed supplementary mop-up equalization for systems of nominal length.

Inside Cabling

Several types of balanced and unbalanced office cable also have been designed for video circuits. The conductors are insulated with a solid polyethylene dielectric and shielded with a double copper braid. The outer covering can withstand pulling into cable ducts so that it may also be used in outside plant but here its use is limited to temporary service, as for pickups or for emergencies. The transmission characteristics of these cables, also given in Table 2, are sufficiently similar to video cable pairs that the same equalizers may be used in conjunction with them.

Cable Terminations

Interconnection between inside and outside wire facilities is made through special cable terminals which most frequently are located in the video equipment bays and are spliced directly to the lead-sheathed PSV or PEV facilities. If the video facilities which enter a building are in a completely video cable, the cable is extended directly to the terminals. If the video facilities are included in an exchange cable with paper pairs, they are separated at the building entrance and extended to the terminals in a separate lead-sheathed video cable. This avoids any exposure to low-frequency noise or impulse noise due to relays, pulse circuits, or switch-hook operation which might occur if the cables were routed through the office distributing frames.

A2A Equalization System

The basic equalization plan provides a highly flexible video-transmission system through the use of blocks of equalization which can be combined in the number and type required to equalize a given repeater section. Amplifier units are then provided to supply the necessary gain. The fixed equalizer units which are used in the A2A system, whose characteristics are shown in Fig. 4, provide for equalization in 2.5-dB steps at 4.5 MHz so that at any repeater point the equalization will not necessarily be flat. In general, the transmitting point will be preequalized, and at the receiving terminal the equalization will be adjusted by fixed equalizers to within ±1.25 dB.

Each block of the attenuation equalizers also provides the amount of phase equalization required for the length of cable involved. Therefore, as the channel is being attenuation-equalized, phase equalization is automatically provided.

In the A2A system the fixed equalizers are supplemented at the receiving terminals by three variable equalizers, each of which in turn consists of several independently controlled shapes. The characteristics of these equalizers are shown in Figs. 5 to 7. It is the function of these equalizers to provide the fine adjustments necessary to compensate for response variations which result from such factors as manufacturing variations in the cable, differences in characteristics between PEV and PSV cable, interaction effects due to impedance mismatch at cable terminations, and seasonal variations due to temperature changes.

Except in the case of very long channels, the provision of these adjustable equalizers largely eliminates the necessity for constructing mop-up equalizers in the field. They also simplify the adjustment of equalization which is necessary to compensate for the seasonal variation of the video cable characteristic.

A2A Amplifiers

Four basic types of amplifiers are provided for the A2A system. These are combined with the fixed equalizers in the arrangement that is required to provide the necessary gain in the channel. A further extension of the equalization range of a repeater point is provided by network input and network output amplifiers.

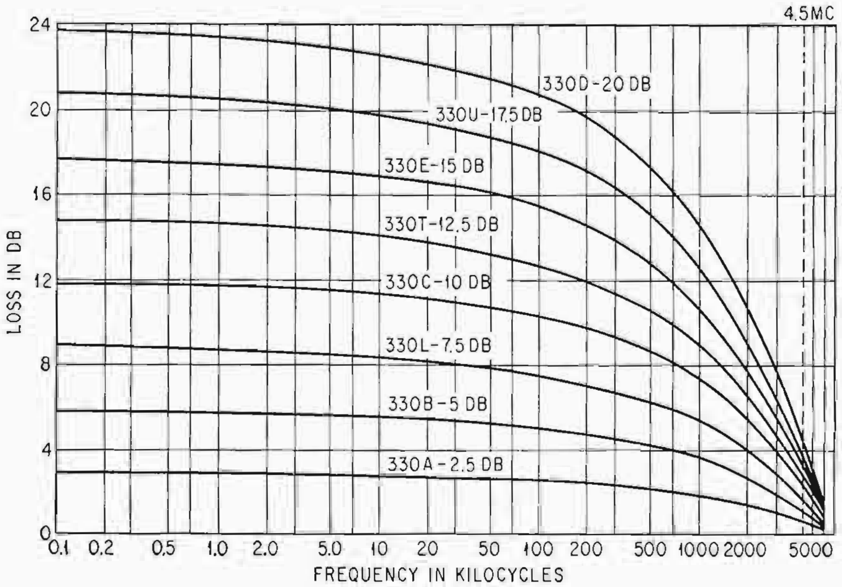

Fig. 4. Characteristics of 330 type fixed equalizers.

The output amplifier, used at transmitting terminals and at repeaters, is a two-stage balanced amplifier whose gain characteristic is flat over the frequency band extending from a few Hertz to 4.5 MHz. The input may be either 75 ohms unbalanced or 150 ohms balanced. The balanced 150-ohm input may be considered as 75-ohms to ground on either side and is provided so that the same unbalanced equalizer that is used in other parts of the system can be used. The output contains a (Z_0 — 124-ohm) network to match the output of the amplifier to 16-gauge video cable at low frequencies. An inductor is connected to provide a high impedance to interfering longitudinal voltages encountered on the cable pair. The amplifier is operated at a nominal gain of 11 dB, which can be adjusted by means of the gain control which is provided.

The input amplifier is used at repeater points and receiving terminals. It contains a Z_0 network in shunt with its input to provide the ter-

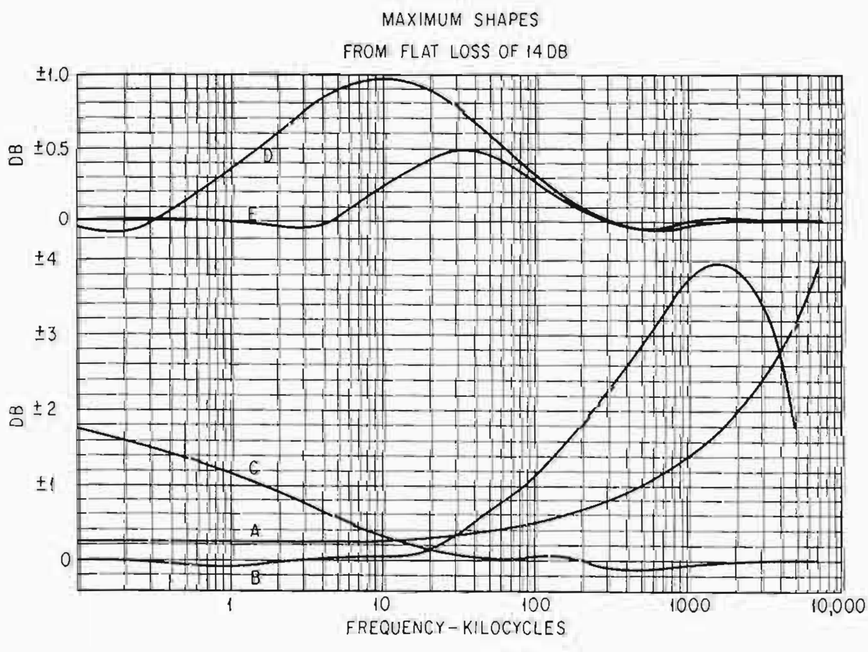

Fig. 5. Characteristics of 331 type variable equalizers.

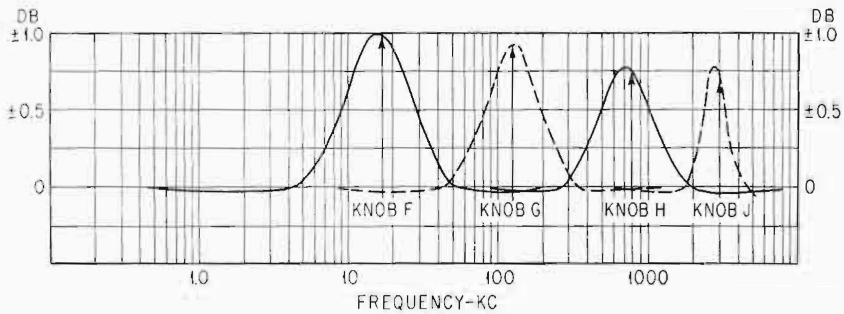

Fig. 6. Characteristics of 330M type variable equalizer.

mination for the 16-gauge cable pairs. It is a two-stage balanced amplifier which is flat to 4.5 MHz. The output is 75 ohms, and it is normally connected to the fixed cable equalizers through jacks and plugs. Suppression of longitudinal noise is accomplished in an electron-tube circuit which acts as a high resistance to longitudinal voltages. The amplifier is operated at a nominal gain of 10 dB and has a manual gain control.

The intermediate amplifier is used at repeater points or at receiving terminals to provide amplification among blocks of equalizers where the gain of the input and output amplifiers is inadequate. It is a balanced three-stage amplifier with 75-ohm input and output impedances that match the equalizers to which it is directly connected through jacks and plugs. The nominal gain of the amplifier is 24 dB, and a small range of manual gain control is provided.

Network input and network output amplifiers are provided when very long repeater sections are encountered. They are two-stage balanced amplifiers whose input and output impedances are designed to match the video cable pairs. They are further equipped with an input and output high-frequency voltage step-up network and an equalizing network. The step-up network results in about 15-dB extra gain at high video frequencies with respect to the low frequencies, and the equalizer adjusts this to have an inverse cable characteristic. The additional available high-frequency gain thus supplements the equalization provided by the fixed equalizers.

The Receiving Terminal Amplifier (RTA) provides the final block of gain in the system at the receiving terminal. The input is 75-ohms unbalanced, and the output is either 75 ohms, with a nominal flat gain of 20 dB, or 124-ohms balanced with a nominal gain of 23 dB. A 7-dB switchable attenuator and a continuously variable gain-control potentiometer permit gain adjustment over a range of 10 dB. This range permits precise gain adjustment of the overall facility.

A2A Clamper

The purpose of the clamper used at the receiving terminal is to attenuate low-frequency distortion and interference, that is, to reduce the low-frequency components which have been added or reduced in transmission. It is bridged on to the circuit at a point where the level ranges from −26 to −14 dBv at an impedance of 37.5 ohms. It operates by sampling the black-negative crests of the synchronizing pulses and detecting the envelope of the pulses to determine the low-frequency distortion. The detected envelope is amplified and returned to the line in phase opposition to the original signal, thereby reducing the signal distortion.

A2A Power Supply

The A2A power supply consists of two units: a regulator and alarm unit and a metallic rectifier. The regulator unit provides 115-volt regulated alternating current to the filament transformer primaries, which are located in the amplifier panels, and to the metallic rectifier, which can

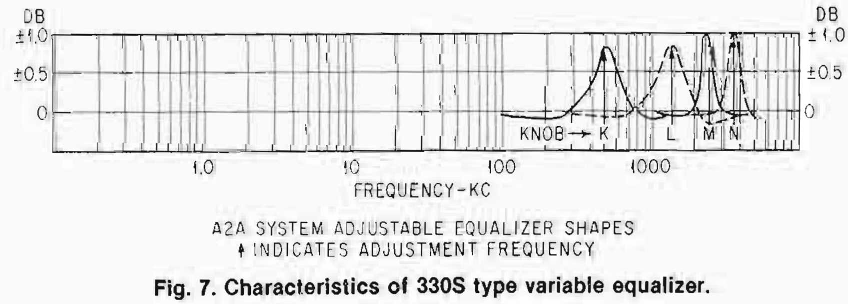

Fig. 7. Characteristics of 330S type variable equalizer.

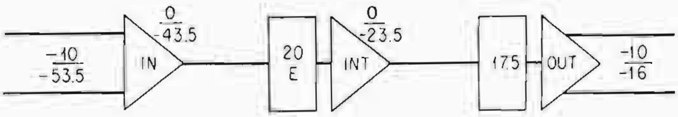

Fig. 8. Typical A2A intermediate repeater.

supply a load of 610 ma. at 200 volts. One regulator supplies four filament supply panels and two rectifiers and provides connections to an alarm circuit to signal power failures. One pair of units will handle a single channel with the largest amplifier load or more than one smaller channel terminal.

Typical A2A System Design

The general design objectives in laying out an A2A system are as follows:

1. Transmitting terminal equipment is required to provide a proper impedance match to the video cable pair. Normally an active terminal with an output amplifier is provided, but a passive terminal can be used.
2. The signal should be preequalized to the maximum amount which will result in a correct level at the input amplifier at the first repeater in order to obtain the best signal-to-noise performance.
3. The number of repeaters should be kept to a minimum for best differential gain and phase performance. Network amplifiers can be used, but if their use does not reduce the number of repeaters required, they should be avoided.
4. The receiving terminal should be made as small as possible.
5. Repeater locations should be in telephone company premises.
6. The low-frequency output level of any output amplifier should not exceed −10 dBv. This will keep the high-frequency, preequalized signals within the output power limit of the amplifiers.
7. The minimum high-frequency input level at any repeater with a nonnetwork input amplifier should be above −57.5 dBv, based on satisfactory random-noise magnitudes in the system.

Based on these general considerations, a typical circuit, as shown in Figs. 8 and 9, would be designed as follows:

It is required to provide a circuit between two points over a cable route consisting of 25,555 ft. of 16 PEV-L cable. The 4.5-MHz overall loss of this cable is 90 dB.

The use of network amplifiers at both terminals will not eliminate the need for an intermediate repeater, so a repeater will be used. It is found that a repeater can be located in an office located 75 dB from the transmitting terminal.

The length of this first section determines the transmitting-terminal and, to a large extent, the repeater design. For a section of this length, the preferred arrangement is to provide a network output amplifier at the transmitting terminal and a nonnetwork input amplifier at the repeater.

The network output amplifier provides 31.5 dBv of equalization. With a low-frequency level of −10 dBv at the output of the amplifier, the 4.5-MHz output level is then +21.5 dBv. The input level at the repeater input amplifier is then +21.5 − 75 = −53.5 dBv as shown in Fig. 8.

The length of the second repeater section is 15 dB. For a section of this length the preferred arrangement is to provide nonnetwork amplifiers at both terminals of the section. This establishes the 4.5-MHz maximum level at the output of the intermediate repeater at +5 dBv and determines the equalization required at the repeater. This is, of course, the sum of the slope at the input of the repeater and the slope at the output, or 43.5 + 15 = 58.5 dB.

Referring to the chart of equalizer losses, it is found that the combination of two 330D (20 dB) and one 330U (17.5 dB) come within 1 dB of the requirement. Two intermediate amplifiers would provide the necessary gain.

Looking ahead to the receiving terminal, however, it is found that this repeater arrangement would result in an unsatisfactory condition at the terminal. A more satisfactory design results if one of the 330D equalizers is assigned to the receiving terminal to provide additional range

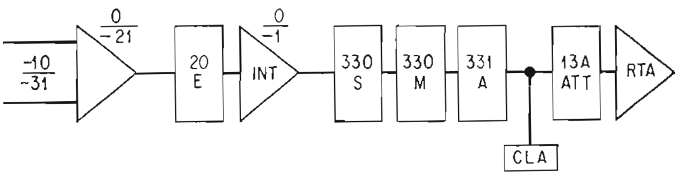

Fig. 9. Typical A2A receiving terminal.

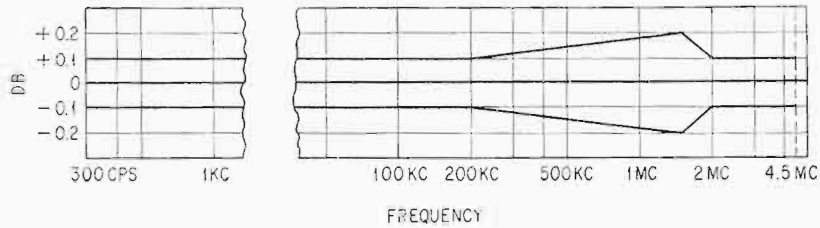

Fig. 10. Typical frequency-response objective, A2A system.

for compensating seasonal variations. When this is done, the 4.5-MHz output at the repeater output amplifier is not at its maximum, but this is satisfactory because the input level at the receiving terminal remains well above the minimum. The intermediate repeater thus contains an input amplifier, one 330D equalizer, an intermediate amplifier, one 330U equalizer, and an output amplifier.

The receiving terminal, as shown in Fig. 9, will therefore consist of an input amplifier, one 330D equalizer, an intermediate amplifier, the three variable equalizers, a receiving-terminal amplifier, a variable attenuator, and a clamper.

A2A Terminating Conditions

The transmitting-terminal input and the receiving-terminal output can both be arranged for either 75- or 124-ohm impedances. A terminal in a telephone company office is usually 124 ohms balanced. Connections to broadcaster's equipment are normally 75 ohms unbalanced. For either condition the A2A system is designed and aligned to receive a 1-volt peak-to-peak flat signal and to deliver a 1-volt flat, clamped signal.

In the design and alignment of the A2A system, equalization is provided and adjusted to compensate for all cabling to the actual point of interconnection with adjacent facilities. It frequently happens that the last (or first) A2A amplifier is some distance removed from the jack where the interconnection is actually made. The inside cable for this run is equalized within the A2A system. It is important that this cable length, at either terminal, be kept as short as practicable because a long run of unbalanced cable might be subject to excessive noise interference.

A2A Transmission Objectives

The A2A system has been designed to transmit either monochrome or NTSC color video signals without noticeable picture impairment. The transmission objectives are such that several channels can be included in an intercity network channel and provide transmission to meet present standards.

A typical frequency response objective for an overall A2A system is shown in Fig. 10. The region below 200 kHz is maintained to very close limits in order to avoid smearing and streaking. The region above 2 MHz is maintained to the same close limits to avoid impairment of color information in that region.

The differential gain objective in a properly adjusted A2A system is ±0.4 dB, and the maximum differential phase less than ±0.5°.

The low-frequency noise components, consisting principally of 60 Hz and harmonics, on an rms basis, should be at least 60 dB below the peak-to-peak signal voltages.

Low-frequency longitudinal noise voltages encountered on the cable pair will be suppressed at least 60 dB by features included in the system.

Impulse noise should be at least 17 dB below the peak-to-peak signal voltage.

Random weighted noise on an rms basis should be at least 65 dB below the peak-to-peak signal level.

Intercity Facilities—The TD-2 System

General

The transmission of video program material requires a channel capable of transmitting a frequency band extending from a few Hertz to 4.5 MHz. In their search for facilities capable of such wideband transmission, the Bell Telephone Laboratories early recognized the attractiveness of the wide-frequency spectrum in the SHF radio range. Work in this field resulted in the development of an intercity radio relay system which was first placed in service between New York and Boston in 1947. Experience with this system and further development work led to the TD-2 radio relay system which was first placed in service between New York and Chicago in 1950. This system now provides a network of channels which virtually covers the United States. All of the video network channel miles in service are derived from the TD-2 or a similar type radio system.

The TD-2 system operates in the frequency range of 3,700 to 4,200 MHz, which is one of

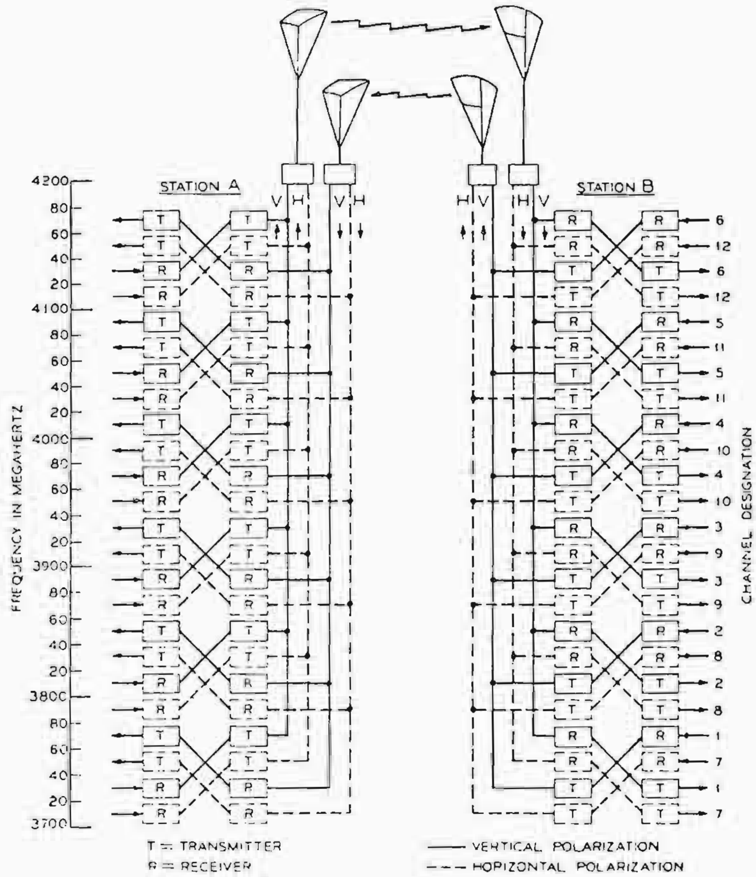

Fig. 11. TD-2 frequency-assignment plan.

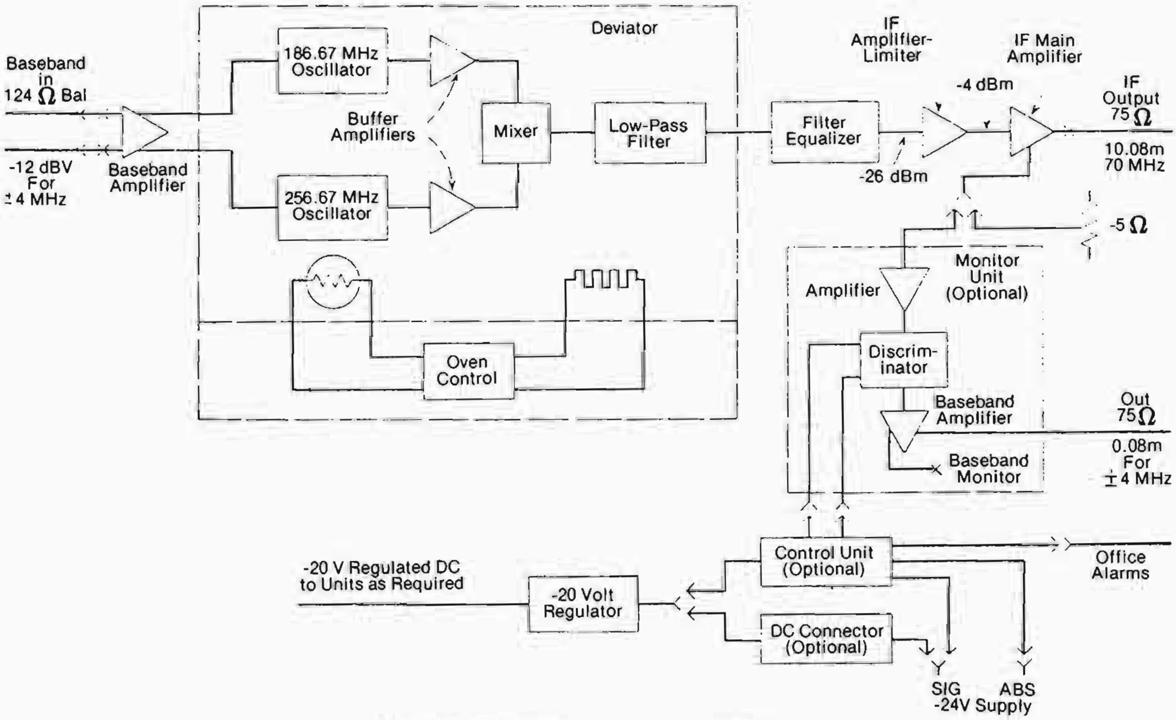

Fig. 12. Block schematic of FM transmitter.

the bands allocated by the Federal Communications Commission for common-carrier use. The overall band is divided into 24 channels each 20 MHz wide.

To provide for two-way service, 12 of the channels are arranged to transmit in one direction and 12 in the opposite direction. As shown in the diagram in Fig. 11, alternate frequencies, 40 MHz apart, are assigned to the two directions of a given channel. At each repeater point the received signal is shifted 40 MHz toward its oppositely directed mate before it is transmitted to the next repeater point. This is done to reduce interference between transmitters and receivers at the same repeater point and to help overcome overreach at adjacent stations.

Each channel on the TD-2 system is capable of transmitting either a video signal or, by the application of carrier techniques, 1,500 one-way telephone messages. Most of the routes now in existence, as is common with other telephone plants, are used jointly for video network service and telephone-message service.

FM Transmitter

The major components of the TD-2 system are:

1. Terminal transmitting and receiving equipment;
2. Intermediate repeaters;
3. Bridging arrangements; and
4. Protection.

Modulation in the TD-2 system is accomplished in two steps, the first of which occurs in the FM transmitter.

The FM transmitter is shown in block schematic form in Fig. 12. The television signal is pre-emphasized by a network which rolls off the low-frequency signal components by 13 dB with respect to the components above 2 MHz. This signal is presented to the 124-ohm input of the baseband amplifier at 0.2 volts peak-to-peak. Two outputs from this amplifier, in antiphase, drive two voltage controlled oscillators with frequencies centered at 186.67 and 256.67 MHz. From these frequencies, a 70 MHz difference frequency is generated in the mixer circuit. The low-pass filter rejects unwanted products and passes the desired 70 MHz frequency. The filter equalizer provides additional suppression to unwanted products, amplitude equalization for the low-pass filter, and delay equalization for the complete transmitter. The amplifier-limiter amplifies the FM signal and through its limiting action, removes any AM introduced in the signal. The main amplifier provides an output signal level of +10 dBm. As an option, part of the output signal can be connected to a monitor circuit to provide alarm indications when the transmitter output power or average frequency departs by a prescribed amount from nominal. This feature is not used when the transmitter is included within an automatic protection switching system.

The frequency of the transmitter is maintained within 100 kHz of nominal by regulating the temperature of the entire deviator and by special pre-aging of critical components. The use of this form of frequency stabilization as opposed to automatic frequency control places no limitation on the low-end frequency response of the transmitter.

FM Receiver

Fig. 13 shows the FM receiver in block schematic form. The 70 MHz FM signal from the

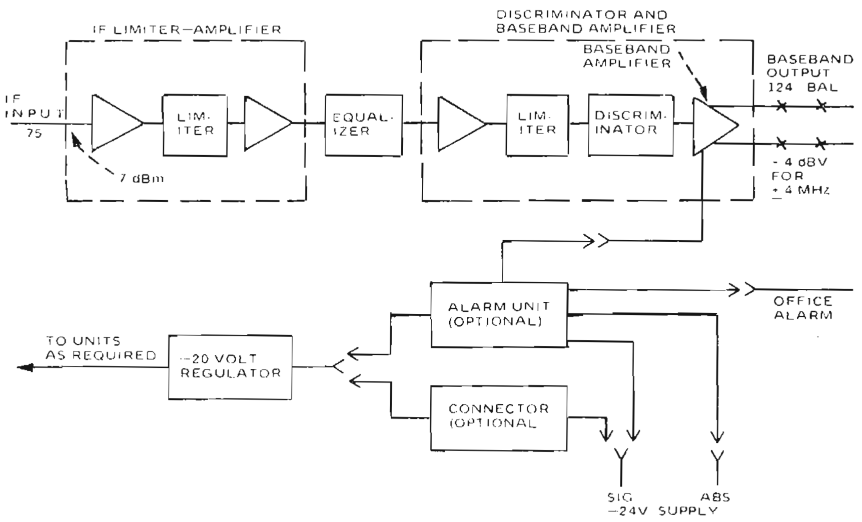

Fig. 13. Block schematic of FM receiver.

TD-2 receiver is presented to the 75-ohm input of the limiter amplifier at a power level of −7 dBm. The first limiter provides a major source of AM suppression with a low amplitude to phase conversion. Following the limiter are several stages of gain and an equalizer which corrects for delay distortion in the overall receiver. The second limiter extends the dynamic range of the receiver such that a 10 dB drop in the 70 MHz FM signal from nominal produces less than a 0.25 dB reduction in the baseband output. The output of the second limiter is applied to the discriminator where it is demodulated. The baseband amplifier provides an output level of +4 dBv from a balanced 124-ohm impedance. An optional alarm unit in the receiver provides an indication of a low or high 70 MHz FM signal level at the discriminator and an indication of changes in the dc conditions on the baseband amplifier transistors. A restorer network, complementary to the pre-emphasis network at the transmitter, restores the signal to a flat characteristic. The necessary gain and clamping are provided by an amplifier and clamper in the connecting circuit to the STOC or TFTP.

Antennas

In the 3,700- to 4,200-MHz range in which the TD-2 system is operated, line-of-sight transmission is required between adjacent stations. This means that repeaters are required periodically on a long route, the locations being governed by such factors as terrain, interference from or with other microwave systems, obstructions, and, of course, the transmission loss of the path. The distances between repeaters on the TD-2 systems vary considerably, but 30 miles is a nominal figure. At main route repeater stations a receiving and transmitting antenna are required for each direction of transmission. Light routes are sometimes built utilizing a single antenna for both transmitting and receiving. These antennas are mounted on buildings or on steel towers at the required heights. Two types of antennas were in use in the early TD-2 systems, the delay lens type and the horn-reflector type, but the delay-lens has largely been superseded.

The delay-lens antenna connects to the waveguide at one end and flares to an opening 10 ft. square in a length of 10 ft. The delay lens is constructed across the opening. It consists of a large number of horizontal aluminum strips sealed into blocks of solidified polystyrene foam. The active part of the lens structure is thickest in the middle and becomes thinner toward the outer edges. The effect of the metal strips is to slow down the waves, and since the lens is thickest in the middle, the waves are slowed down more in that position, with the result that all parts of the wave emerge at the same time. This forms a flat wavefront which travels as a beam along the axis of the antenna and is very accurately directed to the receiving antenna at the next repeater point. Because of the single polarization the lens structure provides, the delay-lens antenna is no longer used except where already installed on light routes. On higher density routes, the delay-lens antennas were replaced with the horn reflector in order to obtain both horizontal and vertical signal polarization and therefore increase channel capacity from 12 to 24.

The horn-reflector antenna opens from a circular waveguide into a vertical metal horn of square cross section. After passing this area, the wave is directed horizontally by a reflector which is an integral part of the antenna structure and whose surface is a portion of a paraboloid. The overall structure is about 20 ft. high and 10 ft. wide at the top. In the TD-2 range it provides the same mid-band gain of 39.5 dB as the delay-lens-type antenna, but since it has no frequency-sensitive elements, it will be applicable in the higher microwave region where new systems will be operated.

Repeaters

At a receiver, the incoming microwave signal from the adjacent station may contain any combination of one to six channel signals. This complex signal is received by the antenna and each polarization is carried by separate waveguide, usually from the base of the tower, to the transmitter-receiver box. Located in the waveguide at the top of each frame is a receiving-channel-separation filter shown schematically in Fig. 14.

The channel-separation filter combines a hybrid junction and a band-reflection filter in such a manner that at each bay the proper channel frequency is dropped, for amplification through that bay, while the remaining frequencies are passed through the waveguide to other dropping filters and amplifier bays.

From the channel-separation filter the signal is passed to the receiver converter, where it is modulated with a frequency generated locally by a microwave generator (main stations) or a microwave generator plus a 40-MHz shifter (auxiliary stations). The 70-MHz IF output is then fed to the IF preamplifier and the IF main amplifier, where the major signal amplification occurs. The IF main amplifier includes an automatic-gain-control circuit which is capable of compensating about 30 dB of fading.

Phase equalization is accomplished by the use of combinations of fixed units inserted in the

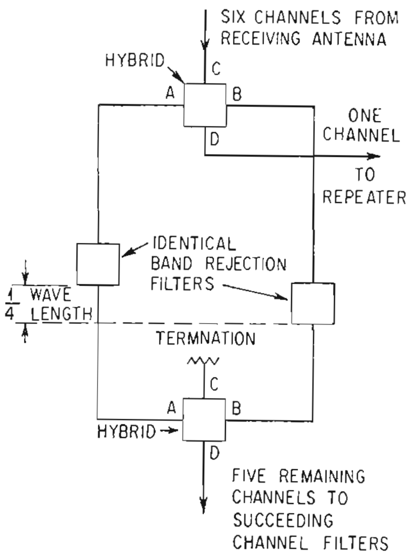

Fig. 14. TD-2 channel-separation filter.

IF circuit. Automatic protection switching, remotely controlled program switching, and bridging and patching arrangements are all provided at the output of the IF main amplifier. At a terminal the IF signal would next be applied to the FM receiver, and at a repeater it is applied to the transmitter equipment.

In the transmitter, the 70-MHz IF signal is introduced by means of coaxial cable to the transmitter modulator. In the modulator, the signal is combined with the local beating frequency to produce a signal of the frequency to be transmitted. After passing through a waveguide filter, the signal is applied to a three-stage microwave transmitter amplifier where it is brought to the desired transmitting level.

The transmitter amplifier consists of three 416C triodes mounted in cavity assemblies for 2 watts of output power. For 5 watts of output power, the final stage uses a 416D triode. The interstage tuners, input tuner, and output resonant filter are all mounted, with the triode cavities, in one rigid waveguide type of assembly which is bolted into the waveguide.

The amplified signal passes through the channel-combining filter where it is combined with a maximum of five other channels and carried by means of waveguide to the transmitting antenna. A directional coupler is introduced in the waveguide system to provide a means of power measurement and to energize alarms in the event of output failure.

Bridging Arrangements

The TD-2 system was designed as a backbone facility with 4,000-mile transmission capability. Video network service, however, requires network interconnections at all points where broadcast stations are located, and these may occur at less than 100-mile intervals. There are also numerous station locations which are not directly on a TD-2 main route, and these must be fed from branches or side legs. In order to maintain the integrity of the main backbone facility and still provide the maintenance and program-switching flexibility required for network operations, an extensive IF switching system has been developed and installed. It was pointed out previously that at each repeater station and terminal office, the microwave frequencies are converted to the 70-MHz IF. It is in this portion of the system that bridging is accomplished rather than at video frequencies, where additional stages of modulation would be encountered.

Where the broadcast station is at or near a city on the main line of a TD-2 route, normal procedure is to provide an IF bridging amplifier on each video channel on the route. The IF bridging amplifier provides two outputs from a single input. One output is for the through channel which passes only through passive elements of the amplifier. The input of a unity-gain amplifier is bridged across this circuit which provides compensation for the shunting effect of the bridging capacitance, and the second path is taken from the output of this amplifier. Each channel obtained by bridging is connected to a receiving FM terminal where the video baseband is derived. The baseband channels are then routed by office cable to the STOC or TFTP where switching or patching operations are performed.

Broadcast stations not located on the main route may be served by TD-2 side legs. The number of channels on a side leg and the amount of flexibility built into the switching arrangements vary greatly from point to point depending upon the service requirements. In general, however, a bridging amplifier is placed in each channel to which access is required. The branches may then be passed through other bridging amplifiers and a series of remotely controlled IF switches. These are coaxial-type switches specifically designed for the IF switching application. The control point for these switches is at a nearby STOC or TFTP where the proper combinations of switches can be operated to connect the desired channel to the desired leg.

Access to a channel at any point for transmitting to the network, either on a temporary basis, as for a remote pickup, or on a recurring basis, is obtained in the same general manner except that an FM transmitting terminal is provided.

Automatic Protection

Radio systems are subject to two types of interruption, equipment failure and radio fades. Equipment failures can be minimized by the use of conservatively designed systems composed of high-grade components and by continuous out-of-service routine maintenance. Radio fades are due to atmospheric and reflection conditions which affect microwave transmission. The repeaters in the TD-2 system are provided with automatic gain control, which can compensate for about 30 dB of fading. During certain periods of the year and particularly in certain sections, deeper fades occur. These are usually of short duration, but they occur frequently enough to prove troublesome on long systems. Manual patching is not effective, not only because of the short fade duration, but because most of these fades are selective, passing through the TD-2 band and affecting different channels successively. To provide protection against these failures an automatic protection switching system has been devised.

A full TD-2 system provides 12 channels in each direction of transmission. To provide the automatic-protection feature, one channel in each direction, normally Channel 1, is not used for service but is designated the protection channel. An overall system is further divided into switching sections. The number of repeater sections included in a switching section varies widely, being dependent upon the system layout as well as on a statistical analysis of the probabilities of failures. In each switching section the equipment arrangements are identical.

The circuits of the system can be divided into three main categories:

1. Switching circuits;
2. Evaluating circuits; and
3. Control circuits.

The purpose of the switching circuity is to transfer the signal from an impaired regular channel to the protection channel. IF switches are employed both at the transmitting and at the receiving end of each switching section. These are the same type of switches (223 type) that are used for program switching.

The evaluating circuits determine when and where a transfer is to be made and when the transfer back to normal should be made. The evaluating function is located at the receiving end of each section and is performed by the initiator.

The control circuits are the connecting links between the evaluating and switching circuits. They accept information from the evaluating circuits and cause the switching circuits to operate. The control circuits are preferably operated over carrier telephone facilities not routed over the TD-2 system to be protected as shown in Fig. 15.

The initiator associated with each channel, including the protection channel, is continuously monitoring the incoming frequency-modulated carrier and the channel noise. The protection channel normally carries an 8.5-MHz protection pilot when it is idle. The initiator will respond to a loss of carrier or an increase of noise, either condition signifying a trouble condition. When this occurs on any channel, the initiator associated with that channel sends a signal to the receiving switching-control circuit. This circuit enables the receiving IF switch but does not operate it. It also sends a discrete identification tone to the switching-control circuit of the transmitting terminal. This circuit then bridges the protection channel across the impaired channel. The signal then is being transmitted over both the regular and the protection channels.

If the signal arrives at the protection initiator in satisfactory condition, the initiator completes the IF switch and the feed is established from the protection channel. If transmission on the protection channel is impaired, or if the signal fed to the protection channel is impaired because of a failure in a preceding switching section, the protection initiator will not operate the switch. This ensures that a switch will take place only in a failed section.

Program-Transmission Facilities

When transmission on the impaired channel has returned or been returned to normal, the initiator so signals the control circuit and the switches are restored.

When transmission is impaired on two or more channels at the same time in the same section, the initiators for each channel will cause the receiving control circuit to apply tone toward the transmit end for each channel. No action will be taken at the transmit end at this time, as the transmitting control circuit is designed to ignore the request for a switch when more than one channel-identification tone is received. At the receive end, however, the control channel locks out all but the lowest numbered channel calling for a switch. When the lockout is completed, the tone of the lowest numbered channel only will be received and the transmitting control circuit will then operate the IF switch for that channel. If, owing to a trouble condition, the switch of the lowest numbered channel cannot be completed within 50 msec, that channel will be locked out for 10 sec. and the control circuit will attempt to complete a switch for the next lowest number channel. When a switch is completed, all other channels

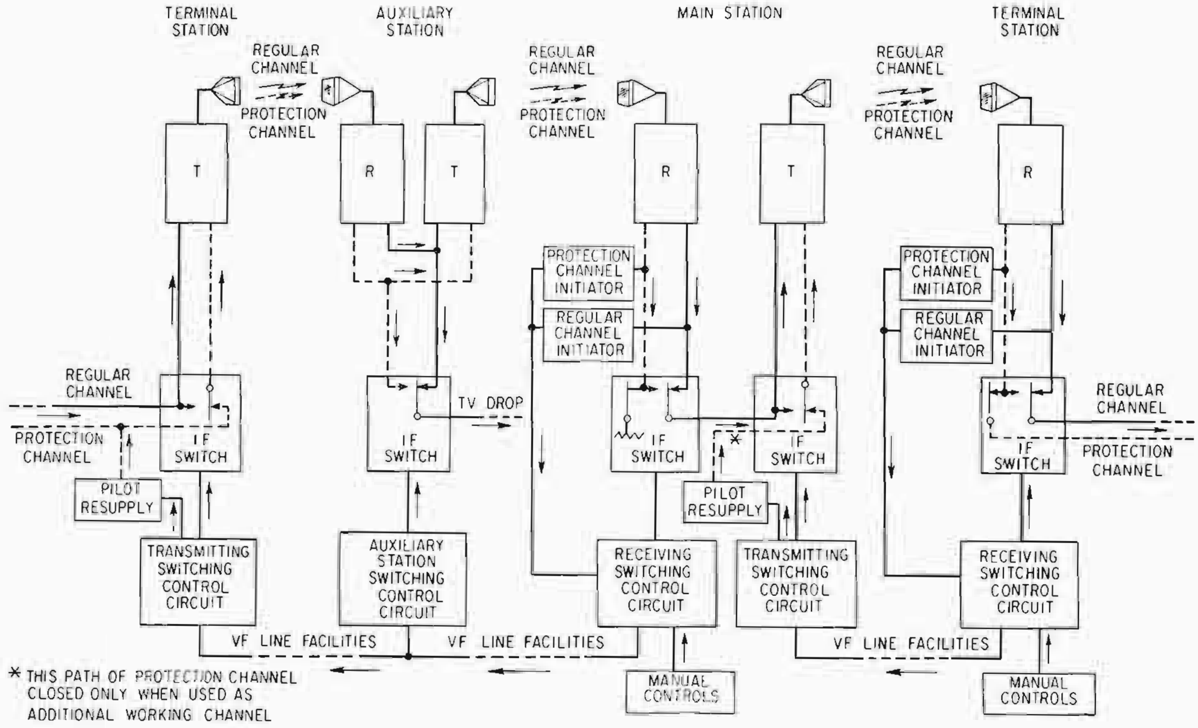

Fig. 15. Automatic protection switching for TD-2 systems.

will be locked out until the protection channel is available again, but if a switch cannot be completed for any channel, the receiving switching-control circuit will try again in 10 sec., starting with the lowest numbered channel.

In order to provide for switching at those stations intermediate in a switching section from which side legs are fed, auxiliary switching circuits are installed. These switches are enabled by a transmitting control circuit but are not actually operated until the IF switch in the backbone receive switching circuit operates. The side-leg feed is then switched to protection channel at the same instant that the backbone route switch is completed.

Serving Television Operating Centers and Facility Test Points

General Functions

Network service is considered by the Telephone Company as a specialized service with respect to both operations and maintenance. For this reason all work incident to network service is concentrated in a single location in any city. These locations, designated program operating centers and Serving Television Operating Centers (STOC) or Television Facility Test Points (TFTP) are normally in a telephone building where long-haul communications facilities which serve that city are terminated. All the intercity network facilities and all the local facilities which provide the interconnections between the broadcasters' locations and the networks are terminated in these centers.

Since audio and video networks are derived from different facilities and are operated independently from each other, the program and the television operating centers are normally separate units, although they frequently are located adjacent to each other and are under the supervision of a single office manager. The functions of program and serving television operating centers are broadly similar.

The functions of a television operating center are briefly as follows:

1. To supervise the establishment and line-up of the network layout ordered by each customer on the facilities prescribed by the Engineering Department;

2. To analyze customer service and operation orders and interpret them in terms of facility requirements and switching operations;

3. To execute the switching operations incident to customer requirements from period to period;

4. To receive trouble reports from broadcasters in their serving area and initiate appropriate action to clear trouble conditions;

5. To make or supervise those routine tests which are necessary to ensure continuously satisfactory performance; and

6. To exercise general supervision over service in the area for which they are responsible.

The functions of a television facility test point are essentially the same as those of a STOC except they do not receive trouble reports from broadcasters. They also provide video patching rather than video switching.

Control-Office Plan

The amount of work performed at the particular STOC or TFTP in any of the general categories listed is dependent upon the responsibilities delegated to that office under a control-office plan. Under this plan, New York operates as the general control office with responsibility for the overall network operations. Other offices located at strategic network points, such as Chicago, Atlanta, Los Angeles, and others, are designated as control or subcontrol offices with specific responsibilities for certain network sections. The office in or nearest to the city where a broadcaster takes network service is responsible for the service to that station. Some offices having no network operating responsibilities, as such, are responsible for the transmission performance of the systems routed through them. It is seen then that any control or subcontrol office, for example, Chicago, will have all responsibilities.

Layout and Service Orders

As was outlined in the general section, customers' orders for network service are converted in the Engineering Department to terms of specific facility and equipment requirements, and orders are issued to all offices involved. The scheduling of the necessary facility changes and the testing and line-up of the new channels are coordinated by the control offices concerned.

Similarly, service orders and operation orders are transmitted to all control offices involved by the New York Facility Management Control (FMC). The FMC makes all video facility assignments. It is the responsibility of the control office to transmit this information to each office in his section. Each office, in turn, correlates the service orders he has received with the assignments and prepares his own detailed schedule.

Troubles and Maintenance

Trouble reports can be originated at any broadcaster's location and referred to his STOC where the trouble-locating procedures are coordinated. The normal procedure is to establish a patch or reroute as quickly as possible and then to clear the trouble on the regular facilities. Maintenance responsibility, like the regular service responsibility, is delegated through a control-office plan to an office which is made directly responsible for the maintenance of the failed facility.

Routine tests are regularly scheduled on all components and on overall channels to ensure reliable service. The intervals during which facilities may be released for testing are scheduled by the control offices. Each office then makes local and sectional tests to coordinate with the overall line-ups which normally follow the local tests.

Office-Equipment Arrangements

From the foregoing it is apparent that, aside from the clerical work of the operating center, the layout must be designed to permit two basic functions: switching or patching and testing. Also, since the load varies among all offices, operating centers are not standardized but vary in size and equipment. Basically, however, a STOC or TFTP provides a point where all the channels in the intercity networks and all the local channels which may be interconnected with the networks are brought to a common voltage and state of equalization. The inside cables by which the channels are extended from the carrier terminal room, the radio terminal room, or the local facility terminals are all equalized and, in the case of radio facilities, also include one or more knob-controlled variable equalizers. At the STOC, therefore, all channels look alike at the switching point and hence can be interconnected by video switches or in the case of the TFTP, may be interconnected by patching.

In an office where only one station is fed, the incoming channel is connected directly to a 1 by 3 splitting amplifier. The amplifier is a solid state device with an input and output impedance of either 75 or 124 ohms. One output is used to feed the station and one to feed the office video monitors. The third output could be used to feed another station channel or a second splitting amplifier if more than three outputs are required.

Low-Impedance Switching System

In the serving television operating centers the switching is accomplished by a low-impedance switching system. The more important features of this system are:

1. Switching is done on a 124-ohm balanced basis;

2. The control panel actuates only dc control leads. The actual switching is done by wire spring relays in the equipment bay;

3. The basic building block is a 10 by 12 unit which can be used in various combinations up to 30 by 36;

4. All unused inputs and outputs on the switch are terminated so that the load on any input circuit is constant;

5. Switch operations can be preselected, checked, and then operated when required;

6. Individual switches can be operated, or groups of switches can be transferred to one of four "salvo" controls. Operation of a salvo causes rapid sequential operation of each switch transferred to that group;

7. The condition of any switch is indicated at all times by signal lamps on the control panel;

8. The control panel can be adapted to remote-control systems to control video, audio, or IF switches; and

9. The cabling and circuitry of the switch are capable of flat transmission through 10 MHz but the amplifiers presently installed are limited to 4.5 MHz. New, solid state amplifiers are being installed which have 10 MHz capability.

Switching Plan

The principle of the switching system is illustrated in Fig. 16, which shows the plan of a 10 by 12 unit.

Each incoming line is connected to a 1 by 12 resistance splitting pad. The through loss of this pad is about 27 dB, and the loss between any two outputs is 54 dB, which is sufficient to prevent interaction between output circuits. Fig. 17 shows the physical structure of the splitting pad. One incoming line is reserved for a test trunk whose function is described later.

Each output branch of each splitting pad is cabled to the 10 by 12 switching unit as shown in Fig. 16. This unit consists of 12 blocks of 10 wire-spring relays which perform the actual video switching. Each of the 10 relays in a block connects to the same output channel, and the 12 blocks care for the 12 outputs. One relay in each block connects with one branch of each input splitting pad, so that every output circuit has access to any input circuit.

When it is desired to expand the switch capacity, a 1 by 3 splitting amplifier is connected to the input of each splitting pad so that each incoming line now can be connected to a maximum of 36 outputs. On the output side of the switch a 3 by 1 relay is added to permit the selection of one of a group of three 10 by 12 units and thereby to increase the input capacity to 30 lines. This is the present design maximum. The cabling arrangement is shown in Fig. 18.

Switching Equipment

The wiring and cabling for each switching system are laid out and installed to meet the anticipated ultimate requirement for an office but are not necessarily fully equipped initially. Careful control is exercised to ensure that all cables between common points in all switching paths are cut to uniform lengths and within definite limitations. By this means uniform transmission is assured between any switch input and any switch output. It is also the reason for installing cabling initially to meet the ultimate requirement.

The transmission losses in the switch are compensated by an amplifier in each output circuit. This amplifier is identical with the receiving terminal amplifier used in the A2A system and is therefore designated an RTA. The 1 by 3 splitting amplifier does not provide gain with respect to the overall switch but provides zero loss between the amplifier input and each of the three outputs. All switch components are designed for 124-ohm balanced interconnection.

Transmission loss through the switch from the input-video patch-bay jack to the output-video patch-bay jack is not flat but is designed to have a cable shape roll-off characteristic which can be compensated by variable cable equalizers associated with the channels connected to the switch. Channels connected to the switch are equalized flat only to a point X internal to the switch at the 10 by 12 switching units where the channels are actually switched. Access to point X is obtained only through input and output test trunks. Interconnections of facilities at points other than point X will not be properly equalized unless special steps are taken.

Test and Monitor Trunks

Depending upon the size of the switch, one or two inputs and outputs are designated as test trunks. Each of the test trunks can be equalized to be perfectly flat from point X to its termination in a "test" bay. Input and output switch-control leads are also extended to the test bay so that the input test trunks can be remotely switched to any outgoing channel or any incoming channel can be switched to an output test trunk. Since the switched connection is made at point X and the test trunks are maintained at zero flat loss, all testing equipment is effectively connected to point X.

From each 10 by 12 switching unit two output trunks are connected directly to monitor and control positions. These trunks are also carefully adjusted to zero flat loss from point X to their termination. Switch-control leads are extended to the monitor positions so that the video

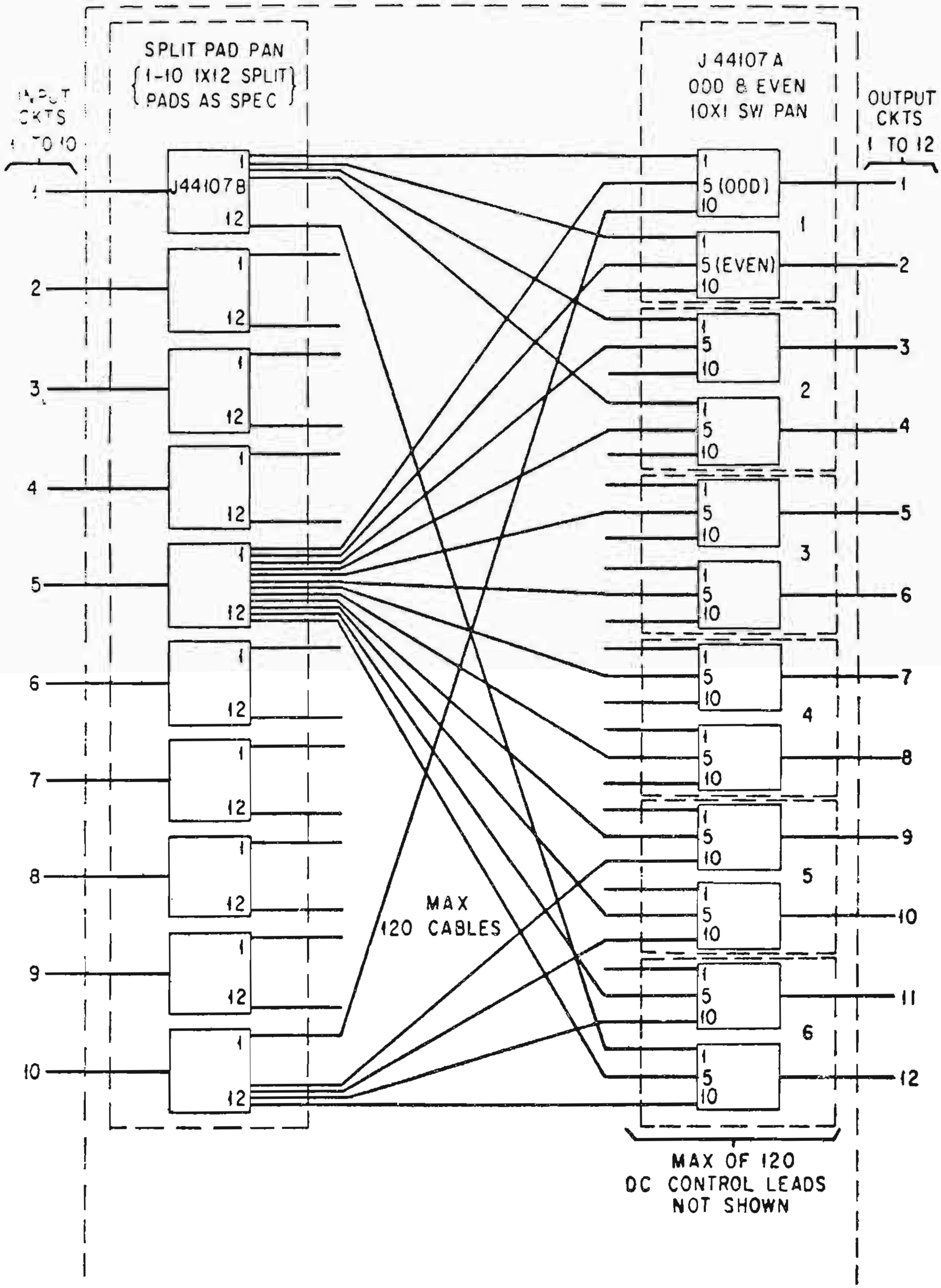

Fig. 16. Basic 10 by 12 switch unit.

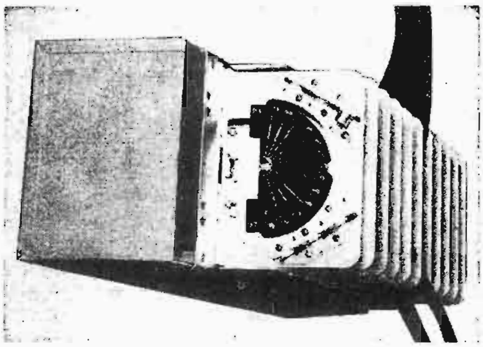

Fig. 17. Mounting arrangement for 1 by 12 splitting pads.

monitors can be connected to monitor any incoming channel. Voice communication circuits which parallel the routes of the channels controlled by a particular office and direct talking circuits to local broadcasters' locations and to other terminal rooms in the building are also terminated in the monitor positions. An attendant, therefore, has immediate access, through automatic signaling, to all points in his control section for directing trouble-locating activity, arranging temporary reroutes, and all other functions incident to video-network operation.

Testing functions are concentrated at the test position(s) where access to all channels is provided by the test trunks previously mentioned, and communication is provided by multiples on the monitor position circuits. All the test equip-

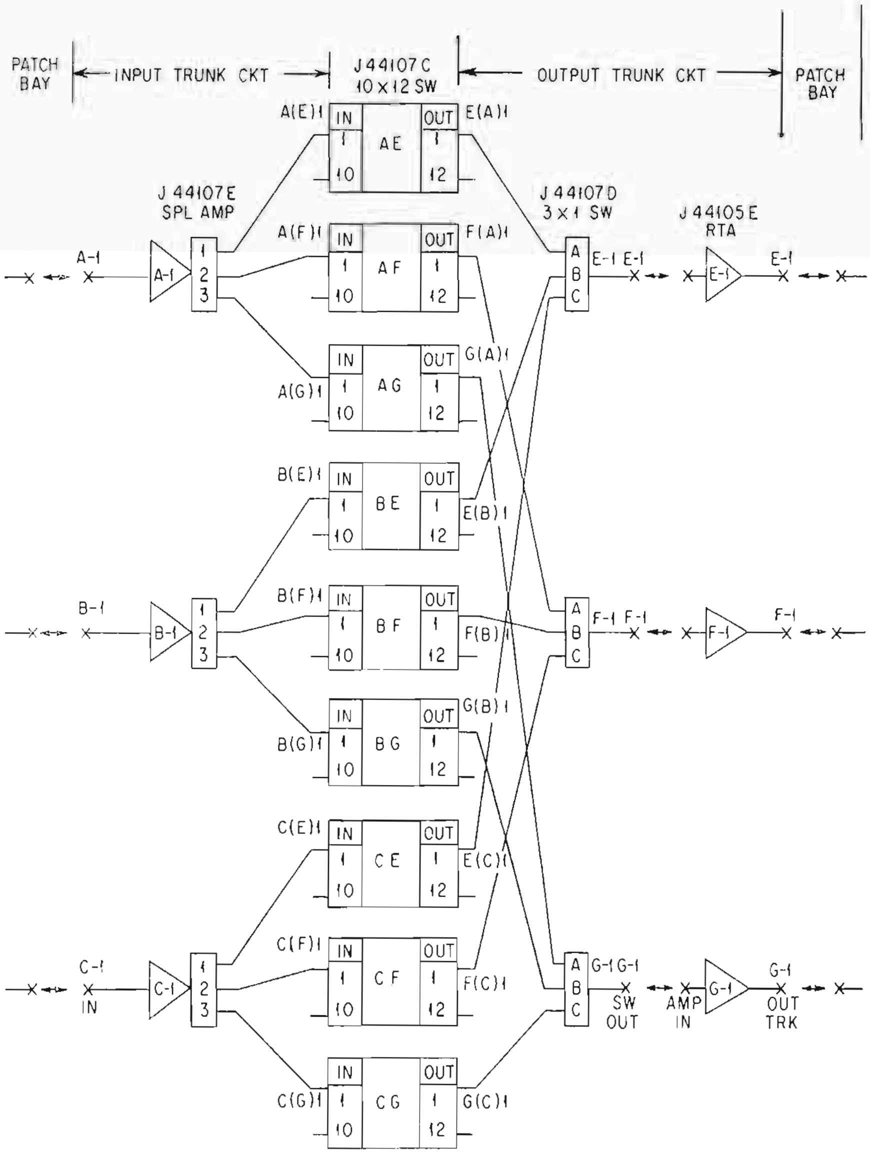

Fig. 18. Cabling plan of a 30 by 36 video switch.

ment is mounted in these positions, and any unit can be connected to the test trunks in a small patching jack field where the units are terminated through cables carefully cut to uniform length.

Switch Control

Switching is controlled from the control panel where dc control leads are terminated in a coordinate pattern. All incoming lines are arranged on the horizontal and all outgoing lines on the vertical rows. Signal lights are provided at each intersection.

Preselection is accomplished by simultaneously operating the buttons opposite the horizontal and vertical which represent the channels to be connected. This brings up a white signal light at the intersection. This preselected switch can, if desired, be transferred to a given salvo row, on a horizontal along with other preselected switches which must be made simultaneously. Four salvo rows can be provided, and any number of preselected switches up to the capacity of the switch can be transferred to any one of the salvo rows. Upon completion of preselection the entire board can be checked against the switching schedule by a second attendant by observing the condition of the signal lamps. Errors can be corrected by operation of an ANNUL button. Actual operation of the switches is completed on cue by simultaneous operation of a MASTER EXECUTE button and the appropriate individual vertical or salvo button. As mentioned previously, the control panel can be arranged to control remote video or IF switches as well as local video switches, and they can be assigned to the same salvo for simultaneous operation. Completion of the switch is indicated by a red signal lamp at the intersection which represents the connected channels.

The master control panel supersedes the switch controls at the test bay in that the test-bay switch controls will not function unless the switches at the master control have been operated to the NO SERVICED position. This makes it impossible for anyone at the test position inadvertently to open a channel which is in service.

Objectives of Video-Network Transmission

General

It was pointed out in the general section that the video network provided for any broadcaster is not necessarily a permanent combination of facilities but rather is a variable combination of television sections (TVSs), probably combining several types of video facilities and provided from day to day as required. Network Transmission Committee Report No. 7 provides network objectives agreed to by all parties of the committee. The objectives either equal or exceed the CCIR recommendations for television facilities. The individual TVSs are lined up and adjusted within tolerances such that all normal combinations, including local interconnecting channels, will provide a satisfactory grade of transmission over all. When certain combinations of facilities, through daily use, become identified with one broadcaster and the pattern of operation is relatively fixed, overall tests are made periodically to check overall network transmission and particularly to verify that the deviations in individual TVSs are not adding cumulatively in the same direction to result in an unfavorable overall characteristic.

Video-network facilities are suitable for the transmission either of a monochrome signal or an NTSC color signal.

For color transmission the frequency response in the region of the 3.58-MHz color carrier must be closely controlled and differential phase and gain must be kept within definite tolerances. A channel which has been lined up for color transmission will, of course, satisfactorily transmit a monochrome signal, since the measures taken to provide color transmission also enhance monochrome transmission.

Levels

All telephone company video-transmission systems are designed to operate with a 1-v peak-to-peak signal at those input and output terminals which are located either at customer locations or at STOCs or TFTPs. Different levels may apply at junctions of different types of facilities at points other than STOCs or TFTPs but they are established with respect to the STOC or TFTP reference level.

Transmission level measurements of single-frequency sine-wave signals are made with the thermocouple-type instruments which are calibrated in decibels. Here, the 1-volt peak-to-peak signal is considered as the reference of 0 dBv and the decibel reading of the meters are based on the fundamental relationship

$$\text{dB} = 20 \log \frac{V_2}{V_1}$$

where V_2 is the measured voltage and V_1 is the 1-v reference voltage.

Single-frequency level measurements and adjustments are made only on an out-of-service basis. Adjustments are provided on all channels, either in the facilities or in the STOC or TFTP terminating circuits, so that they can be adjusted within ±0.5 dB of the required level.

In-service checks of levels are made with oscilloscopes equipped with IRE scales and with vertical amplifiers having a standard IRE roll-off characteristic. In this instance the 1-v peak-to-peak reference corresponds to 140 divisions on the IRE scale. When level variations occur during service, temporary adjustments can be made based on the scope reading. On all scopes used in the STOCs or TFTPs, the amplifier characteristic is switch-selected. It is important that all scopes used to determine where the level has varied and, hence, where the temporary adjustment should be made, are adjusted to the IRE characteristic because use of a wideband scope characteristic could lead to errors. Whenever a temporary in-service adjustment is made to compensate for a variation in network facilities, it is followed up by single-frequency transmission measurements during the next out-of-service period in order to sectionalize and correct the cause.

Frequency Response

The low-frequency-response characteristics, up to about 250 kHz, of all video channels are maintained to very close tolerances in order to avoid streaking and smearing. The characteristics are measured by the use of single-frequency sine waves and power meters. Waveform transmission in the low-frequency range is checked by observing the transmission of a "window signal," which is a critical indicator of low-frequency transmission impairment.

Since color transmission requires closely controlled frequency response in the region of the 3.58 MHz color carrier, video facilities in general are equipped with special equalizers which operate in the range of the color carrier and its sidebands. These equalizers are used to adjust the high-frequency characteristics to close tolerances. Typical objectives for video network channels on TD-2 facilities for single-frequency sine waves measured with power meters are shown in Fig. 19. It will be noted that the objective is to maintain a slight roll-off in order to minimize any tendency of the channel to ring.

Rapid checks of overall channel characteristics are made using the multiburst signal. In addition to giving an indication of the frequency response of the channel at the burst frequencies, this signal also indicates sync compression or other distortions of the synchronizing pulses, video compression, harmonic distortion, and axis shift. Any of these impairments in the transmission of a composite waveform can be related to normal transmission parameters of the facility and can be sectionalized and cleared.

The tendency of a channel to ring, that is, to set up damped oscillations following rapid signal transitions of relatively large magnitude, can be checked by transmitting a sine-squared pulse and observing the magnitude of any oscillations.

Differential Phase and Gain

Differential phase and differential gain, as defined in the IRE Standards, are not significant

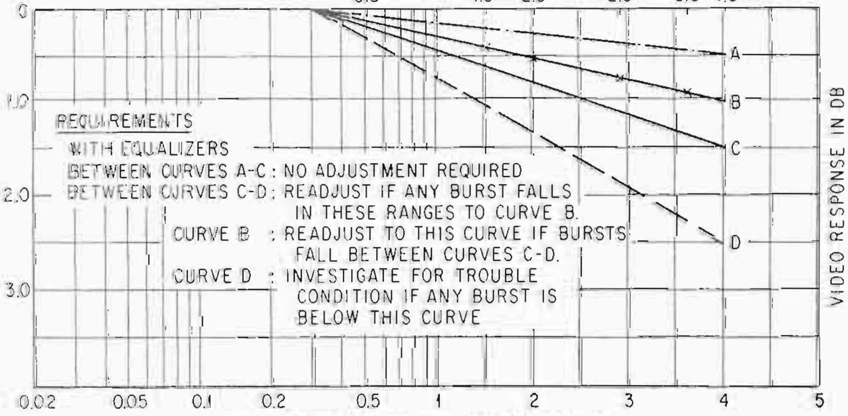

Fig. 19. Typical frequency-response objectives for TD-2 channels.

in monochrome transmission but require close control on channels for NTSC color transmission because of their effect on the hue and saturation of the color signal. All the facilities designed for video transmission, with the exception of the TD-2, exhibit satisfactory differential phase and gain performance without supplementary adjustment when all components are operating normally. Any deviation from the normal differential phase and gain performance on these systems can therefore be traced to some system irregularity, and no supplementary adjustments are necessary.

In the TD-2 system the video signal is converted to a frequency-modulated intermediate-frequency signal centered on 70 MHz. The negative and positive voltage peaks of the video signal thereby are shifted to positions at about 74 and 66 MHz in the IF band. The portions of the signal intermediate between maximum and minimum occupy positions between 74 and 66 MHz in proportion to the amount the rest frequency is shifted in response to the input voltage change. In the IF portion of the TD-2 system therefore, the relative phase shift of the carrier for different levels of the video signal is directly dependent upon the delay-frequency characteristic of the IF path. If the delay in this path can be made uniform, then video differential phase will be zero.

A series of IF delay equalizers has been developed, and all TD-2 channels are delay-equalized periodically on a switching section basis. The equalizers are placed in the main-line IF paths.

For color transmission the differential phase of a 3.58-MHz signal is of particular interest. The overall delay equalization of the radio facilities is therefore supplemented by routine STOC or TFTP to STOC or TFTP measurements of the differential phase and gain at 3.58 MHz. When required, additional equalizers are placed in the IF side leg or dropping leg at each service point to reduce the differential phase to a minimum.

As in the case of other facilities, differential gain is not a problem when all system components are operating normally.

AUDIO-NETWORK FACILITIES

Local Audio Channels

Facilities

Local audio channels include those provided between remote studios and master control, between studio and transmitter, and between master control and the point of interconnection with the intercity networks. These channels normally are concentrated in metropolitan areas and, generally, are relatively short. The wire facilities for these channels, therefore, are usually pairs in exchange area cables.

Whenever the length of the local channel is such that an intermediate amplifier is not required, nonloaded cable facilities are used in preference to loaded cable facilities because they can be equalized by relatively simple means.

If the length of the local channel is such that nonloaded facilities cannot be used without intermediate amplification because of noise or cross-talk considerations, loaded facilities of suitable bandwidth can be used in preference to providing an intermediate amplifier. However, when an intermediate amplifier is necessary, either loaded or nonloaded cable can be used as the wire facility.

Equalization

Equalization is the process by which the loss of a transmission channel is adjusted to be approximately equal at all frequencies in the required transmission band. In the audio range this normally involves introducing low-frequency-loss components which complement the high-frequency loss of the cable facilities. Two methods are widely used to accomplish this on nonloaded local channels. One is to bridge across the receiving terminal of the channel an attenuation equalizer which is adjustable to meet the requirements of different lengths of facilities. The second is to apply 4-to-1 impedance-ratio transformers at the two terminals of the channel with the low-impedance side facing the cable. The transformers introduce mismatch losses at the low frequencies and can, thereby, equalize short lengths of cable depending upon the bandwidth desired and the gauge of the conductors. Transformers can be used alone for equalization, but when an adjustable equalizer is applied it is almost always used in conjunction with a transformer. Transformers alone can be used to provide transmission uniform to within about 1.0 dB from 35 to 8,000 Hz for the cable lengths and gauges shown in Table 3:

TABLE 3

Lengths of Nonloaded Cable Which Can Be Equalized by the Use of 4-to-1 Coils

Gauge	Length, miles
16	5.0
19	2.3
22	1.5

Beyond these lengths an equalizer is required, either by itself or in conjunction with the 4-to-1 transformers. For those circuits involving the transmission of frequencies from 30 to 15,000 Hz, the equalizer and transformers are generally used together to provide a circuit whose transmission frequency response is uniform within about 1 dB of the response at 1,000 Hz.

When facilities are specially constructed for long-term service, loading can be applied in the same pattern as is used on long-distance cables. For these facilities, Type 17 equalizers, which are described later, can be used to secure the required transmission characteristic.

When equalized local channels are furnished and no special requirements are imposed as to the arrangements to be provided, equalizers and 4-to-1 impedance-ratio transformers are likely to be installed in combination. The same transmission characteristics on an overall channel can be obtained when a 1-to-1 impedance-ratio transformer is used, by proper adjustment and choice of the equalizer, except in the cases of channels of irregular make-up or of lengths approaching the limits which can be equalized as one section. Other considerations, such as are involved in the use of volume indicators, may determine the more satisfactory arrangement.

Equalization is always applied at the receiving terminal of a channel in order to minimize the possibility of excessive noise and cross talk being experienced as a result of low signal levels. In those cases where a channel may be used for either transmitting or receiving, duplicate equipment is provided at each terminal which can be connected or disconnected readily to provide equalization at the receiving terminal in either case.

Transmission Objectives

Channels for local service are provided to transmit the band of frequencies specified by the customer in his order. Within this band all frequencies are to be transmitted with uniform loss within about 1 dB.

The overall noise on 5-kHz local channels will not exceed 36 dB above reference noise (program weighting) measured at the receiving end of the circuit with a 3A noise-measuring set and with the input terminated in 600 ohms, and no intelligible cross talk (words or syllables) will be audible. This will be equivalent to a signal-to-noise ratio of 62 dB at the +8 VU transmission level points and will be adequate on all channels on which the equalized net loss does not exceed 12 dB.

Signal levels in excess of +8 VU should not be transmitted over local channels in order to avoid the possibility of cross talk into other communications channels. Signal levels should be carefully checked and maintained by the proper use of standard volume indicators.

Volume Measurements

It has been pointed out that audio program networks are frequently rearranged by switching operations and that the point of program origin is not always the same. Networks are not necessarily lined up as overall entities but are lined up as sections in a manner such that normal switching operations and reroutes due to trouble conditions can be rapidly effected without transmission adjustments. In the overall network, different levels may exist at different points at any one time, depending upon the types of equipment and facilities assigned and their operating requirements, but the overall system is so adjusted that these levels will be correct when the input level is correct. It is obvious that an incorrect level at the input to a system which has been properly lined up will result in incorrect levels throughout the system. It is also apparent that an adjustment made in one part of a system to compensate for a variation in another part of the system can seriously interfere with the entire coordinated operation.

Excessively low volume levels at any point will result in objectionable noise being heard on the overall system, and excessively high levels will result in undesirable distortion, particularly that which results from amplifier overloading. To ensure that neither of these conditions occurs it is essential, therefore, not only that all channels be correctly aligned in transmission tests but also that the volume level of the program material at the source be correctly maintained. The transmission line-up of network facilities is a telephone company responsibility, and the responsibility for maintaining correct levels at the program source rests with the broadcasters.

The local channel is the meeting point between the telephone company and the broadcasters, and it is at this point that the principal need for uniformity of thought and practice exists. For this reason the following discussion of volume measurements, although it applies to overall network operation as well, is included in this section on local channels.

Transmission line-ups of program units are based on the use of a single-frequency signal at 0 dBm level at the +8 VU input point to the unit, and the levels at all points are adjusted with respect to this fixed level. It is the nature of program materials, however, to vary considerably in volume, the range of variation and the maximum volumes being dependent upon the type of program. The operating conditions on a network, therefore, are vastly different from the line-up, so it becomes necessary to correlate the volume of program material with the level of transmission measurements. The standard volume indicator, having the characteristics prescribed in "American Recommended Practice for Volume Measurement of Electrical Speech and Program Waves," ASASPC 16.5, 1942, is accepted as the industry standard for this purpose, and it is used for the measurement and comparison of program volumes at all significant network points. The correct use and interpretation of the readings of these instruments are therefore of primary importance in proper network operation.

To maintain volumes which are satisfactory within the tolerances of network facilities, the technique of controlling volume at originating points consists of keeping the average maximum volume as close as possible to +8 VU without having to reduce too many volume peaks with a consequent loss of volume range. If this average maximum volume is maintained at the zero-transmission-level point at the input to the local channel, then correct levels will obtain throughout the network. It also follows that the same volume should be read at all other network points which have been lined up to zero level on single-frequency line-ups. The readings at any other points can be corrected to an equivalent zero reading. Then by simultaneous readings at various points it is possible to verify that all network sections are operating properly or to determine in which section or sections deviations exist.

Information concerning the circuitry and calibration of the volume indicator is available in other literature. The following information relates specifically to certain conditions which may be encountered in network operation where the proper interpretation of volume indicator readings is dependent upon the manner of connecting the instrument to the circuit.

Methods of Connecting Volume Indicators

In the methods of use of volume indicators illustrated in this section the use of amplifiers with 600-ohm input and output impedances is assumed and the gain of the amplifier is the gain measured with a 600-ohm measuring set.

Fig. 20 shows two variations of a method of use of the volume indicator in which it is connected permanently across the circuit or loop on which the volume is to be measured.

In the arrangement shown in Fig. 20*a*, the indication of the volume indicator plus the gain of amplifier 2 minus the loss of the pad is considered the volume at point *L*.

In the arrangement shown in Fig. 20*b*, the volume indicator reading minus the loss of the pad is considered the volume at point *L*.

Note: In some cases the impedance of the loop or circuit may differ from 600 ohms by such an amount as to require a correction to the actual Volume-Indicator reading. This correction can be determined as given under the Correction of Volume-Indicator readings.

The arrangement shown in Fig. 21 is used by the Telephone Company at many network branching points where it is necessary to feed

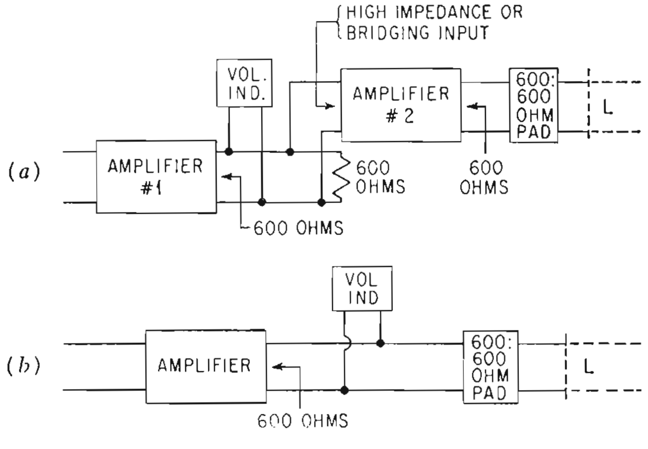

Fig. 20. Volume indicator permanently connected across loops.

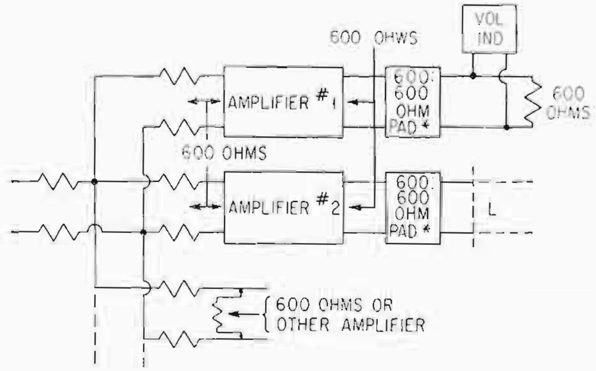

Fig. 21. Volume indicator connected across a bridge output.

a number of circuits simultaneously. The resistance bridge has constant loss and impedance for all branches. Amplifier gains either are identical or differ by calculated amounts, depending upon the types of circuit being fed. The volume indicator is connected to one of the branches through its own amplifier. It does not, therefore, affect the power transmitted to the various branches.

With equal pad values and with amplifiers 1 and 2 set for identical gains, the indication of the volume indicator is considered the volume at point *L*.

The Volume Indicator in the arrangement shown in Fig. 22 does not take any power from the main circuit.

The Volume-Indicator reading minus the gain of amplifier 2 less the loss of the pad gives the volume at point *L* (see note regarding circuit impedances).

Figure 23 shows two ways of connecting volume indicators by means of bridge circuits.

The Volume-Indicator reading, without any correction, is considered as being the volume at point *L*. The loss introduced between the amplifier and point *L* in either case is about 6 dB. The balance obtainable with an amplifier of 600-ohm nominal output impedance should be sufficient (practically) to eliminate any effect of the loop impedance upon the volume-indicator readings. The entire wiring of the unbalanced circuit *A* should be shielded.

Transmitting Pads

The readings of a Volume Indicator on average program material are influenced mainly by the energy in the frequencies below 1,000 Hz. The impedance below 1,000 Hz, presented by a local channel, therefore is of most importance in its influence on the readings and, consequently, on the amount of isolation needed between the volume indicator and the local channel for correct readings. For the usual channel of non-loaded cable this impedance varies with frequenquency, the range of variation depending upon the length, the gauge of the conductors, the equalizing arrangement applied, and, if a transmitting transformer be used, its impedance ratio. If this is a 1-to-1 impedance-ratio transformer or if the transformer is omitted altogether, a 6 dB pad will normally be sufficient

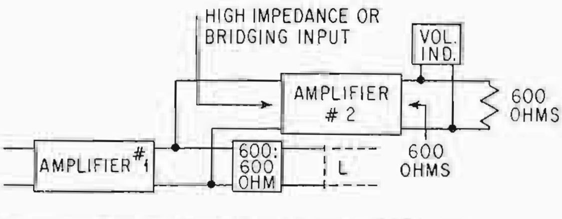

Fig. 22. Volume indicator bridged across a 600-ohm termination.

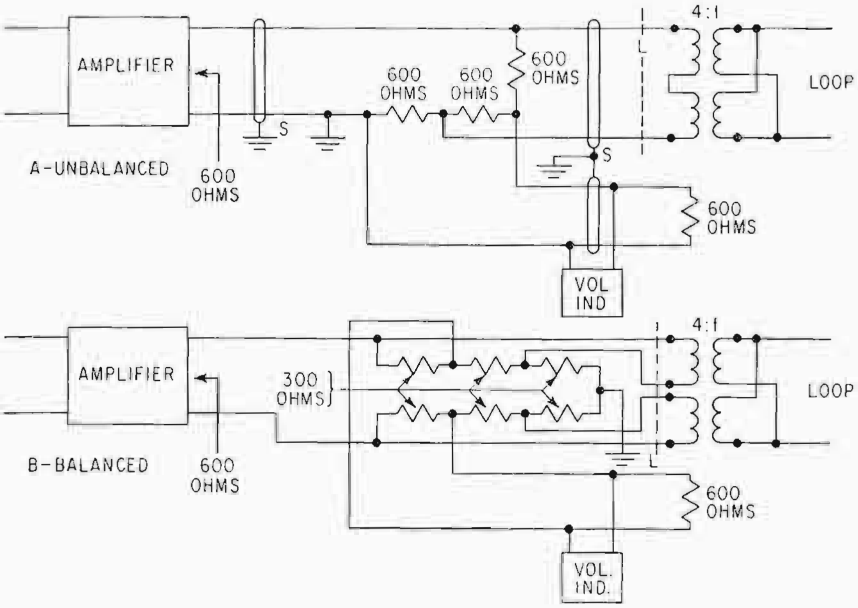

Fig. 23. Volume indicator connected by bridge circuits.

to make the readings of the volume indicator on average program material agree within 0.2 or 0.3 dB with what they would be if the volume indicator faced a pure 600-ohm resistance in the direction of the local channel. If, however, a 4-to-1 impedance-ratio transformer is used at the transmitting point, as is done in most nonloaded cable equalizing arrangements, the impedance faced by the volume indicator will be much higher than with a 1-to-1 impedance-ratio transformer and the errors in the volume-indicator readings, even with a 6-dB pad, may be 1 dB or more. Use of larger pads will reduce these deviations, but this will increase the output requirements on the amplifier, and alternative arrangements, as discussed subsequently, should be considered.

Most amplifiers now in use in broadcasting plants for transmitting into local channels have adequate output capacity to permit use of 6-dB isolation pads and still apply a +8 VU level to the local channels without objectionable distortion.

Taking all the foregoing factors into consideration, 6 dB should be the minimum value for an isolating transmitting pad where a transmitting transformer of 1-to-1 impedance ratio is used or where the transformer is omitted entirely.

Special Isolating Measures

Where a transmitting transformer of 4-to-1 impedance ratio is used, other measures will be required for obtaining a correct indication of the volume being transmitted to the loop. Among these may be mentioned:

1. The use of pads larger than 6 dB where practicable;
2. The application of specially designed impedance-adjusting pads;
3. The use of pads which provide isolation between two branches of a circuit by application of the Wheatstone-bridge principle;
4. The connection of the Volume Indicator to a paralleling branch of the circuit having a separate amplifier, as is shown in Fig. 21. This arrangement is one used quite generally by the Telephone Company in its offices.

An example of a balanced-type output circuit is shown by Fig. 23*b*. The circuit in this case incorporates a 4-to-1 impedance-ratio transformer connected to the local channel. The loss of this circuit is about 6 dB, and the isolation of the volume indicator will, as in the previous example, depend upon the match between the amplifier impedance and 600 ohms but will normally be several times the amount of loss introduced into the circuit by this arrangement.

Correction of Volume-Indicator Readings

Under Transmitting Pads, various measures are considered for reducing the influence of a nonuniform channel impedance on the accuracy of volume-indicator readings. Application of some of the arrangements discussed, particularly in the cases of Figs. 20*b* and 22, may still leave an objectionable residual error. The amount of this error at any given frequency (say 400 or 500

Hz) can be determined by comparing the volume-indicator reading (at that frequency) when the channel is connected in the normal operating condition with the corresponding volume-indicator reading obtained when a 600-ohm resistance is substituted for the channel.

In this test the transmitting transformer, if used, forms part of the channel and should be disconnected along with the channel when the 600-ohm resistor is substituted. Tones of the frequencies mentioned can safely be transmitted at 0 dBm without danger of interference with neighboring circuits, and their effect on volume indicators compares closely with that of average program material for a test of this kind.

Where the difference between the two readings obtained in this test is not more than 0.3 dB, it will usually be satisfactory to care for this by adjustment of the slide-wire resistor in the volume-indicator circuit. The procedure in this case is as follows: Make sure the volume indicator has been properly calibrated for use as in Fig. 20. Connect the 600-ohm resistance in place of the channel, and adjust the testing tone until the volume indicator shows the volume level to be transmitted (e.g., +14 VU with a 6-dB pad). Disconnect the 600-ohm resistance, and reconnect the channel. Adjust the slide-wire until the volume indicator again reads +14 VU.

If the correction is found to be larger than 0.3 dB, compensation by this method might disturb the dynamic characteristic of the volume indicator to an undesirable degree and other measures for reduction of the deviation, as discussed under Transmitting Pads, should be considered.

If a deviation of any appreciable magnitude is not to be corrected physically, the corrections should be applied algebraically in checking measurements with other points.

In the case of the method of use shown in Fig. 22, the correction can be determined by the same procedure as just described for Fig. 20. In this case, however, the gain of amplifier 2 is adjusted to obtain the desired compensation.

In the arrangements shown in Figs. 20*a*, 21, and 23, no deviations due to the effect of loop impedance will be involved.

Volume-Indicator Scale for Peak Checking

Peak checking between the Telephone Company and the broadcasters will normally be done by reference to the 0 to 100 scale on the Volume Indicator.

The broadcasters prefer the use of the 0 to 100 scale because it is applicable to direct indication of the percent modulation of the radio transmitter or the percent utilization of the facilities involved.

Differences in volume should preferably be discussed in terms of decibels. The justification for this lies in the relationship to the need for changing amplifier gains or pad values, which are designated in terms of decibels. The use of term VU in this connection is permissible, although incorrect.

Intercity Facilities

General

It has previously been mentioned that the Bell Telephone Laboratories, in their development work directed toward producing ever more efficient communication transmission systems, had concentrated much effort on carrier techniques. As more advanced systems were developed and placed in operation, each was assigned an alphabetical-type designation. Improved versions of the same general type of system were further identified by numerical additions to the alphabetical designation. Among the systems which are used to provide the long-haul backbone facilities, two types of carrier systems are in wide use:

Type TD-2 and other similar radio systems.

Types L-3 and L-4 cable carrier systems which use coaxial cables.

All these systems use basically the same terminal equipment (channel banks) to modulate 12 message channels into successive frequency positions 4 kHz apart to form the basic groups. These groups are then further modulated as required by the particular system. The message channels thus derived have a bandwidth which extends from about 300 to 3,000 Hz and meet all transmission requirements for high-grade message service.

It is readily apparent that, by appropriate means, a band equivalent to three message channels would provide frequency space for an 8 kHz program channel with adequate margin for filters on either side of the band to eliminate interference completely from or to adjacent message channels. In a similar manner a 5 kHz program channel can be derived from the space of two message channels. The necessary terminal equipment has been developed and is in wide use in audio-network service, particularly for television audio service, where differential delay between the picture and the television sound is an important consideration.

A variety of equipment arrangements are available to meet the network requirements for flexibility; for bridging, dropping, or reversing; for occasional services and similar considerations. As a typical example the 5 kHz system will be described along with a representative bridging arrangement.

Terminal Equipment

The 5 kHz program transmission channels (Schedules A and B) are derived from the carrier systems by the application of C-1 terminal equipment. This equipment may be permanently associated with a particular channel bank, or it may be installed separately and so arranged that it can be associated with any channel bank in the station.

In either case, when it is in use, it occupies the frequency position of message Channels 6 and 7. When not in use, it can be remotely switched out and the message equipment, which is always provided, put in use. A block schematic of the major features of the terminal is shown in Fig. 24.

The terminal is conditioned to transmit or receive by the presence of a control tone from either direction, as described later. In the transmitting direction, message Channels 6 and 7 are disabled and the program terminal is prepared for transmitting by dc signals applied to the simplex channel at the high-frequency patch bay and the program control room, respectively. The voice frequency program material is received from the program control room and passed through a 5 kHz low-pass filter and a preemphasis network to a modulator where it modulates an 88 kHz carrier. The upper sideband and carrier are suppressed, and the lower sideband is combined with an 81 kHz control tone and applied to a branch of a hybrid coil where the signal is combined with the working message channels in the range between 60 and 108 kHz. The entire group is then again modulated for transmission through the carrier system.

At the receiving terminal the reverse action takes place. After the group demodulation, the program and message signals are divided into two paths by the receiving hybrid. The 81 kHz control tone conditions the program terminal for receiving, and the program material is passed through a filter to the demodulator and the delay equalizing networks. The voice frequency program signals are then passed through the restorer network and an amplifier and transmitted to the control room.

A new program terminal has been developed by the Northern Electric Company and is in use in the program networks. Designated MC-2, it provides for transmission of a 5 kHz program on carrier type facilities. It is solid state, has the same transmission characteristics as the C-1 program terminal, and is end to end compatible with it.

Portable transmitting and receiving MC-2 terminals have been developed for rapid start of occasional program services. Use of the portable terminals obviates the need for costly program terminals being permanently installed for only occasional use. The terminals can be transported wherever there is an occasional program channel requirement and placed in service with patch cords.

Bridging Arrangements

Bridging and splitting arrangements can be provided at any amplifier point where the line characteristics have been suitably equalized. Several types of bridging and splitting arrangements are available for use in meeting different requirements. As an example, assume a bridging point which may receive program from the through line most of the time but is occasionally an originating point from which program must be fed in both directions.

To provide for receiving from a 5 kHz program channel, blocking filters are inserted in the main line which pass the line-frequency signals of message Channels 1 to 5 and 8 to 12 and permit the line-frequency program signals to be picked off. The program signals are then passed to a receiving program channel which is conditioned by the control tone and delivers the audio-frequency material in the same manner as at a channel terminal. Normally program is received from only one direction at a time at an intermediate point. One reversible program terminal arranged for switching to the desired direction of receiving would meet the requirement. However, program branching points can be equipped with two reversible terminals for greater flexibility. With two terminals arranged for transmitting, program can be fed in both directions simultaneously by connecting one to each of the oppositely directed main line circuits. It is also possible to receive from one direction and transmit in the opposite direction on the same main-line channel. This is sometimes done to provide "in-and-out" service to the local station.

The filters which are used in the arrangement, however, introduce delay distortion because of their sharp cutoff characteristic. Tandem use of terminals is therefore avoided whenever possible, and at branching points arrangements are provided whereby the blocking filters are removed from the through line and the receiving terminals are bridged on. When transmission from the branching point is desired, the circuit is set up by manually controlled relays for transmission in either or both directions.

Fig. 25 is a block schematic depicting the bridging and splitting example just discussed. The blocking and bypassing equipment provide two alternate paths of transmission and the means to switch from one to the other. One

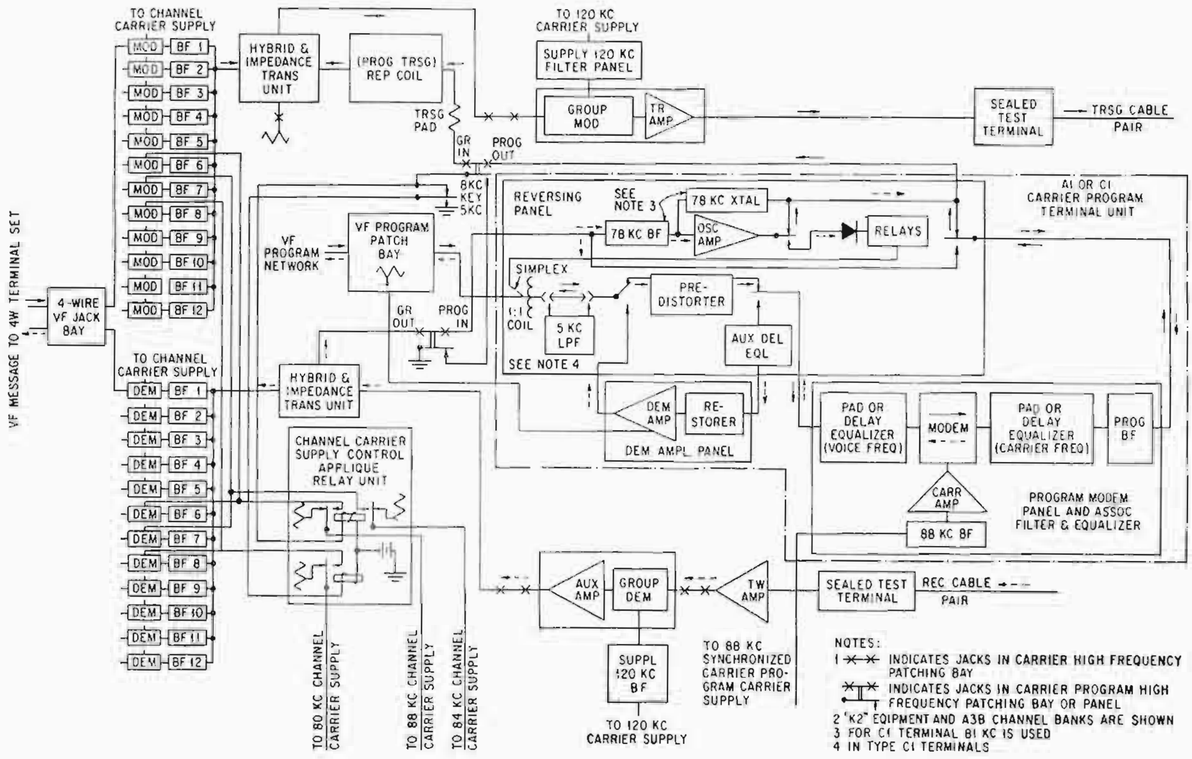

Fig. 24. Schematic of type C-1 program terminal.

path, through the phase equalizing network, provides through transmission for the program circuit and the message channels. This condition, at the branching point, is equivalent to bridging. The second path, through the band elimination filter, provides through transmission for the message channels but blocks the program circuit so that a new program circuit can be introduced for transmission beyond the branching point. Identical arrangements, under common control, are used in both directions.

Diplexers

As mentioned in the section on Network-facility Arrangements, tests were conducted, using diplexers, to derive the TV-audio channel from the video facility. The diplexers transmit a frequency modulated subcarrier in the range of 5.5 to 6.5 MHz. The subcarrier travels together with the television signal through the intercity facilities and local channels. High frequency roll off above 4.5 MHz in the local channels, causes the lower frequency subcarriers to be suited for program transmission. Fig. 26 is a block diagram of a typical diplexer for deriving two audio channels. The audio applied to the modulators, modulates the subcarriers and the subcarriers are combined in a mixer for bridging onto the video signal. The video low-pass filter in the transmitter suppresses products, in the video signal above approximately 5 MHz that may interfere with the subcarriers. The video low-pass filter in the receiver removes the subcarriers from the video signal and delivers the video signal unaltered as received. The audio subcarrier signals are filtered by the proper subcarrier bandpass filter and demodulated to provide high quality audio output signals.

Bridging

A variety of bridging arrangements have been standardized for use in meeting various circuit requirements, as, for example, varying numbers of outlets, terminal or through transmission, in and out or bridged local channels, and the type of program amplifier used. A typical arrangement is described in the following section on Reversible Facilities.

Reversible Facilities

In the general section, it was pointed out that network operation frequently involves a change

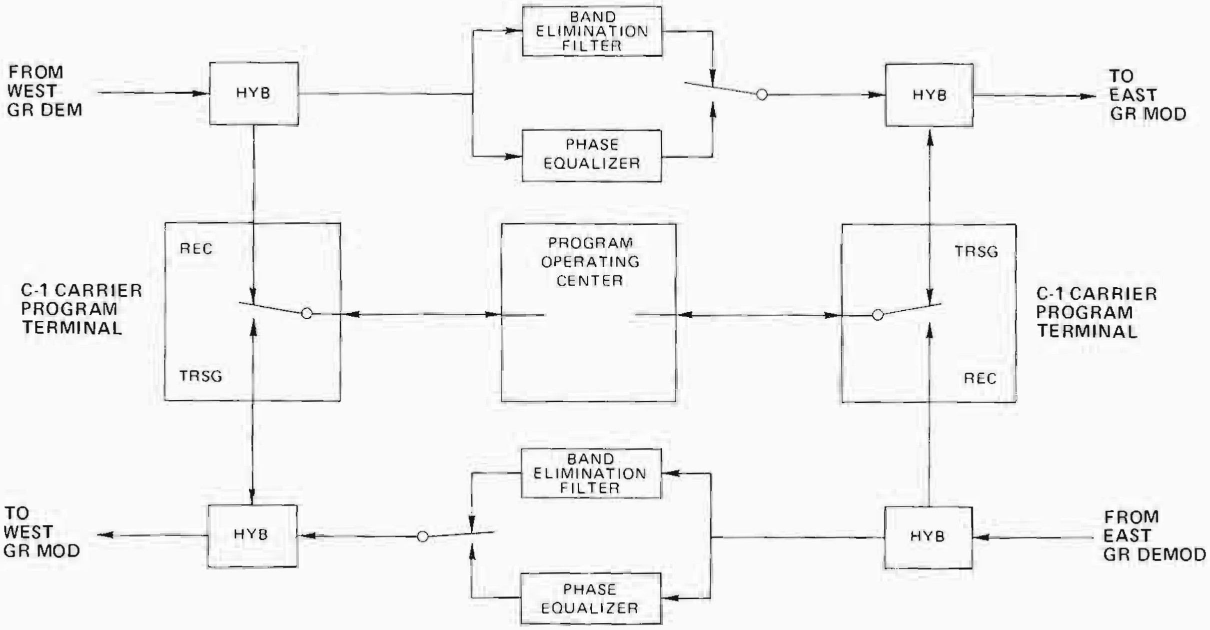

Fig. 25. Schematic of 5 kHz program channel bridging and splitting arrangement.

in the point of program origination. This can be provided either by round-robin operation or by the use of reversible facilities. Reversible operation is obtained by the remotely controlled operation of relays, at bridging point, which interchange the input and output connections of program amplifiers and also condition reversible carrier program terminals for transmitting or receiving.

Relay control at any bridging point is extended to the control point by the 81 kHz control frequency in the C-1 carrier program terminals. A direct current over the simplex of the transmission pair to the transmitting C-1 program terminal activates the 81 kHz control frequency. The control frequency is converted to direct current in the simplex of the transmission pair of the receiving C-1 program terminal and operates the relays in the reversible amplifier at the bridging point. The arrangement is such that the circuit is set up by the control point to transmit away from that point; that is, the direction of the circuit is under the control of the transmitting point and cannot be set up to transmit toward the control point while that point retains control. Any control point, once

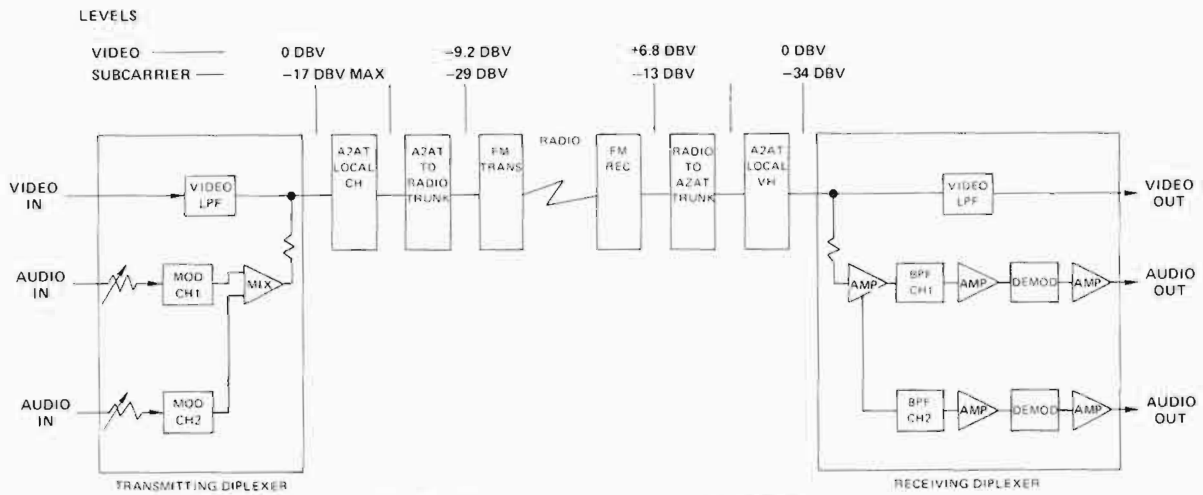

Fig. 26. Schematic of diplexer program terminal.

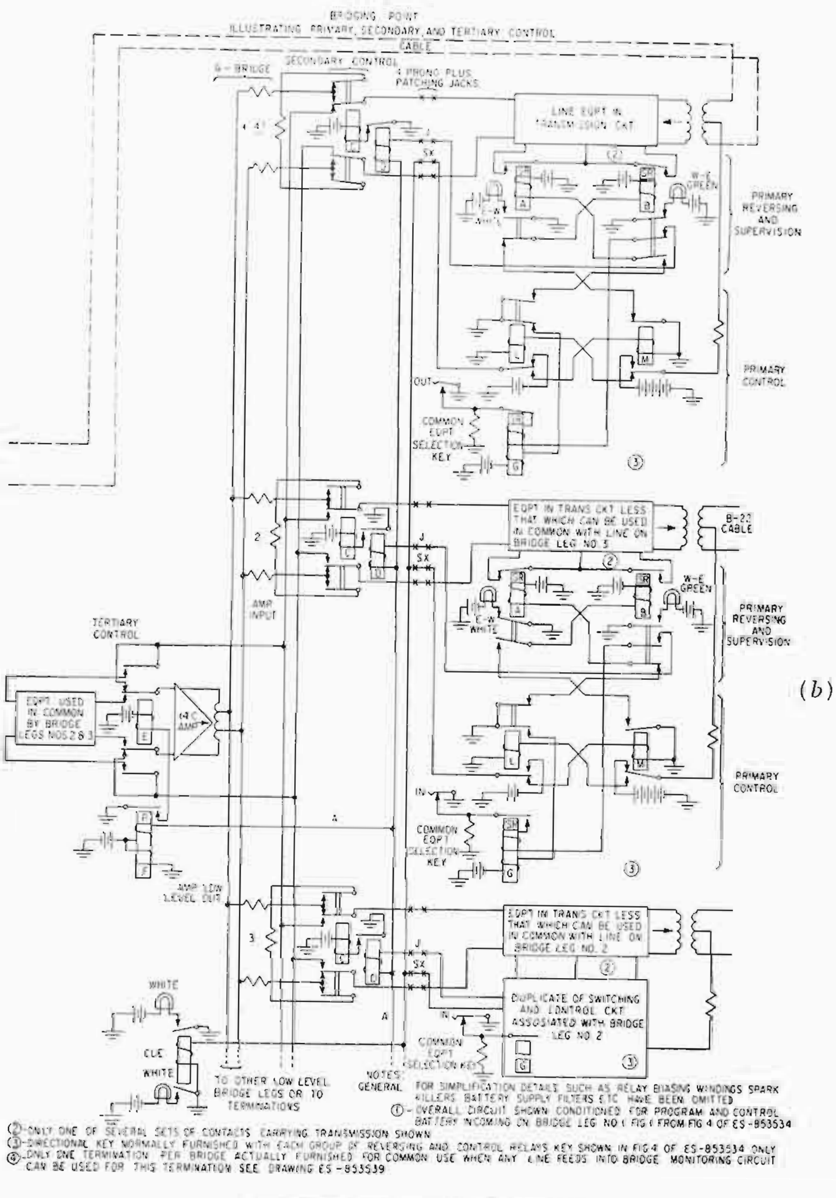

Fig. 27. Typical reversing equipment.

having obtained control of the network, retains control until it is released. In other words, a station having control locks out the control at all other points. Upon release of control, the transmission path remains unchanged until reversed by control from some other point.

A control and reversing panel is provided at each point where transmission into the program network is to take place. This panel is equipped with the keys necessary to perform control and reversing functions on one system. Visual indications of the circuit condition are also provided.

Fig. 27 represents a typical station arrangement at a bridging station employing a 14-C amplifier and associated G-type bridge. The G-type bridge shown is one of several of the general type of resistance-splitting devices designed to provide different numbers of outputs and levels from a single input fed by a 14-C program amplifier. Reference is also made to secondary and tertiary controls.

Secondary controls are associated with G-type bridges to transfer the line associated with a particular leg either to the input of the 14-C amplifier when the primary control is in one direction or to the output of the bridge when the primary control is in the opposite direction.

The function of the tertiary control is to provide switching at the input of the 14-C amplifier to connect or disconnect certain common equipment as required by the transmission path established.

The control current is taken from the program pairs through the simplex leg of the line repeating coil on the incoming program circuit and is relayed through the primary control to an Sx lead which parallels the bridging multiple and is connected to all the primary controls associated with this bridge. It is this Sx lead which ties all the lines together for this bridge as far as the control circuit is concerned so that a control signal coming in on any line can take the proper control and be relayed to all outgoing lines as desired.

In some cases at a bridging point where several similar lines are associated with the bridging multiple, it may be possible that certain line equipment associated with each line is common for several lines, and so economy in equipment can be obtained if such equipment is installed at the input of the 14-C amplifier and used in this position, in common for all those lines. A case where some, but not all, of the lines use common equipment is shown by Fig. 27.

The secondary control is equipped with relay *D* which is controlled by the *J* lead from the primary control. This *D* relay controls the *C* relay for switching at the output of the bridge. In addition, the "tertiary control" is controlled by the *A* lead, which is a continuation of the *J* lead beyond the *D* relay. This tertiary control controls switching at the input of the 14-C amplifier and determines whether or not the common equipment is in the circuit. The operation of the tertiary control is also controlled by means of the common equipment-selection key on the primary control. This is accomplished by controlling the amount of current sent from the primary control over the *J* and *A* leads. The *F* relay in the tertiary control is equipped with a biasing winding and is marginal in its operation. It will not operate when the 250-ohm resistance normally between the *J* lead and ground is in but will operate when this resistance is shorted out by the operation of the selection key when the common equipment is to be used. The *D* relay in the secondary control operates on either value of current. In Fig. 27 the arrangement shown is for the use of common equipment for legs 2 and 3 of the bridge while leg 1 does not use the common equipment but has all the necessary line equipment associated directly with the line itself.

Program Amplifiers

Two types of program amplifiers are in general use with carrier program terminals: the 14-C and the KS-20312, L1.

The 14-C amplifier is a two-stage amplifier, each stage operating push-pull, with negative feedback derived from the output transformer. This results in flat gain-frequency characteristics from 35 to 8000 Hz. The input impedance of the amplifier is 600 ohms. The output is arranged for either 600-ohms impedance for use as a line amplifier of 40 ohms for connection to a bridging multiple. The gain of the amplifier is adjustable over a range of 40 dB. The maximum gain of the amplifier to the 600-ohm outlet is 40 dB. The maximum gain through a bridging multiple to a +8 VU outlet is 34 dB. At 600 ohms the output level may be as much as +20 VU.

The KS-20312,L1 amplifier is a solid state device which meets or exceeds the performance requirements of the 14C amplifier. It provides amplification for 5, 8, or 15 kHz program services either as a line amplifier or connected to a bridge multiple.

21

Microwave Engineering for the Broadcaster

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Broadcast engineers have consistently been the leaders in the use of microwave equipment since the first installations were made over twenty-five years ago. The experience gained by these engineers with actual installations during this period makes it possible now to use sound engineering principles to design systems rather than rely on the trial and error methods necessary in the past. Engineers in the laboratories have advanced equipment design from early lighthouse tubes and reflex klystrons with marginal black and white TV performance to all solid state equipment with negligible distortions of high quality color television signals. The small light-weight low-power drain equipment now available offers the broadcaster new dimensions of flexibility in real time coverage of events outside the studio. The high reliability of modern solid-state equipment removes the tedium of maintenance technician chores and leaves the broadcast engineer free to do more profitable planning and engineering for reducing costs of program production and overall broadcasting operations.

With the rapid advances made during the past seven to eight years in both equipment and system design, it is not necessary for the broadcast engineer to become a communication transmission expert and microwave technician. He can now treat the microwave transmission system almost as if it were a section of hard cable in the system and forget weekly tube meter readings and all night fade watching vigils. In light of this minimum need for concentration on operating details, these discussions are aimed primarily at system planning, equipment selection, and installation.

The author gratefully acknowledges the assistance of the following companies and people in the preparation of this section of the *Handbook*.

Miss Jean McGill for her assistance in typing and preparation of the manuscript: Miss Irene Lambert of Microwave Associates, Inc., for her assistance in making the charts and graphs, Mr. Frank Miani of Microwave Associates, Inc., for his assistance in preparation of the microwave test oscillograms and text, Moseley Associates for their assistance in the preparation of the material on 950 MHz STLs, Jerrold Electronics Corporation for their assistance in the preparation of ITFS material, Mark Products for information on omnidirectional antennas, the Andrew Corporation for information on antennas and feeders, and Microflect Corporation for photographs of passive repeaters.

APPLICATIONS

The flexibility and dependability of solid state equipment makes microwave an indispensable and easily used tool for the modern broadcaster. Its application to almost any kind of transmission problem is now commonplace, and more an exercise in economics than a solution to technical difficulties.

STL (Studio-to-Transmitter Links)

This is the oldest application of microwave in the broadcast industry. Usually only one microwave hop is required in one direction. Both the video and audio program channels may be transmitted over the same microwave link. Many broadcasters find it advantageous to install duplicate, automatically switched, hot standby equipment. In periods of peak activity, the standby equipment from some manufacturers may be removed from the rack and used for portable coverage of outside events. Often broadcasters find that TSL (transmitter-to-studio link) is an economically justified convenience, and if the equipment is capable of rapid tuning to different frequency channels, STL standby equipment may be used for TSL interconnection when not required for protection of the STL. In any event, the second set of equipment is relatively inexpensive because the same antennas, feeders, racks, power plants, etc., are used for both systems. A typical STL transmitter and receiver are shown in Fig. 1.

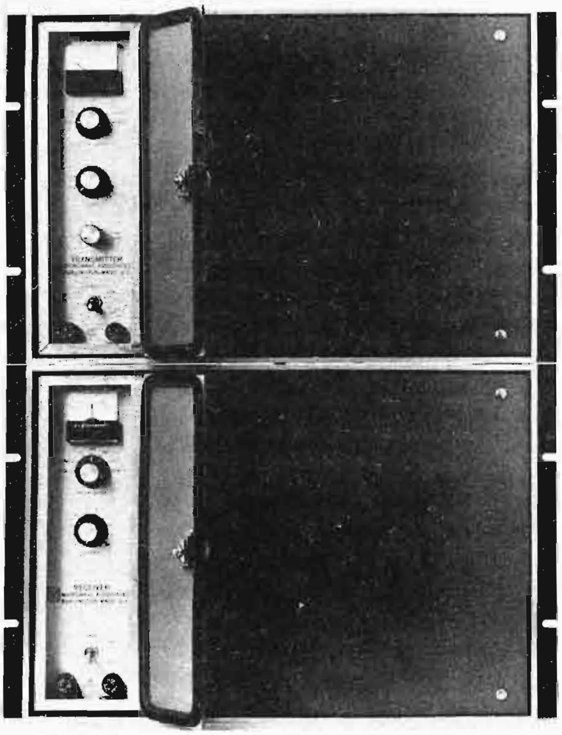


Fig. 1. Typical STL transmitter and receiver. (Courtesy of Microwave Associates, Inc.)

Portable TV Pickup

This application of microwave has shown rapid growth in recent years because of recent technical improvements and portability of all solid state equipment. It is now possible for one man to set up a portable link in a few minutes including switching to the assigned channel frequency. Portable equipment may be used on the ground, on roof tops or on towers as required to achieve line-of-sight transmission back to the studio. When the microwave equipment is installed such that it is not readily accessible, a cable and remote control unit is employed for operating and monitoring the microwave unit at distances up to several hundred feet from the transmitter. Portable equipment should be easily switchable or tunable to several different operating frequencies, and with minimum effort convertible to two or more frequency bands. Frequency agility avoids frequency coordination problems when several broadcasters are simultaneously trying to cover the same event in a local area. As a practical matter, test equipment is not required to set up and operate a portable TV link. Most broadcasters own several sets of portable equipment which can also be used as portable relay repeaters and for standby of the STL or TSL. Fig. 2 shows a typical portable microwave transmitter.

Mobile

This application of microwave is made possible by the low power drain and small size of solid state equipment. Use of mobile microwave adds a new dimension to on-the-spot coverage of any event. Typically, a camera and microwave transmitter are located in a vehicle (van, truck, jeep, blimp, boat, helicopter) which transmits the TV signal back to the program control center. To avoid steering the antenna in the vehicle, omnidirectional antennas can be used. Depending upon the range of operation, a high gain omniantenna may also be used at the control center, or a standard portable receiver with parabolic antenna and manual tracking may be used. Two-way links are often employed, with the link to the vehicle being used for camera sync, cues, zoom control, focus, intercom, etc. Mobile installations are often used for repeater relays especially in aircraft.

An example of mobile application is the Goodyear blimps which are permanently equipped with mobile microwave. The equipment in the vehicle must be rugged and have low power drain. A typical transmitter is shown in Fig. 3, and a 2 GHz omniantenna is shown in Fig. 4.

Backpack

This type of microwave equipment was used extensively for the first time by all TV networks

Fig. 2. Portable microwave equipment. (Courtesy of Microwave Associates, Inc.)

Fig. 3. Mobile microwave equipment. (Courtesy of Microwave Associates, Inc.)

Fig. 5. Backpack camera with microwave. (Courtesy of ABC Television Network.)

at the 1968 presidential nominating conventions in Miami and Chicago. The link consists of a standard portable video microwave receiver and a narrow band UHF or 950 MHz microwave command transmitter at the program control center, and a special miniaturized video microwave transmitter and narrow band UHF or 950 MHz command receiver in the backpack camera. Special attention to antennas is required to minimize transmission interference resulting from reflections from walls, furniture, etc. Circular polarized antennas are often used to minimize reflection problems.

The narrow band UHF or 950 MHz link is used for cue, focus, zoom, remote antenna tracking, sync, intercom, and on-off power control circuits in the backpack. Typical weight of the backpack microwave transmitter and receiver combined is 10-12 pounds, and battery power drain is 10-12 watts. Ranges up to several miles are achievable if line-of-sight conditions prevail. A typical backpack camera with microwave is shown in Fig. 5.

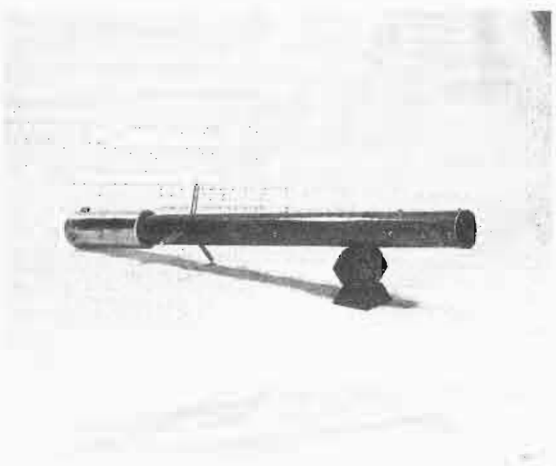


Fig. 4. 2 GHz omnidirectional antenna (6 dB). (Courtesy of Mark Products.)

Intercity Relay

This is another old application of microwave in the broadcast industry which has grown rapidly because of increased system reliability and greatly reduced cost and maintenance requirements. Intercity systems are used to interconnect common owned properties, or to provide network service from main line pickup points in one city to another city. Compared with leased common carrier facilities, some broadcasters find superior performance, lower cost, and greater flexibility of operation as reasons for installing their own microwave facility—the decision is no longer dependent upon technical reasons. The systems are usually one-direction, but often two-direction systems are employed to give greater flexibility and the outside plant costs do not increase with the second system. Hot standby equipment is used in most systems to achieve the utmost in reliability. The repeater stations, when required, are usually powered from a float charged battery bank to eliminate system outages resulting from commercial power failures. In long systems automatic alarm reporting equipment is used to remotely indicate power failures, illegal entry, tower lighting failures, battery charger malfunction, high building temperature, etc. Repeater station equipment is usually less complicated than terminal points, and for this reason special low-cost packages have been developed. Fig. 6 shows typical repeater equipment required to relay one TV and program audio channel.

ETV Networks

Most states in the country utilize a microwave network for distribution of educational programs throughout the state. Some of these systems are relatively short, 100 miles or so, while others

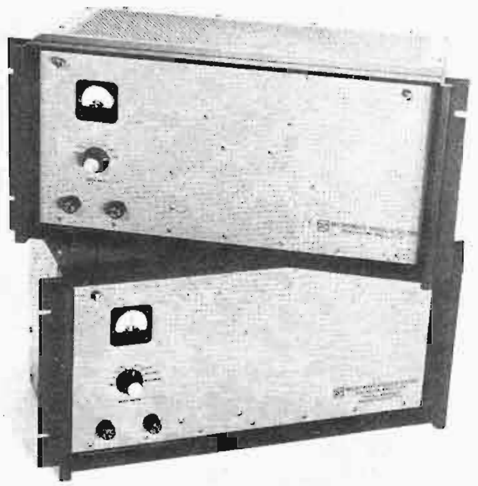


Fig. 6. Solid state remote repeater. (Courtesy of Microwave Associates, Inc.)

extend to many hundreds of miles. Privately state-owned facilities provide excellent service, and the choice over leased common carrier facilities is one of economics and personal preference because of performance or flexibility. Because of the wide variations from state to state in the distance to be covered and the number of repeaters required, two types of equipment have been developed for repeaters—remodulating and heterodyne. The receivers are almost identical in both equipments with the primary difference in the repeater being whether the transmitter accepts an FM modulated IF signal and heterodynes to microwave, or accepts a video baseband signal which directly FM modulates the microwave signal. The choice of one type of equipment over the other is usually based on economics or performance; both methods of operation provide excellent performance, but the heterodyne repeater usually contributes less noise and distortion and costs a little more than the remodulating repeater. The advent of solid state stability in remodulating repeaters removes past problems of high distortion and noise resulting from level variations caused by dying vacuum tubes, so that longer systems can now be built with remodulating repeaters with satisfactory performance.

ITFS (Instructional Television Fixed Service)

In 1963 the FCC allocated the 2.5 to 2.7 GHz band to educators for distribution of instruc-

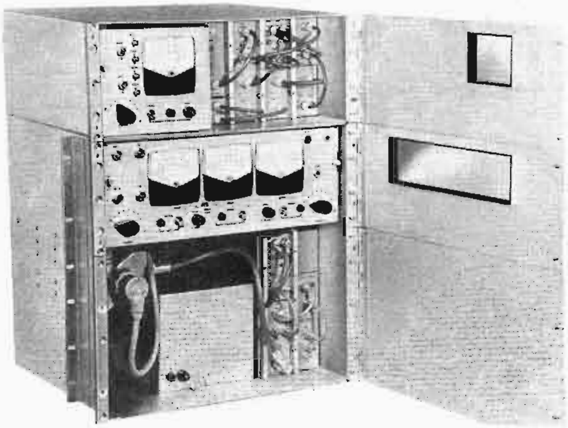
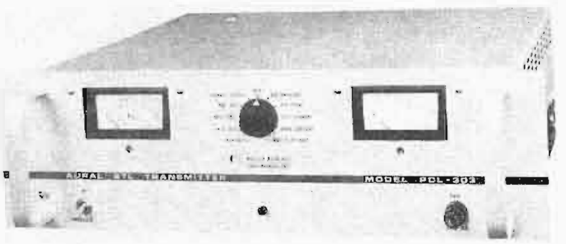


Fig. 7. ITFS microwave transmitter. (Courtesy of Jerrold Corporation.)

tional television signals throughout one or more school districts. The frequency band is made up of 31, six MHz channels which are utilized for video and sound in much the same manner as the standard broadcasting service. Vestigial sideband transmitters are used for the video with an FM subcarrier at 4.5 MHz in the channel used for audio. In some cases separate visual and aural transmitters may be used. An omnidirectional antenna is often used at the transmitter for wide area multipoint coverage. A parabolic antenna is usually employed at the receiving station to provide high gain and minimum interference. The microwave receiver consists of a translator which converts the microwave signal to one of the standard VHF TV broadcast frequencies. Up to four channels can be converted by one receiver translator if several TV channels are used. The translator output is distributed by coaxial cable throughout the building to standard TV sets. Similar engineering principles apply to designing ITFS systems as to broadcast FM links. Fig. 7 shows a typical transmitter and Fig. 8 shows a translator.

Fig. 8. ITFS translator. (Courtesy of Jerrold Corporation.)



9. Audio STL transmitter. (Courtesy of Moseley Associates.)

Audio STL

This is the oldest application of microwave in the broadcast industry and its use is rapidly growing as a result of automated FM and AM transmitter operation and with the availability of all solid state equipment. This service is allocated to the 942 to 947 MHz frequency band which is divided into ten 500 kHz channels. Compared to TV, the microwave equipment is narrow band, but has sufficient transmission capability to handle several 15 kHz program channels as well as numerous telemetry and control tones for automated broadcast transmitter operation. The same system engineering principles apply to audio STLs as to TV, and should be used for establishing performance criteria and designing the transmission link. Fig. 9 shows a typical transmitter and Fig. 10 shows a typical receiver for this service.

Wireless Microphones

This is a new application of microwave, which was used for the first time by the TV networks at the presidential nominating conventions in Miami and Chicago. Previously available wireless microphones operating at VHF or UHF frequencies are subject to severe interference from other services and lack of adequate spectrum for high fidelity studio performance. The new wireless FM microphones operating at microwave frequencies, while more expensive at this time, offer a totally new approach to hi-fidelity sound systems for the broadcasting networks, TV networks, and movie industries. This application is still experimental and the usual engineering rules for fixed point-to-point service are not necessarily applicable. A 1968 change in FCC rules places this service in the 942 to 947 MHz frequency band with a transmitter power limitation of 100 mw, which has proven adequate. As this new microwave service develops, the broadcaster can reduce the audio cost of program production and the complexities of boom microphones in overall TV program production. Fig. 11 shows a typical 950 MHz transmitter.

CARS (Community Antenna Relay Service)

This service was first established almost ten years ago in the 12.70 to 12.95 GHz frequency band on a shared basis with broadcasters. As equipment became available for this application (especially all solid state equipment), use has accelerated and continued to grow at this time. The microwave equipment is normally used to interconnect the head end off-air pickup station with one or more cable distribution systems. The application is characterized by up to ten TV channels being transmitted simultaneously through common feeder and antenna systems. With the advent of all solid state equipment, the trend in this service, as in the broadcast service, has been to treat the microwave system much as a solid piece of cable insofar as the decision to use microwave is concerned. Normally the video and audio are picked off-air together and transmitted together, thereby eliminating the need for separate audio modules in the microwave. Because of the relative simplicity of microwave equipment for this service as compared to broadcast, the equipment cost is usually lower. Both FM and AM equipment is available with the choice being one of economics.

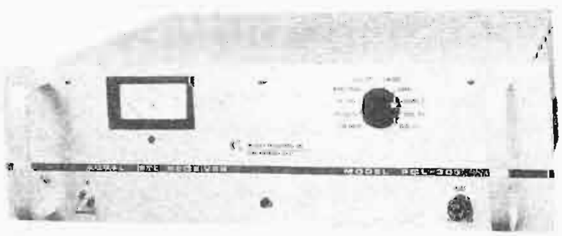


Fig. 10. Audio STL receiver. (Courtesy of Moseley Associates.)

Fig. 11. 950 MHz wireless microphone transmitter. (Courtesy of Microwave Associates, Inc.)

Omni Fixed-Directional Portable

This is a relatively new TV microwave application that is finding rapid acceptance in the broadcast industry because of its simplicity for electronic news coverage. In this application a microwave receiver is installed at the program control center with its high gain (10 dB) omni-antenna elevated enough to provide an unobstructed view of most of the broadcast station's signal area. Often the signal is relayed to the control center through a repeater on a tall building overlooking the city. The microwave transmitter is a standard portable unit which can be set up by one man on location in 5 min or less. Since the microwave receiver antenna is omnidirectional, no effort is required at the program control center or repeater for instant TV coverage of most areas in a given city. The microwave receiver may be installed at the high elevation adjacent to the antenna with a cable extending to a remote control unit located in the equipment room. See Fig. 12.

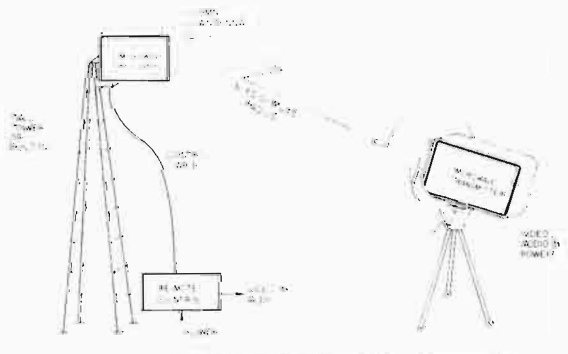


Fig. 12. Omni-fixed directional portable applications.

FREQUENCY SPECTRUM

The FCC has allocated three bands of frequencies for use by the broadcaster for TV relaying and one band for audio relaying. These are referred to as the 950 MHz (narrow band channels for audio program and control circuits), 2 GHz, 7 GHz and 13 GHz bands (wide band channels for TV circuits). Specifically, the frequencies are 942 to 947 MHz (10 narrow band channels), 1990-2110 MHz (7 wide band TV channels), 6875-7125 MHz (10 wide band TV channels), and 12,700-13,250 MHz (22 wide band TV channels). Additionally, the 2500-2690 MHz band is divided into 6 MHz channels for Instructional Television Fixed Service applications. Ten wide-band TV channels in the band 12,700-12,950 MHz are allocated to CARS service on a shared basis with broadcasters.

In past years many arguments have ensued on the merits of one frequency band as compared to another. These arguments were often weighted by past experience, or in the case of a manufacturer, by which equipment he had available. Today excellent equipment is available from many manufacturers in all frequency bands, and the old arguments are being modified to reflect the fact that satisfactory systems can be engineered in all frequency bands. It is primarily a problem of understanding the peculiarities of each band and of allowing for these differences when designing the system. In general, the cost of equipment increases with frequency, and other system costs may also increase because of increasing propagation difficulties as operating frequencies increase. For example, an allowance must be made for rainfall at 13 GHz, but can be ignored at 2 GHz. The main point of discussion now is that good service can be obtained in all bands, providing that the peculiar characteristics of each band are considered when the system is designed. With increasing frequency congestion, the choice of band is often based upon availability of frequencies and not upon user preference. The trend to higher frequencies will continue on up to 40 GHz or more in the future.

FCC LICENSING

After designing the microwave system and selecting the equipment an application is made to the FCC for a construction permit. This application is made on FCC Form 313 with the requested equipment characteristics provided by the manufacturer. In many cases the manufacturer previously files equipment characteristics with the FCC and a notation on the FCC Form 313 to that effect is sufficient. After the installation is complete, the broadcaster runs proof-of-performance tests, the results of which are submitted to the FCC to obtain his regular license.

In the case of CARS service, equipment type acceptance procedures prevail at the FCC. The manufacturer must obtain type acceptance of his equipment from the FCC in accordance with parts 2 and 74 of the rules before it will be accepted on the construction request, Form 402.

In order to retain his license, the broadcaster must establish a log at each station. A properly FCC licensed operator assures continual operation in accordance with the FCC rules by duly recording certain specified measurements in the log periodically as required. In addition, the FCC has another microwave requirement which is primarily directed to broadcasters; this is that each microwave transmitter in the system be turned off when not being modulated. This requirement may be met by either manually turning off the transmitter, or automatically turning it off by a modulation detector built into the transmitter.

The broadcaster and others using this *Handbook* should refer to the FCC Rules and Regulations and to their attorneys for complete and up-to-date information.

CONTRACTING

A broadcaster has a wide range of choices available to him for planning and installing a microwave system. He can do his own system engineering and installation then buying all hardware from a single manufacturer with one purchase order; the manufacturer can then be held responsible for meeting contractual performance specifications of each subsystem (antennas, lines, batteries, etc.), as well as the total system. Or, he can do his total engineering including subsystems then buying his hardware from several sources, with each manufacturer responsible only for his own hardware. Or, he can refer the total responsibility by contract to the microwave manufacturer to meet the contractual system performance specification for transmission of signals between two points for a fixed price. Or, he can employ an independent consulting engineer to design the system, prepare equipment specifications, supervise purchasing, and supervise installation either by construction contractors or the microwave equipment manufacturer. Or, he can refer the total responsibility to the manufacturer except for installation which he can do himself under the supervision and checkout of the manufacturer.

There are many other combinations of responsibilities for contracting engineering, furnishing, and installing microwave systems. The choice is based upon many factors best understood by the chief engineer of the broadcaster. Often he is qualified and has the time to engineer and install an STL or purchase portable gear but does not have the time for an extensive intercity or statewide system. In this latter case a consulting engineer, a single manufacturer, or a combination of the two is usually the best choice.

ECONOMICS

Often economic analysis is necessary to compare cost of owning a microwave system versus leasing, and after deciding to buy a microwave system to decide whether to pay cash, finance, or lease the system. Within these comparisons there are several alternates:

1. Contract with one firm for the total broadcast installation with all equipment financed together.
2. Contract for the microwave system separately and finance separately.
3. Finance through one or more manufacturers or directly from a financial institution.

If credit or leasing is used, the broadcaster must be prepared to quickly furnish necessary financial data on his company to establish his credit rating so that the financial part of the contract can be processed quickly without delaying construction and possible revenue income on the investment. If help is needed in making any financial analysis, the manufacturer will usually assist as part of his proposal effort. In order to determine whether a privately owned system versus common carrier service should be used, all costs including installation, terminal, and disconnect charges of the leased system must be made available in order to make comparison with the various ways of financing the cost of the privately owned system. A good textbook on Engineering Economics will provide a wealth of information on the problem.

PERFORMANCE STANDARDS

An individual broadcaster may have a peculiar situation requiring unique specifications, but in most cases well established industry standards with some expansion should suffice. The broadcaster is referred to the following:

Reference Standards

1. EIA STANDARD RS-250-A, *Electrical Performance Standards for Television Relay Facilities.*
2. EIA STANDARD RS-173, *Emergency Standby Power Generators and Accessories for Microwave Systems.*
3. EIA STANDARD RS-195-A, *Electrical and Mechanical Characteristics for Microwave Relay System Antennas and Passive Reflectors.*
4. EIA STANDARD RS-203, *Microwave Transmission Systems* (Definition of Terminology).
5. EIA STANDARD RS-222-A, *Structural Standards for Steel Antenna Supporting Structures.*

In order to provide the broadcaster with a good summary of practical TV microwave transmission and equipment specifications in one place, the following tabulation is given for guidance in specifying equipment for a TV microwave system:

TV Transmission and Equipment Standards

Transmitter power	Manufacturer's spec.
Transmitter frequency stability	±0.05% (max)—portable ±0.005% (max)—fixed

FM deviation (peak to peak)	8 MHz
Modulation	FM
Transmitter output impedance	50 ohms
Transmitter output connector types	
2 GHz	"N" coax
7 GHz	UG-343 B/U
13 GHz	WR 75 (cover)
Transmitter video input impedance	75 ohms
Return loss (min)	26 dB
Transmitter audio input impedance	600 ohms
Portable transmitter tuning range (min)	5% (of op. freq.)
Receiver noise figure (max)	
2 GHz	10 dB
7 GHz	11 dB
13 GHz	12 dB
With low noise preamp (max)	6 dB
Receiver IF frequency	70 MHz
Receiver noise bandwidth	30 MHz
Receiver L.O. stability	.005% (max)
Portable receiver tuning range	Across operating band
Receiver output video impedance	75 ohms
Return loss (min)	26 dB
Receiver output audio impedance	600 ohms
Video input and output level (P-P)	1 volt
Variation	0.7-1.4 volt
Audio input and output levels	+9 dBm
Input adjustment	0 to 20 dBm
Output adjustment	±2 dB
Transmission polarity	Black negative
Video frequency response	
10 kHz to 4.5 MHz	±0.25 dB
Video low frequency response	
Tilt (60 Hz square wave)	1% max
Video differential gain	
50% average picture level	0.3 dB
10% & 90% APL	0.5 dB
Video differential phase	
10, 50, and 90% APL	0.5° max
Video signal-to-noise (EIA weighted)	60 dB (min)
Video signal-to-hum (P-P to P-P)	46 dBm (min)
Baseband spurious tone levels	
1000 Hz to 4.3 MHz	-60 dB (max)
Video transient response	
Max K factor for 2 T pulse	1%
Audio response	
at 50 Hz	+0 to -1.0 dB (max)
100 to 7500 Hz	+0 to -0.5 dB (max)
at 15,000 Hz	+0 to -1.0 dB (max)
(Referenced to 400 Hz)	
Audio signal-to-noise (with window signal)	60 dB (min)
Audio distortion	
50-100 Hz	1.0% (max)
100-1500 Hz	0.5% (max)
7500-15,000 Hz	1.0% (max)
Temperature range (full spec)	0 to 50°C
Operating without damage	-30 to +60°C
Humidity	up to 95% R.H.
Input voltages	
AC (47-63 Hz)	115 v ± 10%, or 220 v ± 10%, or
DC	21-28 v dc, or 42-56 v dc

950 MHz STL Standards

Transmitter power	Manufacturer's spec.
Transmitter frequency stability	±0.001%
Type modulation	FM
Transmitter program input level	+10 dBm
Transmitter multiplex inputs	2 @ 1 volt rms
Transmitter output impedance	50 ohms
Transmitter output connector	"N" coax
Transmitter program impedance	600 ohms
Type receiver	Double heterodyne
Receiver noise figure	9 dB
With low noise preamp	5 dB
Receiver IF frequency	70 MHz & 10.7 MHz
Receiver noise bandwidth	Manufacturer's spec.
Receiver input connector	"N" coax
Receiver input impedance	50 ohms

Receiver program output level	+10 dBm
Receiver multiplex output	2 @ 1 volt P-P
Program channel S/N	65 dB
Program channel frequency response	±0.5 dB (50 Hz-15 kHz)
Program channel distortion	0.75% (50 Hz to 15 kHz)
Mains voltage (47-63 Hz)	115 v ± 10% 220 v ± 10%
Temperature (to spec)	0 to 50°C
(operate without damage)	-30 to +60°C
Humidity	up to 95% R.H.

Dual STL Stereo

Note: Two standard STLs are operated in parallel in one 500 MHz channel to provide L and R program channels. Performance is the same as single channel STL.

Single STL Composite Stereo Operation

L and R frequency response	±0.5 dB (50 Hz to 15 kHz)
L and R distortion	< 0.75% (50 Hz to 15 kHz)
L and R signal-to-noise	65 dB
L and R separation	> 35 dB
Transmitter composite input level	1.5 volt P-P (10 K ohms)
Receiver composite output	6 volt P-P (1 K ohms)

INTERNATIONAL STANDARDS

The preceding standards are quite satisfactory for use in most countries. For additional special information the reader is referred to the following CCIR documents included in Volume IV, Part I from the most recent Plenary Assembly of the International Telecommunications Union:

1. Recommendation 281	Radio frequency channel arrangement
2. Recommendation 282	Special radio frequency channel arrangements
3. Recommendation 382-1	Channel arrangements in 2 and 4 GHz bands
4. Recommendation 383-1 and 384-1	Channel arrangements in 6 GHz band
5. Recommendation 386-1	Channel arrangements in 8 GHz band
6. Recommendation 387	Channel arrangements in 11 GHz band
7. Recommendation 289	Noise in the reference circuit
8. Recommendation 305	Standby equipment
9. Recommendation 401-1	Continuity pilots
10. Recommendation 276	Frequency deviation and polarity
11. Recommendation 402	TV plus single sound channel
12. Recommendation 403-1	IF frequencies
13. Recommendation 405	Preemphasis characteristics
14. Report 289	TV plus four sound channels
15. Report 376	Diversity techniques

Note: 1. EIA Standards may be purchased from:

Electronics Industries Association
2001 Eye Street, N.W.
Washington, D.C. 20006

2. CCIR Documents may be purchased from:

The International Telecommunications Union
Geneva, Switzerland

3. Microwave transmission performance is directly related to receiver input signal level, it is assumed the designer will use a receiver input level compatible with the standards listed in this section.

BASIC REMODULATING TV EQUIPMENT

The basic equipment consists of transmitters, receivers, and power supplies, and these three elements will be covered.

Transmitters

The basic remodulating transmitter consists of a video amplifier (with preemphasis), an oscillator which can be modulated, a power amplifier and frequency multipliers when required to reach the desired output frequency as shown in Fig. 13. Various optional items are available to extend the usefulness of the transmitter; these include: crystal referenced AFC loops to improve frequency stability to 0.005% or better. Off-air demodulator to monitor quality of output at antenna feeder input. Audio subcarrier modulators for transmitting program channels. A switch for rapidly changing frequency to different channels covering 5% or more of the output carrier frequency. Output filters (wideband or channel width) to further reduce spurious outputs and operate with diplexers

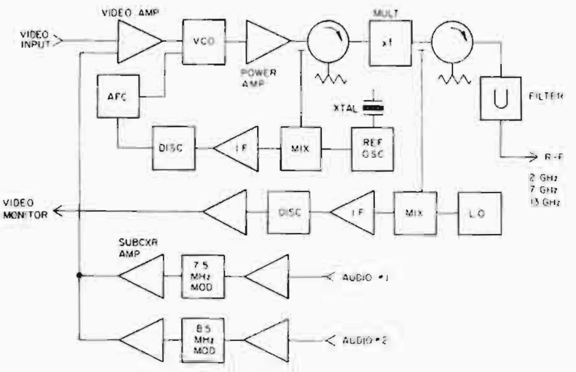


Fig. 13. Remodulating transmitter block diagram.

and duplexers. Special remote control connector plug for portable equipment. Weatherproof housing for portable equipment. Ruggedized packaging for vehicular mobile equipment.

The baseband amplifier is wideband (10 MHz or so) for best linearity and incorporates liberal feedback for stability. A 12 dB preemphasis is used which effectively reduces the possibility of low frequency intermodulation products in the system and improves overall color transmission. Provision is also made for combining one or more audio program subcarrier modulators with the video before frequency modulating the voltage controlled oscillator. The gain of the video amplifier is matched to the modulation sensitivity of the oscillator so that 8 MHz peak-peak deviation is produced on the r-f carrier for a 1-volt peak-to-peak input video signal. The low frequency response of the amplifier extends almost to zero Hz as required for high fidelity transmission.

The transistorized VCO (voltage controlled oscillator) typically runs at 2 GHz where transistors are available with enough power capacity to produce an adequate transmitter output level. As new transistors are developed, the trend will be for higher oscillator frequencies which will result in higher output power and greater power conversion efficiency (lower input power). A number of solid state devices are available which operate directly at the output carrier frequency. The output power of the oscillator may be up to several watts, but is usually lower followed by an amplifier.

The power amplifier consists of one or more broadband stages to provide a gain of 25 to 30 dB at a power output of 8-10 watts at 2 GHz falling off to a watt or less at 13 GHz. As with other transmitter components, the mark of quality is linearity, wide bandwidth (10% or more of the operating frequency) and long-term stability. The amplifier should operate on any assigned frequency channel in the band without retuning.

Early solid state equipment all used frequency multiplier, and the number of varactor diodes used in the frequency multiplier chain depended upon the output operating frequency—typically one multiplier was required for 2 GHz, two for 7 GHz, and three for 13 GHz. These multipliers consisted of varactors, impedance matching circuits, cavities, and filters to efficiently operate over a wide band of frequencies with minimum spurious output signals. No tuning was required to cover up to 10 assigned frequency channels in the three operating bands. Typical power outputs from the varactors was 2 watts at 2 GHz, 0.5 watt at 7 GHz, and 0.25 watt at 13 GHz. At the present time operating frequencies of solid state components is increasing so that the need for frequency multipliers will not exist for any frequency band in the near future.

The AFC option utilizes a crystal controlled source which feeds one side of a mixer. The other side of the mixer is fed with a sample of the transmitter frequency. The mixer output is an IF signal which is amplified and demodulated by a temperature compensated discriminator. The dc output from the discriminator is the carrier frequency error voltage which, when applied through a dc amplifier to the VCO, keeps it on its assigned frequency.

The off-air monitor is essentially a microwave receiver which demodulates a sample of the transmitter output signal for monitoring. To be of maximum value as a transmitter test tool, the monitor signal should be of high quality even though it is slightly more expensive than slope detectors and other lower cost devices sometimes used.

The subcarrier modulators are actually FM transmitters operating in the 7 to 8 MHz frequency range and typically deviated 140 kHz rms. The output of the modulator is mixed with the video signal at a level of -12 to -20 dB below the peak level of the video signal. The modulator may or may not use preemphasis depending on the equipment designer's choice and needs.

The frequency switcher shifts the operating bias on the oscillator to change its frequency and when AFC is used switches crystals in the reference oscillator. Since all circuits are wideband, no tuning is necessary when frequency is changed.

The transmitter output filter is used when the transmitter is diplexed with another transmitter or duplexed with a receiver, or to reduce spurious levels. The filter may be broadband covering 5% or more of the spectrum, or narrow band covering a single assigned channel.

For portable applications, a special weatherproof housing is required which is easily fitted, with an antenna, to a tripod. If remote control is used, special wiring and a connector are installed for mating with the remote control cable. When the portable transmitter is used in hot weather in direct sunlight, a sunshade is recommended to prevent excessive heating.

Equipment for mobile applications must be packaged in a rugged manner to withstand the high degree of shock and vibration experienced in most vehicles. Also size and weight become more important so that special precautions must be used to keep the high density packaged components from overheating.

To prevent interference to or from broadcast microwave equipment, special precautions must be taken for RFI filtering and shielding. The total unit is usually enclosed in an RFI proof case with special gaskets at all access doors and panels. Additionally, all input and output electrical connections must be RFI filtered. Without these precautions, considerable difficulty can be expected, since broadcast microwaves equipment often operates in close proximity to high powered transmitters.

Receivers

All TV microwave receivers are typically super heterodyne with a 70 MHz IF amplifier as shown in Fig. 14. For broadcast work the local oscillator and mixer must be broadband for best stability and to eliminate the need for tuning when switching to a variety of different frequencies.

The mixer typically operates over an octave of frequency and may be single ended or balanced depending upon the need to suppress certain types of noise from the local oscillator. Typically construction is coaxial at 2 GHz and waveguide at 7 GHz and 13 GHz. The mixer determines the noise figure of the receiver which is in turn largely dependent on the diodes used. Noise figures of 8 to 11 dB are typical over the 2 to 13 GHz bands. The mixer function is to produce an IF frequency by subtracting the local oscillator frequency from the receiver carrier frequency.

The local oscillator carrier is usually crystal controlled to 0.005% or better of the output frequency. Fundamental oscillators are usually used, but lower frequency oscillators followed

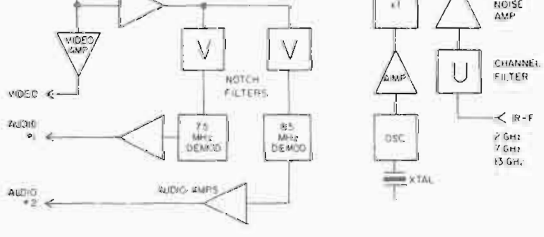


Fig. 14. Receiver block diagram.

by multipliers are also sometimes used. For frequency switchable equipment up to 10 crystals may be used or a suitable synthesizer.

The 70 MHz IF preamplifier is often mechanically integrated with the mixer to achieve best overall noise figure of the reciver. The preamplifier typically has 25 dB gain and is 50 to 60 MHz wide.

Optimum receiver noise performance is achieved when the minimum necessary bandwidth is used—this is typically 30 MHz to the 3 dB points for TV transmission. Since the basic IF amplifier circuits are 50 to 60 MHz or more wide, a lumped constant filter located between the pre-IF and the main IF is employed to reduce the noise bandwidth of the receiver to 30 MHz. The characteristics of this filter must be carefully controlled for good phase and amplitude linearity.

The main IF follows the filter and provides typically 65 dB of gain. In both pre and main IFs, common base transistor design is used which effectively isolates the transistor characteristics from the overall amplifier performance characteristics which are determined primarily by the interstage coupling circuits. With this design approach, the receiver characteristics are essentially independent of the transistor characteristics which may vary widely with temperature. The output level of the IF is 0.5 v or +7 dBm. The input microwave level to a typical receiver may vary from -25 to -80 dBm during fading conditions. Since +7 dBm output is required, the gain needed varies from 32 dB to 87 dB. In order to keep the output constant, 60 dB of AGC is typically used to regulate the 90 dB gain in the two IF amplifiers between 40 and 90 dB. Since portable and mobile equipment operates over wide ranges of distance, it is important that receivers have at least 60 dB of AGC.

The limiters are an important part of an FM receiver because they effectively eliminate the effects of AM variations on the signal. These AM variations will contribute noise at the output of the discriminator and have an appreciable effect on threshold performance. Typically 20 dB of limiting is used.

The discriminator demodulates the FM signal back to video. In a wideband TV system, it is important to keep the discriminator linear over a wide bandwidth, typically ±5 MHz or more about the center 70 MHz IF frequency. Nonlinearity will produce distortion and noise on the signal by increasing intermodulation between various components of the TV signal.

The video amplifier brings the discriminator output signal back up to one volt. It also includes a deemphasis network which is exactly matched to the transmitter preemphasis network so that an overall flat frequency response is achieved through the system. The video amplifier includes a low pass filter to reduce the level of the audio subcarriers at the video output. While the degree of audio subcarrier rejection is not extremely important in TV microwave signals, it is typically 30 to 40 dB below peak video levels. A high degree of feedback is used in the video amplifier to achieve maximum stability.

The audio subcarriers are extracted from the video by notch filters tuned to each subcarrier frequency. The subcarrier demodulator is a high fidelity 7 to 8 MHz FM receiver which delivers +9 dBm audio with low distortion and 15 kHz fidelity.

The preselect filter at the receiver input is used to improve selectivity, prevent local oscillator radiation, and suppress image frequencies. It typically consists of five or more filter sections designed and tuned to cover several channels in switch tunable systems or a single channel in fixed signals. The passband characteristics must be closely controlled to avoid phase nonlinearities in the system.

The same comments made for the transmitter regarding portable and vehicular applications apply to the receiver.

Power Supplies

Most microwave equipment uses several different voltages to power the various active circuit components. These are usually low voltages of 12 to 35 volts that must be highly regulated and filtered for best performance. The power supply function is to convert the ac or dc main supply voltage to those required in the equipment.

Fig. 15 is a block diagram of a typical power supply system. Ac units consist of a transformer and rectifiers to obtain the unregulated operating voltages. Various types of transistor regulators are used to keep the operating voltages within a narrow range of variation. In dc units the battery voltage is first converted to ac by a chopper or inverter after which operation is similar to the ac. Good designs usually employ protection circuits on both input and outputs to

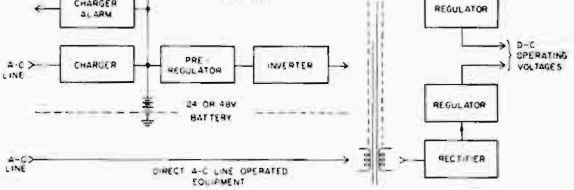


Fig. 15. Power supply block diagram.

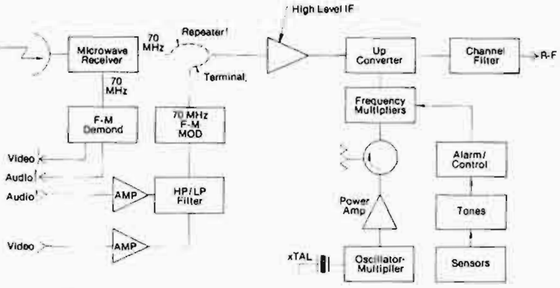


Fig. 16. Heterodyne transmitter block diagram.

protect the power supply from surges, load short circuits, and lightning.

BASIC HETERODYNE TV MICROWAVE

The receiver in a heterodyne system is almost identical to the remodulating receiver already discussed. The only difference being that two 70 MHz outputs are obtained from the IF, and the limiter, discriminator, and video amplifier are usually referred to as the demodulator. One of the 70 MHz outputs feeds the demodulator when used at a repeater and the other feeds the heterodyne transmitter.

The heterodyne transmitter block diagram is shown in Fig. 16. It consists of a high level IF amplifier and a high level microwave source both of which feed a high level up convertor mixer. The high level source is similar to that used in the remodulating transmitter except it need not be modulated. The mixer heterodynes the 70 MHz IF input signal up to a microwave signal ±70 MHz different from the source frequency depending upon the sideband selected. The solid state heterodyne transmitter typically has a lower power output than the remodulating transmitter because the heterodyne loss is about 4 dB. Thus a 2 watt source produces an 800-milliwatt heterodyne transmitter. For this reason traveling wave tubes or solid state amplifiers are used after the heterodyne mixer.

At a repeater the 70 MHz IF input to the transmitter comes from the second receiver IF output at a level of 0.5 volt. If the heterodyne transmitter is used at a terminal station, the video signal first modulates a 70 MHz FM transmitter (modulator) which then feeds the transmitter.

Because the signal is relayed through a repeater station without going through the modulator or demodulator, the noise and distortion of the modulator and demodulator is eliminated and the relay is made with less noise and distortion than through a remodulating repeater.

In long-haul microwave systems, heterodyne repeaters are a necessity to keep end-to-end noise down to reasonable levels. In short-haul systems the remodulating system offers comparable performance at a lower cost and with greater flexibility. For systems up to 8 to 10 hops the remodulating system is normally used, while for longer systems heterodyne equipment is normally used. The other elements in a heterodyne system are not appreciably different from those in a remodulating system.

RF MULTIPLEXERS

When two transmitters or two receivers on different frequencies are connected to a common feeder line and antenna, the combining process is called diplexing. When a transmitter and a receiver are connected to a common antenna, the combining process is called duplexing. When more than two units are connected to a common antenna, the combining process is called RF multiplexing (see Fig. 17).

RF multiplexers usually consist of combinations of bandpass filters and ferrite circulators so that each transmitter or receiver sees only the antenna as a load rather than seeing each other. Unless each unit is isolated from the other, intercoupling takes place resulting in interference between the microwave signals. For example the transmitter and receiver in a duplexed system must be isolated by over 100 dB. Of this amount the ferrite circulator contributes about 20 dB and the filter 80 dB or more.

When channel separations are too close to achieve necessary isolation with circulators and filters, dual cross polarized antennas are used with two feeds to provide another 30 dB or so of isolation between channels assigned to each of the two feeds. The two feeds may be in the same parabolic reflector or in different reflectors where near field isolation of up to 100 dB may be achieved depending on type of reflector and relative location of the two reflectors. Thus the RF multiplexer may include the antenna system in some cases.

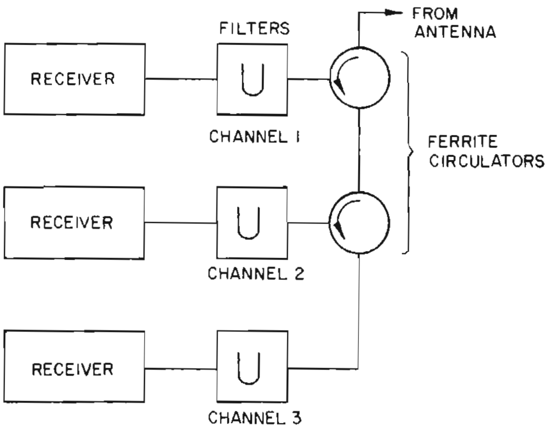


Fig. 17. RF multiplexing block diagram.

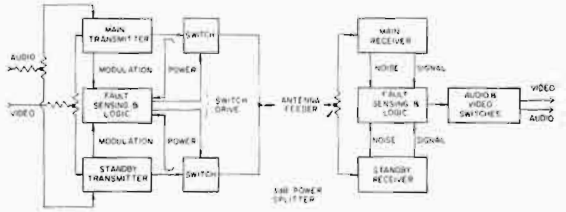


Fig. 18. Hot standby block diagram.

The most complicated and difficult RF multiplexers are required in CARS systems where as many as ten 25 MHz TV channels are sometimes transmitted in parallel in a 250 MHz segment of spectrum. Cross-polarized special-shrouded parabolic reflector antennas are required to achieve the necessary isolation between receivers.

HOT STANDBY

Maximum equipment reliability is achieved by installing duplicate equipment with one equipment automatically replacing the other in the event of failure. The failure mode is detected by comparing several monitored performance indicators in the two equipments and switching when this comparison shows a preset difference. A typical arrangement is shown in Fig. 18.

The same input signal is fed to both transmitters. One transmitter at a time is connected to the antenna through an RF switch which is activated by the logic comparison circuits. Two performance indicators (modulation and power) are normally monitored. Modulation is monitored by detecting the presence of a continuity pilot fed through the system along with the picture and sound signals. This pilot may be a tone operating above the picture and sound spectrum, or for TV microwave the video sync pulse at 15.75 kHz makes an effective pilot.

The RF signal into the receivers is split into two paths—one for each receiver—with a 3 dB loss. The pilot is monitored at both receiver outputs along with receive signal levels. If either of these indicators in one receiver drops below a preset value as compared to the other receiver, the output is switched to the receiver indicating best operation.

The logic circuits must provide an indication when switching has occurred, and prevent switching during periods of fading, loss of input signals to the system, or when the standby unit is inoperative. It should also include visual indicators showing which units are operating at a given time as well as equipment failure. Manual override switches are incorporated to permit disconnection of either equipment for maintenance.

DIVERSITY

Two types of diversity are used in TV microwave systems: frequency and space. In frequency diversity systems identical video and sound signals are transmitted through two different microwave equipments operating on frequencies spaced 4 to 5 percent apart and coupled to a common antenna system. In space diversity two receiver antennas are used with vertical spacing determined to avoid simultaneous fading at both antennas. In each type of system the output is selected from the receiver with the least noise. In general, FCC practices preclude the use of frequency diversity by broadcasters to conserve frequency spectrum. Many other countries use frequency diversity with no restrictions. In both types of operation the receiver logic circuits are identical. Fig. 19 shows a typical configuration for space diversity.

Diversity combiners are of two types: switched and combined. The switch type is similar to the hot standby switcher except transfer between receivers occurs at a preset difference in noise from the two receivers rather than on complete failure as used for standby arrangements. Combiners are universally used for medium density telephone microwave systems, but are still somewhat experimental for wideband TV microwave systems. When used, the functional objective is to combine the two receiver outputs in a way that always produces the optimum signal to noise. Since receiver noise adds on a power (random) basis, and video adds on a voltage (phase) basis, the combiner will give a 3 dB improvement in signal to noise when both receiver input signals are equal in level. The monitored noise for the combiner may be either out-of-band noise, or IF AGC voltage.

LOW NOISE AMPLIFIERS

System fade margins and performance may be improved by using a low noise amplifier at the receiver input. The gain of these amplifiers is typically 15 to 20 dB with a noise figure of 4.5 to 6.0 dB, depending on frequency. Tunnel diodes are used at 7 and 13 GHz and high frequency transistors are used at 1 and 2 GHz. These noise figures represent a 4 to 5 dB improvement in performance for most equipment. The units are available for use inside the receiver or are provided in weatherproof housings for installation outside near the antenna. In the latter case the loss of the transmission line is eliminated and the system improvement is further increased. Another application of the low noise amplifier is between two back-to-back dishes operating as a passive repeater. The low noise amplifier is a useful tool to the microwave design engineer, and its use in the system should not be overlooked.

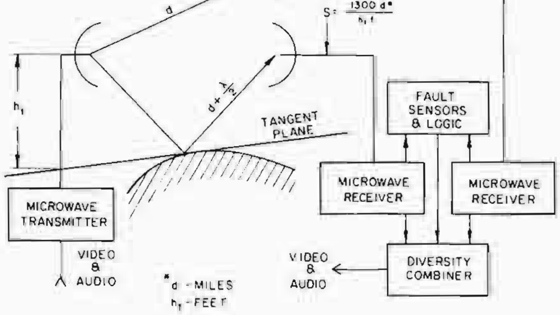


Fig. 19. Space diversity block diagram.

REMOTE CONTROL

In portable and STL applications it is often desirable to locate the microwave equipment at a distance from operating personnel. It may also be desirable to remotely control and monitor the microwave equipment. For this purpose a flexible multiconductor cable is used between the microwave equipment and a remote console. The remote control option includes equalizers for the cable, amplifiers to overcome cable loss, remote main power control, and all equipment metering points. When properly designed, the remote control option will not impair overall transmission quality. Fig. 2 shows a typical remote control console. The distance between equipment and remote control point may be up to several hundred feet. The cable should be weatherproof and remain flexible down to very low temperatures.

ALARM EQUIPMENT

Operating status of remote repeaters is often monitored at one end of the overall system. To accomplish this function, a special alarm channel is multiplexed on the baseband along with the video and sound signals. The monitored alarm indicators are then scanned with a digital scanner which generates pulsed codes indicating the status of each alarm. These pulses key a tone generator which is fed into the alarm channel. At the receiving display station, the pulsed tone is demodulated, usually with a binary counter circuit, and the demodulated code is displayed on a lamp panel which indicates the status of each alarm at each repeater.

Typical alarms are:
1. Transmitter failure;
2. Receiver failure;

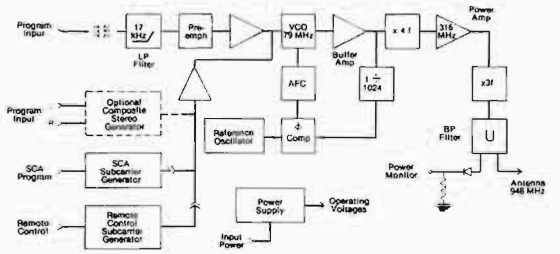


Fig. 20. 950 MHz audio STL transmitter block diagram.

3. Power failure;
4. Battery charger failure;
5. Tower light failure;
6. High building temperature;
7. Illegal entry; and
8. Engine generator fuel.

950 MHz STL EQUIPMENT

Functional block diagrams of 950 MHz audio STL equipment are quite similar to TV microwave equipment. The major difference is that the 950 MHz equipment is narrow band as compared to TV. For this reason the equipment design techniques are somewhat different. The baseband width of an audio STL is typically 100 kHz, while TV microwave baseband width is 10-12 MHz. Figs. 20 and 21 show block diagrams for a typical 950 MHz STL transmitter and receiver. Because solid state components are now available, the need for multipliers has almost disappeared.

The 950 MHz STL equipment is used for audio program transmission and remote control. Stereo FM is transmitted either through a dual STL operating in one 500 MHz channel, or through a single STL using a composite stereo baseband signal. The dual STL stereo system has the added reliability of equipment redundancy, and the composite stereo STL has the advantage of economy.

Transmitter

The transmitter input consists of a multiplexed baseband signal including program channel, telemetering, and control tones and SCA. The baseband amplifiers raise the input levels to the correct level to FM the VCO modulator oscillator. One hundred percent modulation is typically ±40 kHz.

The modulator oscillator may be FM or phase modulated. Phase modulation has the advantage of being directly crystal controlled, whereas FM requires an AFC loop; but direct FM gives superior performance especially at low baseband frequencies. The decision as to which type of modulation to use is normally a compromise between cost and required performance. The oscillator runs from 80 MHz to 947 MHz for FM transmitters and 11 MHz for phase modulated transmitters. The higher multiplication factor for phase modulation is required to achieve rated FM deviation.

The oscillator is buffered from the first multiplier if used by an amplifier. The first multiplier output is typically 316 MHz. The 316 MHz signal is further amplified and then tripled to 948 MHz. Since the 950 MHz equipment need not operate on multiple frequencies on a switched basis, all circuits may be narrow banded for maximum gain and efficiency. Typical solid state power output is 4 to 10 watts.

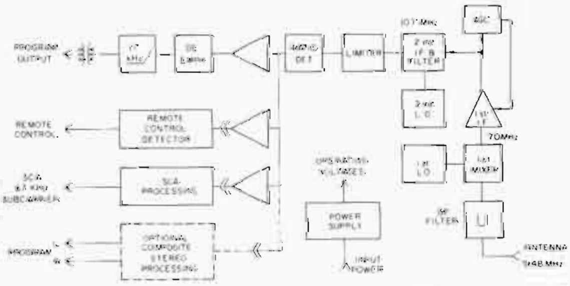


Fig. 21. 950 MHz audio STL receiver block diagram.

Receivers

The receiver is typically double heterodyne to reduce cost, improve selectivity, and simplify design. The first IF is usually at 70 MHz and the second IF with most of the receiver gain and selectivity is at a lower frequency—often 10.7 MHz where standard FM broadcast receiver parts are available. The local oscillator is crystal controlled. The limiter/discriminator is similar to TV microwave except it operates at a lower frequency over much less bandwidth. The video amplifiers deliver the specified signal level to the various program channel, telemetering, control, and SCA outputs. Since bandwidth of the 950 MHz receiver is one-hundredth or less of the TV microwave receiver, its sensitivity is 20 dB or better than the TV receiver. This increased sensitivity decreases antenna requirements so that simple corner reflectors are often used.

Ancillary Equipment

The 950 MHz STL system may include numerous devices associated with the broadcast transmitter operation. Digital alarm scanners, automatic data loggers and printers, and remote control devices are available. Remote telemetering is usually incorporated using VHF equipment at 100 MHz for the return path between FM transmitter and studio.

Duplex Operation

If a TSL link is required, transmitters and receivers may be combined to a common antenna in the same manner as for TV microwave. Because of the limited spectrum available, transmitter to receiver spacing is quite close in frequency and requires special duplexing precautions.

ANTENNA SYSTEMS

Several different types of antennas are used in a TV microwave system. Omnidirectional vertical stacked arrays are used for portable and vehicular applications. Parabolic reflector antennas are used for STL, intercity, ETV, and CARS systems. Corner reflectors and modified parabolas are sometimes used for 950 MHz STLs. Horn or shrouded parabolic antennas may be used for high front-to-back isolation ratios. Simple dipoles are often used for back pack and wireless microphone equipment. Selection of the antenna is usually based upon the application and the antennas available. The reader is referred to EIA Standard RS 195A for mechanical and electrical specifications.

Isotropic

The isotropic antenna is a hypothetical antenna used as a reference against which the gain of other microwave antennas are measured. The term dBi denotes gain over an isotropic antenna. The isotropic antenna by definition has a radiation pattern which is a perfect sphere. The power density per unit area at a point in space due to the power P_T radiated by an isotropic antenna is

$$P = \frac{P_T}{4\,\pi\,d^2} \qquad [1]$$

where: d = Distance from radiator.
$4\,\pi\,d^2$ = Surface area of a sphere with radius d.

By definition, the effective area of an isotropic antenna is $\frac{\lambda^2}{4\pi}$ and the power received P_i is Equation 1 times the isotropic area, or

$$P_i = \frac{P_T \lambda^2}{(4\pi)^2\, d^2} \qquad [2]$$

Other Antennas

For other antennas of effective area A, the power received P_R is from Equation 1,

$$P_R = \frac{P_T A_{ef}}{4\,\pi\,d^2} \qquad [3]$$

The gain of an antenna is defined as the ratio of its radiated or received power to that of an isotropic antenna. The ratio of Equation 3 to Equation 2 gives the gain (G) as,

$$G = \frac{4\,\pi\,A_{ef}}{\lambda^2} \qquad [4]$$

where: A and λ are in same units of measurement.

$$G = 12.77\,A_{eff}^2 \qquad [5]$$

where: G = Gain
A_{ef} = Effective area in square feet
f = Frequency in GHz.

Using Equation 5, the gains of various types of antennas are listed below:

Type	*Gain (dBi)*	
Parabola	$10 \log 5.5\, D^2 f^2$	[6]
Horn (optimum)	$10 \log.\ 10.3\, Af^2$	[7]
Omnidirectional (stacked array)	$10 \log 2\, Lf^2$	[8]

where: D = Diameter of parabola-feet
A = Mouth area of horn-feet^2
L = Length in feet
f = Frequency in GHz.

Parabolas

The parabolic antenna is available with several useful refinements. Radomes, heated and unheated, are available to prevent icing which rapidly reduces efficiency, especially at the higher frequency. Special shrouds are available to improve the radiation pattern and increase front-to-back gain ratios. Dual cross-polarized feeds are available which provide 25 dB or so of isolation between two signals using the same reflector. Antennas at 1 and 2 GHz normally use coaxial dipole feeds while those at 7 and 13 GHz usually use waveguide horn feeds. Standard mounting structures are available for attaching the antenna to a 4-in. OD pipe, along with clamps which can be loosened for aiming the antenna after installation on a tower. Special light weight 950 MHz antennas sometimes mount to a 2-in. pipe. Special roof mounts are available for aiming the antenna upward when passive reflectors are used on the tower. Feeders are air tight so that when pressurized moisture will not enter and reduce feed efficiency. At the lower frequencies grid and mesh construction is often used to reduce weight and wind loading on the towers.

Horns

Several variations of the horn antenna are available for microwave use. They are usually characterized by better radiation patterns than the parabola. For reasons of economy and form factor, they are not often used by broadcasters.

Omni

The omnidirectional antenna is characterized by a radiation pattern resembling a doughnut. Gain is achieved by reducing radiation in the vertical direction. They are often used to eliminate the need for tracking in mobile systems with typical gains of 6 dB on the vehicle or 10 dB at fixed points. The higher gain antenna is not used on vehicles because of signal loss when the vehicle banks during turning. A 2 GHz omniantenna is about 16 in. long for 6 dB gain. The antenna is typically mounted on top of surface vehicles, or hinged beneath aircraft so that it may be dropped to a vertical position after takeoff. See Fig. 4 for a 6-dB omni at 2 GHz.

Passive Reflectors

Passive reflectors are often used at 7 and 13 GHz instead of feeder waveguide to effect radiation at the top of the tower. The choice to use passive reflectors usually reflects lower cost or transmission loss or both. The installation consists of a parabola near the equipment aimed at a reflector tilted about 45° with the earth which reflects the energy away from the tower in a horizontal line. The efficiency of the reflector depends upon how well it is illuminated by the parabola, which in turn is a function of spacing and size ratio between the reflector and parabola. Curved reflectors are sometimes used to improve efficiency by 2 dB or so.

Analysis of the gain of a parabola/reflector antenna system is complex, but useful relationships have been determined empirically which are shown on the transmission work sheet in Fig. 22. These curves may be used to determine gain of any size combination for use in system calculations.

Adjustment of reflectors in the field requires skill but is accomplished with the assistance of surveying equipment for initial adjustment and trial and error for best received signal after the equipment is installed. Most popular sizes are 6 X 8, 8 X 10, 8 X 12, and 10 X 15 feet fed by 4, 6, 8, and 10 foot parabolas.

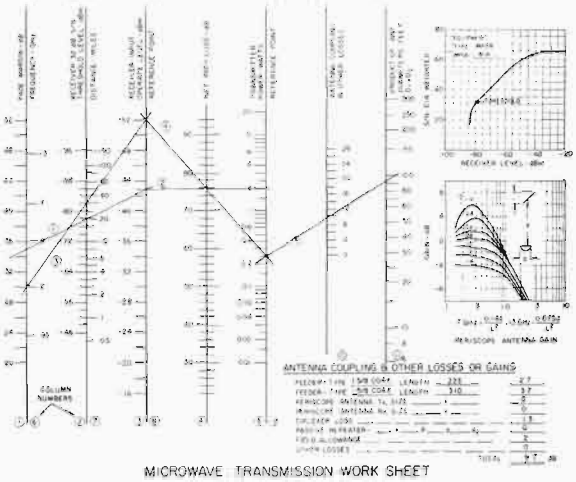


Fig. 22. Transmission calculation worksheet.

TOWERS

Microwave towers are of two types: guyed and self-supporting. The guyed tower is most economical, but requires more land area. The self-supporting tower is used where land is expensive or almost unavailable. EIA Standard RS-222A is the most useful document available for purchasing specifications. All manufacturers meet this minimum requirement. Both types of towers should be equipped with suitable means for safe climbing in case of maintenance.

Installation and height restrictions are imposed by both the FAA and local ordinance. These factors should be checked when making tower decisions. Also towers above certain heights require lighting as specified by FAA rules. Generally, lights must be observed daily by personal observation or by automatic alarm system. Tower painting is specified by the FAA and repainting is required at specified intervals. See Fig. 23 for a typical tower and antenna installation. Microwave equipment manufacturers can provide advice on the most suitable tower for a particular application.

BUILDINGS

Wood, masonry, and metal buildings are used at remote repeater stations. The choice depends upon economics and local ordinances. Concrete buildings are best for security against vandals and require less maintenance. Buildings should be well ventilated or air conditioned to limit temperature extremes—heat is often required in colder climates. The typical repeater building is 8 × 10 feet, which is adequate for electronic gear and standby power. Other factors are important such as drainage, grading, grounding, access, etc.; reference to EIA TR-142 will prove helpful in specifying the building.

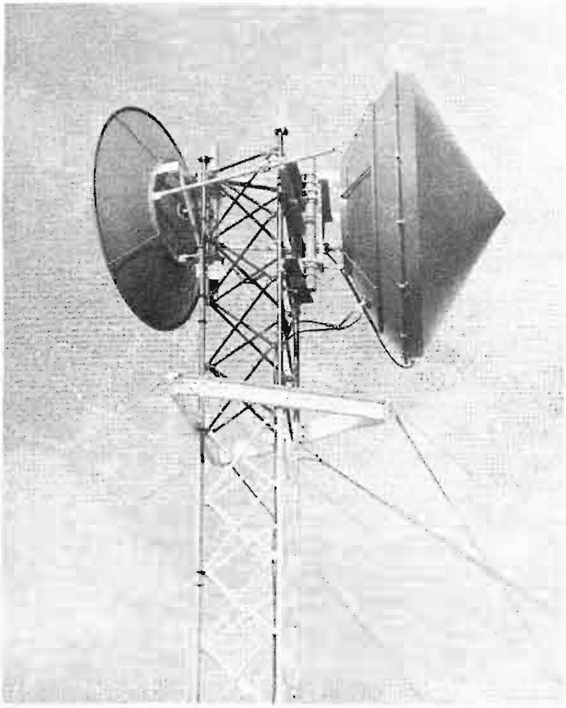


Fig. 23. Typical tower and antenna installation.

POWER PLANTS

With improvements in equipment and systems engineering, the reliability of the main power source becomes more important. With solid state equipment which requires low power and voltages, batteries are the most popular form of standby power. If prolonged commercial power failures are anticipated, engine-generator sets are used to recharge the batteries. In some remote areas, gas fueled thermoelectric generators are used. The reader is referred to EIA Standard RS-173 for further information on standby generators.

Industrial lead-calcium or lead-antimony acid batteries are most often used. Both types are reliable and the choice is often one of personal preference. The one advantage of lead calcium is that equalizing charges are not required which reduces maintenance. The float charge voltage is 2.15 volts per cell for lead-antimony and 2.2 volts per cell for lead-calcium. Batteries should be installed in well-ventilated areas to reduce the possibility of explosion from escaping hydrogen gas. Battery banks usually consist of 12 or 24 cells (24 or 48 volts). Cell voltage typically varies over a range of 1.75 to 2.35 volts when completely discharged and when at maximum charging rate. The communication equipment must be capable of accepting this variation. Battery size is usually selected for a minimum 8-hour capacity and a typical 24-hour capacity. Present day batteries are quite reliable and require little attention for many years. Batteries are also effective filters to protect solid state equipment from power line surges.

Battery chargers operate from standard commercial power and actually provide the power to the equipment with the battery floating as a standby device. Good chargers should incorporate protective devices to limit charging current and to protect against line surges. Alarms for charger and line voltage failure should also be available. Purchase of batteries and chargers from the same source of supply is recommended to insure compatibility.

Batteries and chargers are sound investments which will add many hours of operating time to the average microwave system.

ANTENNA FEEDERS

Microwave equipment is connected to the antenna with either coaxial cable or waveguide. Coax is used for 1 and 2 GHz and may be either foam filled or air dielectric. Waveguide is used for 7 and 13 GHz and may be either rigid rectangular waveguide, elliptical flexible waveguide, or circular waveguide. Short sections of flexible rectangular waveguide are often used to simplify installation. In addition to the lines, various hangers, clamps, bending tools, hoisting grips, and pressurizing equipment are required for installation. It is recommended that transmission lines be installed in continuous lengths to avoid potential problems with splices or joints.

The Andrew Corporation, Orland Park, Illinois, provides a wealth of information in its standard catalogue on the characteristics of feeder systems. Typical losses vary from 1.0 to 10.0 dB per hundred feet, depending upon the type of feeder used. Rather than list all characteristics here the reader is referred to vendor catalogues.

Care must be taken during installation to avoid pressure leaks, dents and discontinuities, all of which will affect the system performance. Professional experienced riggers are normally used with supervision by the equipment manufacturer. Foam filled coax is the easiest line to install but has higher loss than air dielectric.

The typical loss per hundred feet of several types of feeders is listed below:

At 950 MHz

	Loss per 100 feet
Foam dielectric (aluminum) coax:	
1/2 in. diameter	3.7 dB
7/8 in. diameter	2.0 dB
1-5/8 in. diameter	1.6 dB
Air dielectric coax:	
7/8 in. diameter	1.6 dB
1-5/8 in. diameter	0.8 dB

At 2 GHz

Foam dielectric (aluminum) coax:	
1/2 in. diameter	4.7 dB
7/8 in. diameter	3.4 dB
1-5/8 in. diameter	2.6 dB
Air dielectric coax:	
7/8 in. diameter	2.2 dB
1-5/8 in. diameter	1.3 dB

At 7 GHz:

Helical waveguide—Andrew type EW-59	1.5 dB
Rigid rectangular waveguide WR 137	1.8 dB

At 13 GHz

Helical waveguide—Andrew type EW 122	4.1 dB
Rigid rectangular waveguide WR 75	4.2 dB

PASSIVE REPEATERS

On some hops a passive repeater is used to clear an obstacle rather than an active repeater. The passive repeater may be either a billboard type or two parabolas back to back. The flat billboard type has an efficiency near 100 percent while the parabolas have an efficiency near 55 percent.

Because the gain of a passive repeater is proportional to the square of the frequency, their use is mostly limited to 7 and 13 GHz. The gain of a flat billboard is derived from Equation 5 as:

$$G = \left(12.77\, Af^2 \cos\frac{\theta}{2}\right)^2 \qquad [9]$$

where: A = Area of reflector in feet² (width X height)
f = Frequency in GHz
G = Gain in dB
θ = Angle between microwave beams extending to both adjacent stations.

Equation 9 is squared because the passive repeater has equal gain receiving and transmitting.

The performance of the hop may be calculated by considering 2 hops with a passive repeater with gain given in Equation 9.

When θ is too large to realize practical gain, a double billboard is often used, with one reflector illuminating the other. A loss of 3 dB is normally used for reflector—reflector coupling loss. The path is analyzed the same way as a single reflector except for the extra 3 dB loss.

For transmission calculations it is simpler to consider a single hop equal in length to the sum of the two legs extending to the passive repeater. In this case the passive repeater is considered to have a loss given by:

$$\alpha = \frac{2.9 \times 10^7\, d_1^2\, d_2^2}{(d_1 + d_2)^2\, f^2 A^2 \left(\cos\frac{\theta}{2}\right)^2} \qquad [10]$$

and in dB,

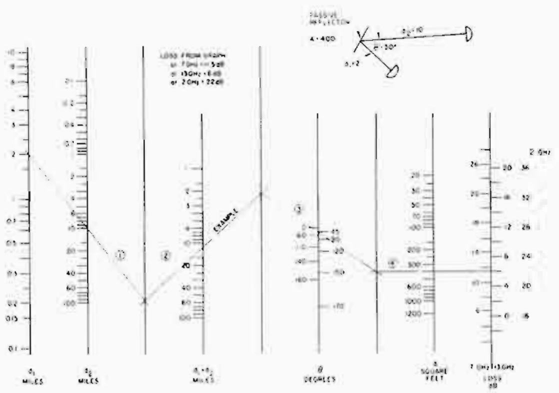
$$a = 74.6 + 20\log d_1 + 20\log d_2 - 20\log(d_1 + d_2) - 20\log f - 20\log A - 20\log\cos\frac{\theta}{2} \qquad [11]$$

A solution to Equation 11 is given in Fig. 24. When back-to-back antennas are used a coupling loss of 3 dB is included. To increase the gain of the two dishes a low noise TDA (tunnel diode amplifier) is sometimes used between the antennas. Performance calculations are best left to the manufacturer because of possible overloading of the TDA. The path is analyzed in the same manner using Fig. 24 as a passive repeater except the πr^2 area of the parabola used is multiplied by 55 percent efficiency, and $\frac{\theta}{2}$ is zero degrees.

The beam width of the flat billboard passive reflector repeater is given by:

$$\Upsilon = \frac{58.7}{fL} \qquad [12]$$

where: Υ = Beam angle in degrees
f = Frequency in GHz
L = Projected length of a side in feet (width X $\cos\frac{\Upsilon}{2}$)



PASSIVE REPEATER LOSS RELATIVE TO DIRECT TRANSMISSION OVER D_1+D_2

Fig. 24. Passive repeater. (Courtesy of Microflect Corporation.)

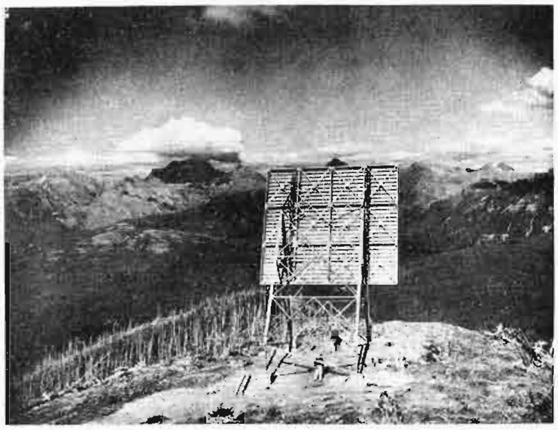


Fig. 25. Passive repeater loss nomogram relative to transmission over d_1 and d_2.

Because the passive repeater does not require maintenance or operating costs, its use should not be overlooked when designing microwave systems. See Fig. 25 for a typical passive repeater 30 X 32 feet in area. Passive repeaters are available in a wide range of areas from about 8 X 10 to 40 X 60 feet.

PROPAGATION

Experimental work with microwave dates back to the 1930s, but it was not until about 1950 that practical systems were first installed. There are many modes of propagation: line-of-sight, diffraction, and scatter. Only line-of-sight will be discussed here.

Microwave propagation takes place in the first few hundred feet of the atmosphere which is called the troposphere. Many physical characteristics of the troposphere affect propagation, and it is well to discuss these characteristics before attempting to further investigate microwave propagation.

Free Space

Most discussions on propagation relate to a model which exists in free space with no obstructions and no tropospheric variations. Free space attenuation represents the loss between two isotropic antennas spaced at a distance d. The loss between two antennas is represented by the ratio of the power transmitted, P_t, to the power received, P_r. Referenced to isotropic antennas, the attenuation α may be derived from Equation 2 as:

$$\alpha = \frac{P_t}{P_r} = \frac{(4\pi)^2 d^2}{\lambda^2} \qquad [13]$$

In decibels,

$$\alpha = 20 \log \frac{4 \pi d}{\lambda} \qquad [14]$$

If λ is expressed as frequency (f) in GHz and d in statute miles the attenuation is:

$$\alpha = 96.6 + 20 \log f + 20 \log d \qquad [15]$$

At the three frequencies used by broadcasters a may be closely approximated by:

2 GHz

$$\alpha = 103 + 20 \log d \qquad [16]$$

7 GHz

$$\alpha = 114 + 20 \log d \qquad [17]$$

13 GHz

$$\alpha = 119 + 20 \log d \qquad [18]$$

Equation 15 is used in the transmission calculations discussed later.

Fresnel Zones

In the early 1800s August Jean Fresnel, the French physicist, made important discoveries in the field of optics and in the wave theory of light transmission. Since microwave propagation is similar to light, his theories are used today by microwave engineers.

Fresnel established that the equivalent free space transmission energy seen at receiving point distant d from the transmitter is contained in an elliptical volume the size of which depends upon wavelength and distance. He further discovered that energy reflected to the receiver from points outside this volume reinforced or cancelled the energy from within the volume depending upon how far the reflecting points are outside the volume. By further experimentation he found that if the distance traveled by energy outside the elliptical volume is an odd number of one-half wavelengths longer than the direct distance between transmitter and receiver, the received signal was reinforced; but if the difference was an even number of wavelengths, the effect was cancellation. From his work, the concept of Fresnel zones was established.

The first Fresnel zone boundary is defined by a loci of points representing all possible paths one-half wavelength longer between transmitter and receiver than a straight line. The second, and interfering, Fresnel zone boundary is defined

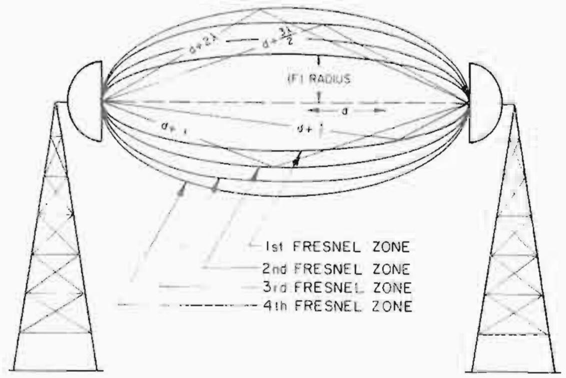


Fig. 26. Fresnel zones.

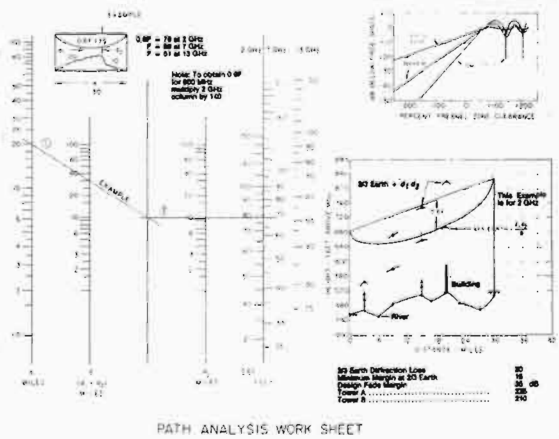


Fig. 27. Path engineering worksheet.

by path differences of one wavelength, the third by one and one-half wavelength, etc. This concept is shown in Fig. 26.

The microwave engineer is interested in the Fresnel zone radius at any point in the microwave path where there is an obstruction or highly reflective surface. If the obstruction blocks more than 40 percent of the first zone, attenuation will result, and if energy is reflected from an even number Fresnel zone, cancellation will occur. As the beam clearance is varied the signal will vary as shown in Fig. 27.

Because the microwave signal attenuation depends upon the situation in the Fresnel zones, it becomes necessary to determine the first Fresnel zone radius at any point along the path. By geometry the following equation is derived,

$$F = 72\sqrt{\frac{d_1 d_2}{fd}} \qquad [19]$$

where: F = First Fresnel zone radius—feet
d = Microwave path length—miles
d_1 = Distance from transmitter to point of calculation—miles
d_2 = Distance from receiver—miles
f = Frequency—GHz.

Other Fresnel zone radii can be calculated by multiplying Equation 19 by the square root of the Fresnel zone number. A nomographic solution to Equation 19 is shown in Fig. 27.

Diffraction

Francesco Grimaldi first noted and commented on light diffraction in a paper published posthumously in 1665. His work, followed by Newton and Fresnel, related the phenomena to wave theory in 1819. Fraunhofer classified the lines of the spectrum with a diffraction grating in 1821. If the ray theory is used, diffraction is the bending of rays over an obstruction due to Fresnel zone interference as discussed earlier. When an obstruction blocks all or part of the Fresnel zone, the energy received in the shadowed area is a function of the height of the obstruction and its shape. A sharp knife edge type obstruction blocks much less energy than a smooth sphere. These variations of received energy over different obstructions account for terms such as knife edge diffraction and obstacle gain. If the signal is diffracted over several successive obstacles the total loss is the sum of the diffraction losses over each obstacle. Fig. 27 may be used to calculate these losses.

Refraction

The velocity of propagation is a function of the medium through which the wavefront of energy passes. In microwave transmission the useful wavefront may extend several hundred feet above the surface of the earth. The atmosphere or troposphere varies with height in density depending upon temperature, water vapor, and pressure. Normally the temperature, water vapor, and pressure decrease with height and the density also decreases. Thus the energy in the upper part of the wavefront travels faster than the lower and the energy between transmitter and receiver is refracted (bent) downward.

Under "abnormal" weather conditions, one or more characteristics of the troposphere might increase with height so that the microwave energy is refracted upward. Such a condition occurs fairly frequently when radiational cooling lowers the earth's surface temperature below that of the atmosphere above. This phenomenon is known as an inversion.

Occasionally, the characteristics of the troposphere might first decrease then increase and, finally, decrease again with height. Such conditions result in a propagation phenomenon known as ducting. Ducting is usually associated with weather fronts.

The degree of refraction varies with time of day and year and upon the weather at different geographic locations and elevations. Most of the time the microwave energy is refracted downward. Engineers have found it convenient to think in terms of straight beams or rays of energy propagated over a model earth with varying radius. Under normal tropospheric conditions, the energy beam can be thought of as straight if the earth's radius is increased to 4/3 true earth radius. For other conditions, true earth radius is multiplied by a factor K. Thus, we hear terms such as 4/3 earth, 2/3 earth, etc., as descriptions of propagation conditions.

When microwave energy is propagated over the earth, refraction affects the path clearance or degree of obstruction by the earth's surface. Over smooth flat earth the distance to the geometric horizon is given by,

$$d = \sqrt{\frac{3Kh_t}{2}} \qquad [20]$$

where: d = Distance to horizon in miles
h_t = Height of transmitting antenna in feet
K = Constant to account for degree of refraction.

Because K is normally 4/3 in microwave transmission, the horizon is extended beyond the geometric horizon obtained when K is equal to 1.

Under conditions of upper ducts or dense layers, microwave energy may be refracted strongly enough to appear as a reflection. This situation sets up Fresnel zone interference patterns. As the elevated layer moves up and down, the receiver signal strength varies widely as shown in Fig. 27. This condition is known as multipath fading.

Reflection

When microwave energy impinges on a smooth surface, it is reflected much as light is reflected from a mirror. When reflected, the energy undergoes a 180° phase shift such that it tends to cancel the directly received energy if the reflection is from even numbered Fresnel zones. Reflected energy from odd numbered Fresnel zones reinforces the directly propagated energy. The degree of cancellation or reinforcement depends upon the coefficient of reflection and shape of the reflecting surface. Reflection from a knife edge is nil, while reflection from the smooth earth covered with salt water approaches 100 percent efficiency. Most dry land surfaces with vegetation are considered rough; however, wet vegetation makes a good reflector. Reflection obeys Snell's law which states that the angle of reflection must equal the angle of incidence.

Absorption and Scattering

In the microwave spectrum below about 10 GHz, very little energy is absorbed or scattered by rain drops in the atmosphere. As frequency is increased above 10 GHz, the size of the rain drops becomes appreciable in comparison to the wavelength of the energy and significant absorption and scattering occurs. Fog, snow, and other similar tropospheric conditions do not absorb significant amounts of energy at frequencies below 13 GHz, although inversions and ducts accompanying these conditions might otherwise affect propagation.

The size of irregularities on the earth's surface affect the coefficient of reflection and degree of scattering. Likewise, the conductivity of the earth's surface affects the coefficient of reflection and degree of absorption. Thus energy impinging on a smooth sea or salt water flat is highly reflected, while energy impinging on a dry rocky surface is scattered and absorbed.

In the upper microwave frequency bands (above 10 GHz) the effect of absorption by rainfall must be considered. The following empirical formula can be used to estimate attenuation due to rainfall at 13 GHz.

$$a = 1.5Rd \qquad [21]$$

where: a = Attenuation due to rainfall
d = Distance along path covered by rain in miles
R = Rate of rainfall in inches per hour.

This formula is an approximation but can be used for design of 13 GHz systems.

Maximum rainfall rates vary widely with geographic location and along a path from one location to another. Average rainfall over a path of 10 miles may be only 40 percent that at a point of maximum rainfall rate in the path. Existing data show that for 0.01 percent of the time maximum rates of rainfall at a point vary with geography by 20 times from 0.25 in. per hour at Corvallis, Oregon, to 5 in. per hour at Miami, Florida. With such wide variations, it is difficult to give a rule-of-thumb for design purposes. If one designs for 0.01 percent annual rainfall outage on a 10 mile path, a maximum rainfall rate of 2 in. per hour will be adequate in most locations. A check with the local weather bureau might prove useful when designing 13 GHz paths.

Tropospheric Variations

For a fixed set of tropospheric conditions, prediction of the level of a received microwave signal is relatively easy using the principles discussed in foregoing sections. Unfortunately, the troposphere is a continually varying medium which in turn causes frequent variations in the level of the received microwave signal.

Standard conditions are defined by a well-mixed and turbulent troposphere with a negative height gradient (pressure, temperature, and water vapor) resulting in microwave beam curvature (refraction) equivalent to straight line transmission over an earth with a radius 4/3 times true earth. If the center of the microwave beam clears all terrain obstructions (allowing for 4/3 earth radius) by at least 0.6 first Fresnel zone radius, the microwave attenuation is equal to that in free space.

Tropospheric variations from standard vary with geography, time of day, time of year, and weather. Variations also occur from year to year. Dry and cool weather normally result in a standard troposphere at midday. Areas with prevailing strong winds have a standard troposphere most of the time. Standard tropospheric conditions prevail most of the time in areas with low rainfall (southwest US). Areas with heavy rainfall and/or wide variations of diurnal temperature often have a nonstandard troposphere with widely varying temperature, pressure and water vapor gradients with height—the southeastern US and Gulf Coast are typical of such areas. Prevailing weather conditions in the remaining areas of the US result in tropospheric conditions somewhere between the standard in the southwest and extreme nonstandard in the southeast and along the Gulf Coast.

Radiation cooling lowers the temperature near the earth such that the troposphere temperature rate of decrease at higher elevations is less than that near the earth. This reversal of standard temperature gradient conditions results in less refraction of a microwave beam toward the earth, and may result in refraction away from the earth when the temperature gradient is negative. During the same period of the year, the upper part of the troposphere may cool faster in the early evening hours than the earth's surface which was warmed during the day. This early evening upper elevation cooling increases the refraction of a microwave beam toward the earth such that the "radio horizon" is extended several times further than when standard conditions prevail. During the summer in many areas of the country, increased microwave refraction toward the earth (surface duct) occurs in the early evening followed by refraction away from the earth in the early morning. Both conditions can seriously degrade or disrupt microwave communications unless allowed for in the system design.

Weather fronts often result in nonstandard tropospheric conditions. Either refraction away from the earth or increased refraction toward the earth may result depending upon the type of weather front and prior weather conditions. For example, a warm front moving in over an area covered with snow can result in increasing temperature with altitude and refraction away from the earth. On the other hand a cold front can result in greater refraction toward the earth.

Elevated weather conditions occur at a frequency depending upon the geographic location. During these abnormal conditions, refraction may be standard near the earth, but substandard several hundred feet above the earth. Standard refraction near the earth results in normal line-of-sight microwave transmission, while super refraction high above the earth results in additional energy reaching the receiver which either adds or subtracts from the direct beam depending upon phase or difference in distance traveled. This condition is sometimes called an elevated duct.

Since the refraction gradient is a function of rate of change in pressure and water vapor as well as temperature and variation of these parameters is not always related to temperature in a constant matter, weather conditions other than those discussed can cause changes in the gradient. Since such changes are usually less severe than those discussed, special precautions are not usually necessary for these less frequent conditions.

The microwave transmission engineer should acquaint himself with weather variations expected in a given area and then make allowances for the extremes in his design. The degree to which varying tropospheric conditions degrade a microwave signal depends somewhat on the terrain of the earth as well as the weather.

Earth Terrain

Because microwave propagation occurs in the lower part of the troposphere, the earth's surface with or without irregularities affects the attenuation. Standard propagation conditions prevail relative to the effect of the earth, when the center of the microwave beam has adequate clearance over a rough and dry surface. The microwave transmission engineer must consider variations from this standard. A rough dry surface will absorb and scatter microwave energy, while a smooth reflective surface will act as a mirror.

The criteria for roughness is a complex problem which among other things is a function of wavelength or frequency of the microwave energy being propagated. In addition to roughness, the reflection coefficient of the surface is important. In microwave work a smooth sea is a good example of a highly reflective smooth surface—the Rocky Mountains are a good example of a rough, low-reflection area. As a rule-of-thumb, if the microwave beam passes over water, salt flats, desert or marshland, significant reflections are likely to occur. Whether or not such reflections affect propagation depends upon whether or not the reflected energy reaches the receiving antenna as determined by Snell's law and plane geometry. On the other hand, transmission over woodlands, mountains and farm lands does not usually produce surface reflections, which have a pronounced effect on propagation, unless there is dew or rain on heavy vegetation. Transmission in highly populated areas can be unpredictable because possible reflections from buildings, tanks, etc., can cause unexpected degradation of signal.

Another important variation from standard conditions is the shape of an obstruction in paths with less than 0.6 first Fresnel zone radius clearance. If the obstruction is a single mountain or building, attenuation is considerably less than when the obstruction is smooth earth or a series of mountains or buildings. In the first case, propagation occurs by diffraction over the single obstacle, while in the second case, propagation is supported by a series of diffractions and losses over each obstruction. The amount of attenuation is a function of the size of the obstruction relative to the Fresnel zone radius rather than the absolute size in feet.

When the center of a microwave beam clears earth terrain obstructions by more than 0.6 first Fresnel zone radius, the attenuation between the transmitter and receiver may be greater or less than standard depending upon both shape and reflection coefficient of the obstruction, as well as the amount of clearance relative to Fresnel zone radius. If the obstruction is knife edge and/or rough and nonreflective, the variation in attenuation as clearance is increased and is negligible, but if the surface is smooth and highly reflective, attenuation may vary in accordance with Fresnel's theory alternately from 6 dB less to infinitely greater than standard free space values.

Because of refraction in the troposphere, the effective clearance above obstructions may be more or less than that determined by absolute measurements. As discussed earlier, the effective clearance is normally greater than that measured over a true earth model because of downward refraction. Fig. 27 shows variations of attenuation from the free space model for smooth, average, and knife edge conditions as a function of beam clearance. For convenience, clearance is shown as a percentage of first Fresnel zone radius.

Fading

Variation of attenuation versus time is called fading. The foregoing discussions treat independently the various mechanisms and variations of propagation. In an actual installation, one, some, or all of these conditions may prevail independently or simultaneously. Fading is of two general types: multipath or earth bulge (below average refraction) and may exist independently or together.

Multipath fading is characterized by rapid variations in received signal level between stronger than standard and less than standard values. In general, the duration of these variations decreases with frequency, but the frequency of the variations increases with signal frequency. Interference results from either an out of phase reflected or refracted signal combining with the direct line-of-sight signal at the receiving antenna. Because the refractive index of the troposphere is constantly changing, the interfering signal alternates between reinforcement and cancellation of the directly propagated energy. At a given instant of time, fading (cancellation) may or may not occur depending upon frequency and receiver antenna location. Because effective path clearance either above the earth or below an elevated duct is a function of Fresnel zone radius and refractive index, a geometric layout and analysis of the transmission path will show the relationship with frequency and antenna location. When multipath fading is caused by reflected energy from the earth's surface, the depth of the fade depends upon the reflection coefficient of the obstruction; if it is caused by refracted energy from an elevated duct, the fade depth depends upon the refractive index. As a practical matter, depths may exceed 50 dB in severe cases, but are less than 40 dB in most cases.

There are several ways to combat multipath fading. These include frequency diversity, space diversity, or by greater fade margin obtained by increasing power, antenna sizes, or receiver sensitivity. If two microwave beams are propagated with a frequency difference of 4 percent or more, experience and calculations indicate that the signal level into both receivers rarely reaches a minimum at the same time. If two receivers with antennas physically located sufficiently far apart (usually vertically) are used, experience and calculations indicate that the energy from a single transmission beam rarely reaches a minimum at both receivers simultaneously. If a device (combiner or switch) is bridged arcoss the two receiver outputs, which constantly selects the strongest signal, either frequency or space diversity can significantly reduce interference fading. As the normal non-faded received signal is increased above the minimum usable signal level (higher fade margin), the amount of time the system is disrupted is decreased. The approach or combination of approaches to multipath fade reduction is usually determined for each case and is a function of economics and the fading mechanism predicted.

Earth bulge (inverse beam) fading may be reduced by increased beam clearance or increased fade margin or both. Neither space nor frequency diversity has an appreciable effect on this type of fading. Increased beam clearance might increase multipath fading caused by reflections, and unfortunately, transmission paths with high earth bulge fading might also have high multipath type fading. Actual beam clearance is usually a compromise which is assisted with higher fade margins (40 dB or better).

High-low antenna techniques are sometimes effective for multipath interference fading caused by surface reflections and are of some value in earth bulge fading. This technique involves varying the height of the transmitting or receiving towers in order to shift the point of reflection. In general, if one antenna is high and the other low, fading of both types is minimized. If a transmission path crosses water located in the reflection zone, increasing the height of one tower and reducing the other will shift the point of reflection toward the lower antenna and in some cases to a zone of rough terrain which has a lower reflection coefficient. This technique is useful but not always feasible because of high cost or other restrictions on the higher tower.

For upper tropospheric layer refraction type multipath fading, optimum space diversity antenna spacing is not well understood, but the following equation, which assumes fading reflections, are from the second Fresnel zone, has proven satisfactory in many cases:

$$S = 25\sqrt{\frac{d}{f}} \qquad [22]$$

where: S = Spacing in feet
d = Path length in miles
f = Frequency in GHz.

Space diversity will often be necessary on over water paths, and spacing of only 25 percent that of Equation 22 will be helpful.

When transmitting over smooth terrain, multipath fading is often a result of interference from surface reflections. In this case, space diversity has proven very effective in reducing outage time. See Fig. 19 for an analysis of how to design this type of space diversity. Optimum spacing between antennas is given by,

$$S = \frac{1300\, d\,(\text{miles})}{h_T\,(\text{feet})\, f\,(\text{gigahertz})} \qquad [23]$$

If the spacing obtained from Equations 22 or 23 is not feasible because of economics, spacing of as little as 50 percent of the optimum value will be helpful. See Fig. 19 for explanation of Equation 23.

Fading Predictions

A statistical distribution attributed to the English physicist Lord Rayleigh is used widely in predicting fading outages in microwave systems. Multipath type fading follows the Rayleigh distribution. Fig. 28 shows the maximum amount of multipath fading anticipated for a given fade margin. Many measurements taken over the years show this value forms an outside limit for multipath fading in most areas, although in some areas fading time has exceeded that in Fig. 28. If adequately separated frequency or space diversity is used a minimum of 10 dB improvement is obtained, or outage time is reduced by about one-tenth—usually more.

In a system containing many paths in tandem, the probability of two paths fading simultaneously is small, but, of course, increases with the number of paths. In most practical systems, the total outage time of the system is equal to the sum of the outages for each path of the system. This summation applies to multipath fading only.

Earth bulge is characterized by long periods of low signal level and does not follow a Rayleigh distribution. In addition such fading might be in addition to multipath fading. Design precautions against earth bulge fading include a separate analysis of each path with an assumed re-

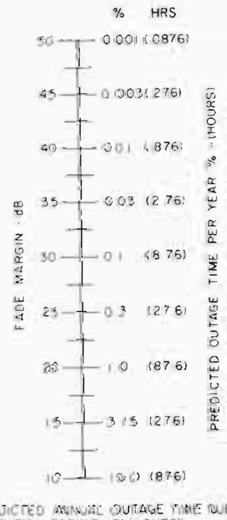


Fig. 28. Reliability versus fade margin.

fractive index equivalent to $K = 2/3$ or less in the southeastern US. From knowledge of the weather and type of obstruction in the path, one of the three height-gain curves of Fig. 27 may be used to determine maximum earth bulge fade depth. The fade margin should be at least 15 dB above the maximum expected earth bulge loss to allow for simultaneous multipath refraction from elevated ducts. Achievement of this fade margin might require larger antennas, higher towers, a shorter path, or a combination of all three.

PATH ENGINEERING

Path engineering consists of plotting the course of the microwave beam from one end of the system to the other including repeater stations, plotting elevation profiles for each path, station site selection, field survey, tower height calculations and a propagation analysis of each path to determine required fade margins. In many cases the path for an STL is short and little or no engineering is necessary. In others considerable time and analysis must be spent to insure reliable operation.

Map Study

The first step requires obtaining topographic maps for the area and locating all known stations. Aeronautical maps are useful for first approximations. Geological Survey maps are useful for map profiling. Using the maps, the microwave path is plotted and path profiles made including estimates for trees and man made obstructions. Towers are plotted to provide a minimum of 0.6 Fresnel zone clearance over 4/3 earth for 1 and 2 GHz systems, and full Fresnel zone clearance for 7 and 13 GHz systems. Trial and error methods are used until the most economical solution is obtained. In multihop systems, the hops should be zigzagged to avoid overshoot interference.

After the profiles are complete, a propagation analysis should be made to determine if the proposed solution will provide reliable operation. This analysis is described in the propagation section and shown in Fig. 27.

Field Survey

Before proceeding with station construction, the profiles are checked by a field survey. At the same time availability of land is checked. The field survey may be accomplished by hiring a land surveyor, or by the use of surveying altimeters which must be checked frequently against bench marks. If bench marks are not available known elevations can often be found on highways or railroads. Two altimeters are often used with one left at the bench mark with its reading recorded every 15 min or so for use in correcting the other unit being used on the microwave path. Complete instructions are included with the altimeter which may be purchased from American Paulin System, 1524 Flower Street, Los Angeles, California.

Fig. 27 is a work sheet including all information necessary to engineer and analyze the path. A supply of these sheets will be helpful throughout the path engineering project.

Most equipment manufacturers are prepared to contract for the path engineering task. Likewise, consulting engineers may be hired to do the task. The choice of do-it-yourself or by contracting is left to the broadcaster. In recent years the problem of obtaining the necessary permits for construction is the largest obstacle to building a microwave system.

Field Report

After the field work is complete an engineering report is prepared including survey notes, profiles, tower heights, site locations, and propagation analysis to determine desired fade margin. With this information the project is ready for system transmission calculations.

Propagation calculations may be made with the assistance of the work sheet in Fig. 27. The profile is plotted using any convenient scales. Controlling obstacles are adjusted for both 4/3 (normal) and 2/3 (abnormal) propagation conditions (see points at 9, 15 and 20 miles in Fig. 27). The first Fresnel zone radius (0.6 for 1 and 2 GHz) is calculated (use nomogram in Fig. 27) at each of these points. Antenna heights are selected to clear each obstacle by at least the required Fresnel zone radius. Next, the first Fresnel zone (0.6 for 1 and 2 GHz) is sketched as shown in Fig. 27. Under 2/3 earth conditions the clearance over each obstacle is determined in percentages of first Fresnel zone (8 percent at 15 miles and -30 percent at 20 miles in Fig. 27). From the loss curves in Fig. 27 using the average values, the loss at 15 miles (8 percent clearance) is 8 dB and at 20 miles (-30 percent clearance) is 12 dB which gives a total diffraction loss of 20 dB. If the rule of 15 dB margin above 2/3 diffraction loss is followed, a total fade margin of 35 dB is required in the example. The small loss due to the obstruction at 9 miles is ignored. If the frequency is at 13 GHz, the fade margin calculated should be modified to account for expected rain attenuation using Equation 21.

TRANSMISSION CALCULATIONS

After all path data are available, transmission calculations can be made to determine antenna size, type of feeders and any other equipment characteristics necessary to meet specified performance.

The basic transmission equation to determine fading margin is:

$$FM = P_T - (\text{Transmitter plus Receiver Coupling losses}) + G_T - a + G_R - \text{Field allowance loss} - P_R \text{ (threshold)} \quad [24]$$

where:
FM = Fade margin in dB
P_T = Transmitter power—dBm
G_T, G_R = Antenna gains—dB
a = Free space loss—dB
P_R = Improvement threshold power—dBm.

A solution to Equation 24 is given in Fig. 22 in a form which should greatly reduce the time for calculations. Completion of this work sheet will completely describe basic equipment characteristics and path performance. A supply of these work sheets will be helpful to the microwave design engineer.

The use of Fig. 22 is best explained by following through an example. From Fig. 27, the required fade margin for propagation reliability is 35 dB which is plotted on Column 1 in the nomogram. From the equipment curve in Fig. 22, threshold (32 dB S/N) occurs at a receiver input of -78 dBm, which is plotted on Column 2. Connecting these two points together gives the operating receiver input level in Column 3 (-43 dBm). From the equipment specification, the transmitter power is 2 watts, which is plotted in Column 5. By connecting Columns 3 and 5, the net path loss (NPL) is determined in Column 4 as 76 dB. This NPL represents loss between transmitter output and receiver input ports of the equipment. The frequency of the transmitter is plotted in Column 6 as 2 GHz. The path length in miles is plotted in Column 7 as 30 miles. Columns 6 and 7 are interconnected to intersect at a reference point on Column 8. This point on Column 8 is connected through the net path loss of 76 dB in Column 4 to a reference point in Column 9. The coupling losses are calculated in the table in the lower right corner of Fig. 22 as 9.7 dB and plotted on Column 10 of the nomogram. A line drawn from the reference point on Column 9 through the coupling loss on Column 10 will give the required product of antenna diameters (95) on Column 11. Thus two 10-ft. antennas are required.

Other sequences may be used to determine any unknown—for example, fade margin if antennas are known. In any sequence, plot all known values on appropriate columns. Draw lines to determine unknowns. Rather than use the work sheet in Fig. 22, some engineers prefer to tabulate Equation 24 as follows. The numbers shown are for the example in Fig. 22.

Free space loss (Equation 16, 17, or 18) 30 mi.	-132.6 dB
Feeder loss—transmitter	-2.7 dB
Feeder loss—receiver	-3.7 dB
Diplexer loss	-1.3 dB
Passive reflector loss/gain, transmitter	0 dB
Passive reflector loss/gain, receiver	0 dB
Field allowance	-2.0 dB
Total losses	-142.3 dB
Plus antenna gain, transmitter (10 ft.)	+33.4 dB
Plus antenna gain, receiver (10 ft.)	+33.4 dB
Net path loss	-75.5 dB
Plus transmitter power	+33.0 dBm
Receiver input level*	-42.5 dBm
Less receiver threshold	-78.0 dBm
Fade margin*	35.5 dB
Signal-to-noise (from equipment specification curve in Fig. 22)	62.5 dB

*One-half dB greater than Fig. 22 because two 10-ft. antennas are slightly larger than required from Column 11 of Fig. 29.

TELEVISION MICROWAVE EQUIPMENT TESTING

Microwave equipment is set up and tested in the factory as a system before shipment. All values specified are checked and equipment is adjusted for best performance. After installation all tests are redone on an over-the-air system basis. Since operating procedures for microwave equipment from different manufacturers varies, the instruction book should be referred to for specific setup and testing procedures. In addition to the brief measurement discussions presented here, the reader is referred to instruction books for the test equipment used for detailed information on method measurement.

Initial Setup

Before performing individual tests, a preliminary checkout and readjustment is advisable. To perform this test, the transmitter and receiver of each hop are connected together through an attenuator to simulate over-the-air transmission path loss (NPL)—an attenuation value of 70 dB or less is normally used in the factory, but the value calculated in Fig. 22 may be used for the field check. The attenuator should be variable up to 115 dB to check the threshold performance of the receiver. A waveform generator (Telechrome 3508 or equivalent) is connected to the input of the microwave transmitter in the system. A waveform monitor (Tektronix 529, or equivalent) is connected to the output of the microwave receiver (to preserve correct termination, check that the waveform monitor is terminated in 75 ohms). See Fig. 29 for test setup. The following procedure is followed:

1. Connect transmitter to receiver through attenuator pad (70 dB);
2. Connect main power to equipment and turn on;
3. If the microwave is built for multiple frequency operation, turn channel selector switches on transmitter and receiver to same channel;
4. Connect test equipment as shown in Fig. 29;
5. Compare meter readings on both transmitter and receiver with factory test data sheet;
6. Check receiver discriminator meter reading, and, if necessary, adjust transmitter frequency for zero meter reading (use internal receiver meter);
7. Set waveform generator for window signal and adjust level for 1-volt sync peak to window peak signal as observed on waveform monitor;
8. Check transmitter power output using internal meter reading or external power meter for same value as on factory test sheet;
9. Check and adjust if necessary transmitter FM deviation, using procedure in microwave equipment instruction book;
10. Check receiver sensitivity by noting that the AGC meter reading is the same as factory test data sheet for 70 dB path loss;
11. Check receiver signal outputs (usually two) for 1.0 volt output on waveform monitor—adjust if necessary; and
12. Vary attenuation between transmitter and receiver and note that AGC meter reading in receiver agrees with factory test data sheet.

Multiburst Test

The multiburst signal is used to observe the medium and high amplitude—frequency characteristics of the system. The signal generator (Fig. 29) is set for a multiburst output which consists of a peak white pulse (1.0 volt from sync peak to pulse peak) called the white flag, followed by six sine-wave bursts at frequencies of 0.5, 1.5, 2.0, 3.0, 3.6, and 4.2 MHz. This series of signal bursts are observed on the monitor for one horizontal line interval (62 microseconds or at a 15.750 kHz rate). While the multiburst signal is not a complete check on frequency response, if all bursts are within two to three percent of the one volt reference, the equipment is functioning properly with a medium and high frequency response within 0.2 to 0.3 dB of reference value. See Fig. 30 for a typical waveform, and see Fig. 31 for a waveform at the output of a system with a rising frequency response.

Window Signal

With the waveform generator of Fig. 29 set at window signal a good check on several system characteristics may be made, including:

1. Level check—peak-to-peak signal level (usually 1 volt);
2. Observation of low frequency response by checking tilt (roll off) of the window signal. Waveform monitor should be set for two field observations, tilt should be 1 percent or less of the 1 volt reference signal. See Fig. 32;
3. Ringing check (transient response) measured by observing the amplitude of any oscillation following rise or fall of the window signal pulse. The amplitude of such ringing is usually less than 2 percent in a good microwave system; and
4. System low frequency hum measured by observing the amplitude of low frequency modulation on the two field window signal as a percentage of reference level of 1 volt. In a good system, hum level is less than 0.5 percent and is not noticeable on the waveform monitor. (See Fig. 32.)

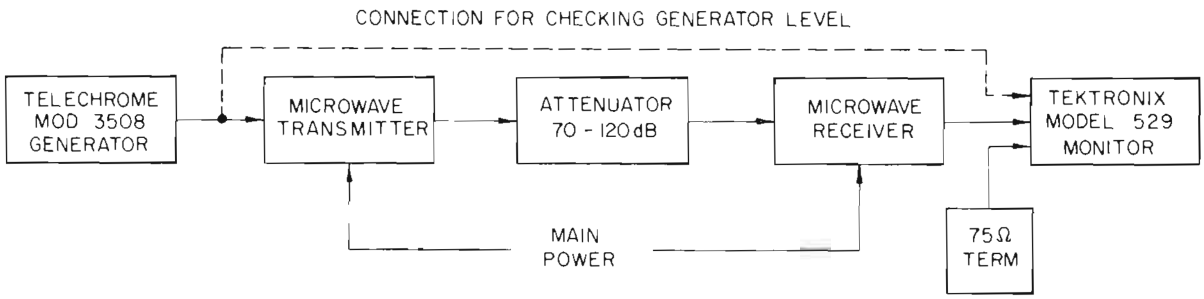


Fig. 29. Test setup for initial checkouts. Differential gain and multiburst measurements.

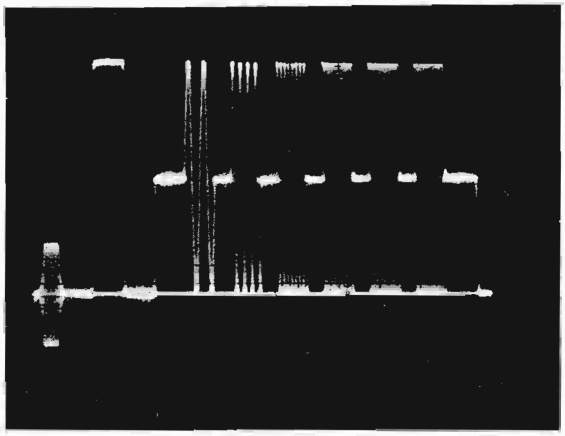


Fig. 30. Input multiburst signal.

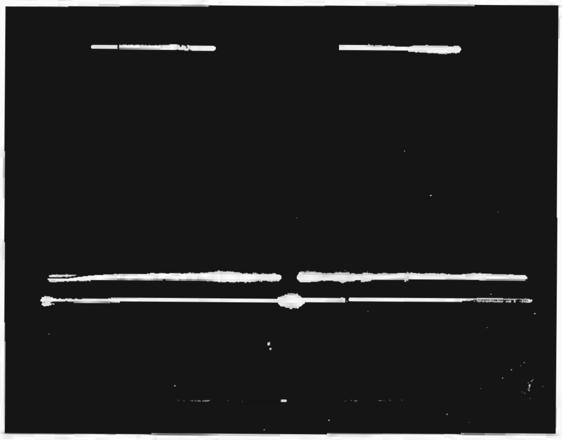


Fig. 32. Two field window signal.

Pulse and Bar Test and Transient Response

The transient response of the microwave system is important to prevent ringing of the video signal and resultant multiple echo effects on the picture. It is measured by using the pulse and bar test, which consists of a modified window signal plus a $\sin^2$ pulse (see Fig. 33). The $\sin^2$ pulse has no significant energy content above a frequency equal to $1/T$ (where T equals width of pulse at mid amplitude). Since the leading and trailing edge of the bar have a rise and fall equal to the $\sin^2$ pulse, it too has low energy content at frequencies above $1/T$. The pulse and bar input signal is obtained from the waveform generator (see Fig. 29), and the pulse for a 4 MHz system may be either a T pulse 0.125 microseconds or a $2T$ pulse 0.250 microseconds as measured at its 50 percent amplitude. The T is equal to $\frac{1}{2F}$ where F is equal to the highest frequency of the system—about 4 MHz for an NTSC system.

The pulse and bar test is an important measurement because the bar gives a good indication of high frequency performance. Poor low frequency response will show up as tilt of the bar and poor high frequency response will show up as decrease in amplitude of the pulse and increase in pulse width. Phase distortion in the system will show up as skewing of the pulse. Poor transient response will be observed as ringing on the trailing edge of the pulse and on the peak of the leading edge of the bar as well as the bottom of the trailing edge of the bar. The $2T$ pulse (energy up to 2 MHz) gives an evaluation of the lower frequencies (0.5 to 2.0 MHz) in the system, while the T pulse gives an evaluation of the upper frequencies (2.0 to 4.0 MHz). Fig. 34 shows a system oscillogram for a $2T$ pulse at the output of the microwave receiver in a system with good transient response.

To assist in evaluating the transient response of the system, a special graticule is available for the waveform monitor which outlines an envelope into which the pulse must fit (see Fig. 34). Along the baseline, two envelope limits are included:

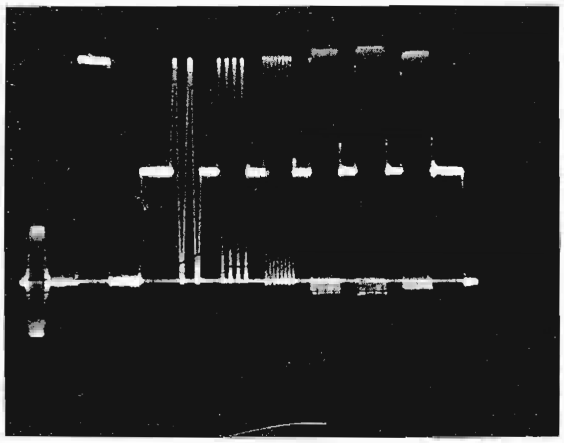


Fig. 31. Output multiburst signal with rising frequency response.

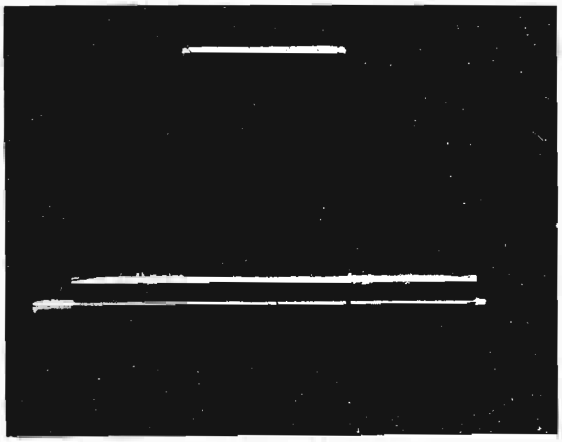


Fig. 33. Pulse and bar signal.

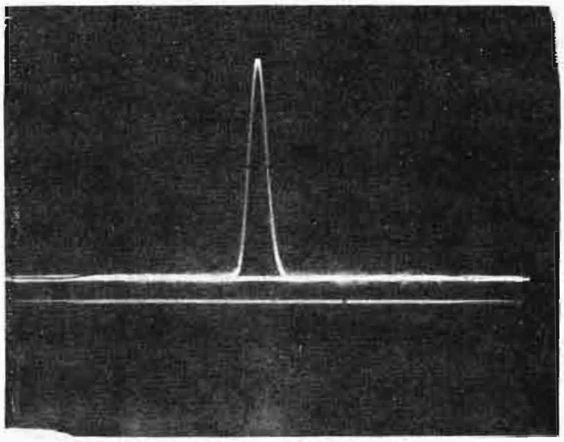


Fig. 34. System output 2*T* pulse (250 microsecond).

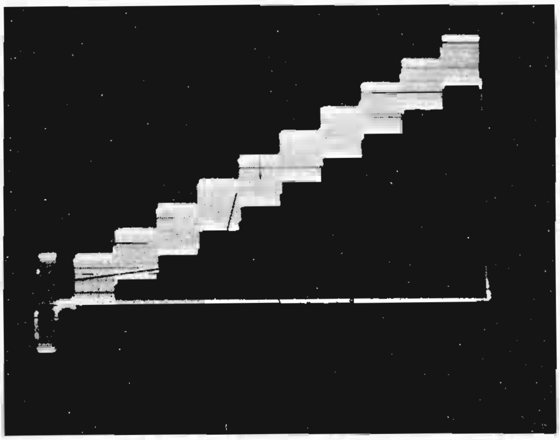


Fig. 36. Stairstep signal plus 3.58 MHz subcarrier.

one representing a 2 percent ringing and the other a 4 percent ringing, which represents the maximum allowable amplitude of the ring as compared to the pulse.

The test is usually made with a 2*T* pulse but for good microwave systems the *T* pulse ringing will also stay well within these limits, and the 2*T* pulse ringing will not exceed 1 percent. The results of these tests are called the *K* factor which is specified as 1 percent, 2 percent, etc. See Fig. 34 for a normal *T* pulse at the microwave receiver output.

The pulse and bar test is especially useful for giving a quick overall check on most important characteristics of the microwave system. With experience, maximum information regarding frequency response, phase distortion, and transient response may be determined.

Differential Gain

Differential gain at 3.58 MHz (color subcarrier frequency) is important in a color TV transmission system because excessive differential gain will cause changes in amplitude of the 3.58 subcarrier as the luminance signal varies from black to peak white. Differential gain is measured by transmitting a stairstep signal through the system. It is called stairstep because the change from black to white is effected by 10 step changes in level. See Fig. 29 for test setup and Fig. 35 for an oscillogram of the stairstep.

System linearity may be quickly checked by noting whether or not the steps as viewed on the waveform monitor at the receiver output are all of equal amplitude. To measure differential gain, the stairstep signal is modulated with a 3.58 MHz signal (see Fig. 36). Differential gain at 3.58 MHz is measured by determining the maximum difference in level of the 3.58 MHz modulated signal between the various 10 steps of the stairstep signal. For convenience in measurement, the receiver output is connected through a low pass filter in the waveform monitor which removes the stairstep and leaves only the 3.58 MHz subcarrier. Differential gain is determined by noting the difference in amplitude of the subcarrier bursts as viewed on the waveform

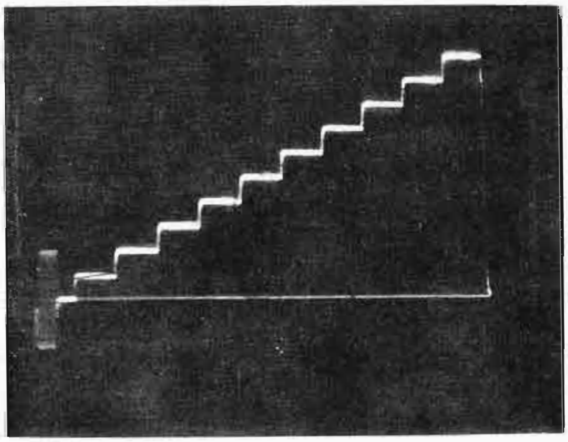


Fig. 35. Stairstep signal (no modulation).

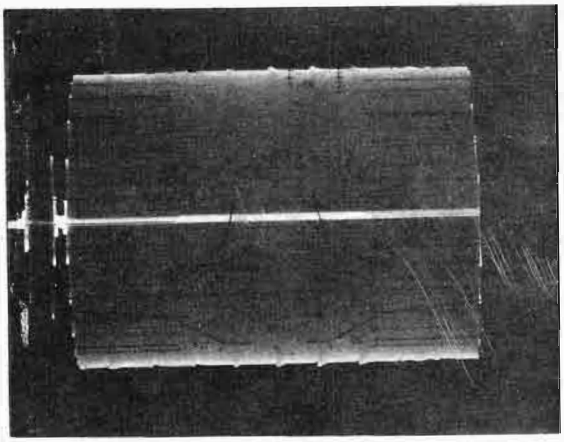


Fig. 37. Differential gain measurement at 50 percent APL.

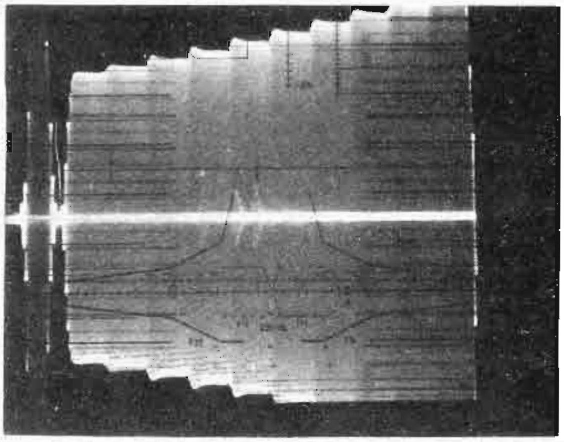


Fig. 38. Excessive differential gain at 50 percent APL.

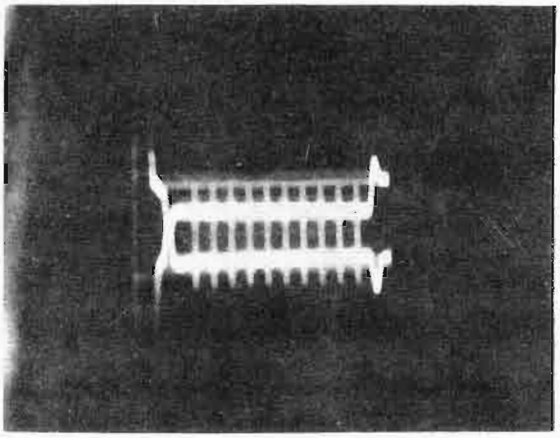


Fig. 39. Differential phase (0.6 degrees).

monitor. See Fig. 37 for an oscillogram from a good system and Fig. 38 for an oscillogram from a system with almost 10 percent differential gain.

Differential gain is usually specified at 10 percent, 50 percent, and 90 percent APL (average picture level). These measurements are made as discussed above with the waveform generator set in turn to each of the picture levels. Fig. 38 is 50 percent APL.

Differential Phase

Differential phase affects hue of the color picture and represents changes in phase of the 3.58 MHz subcarrier as video luminance level changes from black to peak white. It is measured by transmitting the stairstep signal from the waveform generator plus 3.58 MHz subcarrier through the system. Differential phase is measured using a phase detector built into a vectorscope (Tektronix 520) to compare the phase of the waveform generator reference signal with the phase of the 3.58 MHz subcarrier signal transmitted through the system on the stairstep. The test setup in Fig. 29 is used with the high impedance vectorscope connected in parallel with the waveform monitor. Differential phase is measured directly in percentages on the waveform monitor by noting a dial reading corresponding to phase adjustment of the reference signal to zero out the differential phase of the transmitted signal as viewed on the vector scope. Fig. 39 is an oscillogram with excessive differential phase.

Differential phase is measured at 10 percent, 50 percent, and 90 percent APL. It should be less than 0.5° at all picture levels.

Video Signal-to-Noise

Video signal-to-noise is measured as the ratio in dB of peak signal level (usually 1 volt) to rms noise. The test setup for measuring signal-to-noise is shown in Fig. 40. Note that low frequency noise is attenuated by the EIA filter and hum reject filter. To make the measurement, first check that gain through microwave system is unity (1 volt input and output), and then measure rms value of noise on the voltmeter. Signal-to-noise is determined from 20 log of the ratio of peak signal to rms noise voltage. The value of signal-to-noise usually exceeds 60 dB.

Equipment Gain

To determine the equipment gain or maximum net path loss of the equipment (approximately 78 plus transmitter power in dBm for most systems) the value of the path attenuator should be increased until the S/N decreases to 32 dB (minimum acceptable value). Use of MTA (microwave transistor amplifier) or TDA (tunnel diode amplifier) will result in 4 to 5 dB improvement

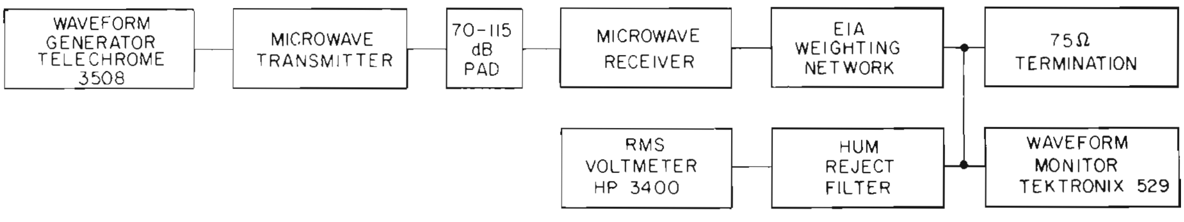


Fig. 40. Test setup for measuring video signal-to-noise.

in receiver threshold. The amount of attenuation used to obtain 32 dB S/N is the equipment gain figure.

Video Signal-to-Hum

This measurement represents the ratio in dB between peak signal level (usually 1 volt) and peak hum level. The test setup in Fig. 29 is used except a low pass hum filter is inserted ahead of the oscilloscope. Although the Tektronix 729 Waveform Monitor may be used for this measurement, the sensitivity is not adequate for a precise observation. It is recommended that any high gain oscilloscope be used in place of the waveform monitor for this test. With the waveform generator disconnected the peak-to-peak hum level is observed on the oscilloscope. The video signal to hum ratio in dB is calculated from 20 log (ratio p-p signal to p-p hum). Typically the ratio exceeds 46 dB.

Audio Channel Measurements

The audio channel (TV or 950 STL) frequency response is measured by the point-to-point method using an audio signal generator at the input and an rms voltmeter at the output of the system. The response from 50 Hz to 15 kHz should be better than specified in EIA Standard RS 250A.

The audio channel signal-to-noise is measured using a HP 650 generator set at rated level at the input of the transmitter and an HP 3400A rms meter at the receiver output. For an audio channel transmitted on a subcarrier above video, a window signal should be transmitted through the video channel to simulate actual operating conditions which can result in crosstalk from video to audio channels. The audio signal-to-noise should exceed 60 dB, including any crosstalk from the video signal, in most microwave systems.

The audio channel distortion is measured by connecting a signal generator (HP 650A) set for rated level to the transmitting input and a distortion meter (HP 333A) connected at the receiver output. With the transmitter set for rated modulation, the receiver is set for rated output level. The distortion meter (set at the measuring frequency) reads total harmonic distortion. Measurements are made at frequency intervals between 50 Hz and 15 kHz (see EIA RS 250A). Distortion in most systems will not exceed 1 percent at all frequencies.

While making all audio measurements, the use of correct terminating impedances should be strictly observed. Experience shows that the most frequent problem with audio measurements is incorrect termination—follow test equipment instructions carefully.

MULTIPLE HOP MEASUREMENTS

After the equipment has been checked in accordance with the aforementioned procedures on a per hop basis, it is then connected together as a system and rechecked on a systems basis. For multiple hop systems the procedure as given previously cannot always be followed on a hop-by-hop basis because the repeater equipment may not have audio/video separation equipment or pre- and deemphasis circuits. For these reasons multiple hop systems may have to be checked directly on a systems basis without performing the per hop test. Each situation will have to be decided on its own merits, and close adherence to the manufacturer's test instructions is recommended. During the multiple hop test at least the RF characteristics of the microwave equipment at each repeater should be checked by varying a path loss attenuator to determine receiver sensitivity and equipment threshold characteristics. The S/N of a multiple hop system is usually degraded by 10 log n dB from the single hop S/N, where n is the number of hops. Likewise other characteristics such as frequency response, diferential phase, and differential gain may also degrade on a 10 log n basis. It is common practice to recheck the multiple hop system on an end-to-end basis after installation is complete.

MAINTENANCE OF MICROWAVE SYSTEMS

Along with the trend to all solid state systems maintenance procedures have changed completely during the past few years. Previously system reliability depended heavily upon frequent maintenance checks and logging of various meter readings from which many tube failure predictions could be made. From records of these preventive maintenance checks, vacuum tubes were replaced and equipment realigned as necessary. In many systems preventive maintenance was required on a weekly basis.

Since the advent of solid state equipment, preventive maintenance checks have been dropped from the operating procedures. The broadcaster keeps an adequate supply of spare modules as recommended by the manufacturer. In the event of equipment failure the faulty module is isolated quickly using built-in metering. It is then replaced by a spare module, and in well-designed systems no realignment is required. The faulty module may be repaired either at the broadcaster's repair facility or may be returned to the manufacturer. The latter practice is recommended because the manufacturer is more experienced and better equipped to restore the faulty module to its original performance characteristics than the broadcaster. Field experience shows that the cost of spare modules for today's solid state equipment is much less than the cost of maintenance technicians for yesterday's tube equipment.

Most equipment in a microwave system other than electronic gear, such as towers, antennas, feeders, power supplys, etc., requires very little maintenance. In the case of towers and lighting, the FAA has certain requirements regarding painting and observation that the tower lights are working. The reader is referred to the FAA Rules and Regulations for more detail on this requirement.

The reliability and life of solid state equipment is somewhat dependent upon the operating temperature and the variation between temperature extremes. Investment in air-conditioning equipment can be economically justified on the basis of fewer equipment problems. In most areas, the low temperature extremes are not severe enough to require heating in the winter except for the comfort of any personnel who may be working in the area.

REFERENCES

1. Alvira, A., & Corbell, I. T., "Reliable Microwave System Parameters," *Power Apparatus and Systems,* Institute of Electrical and Electronics Engineers, December 1955, pp. 1100-1107.
2. *Microwave Path Engineering Considerations,* Lenkurt Electric Company, San Carlos, California, September 1961.
3. EIA Standard RS-250-A, *Electrical Performance Standards for Television Relay Facilities,* Electronics Industries Association, Washington, D.C., February 1967.
4. *Television Signal Analysis,* Second Edition, American Telephone and Telegraph Company, Long Lines Department, April 1963.
5. Documents of the XIth Plenary Assembly, Volume IV, CCIR, International Telecommunication Union, Geneva, Switzerland, 1967.
6. *The Lenkurt Demodulator,* Second Edition, Lenkurt Electric Company, San Carlos, California, 1966.
7. *Reference Data for Radio Engineers,* 5th Edition, International Telephone and Telegraph Corporation.
8. *Planning and Engineering of Radio Link Paths,* 6th Edition, Siemens and Halske Aktiengesellschaft, Munich, Germany, March 1961.
9. Egli, J. J., "Radio Relay System Engineering," *Proceedings of the IRE,* January 1953.
10. Hogg, D. C., "Statistics on Attenuation of Microwave by Intense Rain," *Bell System Technical Journal,* November 1969.
11. Jakes, W. C., Jr., "A Theoretical Study of An Antenna—Reflector Problem," *Proceedings of the IRE,* February 1953.

22

Television Signal Analysis[1]

Revised by
Network Transmission Committee
of the
Video Transmission Engineering Advisory Committee
(Joint Committee of Television Network Broadcasters and the Bell Telephone System)

This chapter has been prepared as a general reference for technical employees who are concerned with the analysis of television signals. Such analysis has as its purpose a determination of the quality of the signal as received at various points along its transmission path; and, if signal impairment appears, a diagnosis of its probable cause. This would naturally lead to the taking of corrective measures as may be indicated.

It is clear that, to have any significance, the observation of signals requires the use of monitoring devices that are always capable of giving a faithful representation of the actual signal on the line. Correct adjustment and proper maintenance of these devices must, therefore, be assumed. Granting this, any observed deficiency in the signal must either be present in the output of the camera equipment or be the result of failure of the transmission system to carry the signal without distortion from its point of origin to a distant monitoring point.

To properly discharge his responsibilities, the technician must know how the signal delivered by the camera looks in comparison with the signal which he is receiving. If this comparison indicates that undue distortion is being introduced by the transmission system, he may wish to compare his received signal with the signals received by other monitors back along the line in order to isolate the section of the transmission system that is at fault.

A single observer, of course, cannot make simultaneous observations of a signal at a number of different points. Comparisons, therefore, depend upon telephone communication between observers who may be located at widely separated points and who may be associated with entirely different communications or broadcasting organizations.

For such communication to be fully effective, it is necessary that the observing devices employed at all points be sufficiently alike to produce signal presentations that are directly comparable in kind. It is also necessary that all observers have a common understanding of what constitutes the normal signal presentation. Each observer should be able to recognize the appearance of the more usual types of signal impairments that may occur from time to time. In addition, skill in diagnosing the probable general cause of any observed impairment is highly desirable as a first step in facilitating the location and correction of the fault responsible.

It is obvious that effective communication between observers requires that each use a language that is readily understood by the others. The growing television vocabulary has tended to develop some confusion, with several different words or phrases being used for the same thing in many cases. In this booklet, an attempt has been made to select the particular words or designations that seem to have gained the widest acceptance.

Since the primary objective of this report is to promote common understanding of signal forms and their nomenclature, the following pages first discuss and illustrate satisfactory monochrome and color television signals as they appear in standard picture monitor and oscilloscope presentations. Various types of test signals and their uses are discussed, followed by the major video signal impairments. Each impairment is considered separately, with emphasis placed on significant features which are apparent when viewed on picture monitors and oscilloscopes. Finally a glossary of the more commonly used video terms is presented.

The information contained in this book is based on technical standards used in the United States. Much of it is also applicable to TV signals based on other standards.

Much of the photographic and descriptive material included has been prepared with the help of the Engineering groups of the American

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Broadcasting Company, the Columbia Broadcasting System, and the National Broadcasting Company, all of whom have been extremely cooperative. This chapter, then, endeavors to represent the viewpoints of both the broadcasting and telephone industries.

THE TELEVISION SIGNAL

A picture monitor in a broadcaster's studio or in a telephone company television operating center might depict a test pattern as shown in Fig. 1. This picture is free of discernible defects as evidenced by straight lines, undistorted circles and a complete range of grays.

The complete analysis of the picture signal, however, cannot be determined by the picture monitor alone. In the operation and maintenance of network television transmission, it is also necessary to analyze the signal using a cathode ray oscilloscope (A-scope). The A-scope permits the display of the voltage-time characteristics at the horizontal and vertical scanning rates.

Horizontal Scanning Interval

Fig. 2 is the horizontal video signal presentation of the monochrome test pattern of Fig. 1 as seen on the A-scope with a sweep rate of about 7,875 Hz (one-half the 15,750-cycle line rate). As shown, polarity of the signal generally displayed on A-scopes used in broadcasters' control rooms and telephone company television operating centers is "Black Negative."

The complete video signal for one scanning line (h), included between E and G, requires a time interval of 1/15,750 second or 63.5 microseconds. The horizontal blanking interval occupies nominally 11.11 microseconds of this time and the picture information, the balance of the time, or 52.39 microseconds.

The horizontal and vertical sync pulses, which synchronize the sweep circuits in the receiver with those of the camera, determine the timing of the scanning lines, thus accurately placing each element being scanned. The horizontal sync pulse is shown during the horizontal blanking interval, with a voltage level corresponding to D.

The picture brightness information varies between A and B, with the peak white amplitude of the picture at A and the peak black amplitude of the picture at B. In the case of test pattern signals, these peaks correspond to reference white and reference black levels, in which range it is expected that normal program picture information will fall. Any video voltage less than A will produce decreasing brightness until black is reached at B. Thus the region between A and B represents the picture brightness information. In terms of voltage, the instantaneous level corresponds to the brightness of the televised scene at that particular instant.

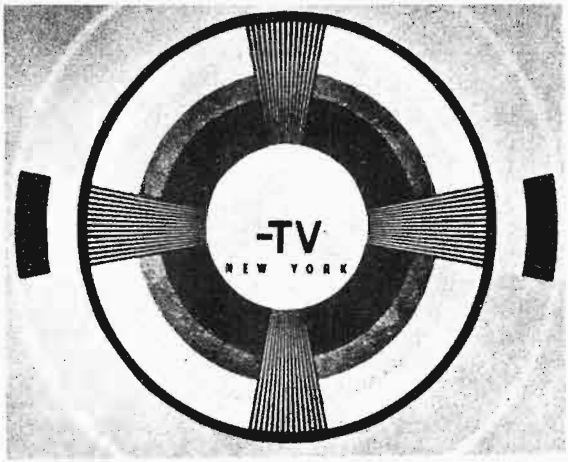

Fig. 1. Normal video signal—picture monitor presentation.

The "Setup" of the picture is the difference in voltage between the blanking and reference black levels, as indicated between C and B in Fig. 2. On the IRE scale, which has been adopted for industry-wide use, the setup value for network transmission is normally 7.5 IRE units.

It may be seen that if a picture has no black information, but only goes from white to gray, the black peaks will not approach black level as closely as they would if the picture contained full blacks. This picture would appear to have a high setup. On the other hand, black peaks should not extend below the reference black level. Broadcasters attempt to maintain a reference black in the picture during all transmissions to produce the most pleasing effect. FCC technical standards require that setup remain between 5 and 10 IRE scale divisions during

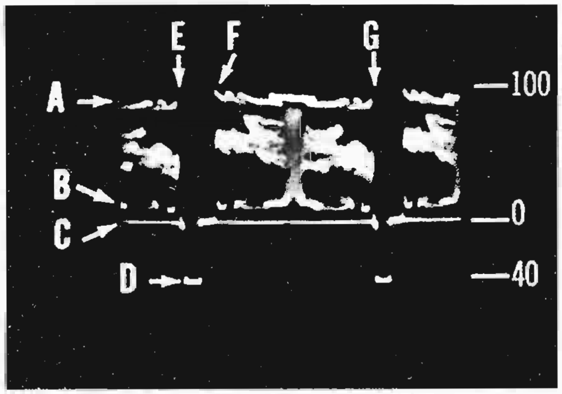

Fig. 2. Normal video signal—A-scope horizontal presentation: A. White peak; B. Black peak; C. Blanking level; D. Synchronizing level; E-G—Complete horizontal interval = 63.5 microseconds (μs); E-F—Horizontal blanking interval = 11.11 microseconds (μs); F-G—Picture signal = 52.39 microseconds (μs).

broadcast periods. Many studios are now equipped with electronic devices to maintain minimum setup leaving the studio.

Typical proportions for a one-volt peak-to-peak composite signal as displayed on an oscilloscope with an IRE scale are 40 divisions of sync, 7.5 divisions of setup and 92.5 divisions of picture information, as shown in Fig. 2.

Fig. 3 is an expanded view of the horizontal blanking interval with component parts, including the horizontal synchronizing pulse and adjacent signals identified. The nomenclature tabulated here, if universally used, will minimize confusion when tracing a signal impairment to its source.

The front porch isolates the synchronizing pulse from transients or overshoots in the video signal at the end of the scanning line. This is done in order that the synchronizing circuits in receivers or customer processing or stabilizing amplifiers will not be triggered prematurely, thus producing a picture with successive horizontal lines displaced in a sporadic manner causing jitter or possible tearing.

The leading edge of the sync pulse is used to synchronize the horizontal sweep oscillators in most monitors and receivers, and to trigger some clamping circuits. Excessive slope or curvature of the leading edge of the sync pulse, if sufficiently serious, may cause erratic or even complete failure of synchronization in monitors or receivers. It may also cause clamping failure in transmission equipment.

The tip of the sync pulse is used as the reference point in the dc restorers of monitors and

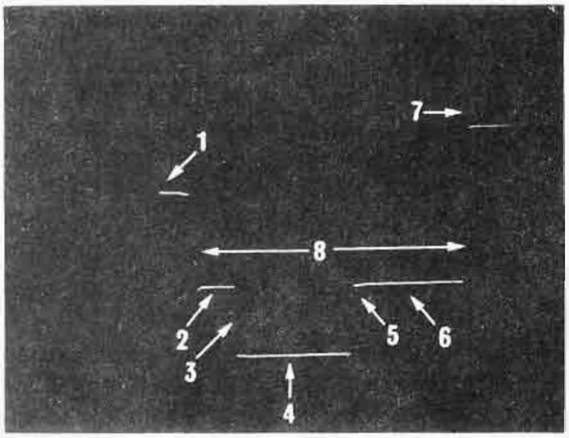

Fig. 3. Normal video signal—A-scope expanded horizontal presentation.

1. Video voltages at right side of picture;
2. Front porch = 1.59 μs or 2.5% horizontal interval (h);
3. Leading edge of sync;
4. Tip of sync = 4.76 μs or 7.5% h;
5. Trailing edge of sync;
6. Back porch = 4.76 μs or 7.5% h;
7. Video voltages at left side of picture;
8. Horizontal blanking interval = 11.11 μs or 17.5% h.

some oscilloscopes, and in the dc restoration or clamping stages of telephone company equipment.

A pulse derived from the trailing edge of the sync pulse is used to trigger the clamping circuits in most types of stabilizing amplifiers used by broadcasters. Serious slope or curvature of the trailing edge of the sync pulse will cause improper operation of these stabilizing amplifiers, causing tearing and rolling in the reproduced picture.

The back porch completes the horizontal blanking interval. If the operation of the sweep circuits of a monitor or receiver is considered, it will be apparent that when the electron beam has traversed the picture tube from left to right, it cannot return to the left side of the tube (retrace) instantaneously, but requires a small amount of time to do so. If picture voltages were allowed to begin immediately after the horizontal sync pulse, the picture components they represent would be visible during retrace. The duration of the back porch interval provides enough time for the sweep circuits to retrace completely, prior to the occurrence of the next line of picture information.

While the customers' processing or stabilizing amplifiers are triggered by the trailing edge of the sync pulse, they actually clamp during the back porch interval. This type of clamper-amplifier employs a time delay RC circuit which is generally adjusted to delay the start of the clamping action until sometime during the first quarter of the back porch interval. The clamping or reference level is usually an average of the voltage level during the first microsecond (one quarter) of the back porch interval. Therefore, if the back porch is seriously deformed or contains a large amount of noise, these amplifiers will clamp improperly, resulting in an impaired or useless picture to the customer although the picture may appear usable at the serving telephone office.

Vertical Scanning Interval

Fig. 4 is the video signal presentation of Fig. 1 as seen on the A-scope at the vertical scanning rate, approximately 30 Hz.

The levels of white peaks, black peaks, blanking and tip of sync indicated in Fig. 4 are of the same value on the IRE scale as shown for Fig. 2. The vertical synchronizing pulse, with the associated equalizing and blanking pulses, may be seen in the center of the picture. This presentation can reveal many of the common types of low-frequency trouble, such as clamping failures, 60- or 120-Hz interference or other serious signal distortions.

Fig. 5 is an expanded view of the vertical blanking interval with the component parts

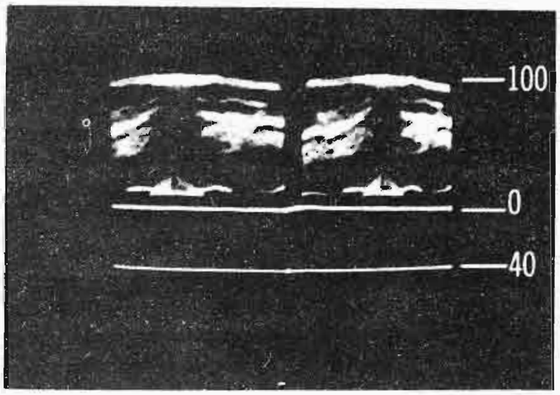

Fig. 4. Normal video signal—A-scope vertical presentation.

identified. Certain signal distortions that cannot be detected in the normal presentation may be seen in the expanded view.

The requirements imposed by interlaced scanning create the need for the equalizing pulses. The odd and even fields occur alternately at the rate of 60 fields per second. The first line of an odd field starts at the top left corner of the raster and the last line ends at the bottom center of the raster, while the first line of an even field starts at the top center of the raster and the last line ends at the bottom right corner of the raster. Therefore, it may be seen that if the vertical synchronizing pulse occurred immediately following the last horizontal scan, the vertical pulse integrator capacitor in a receiver would have a different residual charge depending upon whether the vertical sync pulse followed an even or odd field. The fact that the vertical synchronizing pulse occurs one-half line nearer a horizontal sync pulse following an odd field than when following an even field would result in imperfect interlacing if the first group of six equalizing pulses were not provided. These equalizing pulses preceding every vertical synchronizing pulse assure that the vertical pulse integrator capacitor in a receiver will have the same residual charge at the beginning of the vertical sync pulse, regardless of whether it follows an odd or even field. These six equalizing pulses each occur at one-half horizontal line intervals, which is twice the line frequency, or approximately 31,500 pulses per second.

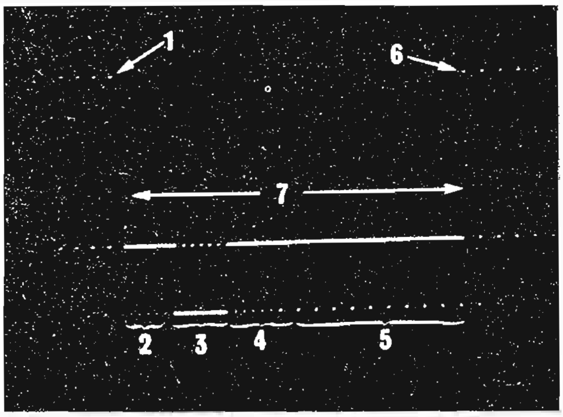

Fig. 5. Normal video signal—A-scope expanded vertical presentation.
1. Picture voltages, bottom of picture;
2. First group of 6 equalizing pulses;
3. Serrated vertical sync pulse;
4. Second group of 6 equalizing pulses;
5. Horizontal sync pulses;
6. Picture voltages, top of picture;
7. Vertical blanking interval.

The serrated vertical pulse has a duration of approximately three full lines. The serrations occur at the same rate as the equalizing pulses and keep the horizontal sweep oscillators in receivers and monitors synchronized and running smoothly during the vertical synchronizing pulse. Alternate serrations function as horizontal sync pulses.

The second equalizing pulse group follows the serrated vertical sync pulse. These equalizing pulses also occur at twice the line frequency. The first and second set of equalizing pulses, along with serrations of the vertical sync pulse, permit stable operation of the horizontal sweep oscillator for the two different horizontal line conditions between the odd and even, and between the even and odd fields.

The portion of the vertical blanking interval between the end of the second set of equalizing pulses and the first video information of the new field (5 of Fig. 5) is provided to allow time for the vertical sweep circuits in receivers to return the electron beam completely to the top of the raster before the video information of the new field starts. By adjusting the vertical hold control of the picture monitor and increasing the brightness, a presentation similar to Fig. 6 can be obtained. This shows the vertical blanking interval as a wide dark bar. The black bars within the vertical interval represent equalizing and vertical sync pulses.

NTSC Color

Fig. 7 represents the horizontal display of an NTSC color signal on a wide-band A-scope. As shown, the A-scope presentation is similar in appearance to that of a monochrome signal insofar as horizontal blanking, sync and picture information are concerned. The burst of high-frequency during the back porch interval represents the most distinguishing feature of the A-scope presentation of the color signal. This is the color sync burst, comprising 8 or 9 Hz of a sine wave signal of approximately 3.6 (3.579545) MHz.

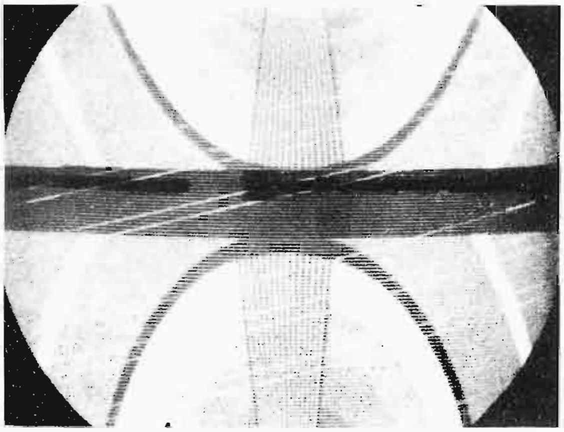

Fig. 6. Vertical blanking—picture.

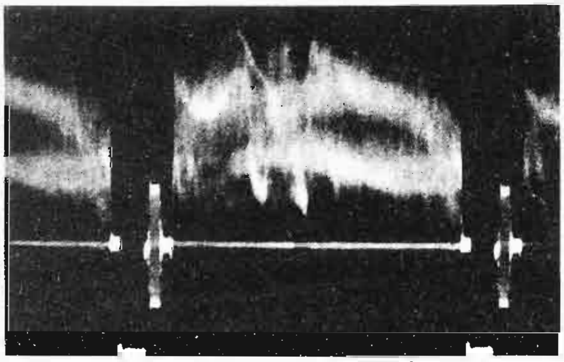

Fig. 7. Color signal—horizontal—wideband.

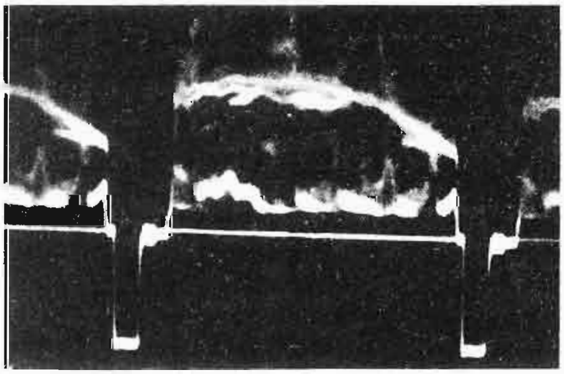

Fig. 8. Color signal—horizontal—IRE roll-off.

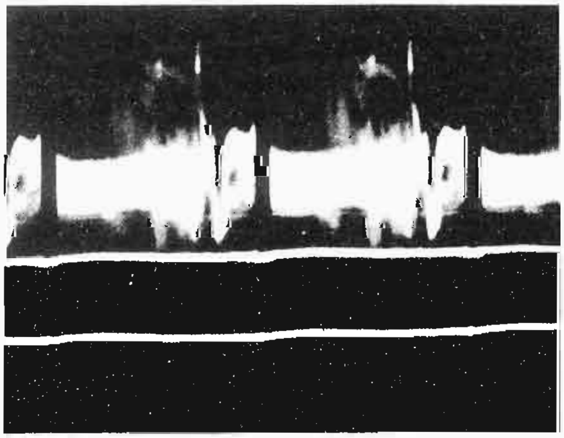

Fig. 9. Color signal—vertical—wideband.

The peak-to-peak amplitude of the color burst should be the same as the amplitude of the horizontal sync pulse, i.e., 40 divisions on the IRE scale. The color burst is centered at blanking level, and with respect to time starts about one-tenth of the total back porch interval from the trailing edge of the sync pulse. Another distinguishing feature is the presence of video information below black level, which varies with the hue and saturation of the colors being televised.

For color transmission the horizontal scanning frequency is 15,734.264 ± 0.044 Hz rather than the nominal value of 15,750 Hz. The vertical scanning frequency is 59.94 Hz rather than the nominal value of 60 Hz. The complete video signal for one scanning line requires a time interval of 1/15,734, or approximately 63.6 microseconds. The horizontal blanking interval requires approximately 11.1 microseconds of this time with the picture information utilizing the balance of the time, or 52.5 microseconds. This compares closely with the nominal intervals shown in Fig. 2 for the monochrome signal.

If an A-scope presentation of a color signal were expanded, the color information would be seen varying in amplitude according to the saturation of the colors being transmitted. By operating the A-scope with the IRE roll-off characteristic, the color signal appears as in Fig. 8, with practically all of the color information removed. The scope presentation shows mainly the luminance, or monochrome portion of the signal.

A-scope presentations of color signals at the vertical sweep rate, using either the wide-band or IRE roll-off characteristic, do not differ from the monochrome signal presentations except for the presence of the high-frequency color information. Such a presentation is shown in Fig. 9, with the A-scope in the wide-band position.

TELEVISION TEST SIGNALS

This section describes some of the test signals used in line-up and maintenance of television channels.

Sine Waves

Sine wave measurements are frequently used to determine gain-frequency characteristics of transmission channels. These signals are generally obtained from the 61B or 61C signal generator. The 70A or 70B power meter, a thermocouple instrument, is used for making the measurements. To provide accurate measurements at frequencies below 10 kHz, clamping circuits along the transmission path must be disabled. Simple sine wave measurements cannot be made where gating circuits are used, as in certain types of radio relay systems, to set the carrier rest frequency at the time of the horizontal sync pulse. In such cases, synchronizing pulses must be present for faithful reproduction of transmission conditions.

Monoburst

The name "monoburst" has been applied to the resulting composite signal which is illustrated in Fig. 10. The complete monoburst signal consists of single frequency sine waves plus sync pulses at the line rate, a blanking interval, and a means for varying the setup and the amplitude of the sine waves. The presence of sync enables the gating and clamper circuits to operate in their normal fashion. Monoburst signals are measured and interpreted by using a calibrated oscilloscope.

Window Signal

The window signal is a large square or rectangular white area with a black background. Fig. 11 is a typical broadcasters' window signal (with sine-squared pulse) viewed on a picture monitor. Figs. 12 and 13 show the horizontal and vertical presentations on an A-scope. The picture signal has two normal levels, reference black and white. The white level can be adjusted, but is usually set at reference white. In order to locate the maximum energy content of the signal in the lower portion of the total frequency band, the white area is adjusted to cover ¼ to ½ total picture width and ¼ to ½ total picture height.

The window signal is useful for a number of checks and tests when observed on picture monitors or A-scopes, including:

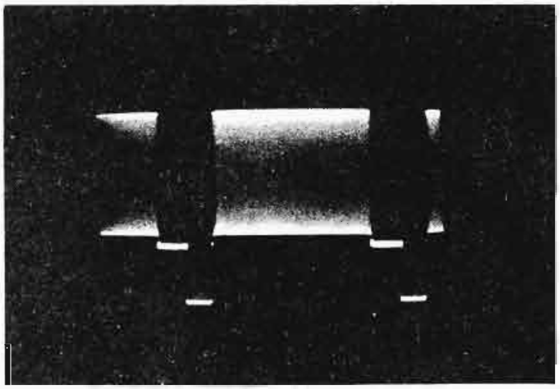

Fig. 10. Monoburst signal—horizontal.

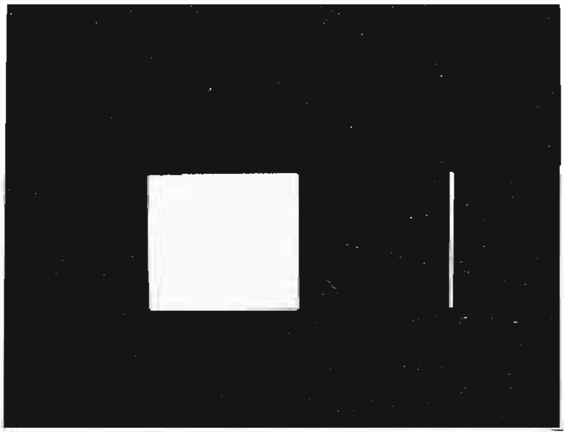

Fig. 11. Broadcaster's sine-squared window and pulse—picture.

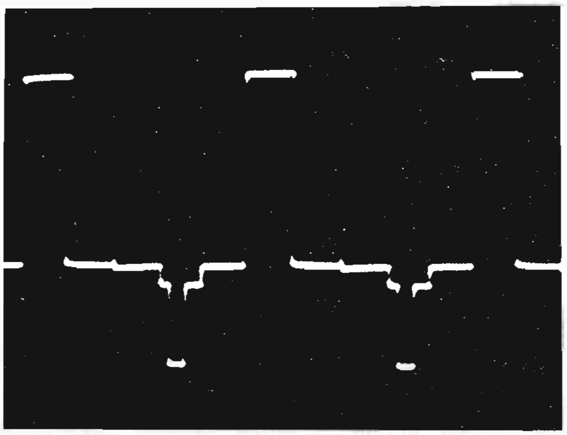

Fig. 12. Broadcaster's sine-squared window and pulse—horizontal.

1. Level or continuity check—Using a window of known white level, the peak-to-peak voltage of the signal may be read easily on a calibrated oscilloscope, using the IRE roll-off characteristic.

2. Measurement of sync compression or expansion—Comparison of the locally received

Fig. 13. Broadcaster's sine-squared window and pulse—vertical.

window signal with that of the office transmitting the signal with respect to horizontal sync and white levels on calibrated scopes using IRE roll-off permits accurate evaluation of these linearity characteristics at the receiving point, in order that necessary correction can be made.

3. Minimizing streaking—Observation of the test signal on scopes using the IRE roll-off characteristic at both vertical and horizontal rates enables evaluation of streaking so that adjustments can be made on clamper-amplifiers and low-frequency equalizers to minimize the impairment. When using a picture monitor for observation of streaking, it is essential to make sure that it is properly adjusted and free from internal defects which might give false indications.

4. Observation of ringing—The presence of ringing may be detected by using properly calibrated wideband scopes and expanding the horizontal presentation to a convenient scale. Ringing amplitude may be measured directly. Its frequency may be calculated by adjusting the horizontal gain of the oscilloscope until the width of sync (about 5 μs) covers 5 scale divisions. Then, by placing the ringing of the window on the horizontal scale with the centering controls, the approximate frequency (in MHz) can be determined by dividing the number of complete cycles by the number of divisions over which they extend. Ringing also may be seen on picture monitors.

The window signal generally used by the broadcasters contains both horizontal and vertical sync as in Figs. 11, 12, and 13. In this type of signal, the white window is adjustable in size both horizontally and vertically, and also is adjustable in position anywhere on the black background.

The window signal provided by most telephone company generators, such as the 61C signal generator, produces a white area adjustable in width from the left edge of the raster, with a black area in the remaining portion as shown in Figs. 14 and 15. Sync pulses are provided at the horizontal rate (15,750 per second). The window signal produced by the earlier model signal generator (61B) is similar (but not as suitable) to the 61C for streaking tests because the black and white areas are reversed. There is no adjustment of picture height for either the 61B or 61C white window, but by modulating these signals at a 60-Hz rate, by means available within the set, a window of approximately ½ the picture height can be obtained, as shown in Fig. 16. Horizontal and vertical A-scope presentations are shown in Figs. 17 and 18. Since none of these signals has vertical sync information, the vertical retrace of the monitor is not blanked, and the retrace lines

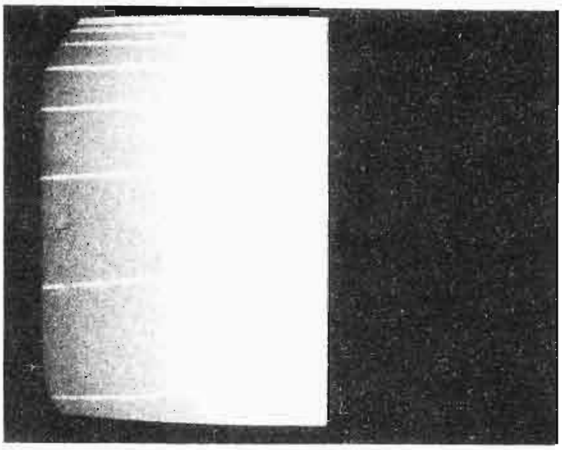

Fig. 14. 61C window signal—unmodulated—picture.

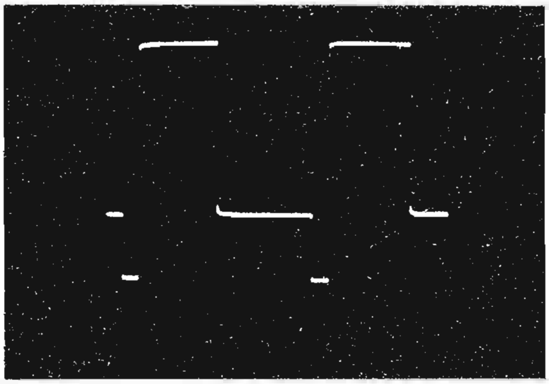

Fig. 15. 61C window signal—unmodulated—horizontal.

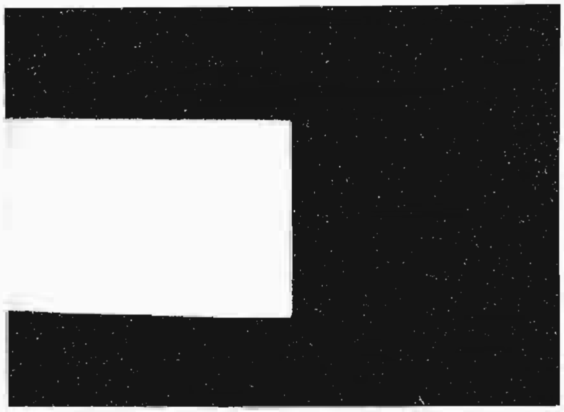

Fig. 16. 61C window signal—modulated—picture.

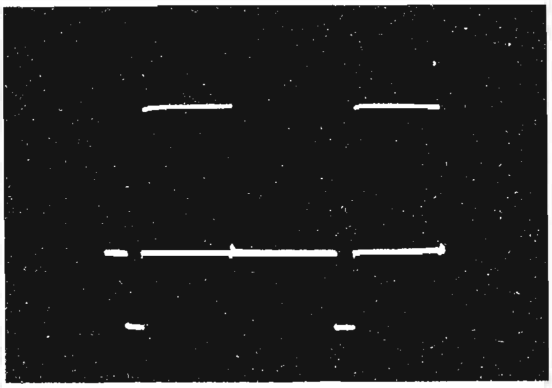

Fig. 17. 61C window signal—modulated—horizontal.

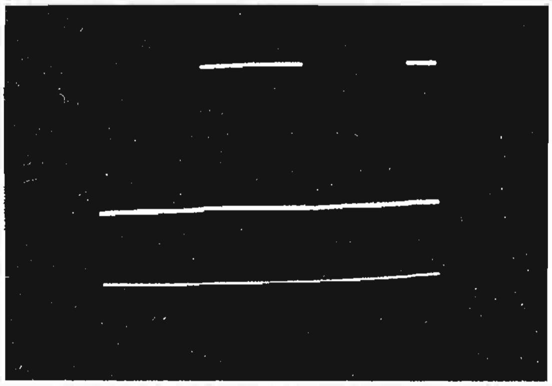

Fig. 18. 61C window signal—modulated—vertical.

are visible. This does not, however, interfere with observation of the waveform.

Sine-Squared Test Signal

Another test signal which has proved very useful is the sine-squared signal shown in Fig. 19. Use of this pulse permits an evaluation of amplitude vs. frequency response, transient response, envelope delay and phase. An indication of the high-frequency amplitude characteristic can be determined by the pulse height and width, and the phase characteristic by the relative symmetry about the pulse axis. The principal application of this pulse, however, is for checking transient response and phase delay. When the phase delay is not uniform with frequency, undesired overshoot or ringing may occur. The sine-squared pulse provides a sensitive check for this condition. Although the square wave signal has been used for this application in the past, it has serious shortcomings not found in the sine-squared signal. A square wave, having an almost infinite harmonic content, can indicate the presence of overshoot or ringing at frequencies so far beyond the transmission system bandwidth that they have no effect on picture quality.

The sine-squared signal by contrast, has a limited harmonic content and, when applied to a limited bandwidth system, will yield no irrelevant information. In addition, this pulse has the added advantage of closely resembling in wave form the output of a camera, since the electron beam has a density distribution which varies as a sine-squared function. The pulse used for checking television systems should have a repetition rate equal to the line frequency, and a duration, at half-amplitude, equal to one-half of the period of the nominal upper cutoff frequency of the system. Thus for a 4 MHz bandwidth the half amplitude width becomes 0.125 microseconds. The resulting spectrum distribution is then almost flat to 2 MHz, 6 dB down at 4 MHz and virtually zero beyond 8 MHz.

When this pulse is passed though a television system having gradual roll-off at the upper end of the pass band and constant delay with frequency, the pulse is transmitted with negligible distortion. If, however, there is increasing delay with increasing frequency, one or more overshoots will appear following the main pulse, as shown in Fig. 20. Conversely, decreasing delay with increasing frequency shows as overshoots or ripples preceding the main pulse. Under conditions of constant delay, but too rapid cutoff, overshoots will appear both preceding and following the main pulse.

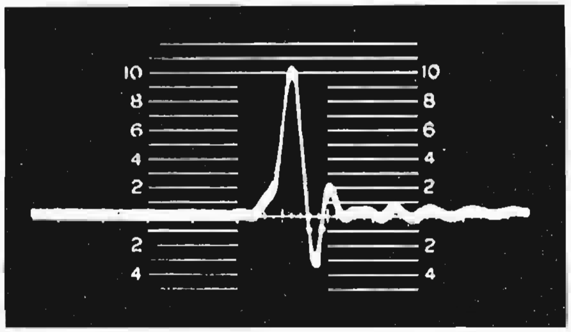

Fig. 20. Sine-squared pulse signal—signal impaired with severe phase delay.

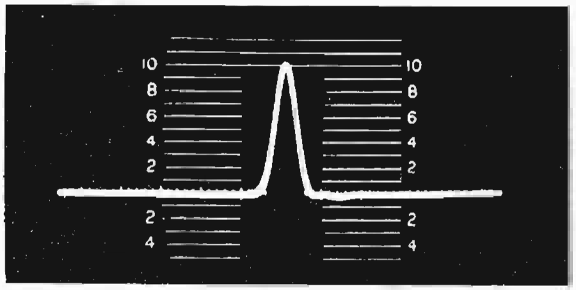

Fig. 19. Sine-squared pulse signal.

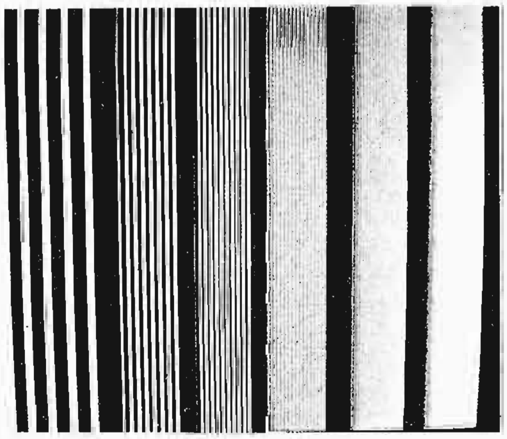

Fig. 21. Multiburst signal—picture.

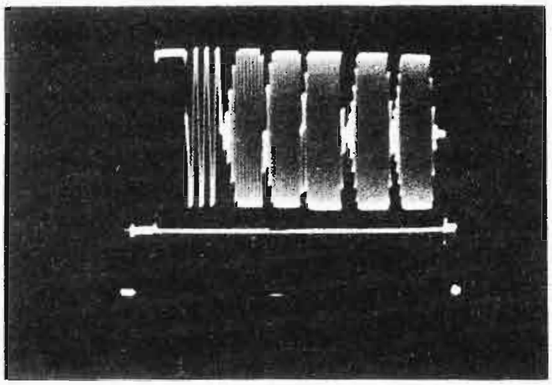

Fig. 22. Multiburst signal—horizontal.

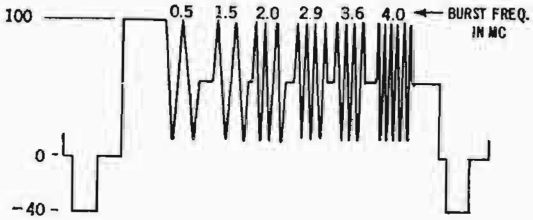

Fig. 24. Multiburst signal—horizontal—frequencies normally used.

It has been found that there is a very close relationship between the magnitude and number of cycles of ringing as observed on a picture monitor, and the amplitude and shape of the overshoots observed with the sine-squared pulse on a waveform monitor. It has become common practice to include the previously described window signal along with the sine-squared signal on the same scanning line as shown in Figs. 11 and 12. When this is done the transitions of the window signal are processed through the same shaping network that produces the sine-squared pulses. This arrangement does not introduce any additional high-frequency components.

Multiburst

A multiburst signal is used for a quick check of gain at a few predetermined frequencies.

One form of multiburst signal, illustrated in Figs. 21 and 22, consists of a burst of peak white (white flag) followed by bursts of six sine wave frequencies from 0.5 MHz to 4.0 MHz, plus a horizontal sync pulse, all transmitted during one line interval. The white flag provides white level reference. Fig. 24 indicates the burst frequencies normally used by the telephone company. Most broadcasters use frequencies of 3.0 and 4.2 MHz instead of 2.9 and 4.0 MHz. However, all the frequencies may be varied. Vertical sync information is usually provided in multiburst generators.

Some of the earlier models of multiburst generators do not include the white flag; that is, six sine wave bursts occupy the entire interval between sync pulses.

At the receiving point the signal is observed on an oscilloscope. For gain measurements, the peak-to-peak amplitudes of the individual burst are measured and compared. The accuracy of measurement is subject to the limitations of the oscilloscope. The principal uses are to observe:

1. Quick check of amplitude-frequency response.
2. Changes in setup.

Figs. 25 and 26 illustrate, respectively, gradual dropping and rising gain-frequency characteristics. These figures should be compared with the normal signal illustrated by Fig. 22. For information, the A-scope vertical presentation is shown by Fig. 23.

An arrangement has been made to facilitate identification of the originating source of a multiburst signal. All West Coast broadcasters will send 3 Hz of .5 MHz burst, as shown in Fig. 22. East Coast broadcasters will set up their generators with four Hz of .5 MHz

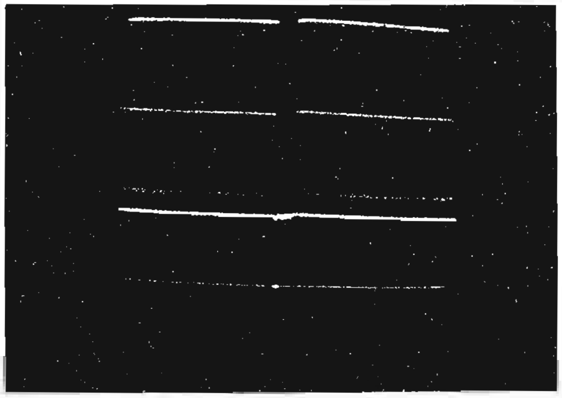

Fig. 23. Multiburst signal—vertical.

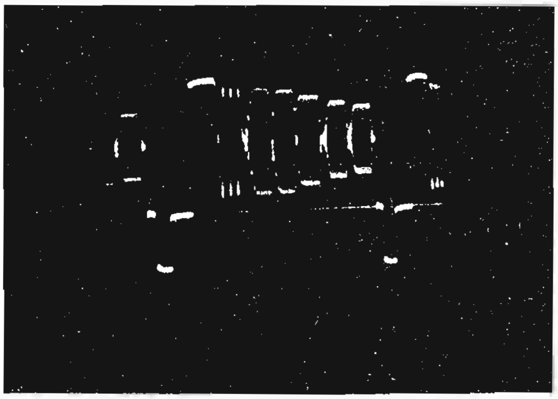

Fig. 25. Multiburst signal—horizontal—impaired with gradual loss of higher frequencies.

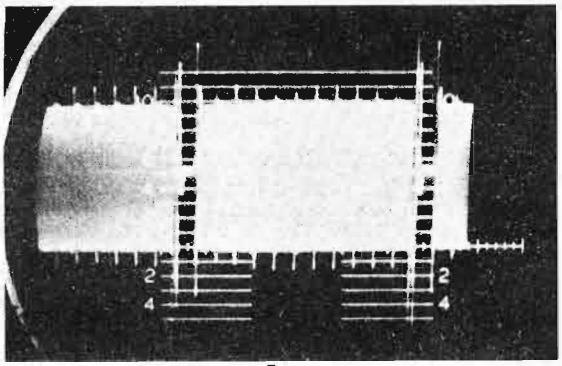

Fig. 26. Multiburst signal—horizontal—impaired with gradual gain at higher frequencies.

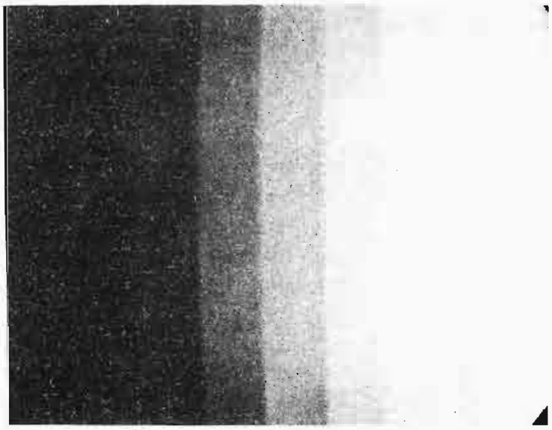

Fig. 27. Stairstep signal—picture.

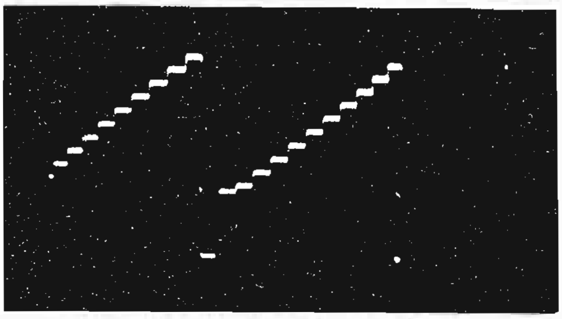

Fig. 28. Stairstep signal—unmodulated—horizontal.

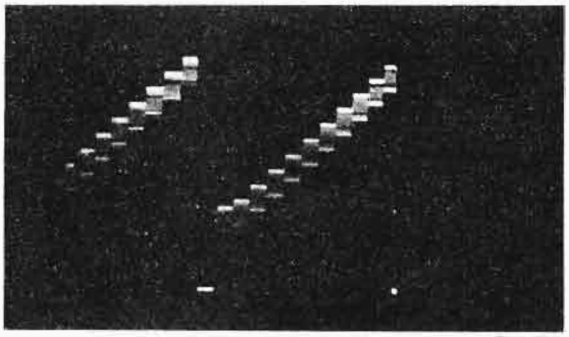

Fig. 29. Stairstep signal—modulated—horizontal.

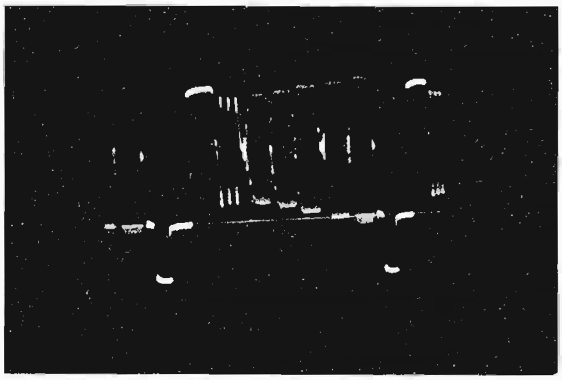

Fig. 30. Stairstep signal—modulated—horizontal—through high-pass filter.

burst, while all telephone company offices will transmit 5 Hz. Thus, with only a general knowledge of network routes, a casual glance will indicate the source of a particular signal.

Stairstep

The techniques most commonly used by the broadcasters at present for the measurement of differential phase and differential gain involve the transmission of a 10-step stairstep signal, as in Fig. 29. A sine wave of 20 IRE divisions at 3.6 MHz is superimposed on the 10 steps which extend progressively from black to white level. At the receiving point, the high-frequency sine wave is separated from the low-frequency steps by a high-pass filter and displayed on the oscilloscope as in Fig. 30. The largest amplitude 3.6 MHz sine-wave block is normally adjusted on the monitoring oscilloscope to 100 IRE divisions and becomes a reference block. Then the 3.6 MHz sine waves from the other steps are measured in relation to the reference block. Any difference in the amplitudes of the remaining blocks represents differential gain. By means of a color signal analyzer, used in conjunction with the receiving oscilloscope, differential phase may be measured.

The stairstep signal, without sine wave added, is also used in some cases as a linearity check, as

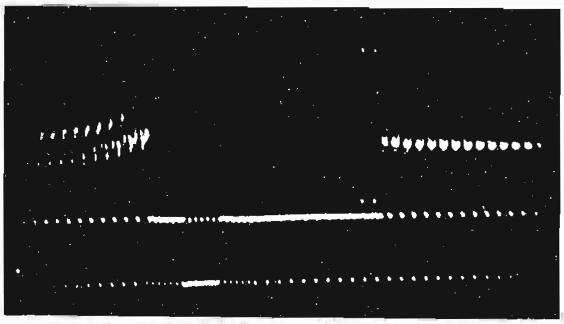

Fig. 31. Vertical interval signal placement.

shown in Fig. 28. In this case, the relative height between steps is used as an indication of compression or nonlinearity. Fig. 27 shows a stairstep signal on a picture monitor.

Vertical Interval Signals

FCC transmission standards [FCC Rules & Regulations, Section 73.682(a)(21)] specify that the interval beginning with the last 12 microseconds of line 17 and continuing through line 20 of the vertical blanking interval of each field may be used for the transmission of test signals. Test signals may include signals used to supply reference modulation levels; signals designed to check the performance of the overall transmission system or its individual components; and cue and control signals related to the operation of the television broadcast station. Fig. 31 shows the placement of these signals during the vertical interval.

At present, all the network broadcasters are using vertical interval test signals, each with some variations. The standard test signals, multiburst, window, and stairstep are being used in either their normal form or with slight alterations. These changes include transmitting the window signal at half level, deleting the white flag of the multiburst, as in Fig. 32, and transmitting the stairstep signal without the 3.6 MHz modulation. Normally when the vertical interval test signals are being used, they are transmitted on a rotation basis. For example, the multiburst, window, and stairstep might each be transmitted for about five minutes before the next one is automatically keyed into the proper place in the vertical interval.

Some of the broadcasting networks use vertical interval reference signals. Fig. 33 is one of those currently being used. In some instances the test signals are combined with the reference signals.

Test Pattern—EIA

Standard test patterns are valuable in determining the performance of video systems be-

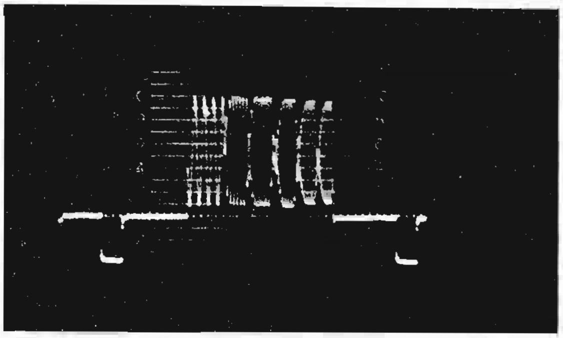

Fig. 32. Vertical interval—multiburst without the white flag.

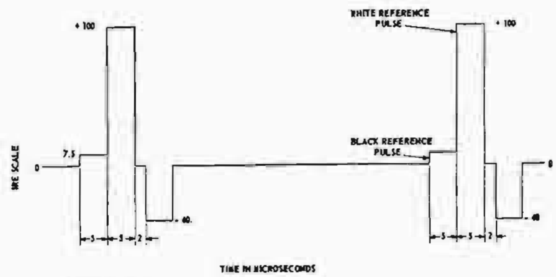

Fig. 33. Typical vertical interval reference signal.

cause the distant viewer knows what the original picture looks like, and can therefore readily detect distortions. The test pattern illustrated in Fig. 34 is a reproduction of a test chart developed by the Electronic Industries Association. It is used mainly as source material for local test of broadcasters' equipment, such as cameras.

The following is a description of the use of the pattern in checking the quality of the picture and interpreting the results. In all cases it is assumed that the picture monitor has been properly adjusted.

Horizontal Linearity: This may be determined by checking the large circle, the four corner circles, and the three squares of "200 line" vertical bars, one on each side of the picture and one in the center. The circles should show no distortion and the horizontal length of all squares should be equal.

Vertical Linearity: The circles plus the six sets of short "200 line" horizontal bars may be used to check linearity of the vertical sweep. The circles should show no distortion and the overall height of the sets of bars should be equal.

Contrast: The four bars at the ends of the central wedges are the gray scales. Each is composed of 10 steps varying from maximum white brightness to approximately 1/30th of this value. If the received signal has the proper distribution

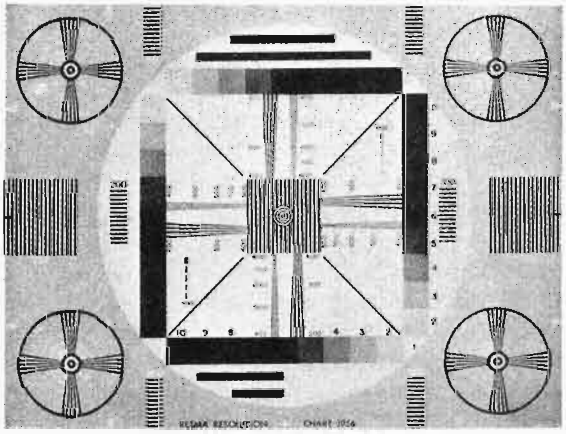

Fig. 34. EIA test pattern—picture.

of grays, it will be possible to distinguish all squares in the scales. Loss of distinction between the individual squares is an indication that the gain of the overall system is not constant over the full range of the input voltages.

Aspect Ratio: The four gray scale bars should form a perfect square.

Interlace: The quality of interlace may be checked by noting the condition of the four diagonal lines in the center. A serrated or jagged line indicates pairing of the interlace lines.

Streaking: Streaking following any one of the two horizontal black bars, at top and bottom of the large circle, indicates low-frequency phase and/or amplitude distortion. The bars represent half cycles of square wave signals ranging from about 30 kHz for the longest to 100 kHz for the shortest. They help to locate the frequency range where the phase distortion takes place. For instance, if it is near 100 kc, the short bar will have more intense streaks than the others.

Ringing: The vertical wedges and the short vertical lines or ringing bars, between 100 and 300 in the lower left quadrant of the circle, along with those between 350 and 550 in the upper right quadrant, are used to check ringing. The frequency of the ring will be indicated on the vertical wedges by the vertical position at which the strongest ring is indicated to the right or left of the wedge. Similarly, the short vertical line that gives the strongest ring will also indicate the ringing frequency.

Resolution: Resolution is measured in terms of "lines."

Vertical resolution, the resolution from top to bottom of the picture, is expressed as the number of horizontal lines than can be resolved. Therefore, the horizontal wedges in the test pattern are used to measure vertical resolution. Vertical resolution depends primarily on the size and shape of the picture tube scanning beam spot, rather than the high-frequency response or bandwidth of the receiver or transmission path. For this reason, vertical resolution measurements are omitted from network operating tests.

Horizontal resolution is based upon the number of distinct black and white dots (vertical lines) that can be reproduced by the picture monitor in three-quarters of the usable (visible) length of a horizontal scanning line. This length of three-quarter width is selected because it equals the height of the picture, and therefore gives a basis for direct comparison between horizontal and vertical resolutions. The vertical wedges are used to determine horizontal resolution.

Vertical or horizontal resolution can be measured in terms of lines by determining the point on the horizontal or vertical wedges, respectively, up to which it is possible to distinguish distinct lines.

The wedges in the center and the four corners are calibrated in lines. The central wedges vary from 200 to 800 lines, while those in the corners vary between 200 and 600 lines. The vertical and horizontal linearity bars are all spaced for 200 line resolution. The concentric circles in the centers of the corner circles are at 150 line spacing. Those at the center of the large circle are at 300 line spacing.

Broadcaster's Test Pattern

Various types of test patterns are employed by broadcasters for alignment of their circuits and monitors, and for use by servicemen in the adjustment of home receivers. The test pattern illustrated in Fig. 1 is a typical pattern and employs many of the features included in the standard EIA pattern.

The following is a description of the use of this test pattern.

Linearity: The circles, and the horizontal and vertical wedges, can be used to check both the horizontal and vertical linearity. The circles should be round and the wedges of equal length.

Contrast: The five circles extending from black to white offer a check of the grays in the received signal. If the signal has the proper distribution of grays, all circles will be seen in varying shades of gray from black to white.

Streaking and Smearing: Streaking following any of the letters in the center of the test pattern indicates low-frequency distortion. Echo, smear, following whites, etc., can also be noted at these points. Streaking can also be seen at the right outside edge of the horizontal wedge.

Resolution: Resolution can be determined by noting the point to which the lines can be distinguished on the vertical and horizontal wedges. The resolution of the vertical wedges on the test pattern illustrated extend from 150 to 325 lines, and on the horizontal wedges from 150 to 350 lines. This value will differ among the various broadcasters' patterns, depending upon the width of the wedge lines.

Ringing: Ringing can be noted on the sides of the vertical wedges. Ringing frequency will be indicated by the vertical position at which the strongest ring is observed.

Color Bars

The broadcasters use various color bar signals for the adjustment of their equipment including color monitors. They may also transmit this signal over transmission facilities for test purposes.

As shown in Fig. 35, on a monochrome picture monitor, the color bar signals will appear

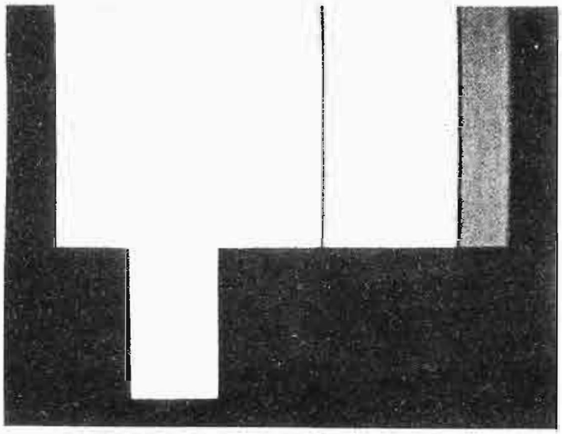

Fig. 35. Color bar signal—monochrome picture.

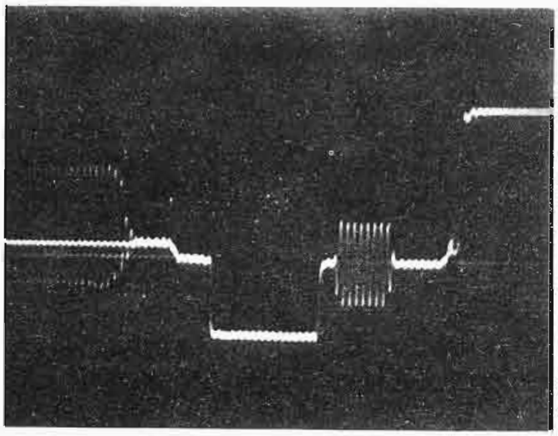

Fig. 38. Color bar signal—expanded horizontal.

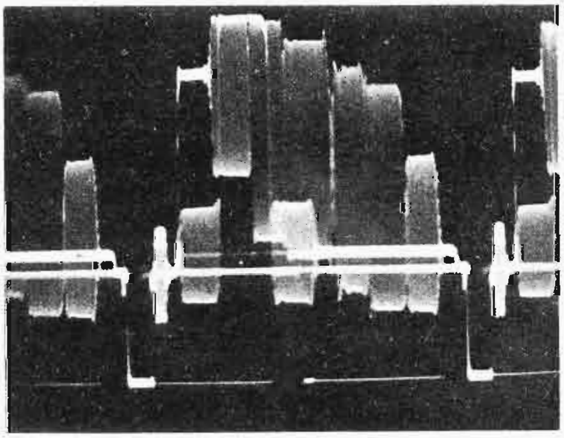

Fig. 36. Color bar signal—horizontal—wideband.

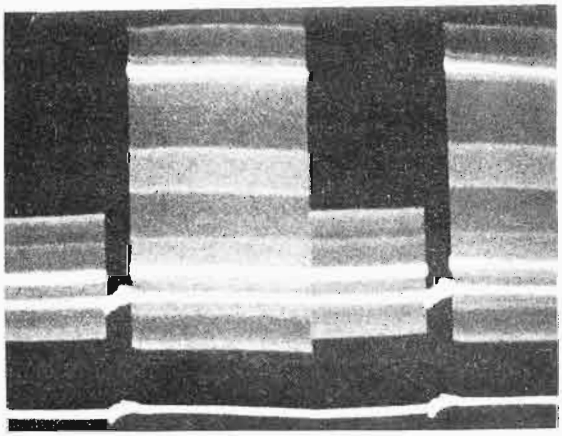

Fig. 39. Color bar signal—vertical.

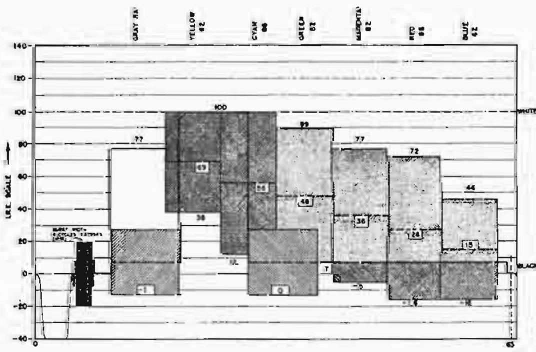

Fig. 37. Color bar signal—typical color information.

as corresponding bars in various densities of gray, the densities depending upon the individual values of luminance. The wideband A-scope horizontal presentation can indicate whether or not the white reference of the luminance signal and the color information have the proper amplitude relations. Fig. 36 illustrates a typical A-scope presentation, the colors for this particular pattern being identified in Fig. 37. For this color bar signal, if the color burst signal is of correct amplitude, and if the positive excursion of the cyan bar is at white level, with the negative excursion of the green bar at black level, it can be assumed that the overall signal is in good condition from an amplitude standpoint. Figs. 38 and 39 show expanded horizontal and vertical presentations of this signal.

The broadcaster may observe the color bar signal on a vector display oscilloscope (variously known as a vectorimeter, vectorscope, chromascope, etc.) to measure absolute amplitudes and phase angles for equipment adjustments. Differential phase and gain measurements may also be made by this means.

47A Transmission Measuring System

The 47A Transmission Measuring System is used for the measurement of differential phase and gain of facilities used in color television transmission (change in phase or gain at 3.6 MHz at the level is varied from black to white).

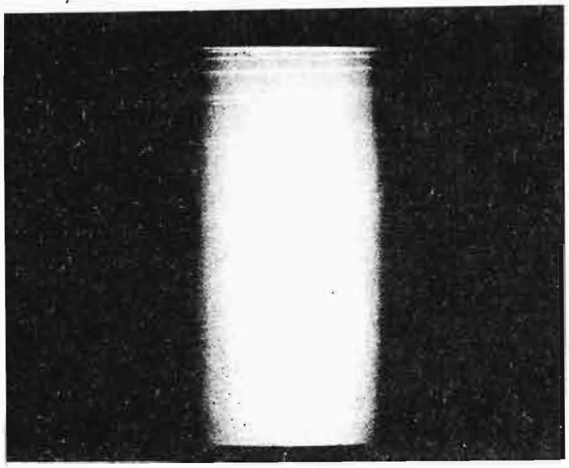

Fig. 40. 47A TMS—test signal—picture.

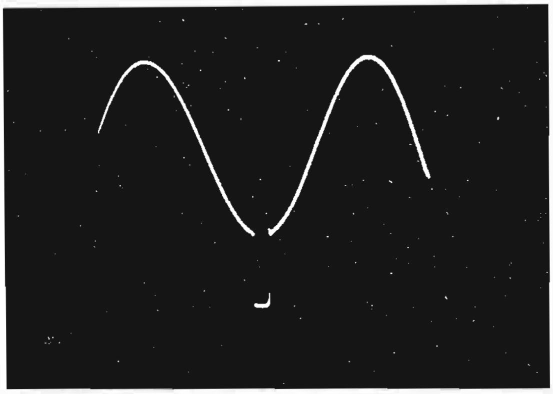

Fig. 41. 47A TMS—test signal—unmodulated—horizontal.

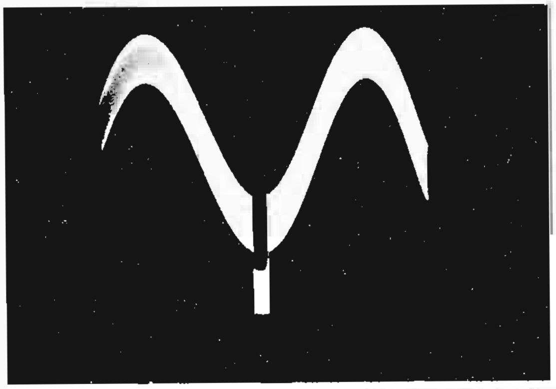

Fig. 42. 47A TMS—test signal—modulated—horizontal.

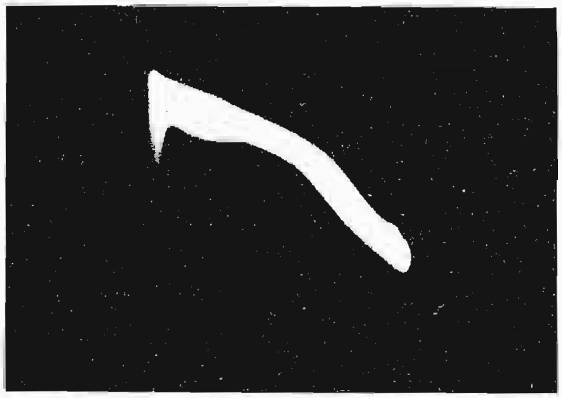

Fig. 43. 47A TMS—receiving unit presentation—minus differential gain.

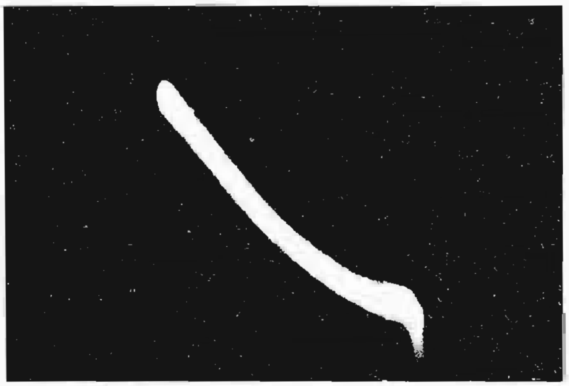

Fig. 44. 47A TMS—receiving unit presentation—minus differential phase.

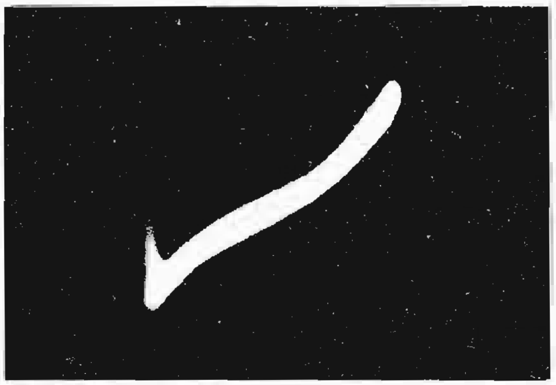

Fig. 45. 47A TMS—receiving unit presentation—plus differential phase.

The test signal consists of a 15.75 kHz sine wave with positive peaks at reference white level and negative peaks at blanking level. Horizontal sync pulses are inserted on the negative peaks. On this sine wave, which corresponds to the luminance signal, there is superimposed a lower level 3.6 MHz (3579.545 kHz) sine wave signal corresponding to the chrominance signal. The 3.6 MHz signal is thus periodically raised and lowered through the region between blanking and white levels. At the receiving locations, instantaneous differential phase or differential gain at 3.6 MHz is displayed on a high gain oscilloscope with good low-frequency response. Differential phase is measured at the maximum departures, both plus and minus from the imaginary horizontal line beginning where the sync pulse disturbance meets the remainder of the trace.

Measurements of differential gain are made between the maximum positive and negative deviations, disregarding the signs. To give an indication of the type of variation, the positive and negative deviations from the imaginary horizontal reference line may be given.

The 47A system consists of a transmitting unit (47B), and a receiving unit (47C). Test signals and presentations on receiving sets are illustrated by Figs. 40 through 45.

9A Video Distortion Meter

The 9A Video Distortion Meter is used to measure amplitude and phase distortion at frequencies between 15 kHz and 300 kHz, where most of the luminance energy of a TV signal is concentrated. This measurement indicates the amount of distortion in a circuit expressed in dB below the signal level (1 volt peak-to-peak).

The 9A signal, illustrated by Fig. 46, consists of a one volt rectangular pulse generated at the horizontal rate. The pulse is such that all equipment, including working clampers, can be left in the circuit.

The amount of distortion is measured by generating and transmitting the rectangular pulse over a circuit, removing the pulse from the received signal at the far end of the channel and measuring the remaining energy. If the transmitted pulse is received without impairment, the removal of the pulse leaves little or no energy.

A provision has been made for connecting an oscilloscope to observe the amplified received test signal after the pulse has been removed. The meter reading is a measure of the distortion at frequencies between 15 kHz and 300 kHz, but the oscilloscope display includes distortion effects outside this band of frequencies because the signal is applied before these frequencies are filtered out. Fig. 47 shows a well equalized circuit with a 9A reading of 48 dB. Figs. 48 to 52 show what various circuit conditions would measure and how they would appear on an oscilloscope.

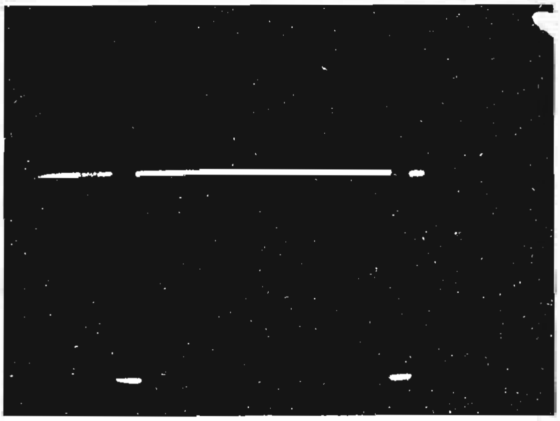

Fig. 46. 9A distortion meter—horizontal.

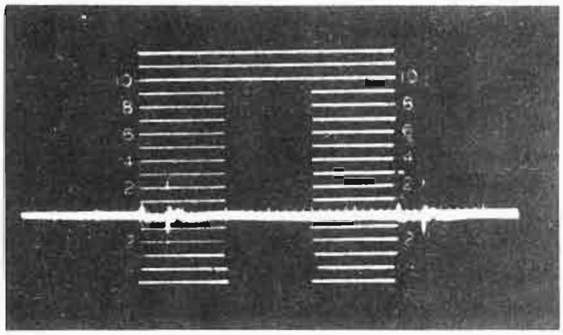

Fig. 47. 9A distortion reading—48 dB well-equalized circuit.

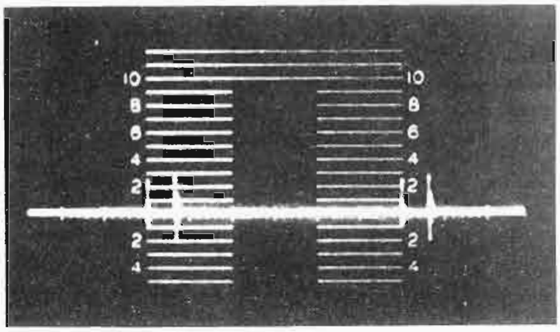

Fig. 48. 9A distortion reading—59 dB sharp cutoff at 4.5 MHz.

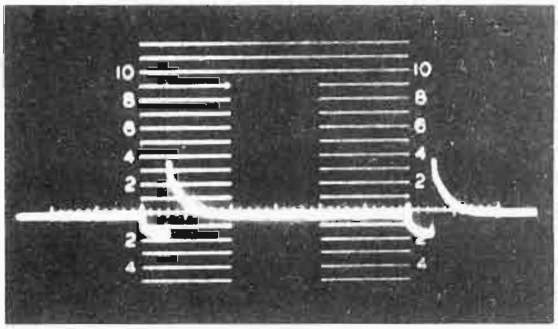

Fig. 49. 9A distortion reading—37.5 dB .2 dB step level drop at 50 kHz.

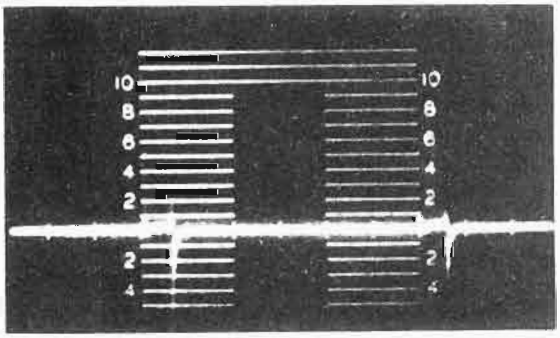

Fig. 50. 9A distortion reading—46 dB .2 dB step level rise at 250 kHz.

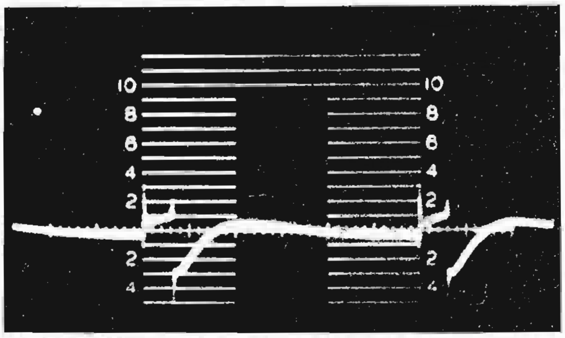

Fig. 51. 9A distortion reading—34 dB .2 dB bump level rise at 15 kHz.

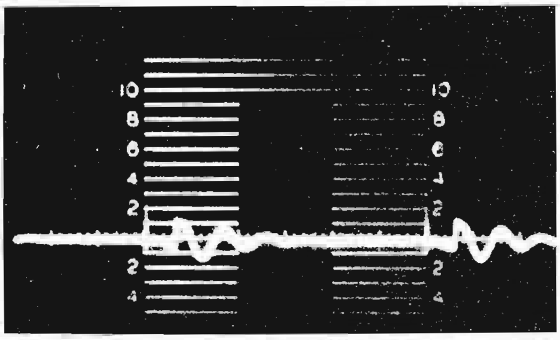

Fig. 52. 9A distortion reading—42 dB .2 dB bump level rise at 105 kHz.

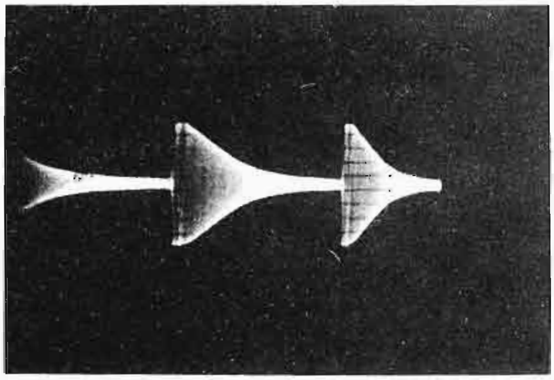

Fig. 53. 62 video visual set—vertical—IRE roll-off.

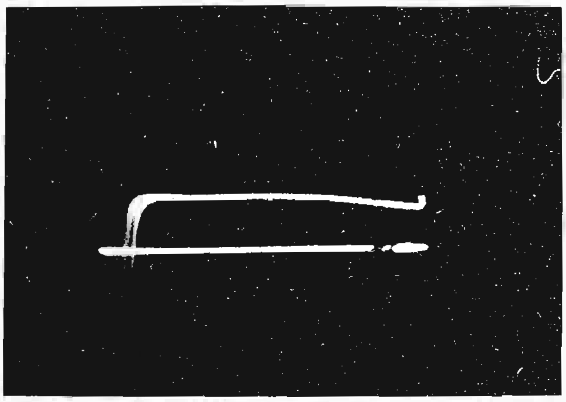

Fig. 54. 62 video visual set—detected—transmitter output.

A person with some experience in the observation of video signals may use the scope pattern to determine the probable cause of the distortion in terms of transmission irregularities.

62 Video Visual Test Set

The 62 Video Visual Test Set measures the gain-frequency characteristics of a broadband transmission system and displays them as a trace on a cathode ray oscilloscope. The transmitter generates a sweeping oscillator signal which varies linearly with frequency from as low as 100 kHz to as high as 10 MHz at a rate of 74 times a second. The actual sweep width and the location of this sweep can be adjusted within these limits to suit the particular purpose. Since the test set transmitter sends a constant level signal, the gain-frequency response of the system being measured amplitude-modulates this signal. Fig. 53 illustrates the transmitted signal as seen on an A-scope having an IRE roll-off characteristic. A provision is made in the transmitter unit for adding simulated television horizontal synchronizing pulses to permit measurements on video equipment requiring sync for normal operation.

The test set receiver detects the envelope of the input wave and displays it on the CRO. In addition, a calibrated reference trace also appears on the CRO so that the characteristics of the system under test can be measured directly in dB. The reference trace also includes a frequency marker in order to determine the amplitude of any given frequency. Figs. 54 and 55 illustrate the detected appearance of this signal. In both cases, the frequency marker is on 3.6 MHz.

Some receiving locations will use the simplified receiver, often called a detector, which serves the same purpose as the regular receiver. It does not, however, provide a reference trade or a frequency marker. Frequency can be determined by inserting a sine wave signal from an external signal generator and observing the marker caused by addition of the energy in the two signals. The simplified receiver includes a high-pass filter to eliminate the effects of the sync pulses. This filter limits the lower usable frequency to 500 kHz. However, if no sync pulses are used with the test signal, this filter may be patched out, lowering the range to 200 kHz. Fig. 56 illustrates the signal as detected by the simplified receiver. Note the roll-off below 500 kHz and the "beat" from the external oscillator at 3.6 MHz.

SIGNAL IMPAIRMENT ANALYSIS

Television network facilities are designed to transmit picture signals in order that they will

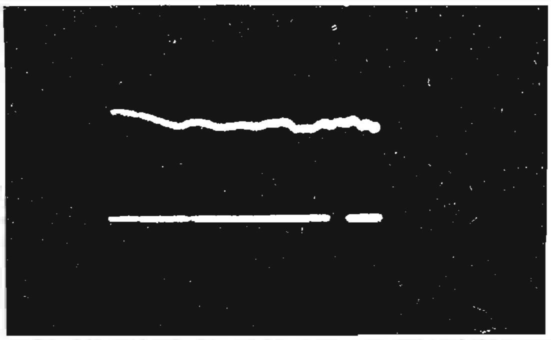

Fig. 55. 62 video visual set—detected—actual circuit.

be received at the distant connection in a condition to give satisfactory reproduction of the signal furnished by the customer. The network transmission facility is only part of the transmission path from camera to receiver. The other elements contributing to the faithfulness of the reproduced scene are:

1. Performance of cameras, videotape recorders, and other studio equipment (see Network Transmission Committee Engineering Report No. 2, Video Tape Signal Analysis, March 1959).
2. Performance of local loop facilities not included as part of the network facilities; i.e., studio to transmitter link.
3. Performance of the broadcaster's transmitting facilities.
4. Radio path between broadcast transmitter and the receiver; i.e., distance, obstructions, interference and propagation effects.
5. Ability of the receiving system to reproduce a picture from the signals received.

Since all of the above elements must work together, discrepancies occurring in any one of the individual elements will affect the received picture adversely. The broadcaster and the telephone company have no control over the last two links in the chain—the path from the transmitter to receiver, and the home receiver. However, network transmission from camera to the broadcaster's transmitter generally involves close cooperation. Because of the necessity of using different pickup points and cameras, or the necessity of rearranging the network facilities to meet customers' requirements, it is essential that each transmission element be engineered and maintained with this flexibility in mind.

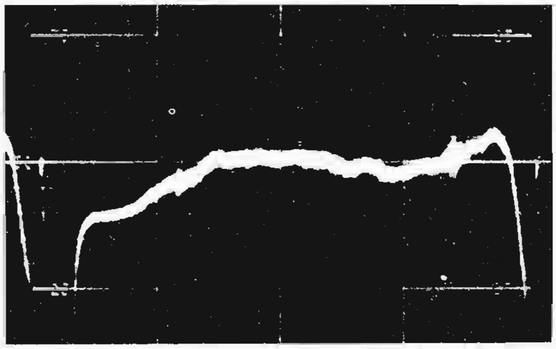

Fig. 56. 62 video visual set—simplified receiver.

The composition of a television signal, as discussed previously, determines the objectives for network facilities. Compared to telephone transmission, the bandwidth is of the order of 1000 times greater. Also, amplitude distortion, interference and delay distortion requirements are much more severe. Since color television signals are much more complex than monochrome signals, they are correspondingly more difficult to transmit.

Distortion of video signals during transmission may be the result of trouble or inherent limitations of the facilities within the transmission path. This distortion will usually be readily apparent in the oscilloscope signal presentation. The A-scope signal distortions and picture monitor impairments fall into several different categories. The following pages illustrate a number of these distortions as observed on picture monitors and A-scopes, together with an explanation of the causes. In many instances it has been necessary, for photographic reproduction reasons, to introduce impairments beyond the degree to which it would be expected to find them under actual conditions. This is particularly true of the picture monitor photographs where a given impairment generally has greater effect upon the eye under actual conditions than is evident in the photographs.

Level Irregularities

General

An essential factor in good television operation is the maintenance of correct video levels both at broadcasters' and telephone company locations. The observed effect of incorrect levels as seen on picture monitors and A-scopes is dependent upon the magnitude of error, whether the level is constant or varying, and whether all or only part of the frequency range is affected. This section is concerned with level errors that affect the entire frequency range in a relatively uniform manner. Such level irregularities can be caused by improper amplifier gains or pad losses along the transmission path, defective electron tubes or other components, or by change in camera level from broadcasters' studios or pickup points.

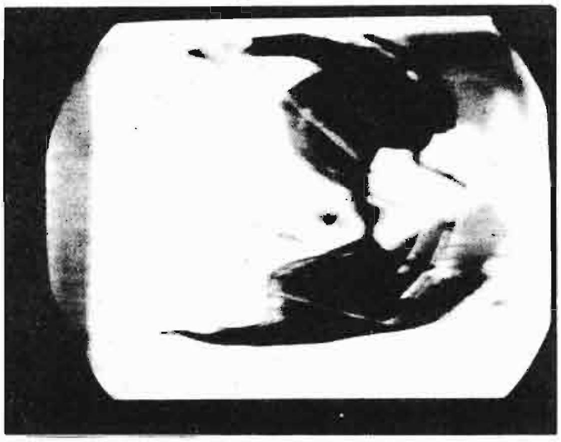

Fig. 57. Blooming.

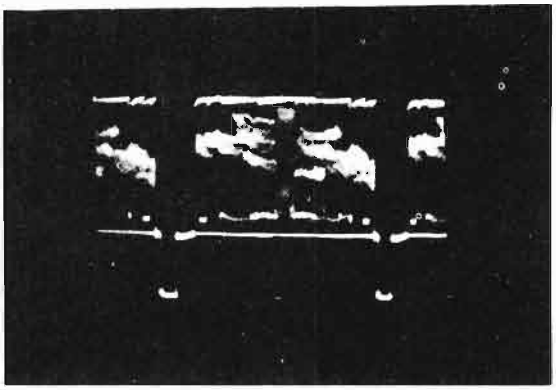

Fig. 59. Bleeding whites—horizontal.

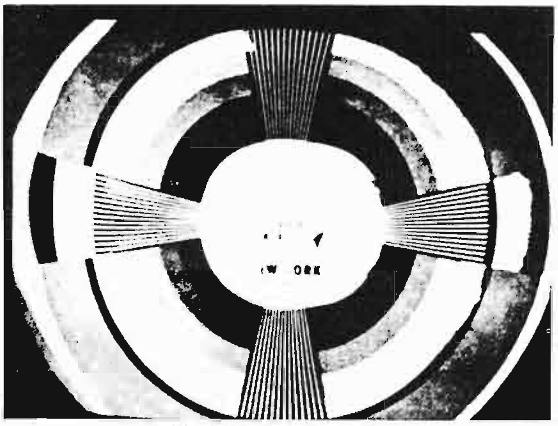

Fig. 58. Bleeding whites.

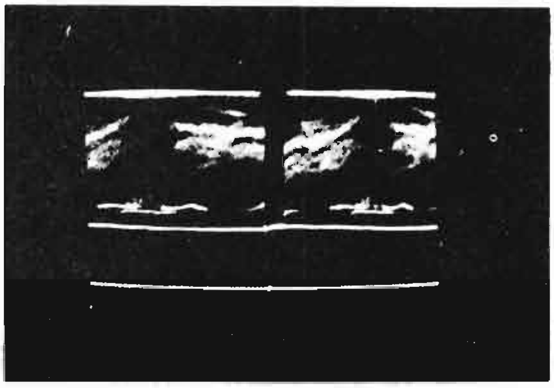

Fig. 60. Bleeding whites—vertical.

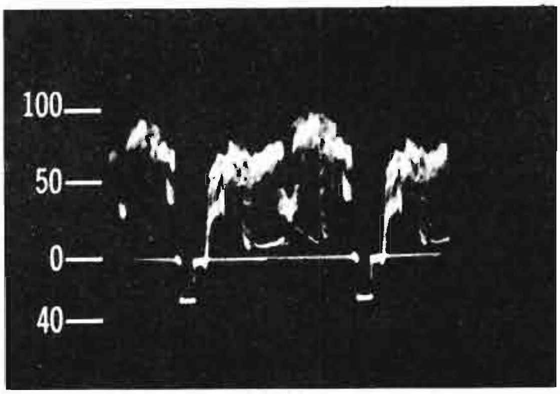

Fig. 61. Sync compression—horizontal.

Long Duration Level Changes

High Levels. Excessive levels can result in serious defects such as blooming, bleeding whites, clipping and sync compression. These long duration effects are caused by overloading.

Blooming (Fig. 57). An increase in the size of the scanning spot with resultant loss of detail in white areas due to overloading the picture tube. When the A-scope presentation appears normal, the difficulty is probably due to a high gain setting of the monitor itself.

Bleeding Whites (Figs. 58-60). As the level is increased to the extent that overloading occurs, the A-scope, in addition to indicating high level, will also show evidence of clipping, or compression, as indicated by the square tops of the wave forms in Figs. 59 and 60. The picture (Fig. 58) will have lost contrast, and may appear to have white areas "bleeding" into black, although the defocussing found under blooming may not exist.

Black or Sync Compression (Fig. 61). High level conditions sufficient to cause overloading may also result in black peak or sync compression. Here the sync pulse amplitude is reduced and setup may be affected. If the sync signals are sufficiently compressed, difficulty with horizontal stability will be experienced. Fig. 61 illustrates sync compression as seen on the oscilloscope at horizontal rate. The sync level in this case reads approximately 30 on the IRE scale,

Fig. 62. Partial clamping failure—horizontal—(A-scope presentation expanded to normal height).

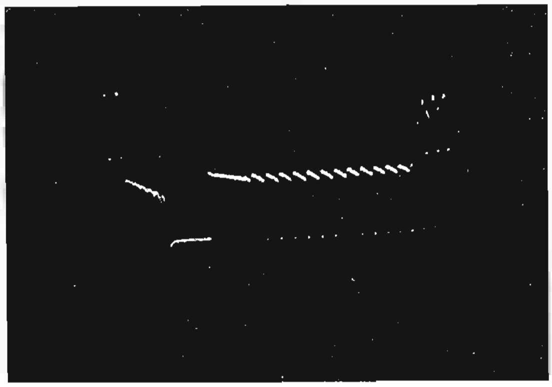

Fig. 63. Partial clamping failure—expanded vertical.

or about 10 divisions lower than normal. The picture monitor, in this case however, showed no evidence of trouble.

Low Levels (Figs. 62, 63). Lower than normal levels cause a decrease in average picture brightness and make the signal more susceptible to interference. When the television signal level is reduced by only a small amount, ill effects are not likely to be noticed. As the signal is transmitted through clamping or stabilizing circuits at still lower levels, clamping action may be partially or completely lost. Streaking, smearing and loss of synchronism may occur. Figs. 62 and 63 illustrate a signal transmitted through a clamper-amplifier at about one-half normal level. Partial failure of clamping can be seen on the A-scope, although the picture is not affected appreciably. The impairments observed, when clamper failure occurs, will depend upon the amount of low-frequency distortion present in the signal. The results of complete clamping failure are discussed later.

Short Duration Level Changes

Intermittent level changes may have several causes. Fluctuating ac line voltage and hunting regulators in power supplies or transmission facilities are some of the possible causes of this trouble. These usually give short changes in pic-

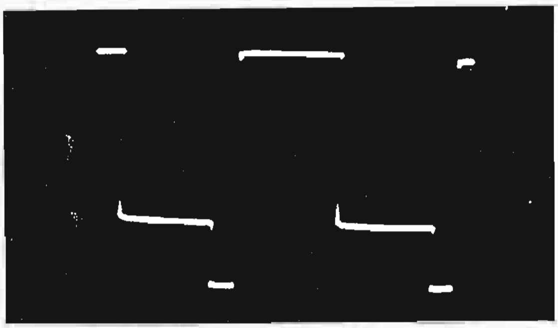

Fig. 64. Window signal normal—horizontal.

ture brightness, evident on A-scopes as momentary voltage changes. If of sufficient magnitude, frame rolls, momentary tearing, etc., may be observed.

Bounce and Breathing. In operating parlance *bounce* is the condition where there are sudden irregular changes in level, while *breathing* is the condition where the changes occur more slowly and at a regular rate.

Transmission-Frequency Irregularities

General

Uniform amplitude response and linear phase shift throughout the pass band of a television network transmission system are two highly desirable characteristics. In addition, the gain characteristic should be such that it gradually rolls off beyond the pass band without affecting the phase characteristic. A large number of impairments to picture transmission are caused by inability to attain these conditions. In this section, the impairments resulting from distortion in different parts of the video band are grouped together; that is, those affecting field rate and harmonic frequencies, those affecting line rate and its first 10 or so harmonics, and those affecting frequencies above about 200 kHz.

The set of figures from 64 to 70 shows some of the relationships between low- and high-frequency distortion. A telephone company window signal was used for these tests. Fig. 64 shows an essentially undistorted test signal for reference. In the remaining figures both attenuation and related phase distortion are present.

Low-Frequency Gain Changes. Figs. 65 and 66 illustrate a relative 1.0 dB increase and decrease, respectively, of frequencies below about 100 kHz. With the low frequencies increased, Fig. 65 illustrates the case of positive streaking in which the length of time for the streak to disappear is determined by the shape of the curve at the transition from white to black. In the re-

Fig. 65. Window signal—lows raised—horizontal.

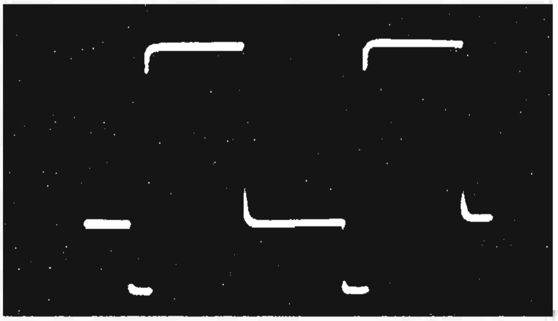

Fig. 67. Window signal—highs depressed—horizontal.

Fig. 66. Window signal—lows depressed—horizontal.

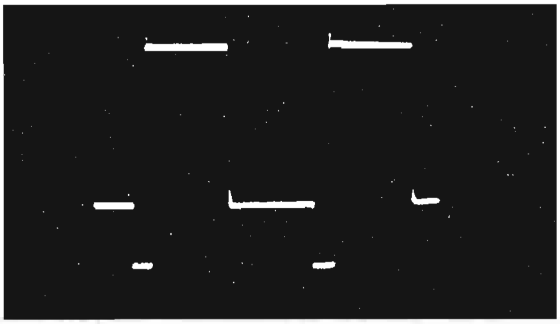

Fig. 68. Window signal—highs raised—horizontal.

verse case, Fig. 66, low frequencies are decreased causing long duration overshoots at transitions and negative streaking.

High-Frequency Gain Changes. Figs. 67 and 68 show results when frequencies above 100 kHz are affected. The networks used give a gradual modification of characteristics with frequency, so that at 3.0 MHz the gain-frequency characteristic is changed by minus and plus 1.5 dB, respectively. Fig. 67, with the high frequencies depressed, shows some loss of sharpness or rounding-off of transitions, much less and of shorter duration than Fig. 65. Fine picture detail would be impaired in this transmission. The small overshoot or spike evident in Fig. 68 is the result of raising 3.0 MHz by only 1.5 dB. This spiking is similar to that in Fig. 66 but of much shorter time duration. With even more distortion, and possibly at a somewhat lower frequency, this sort of thing will result in "edge effect"—a distinct outline following an object, of a tone opposite to that of the object itself.

Both Low- and High-Frequency Gain Changes. Figs. 69 and 70 illustrate cases wherein the gain-frequency characteristic is not flat at either end of the spectrum. In each case there is a 3.0 dB rise at approximately 3.0 MHz. At the lower frequencies, Fig. 69 has a 1.0 dB loss and Fig. 70 a 1.0 dB gain. It can be seen that the individual characteristics previously illustrated are still recognizable, and that adjustments at one end of the band do not compensate, in general, for maladjustments at the other end. The short duration spike, for example, is evident regardless of the low frequency adjustment.

It should be noted that the sync pulse itself shows evidence of all these distortions. In some cases clamper action will tend to minimize these effects on the tips of sync pulses.

Streaking and Smearing

Streaking is caused by transmission distortions in the frequency region up to about 200 kHz. Smearing generally is caused by distortions of somewhat higher frequencies. They affect almost equally color and monochrome transmission.

Distortions that cause streaking and smearing can occur in any part of the transmission system from the camera to the television receiver. Prevention of these defects requires very close control of transmission characteristics in the lower frequency portion of the video band.

The amplitude and phase characteristic tolerances at the very low end of the frequency band, say below half line frequency, are probably not so critical. When a signal is clamped, the ampli-

Fig. 69. Window signal—lows depressed, highs raised—horizontal.

Fig. 70. Window signal—lows raised, highs raised—horizontal.

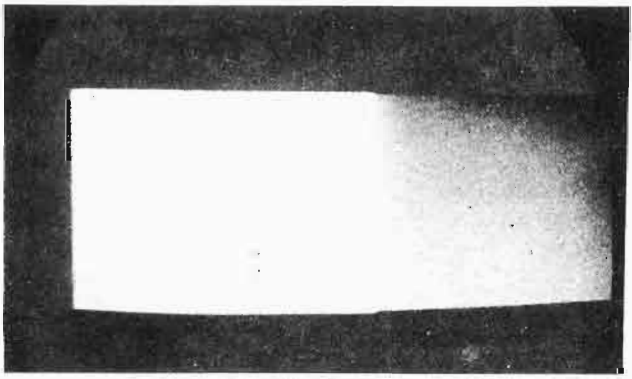

Fig. 71. Positive streaking—window signal.

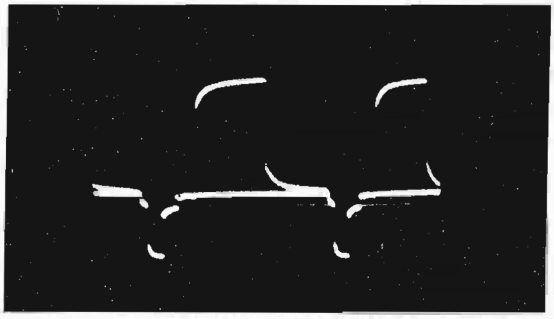

Fig. 72. Positive streaking—window signal—horizontal.

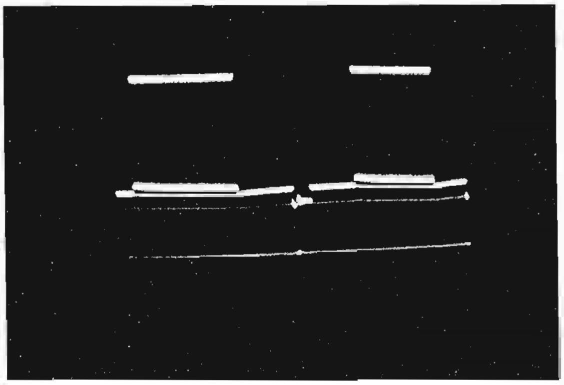

Fig. 73. Positive streaking—window signal—vertical.

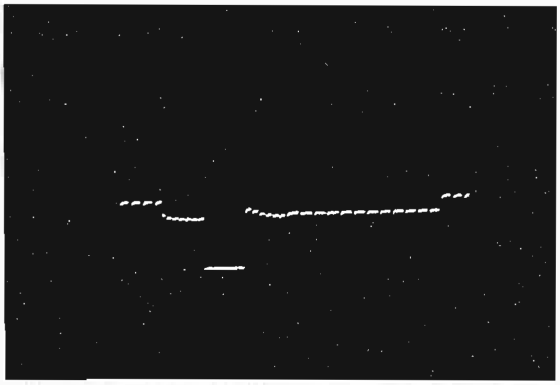

Fig. 74. Positive streaking—window signal—expanded vertical.

tude characteristic at 60 Hz can be allowed to vary considerably. Furthermore, it can be deliberately adjusted to depart from a uniform response at 60 Hz, or other points below half line frequency, in order to provide phase correction at line frequency and its harmonics.

At times it is expedient to make simultaneous in-service measurements of streaking and smearing using monitors and viewing picture information. Observation should be made at a time when the picture contains relatively prominent horizontal elements followed at the viewer's right by contrasting background. Block lettering used in titles is a good example. Suggested terminology to describe the degree of streaking, designed to encourage more uniform reporting of trouble are:

S0—streaking barely perceptible;
S1—streaking up to approximately 1/10 of picture width;
S2—streaking up to approximately 1/5 of picture width;

S3—streaking in excess of 1/5 or more of picture width.

The following paragraphs discuss streaking and smearing separately with emphasis on the use of test signals.

Streaking (Figs. 71-82). Streaking is the appearance of an error luminance in the picture, extending horizontally toward the right edge of the picture from some point in the picture marked by a sharp transition in luminance. Streaking is most apparent in changes from high to low luminance or vice versa. Since this type of impairment is generally caused by transmission irregularities in the region of the 15,750-Hz line scanning rate, or its first few harmonics, the horizontal size of the object affects the amount of streaking. An object whose horizontal length is 1/2 that of a complete scanning line would generally be most vulnerable to streaking. Streaking is especially apparent when the objects move vertically in the scene and the streaking moves with them.

If the streaking is the same shade as the original figure (white following white, or black following black) it is called positive. If the streaking is the opposite shade, it is called negative. Figs. 71-82 illustrate picture monitor and A-scope presentations of positive and negative streaking.

In Fig. 72, the leading edge of the white window approaching white level is heavily rounded, while the trailing edge of the white window approaching black level rolls off gradually, indicating black following black, and white following white, or positive streaking. The vertical presentation, Fig. 73, reveals in the signal region below the white level a heavy trace above black level, the height of this trace being a measure of the streaking or white following white. In like manner, Fig. 76 is the horizontal presentation for negative streaking, or black following white, and white following black. Here the manifestations are just the opposite from Fig. 72; that is, there is a high peak, or white level, on the transition from black to white, while the trailing edge of the white window dips below blanking and gradually restores to reference black level. The vertical presentation, Fig. 77, shows a heavy trace, or following black, in the window signal region, which is the opposite of Fig. 73. The picture monitor presentations (Figs. 71, 75, 79) show this streaking; however, in practice, a comparison of A-scope presentations using suitable signals is preferred because of the possibility of streaking caused by the picture monitors.

In addition to the foregoing, comparison of the A-scope presentations for positive and negative streaking reveals opposite tilts of front and back porches and tip of sync for the horizontal presentations (Figs. 72, 76, 80), and of the trace between the first and second sets of equalizing pulses for the vertical presentations (Figs. 74, 78, and 82).

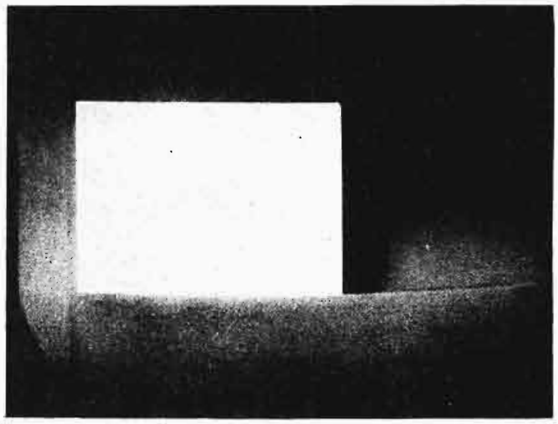

Fig. 75. Negative streaking—window signal.

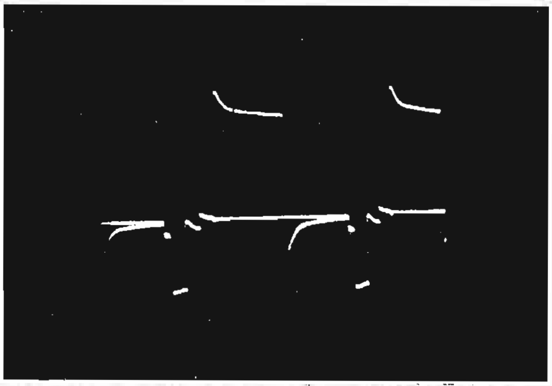

Fig. 76. Negative streaking—window signal—horizontal.

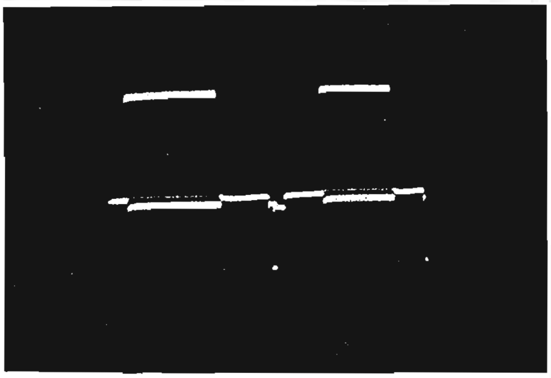

Fig. 77. Negative streaking—window signal—vertical.

Streaking is indicated by tilt of the window signal. This is measured as the difference in height (because of curvature or tilt) along the top of the window pulse, expressed as a percentage of the window height above setup. A tilt of only a few percent will indicate objectionable streaking.

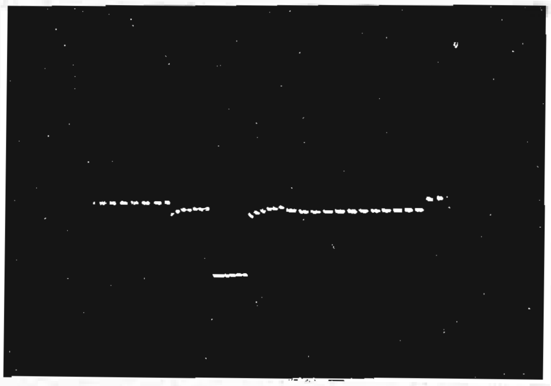

Fig. 78. Negative streaking—window signal—expanded vertical.

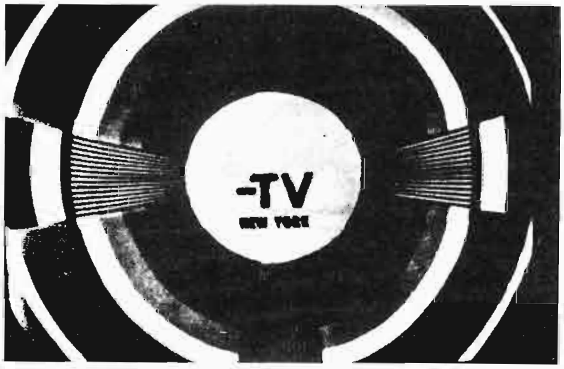

Fig. 79. Negative streaking—test pattern.

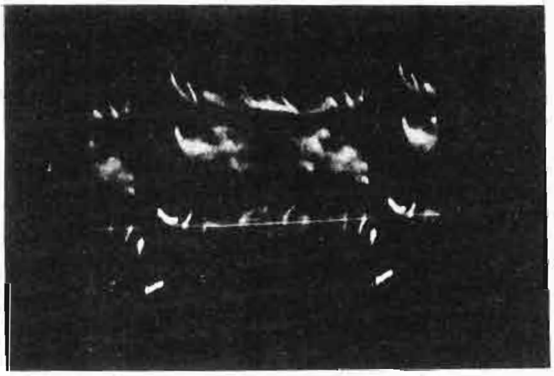

Fig. 80. Negative streaking—test pattern—horizontal.

Smearing (Figs. 83-86). Smearing is a distortion similar to streaking. Vertical edges of objects in the televised scene become indistinct and the whole picture looks blurred along the horizontal axis. The smearing error luminance may also be of the same or opposite sign as the luminance it follows.

Change of Setup (Figs. 87-92)

The setup of the picture is the difference between the blanking and reference black levels as viewed on the A-scope using IRE roll-off. For normal operation this is 7.5 divisions on the IRE scale. Setup variation on network facilities is mainly caused by distortion in the lower portion of the frequency band. Excessive transmission-frequency loss in this region causes too little setup, and excessive transmission-frequency gain in this region causes too much setup.

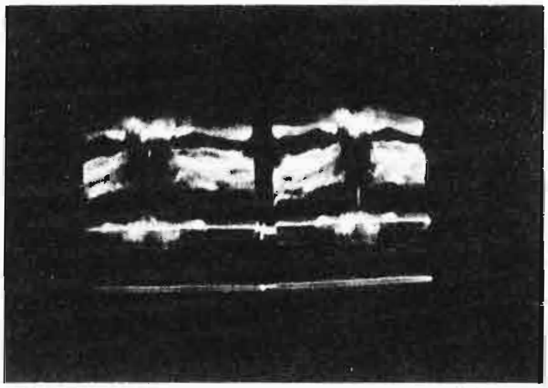

Fig. 81. Negative streaking—test pattern—vertical.

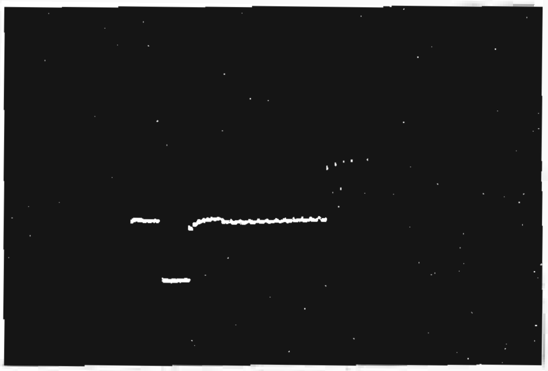

Fig. 82. Negative streaking—test pattern—expanded vertical.

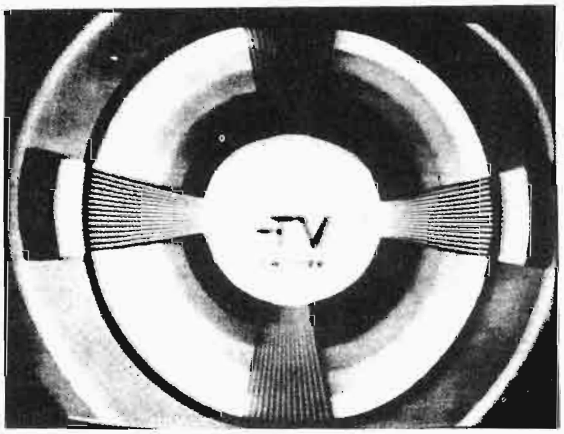

Fig. 83. Smearing—test pattern.

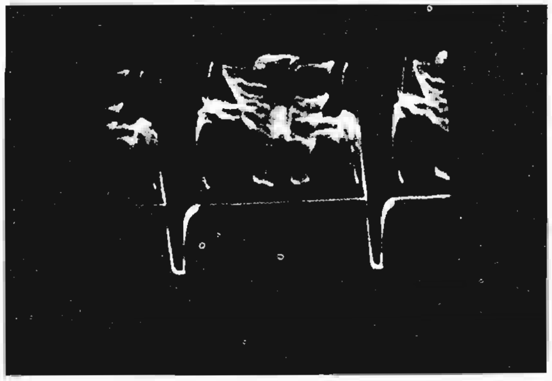

Fig. 84. Smearing—test pattern—horizontal.

Fig. 85. Smearing—test pattern—vertical.

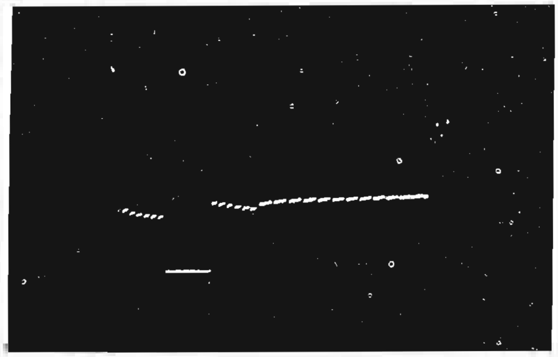

Fig. 86. Smearing—test pattern—expanded vertical.

Loss of Setup (Figs. 87-89). Low setup results in pictures having more contrast than normal. The whites in the scene will be unchanged but some of the normal grays may become almost black. Some streaking may also occur due to the deviations in the gain and phase characteristics at low frequencies. When loss of setup occurs to the degree where the picture signal punches through the blanking level, the normal clipping action of the customer's processing or stabilizing amplifier may cause loss of this picture information. In severe cases, erratic operation of the customer's equipment may occur, and the picture will be unusable.

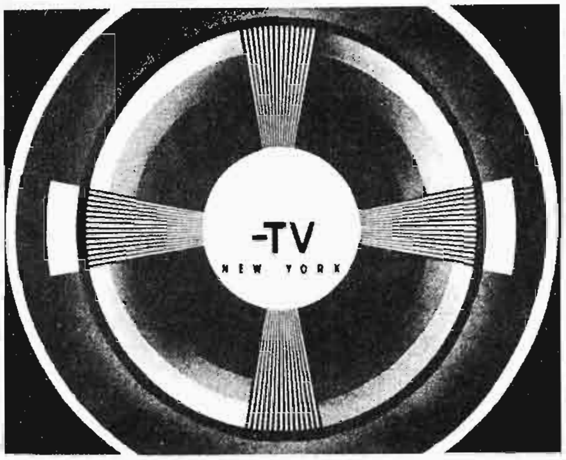

Fig. 87. Low setup—test pattern.

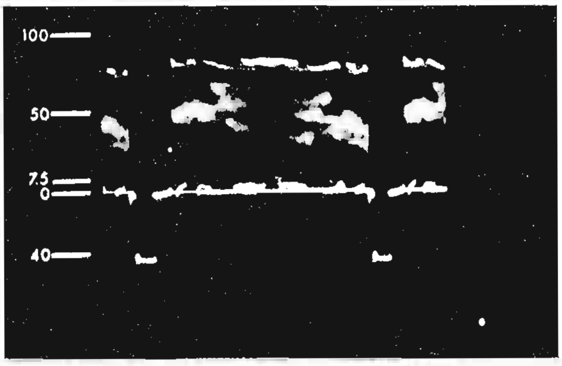

Fig. 88. Low setup—test pattern—horizontal.

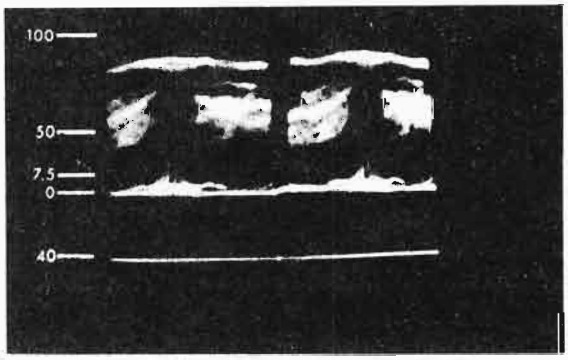

Fig. 89. Low setup—test pattern—vertical.

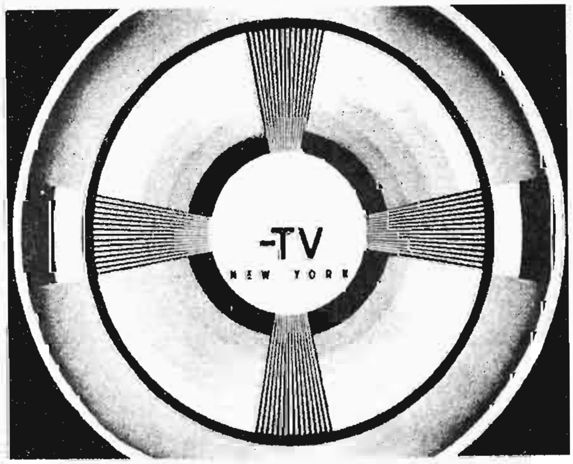

Fig. 90. High setup—test pattern.

Fig. 91. High setup—test pattern—horizontal.

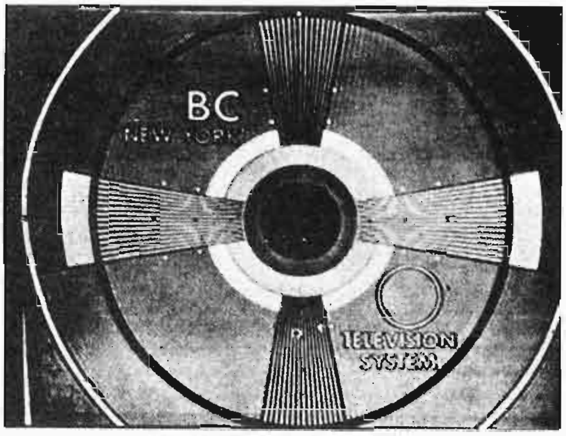

Fig. 93. Ringing—test pattern.

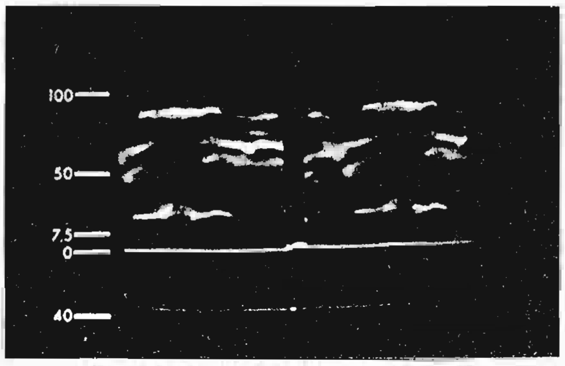

Fig. 92. High setup—test pattern—vertical.


Fig. 94. Ringing—test pattern expanded horizontal.

Increase in Setup (Figs. 90-92). High setup results in reduced contrast range and reduced signal-to-noise ratio.

Ringing (Figs. 93, 94)

Ringing generally results from the transmission of sudden tonal transitions over a system that has a finite pass band with a sharp cutoff at the upper end of the frequency range. It may also result from a marked transmission discontinuity at some frequency below cutoff. When a signal containing a sudden transition is applied to such a circuit, damped oscillations or ringing will occur at approximately the frequency of cutoff or other discontinuity, the duration of the ringing depending upon the sharpness of the discontinuity. Ringing will be accentuated by a rising gain characteristic preceding the discontinuity.

The EIA test pattern shown in Fig. 34 is a sensitive indicator of ringing. The phenomenon will be apparent as additional lines on either or both sides of the vertical wedges. These lines will be the strongest at the position along the vertical wedge corresponding to the frequency of cutoff or other discontinuity of the circuit elements causing the ring.

Ringing may also be detected by using the A-scope horizontal presentation to note the presence of damped oscillations following sharp transitions in the signal. It is recommended that observations be made of the transitions during the blanking interval, such as sync pulse to back porch. A sine-squared pulse or window with sine-squared characteristics is best suited for noting this type of distortion. There are several reasons for this: (1) the pulse represents one complete cycle of the upper cutoff frequency; (2) it has approximately the same shape as the output pulse of a camera scanning a minimum resolvable element; and (3) it has substantial energy in the vicinity of the cutoff frequency, making the pulse sensitive to cutoff characteristics.

The ringing frequency can be determined by counting the number of complete oscillations appearing in a known time interval and converting to frequency by using the following formula:

Ringing frequency = Number of oscillations X 10^6 ÷ Time interval in microseconds.

$$f = n \times \frac{10^6}{t\ (\mu s)}$$

Fig. 95. Edge effect.

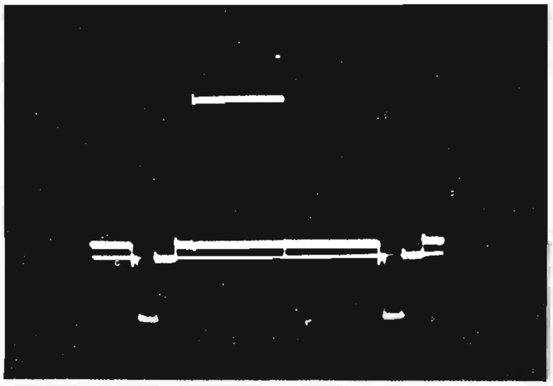

Fig. 96. Overshoots—window signal—horizontal.

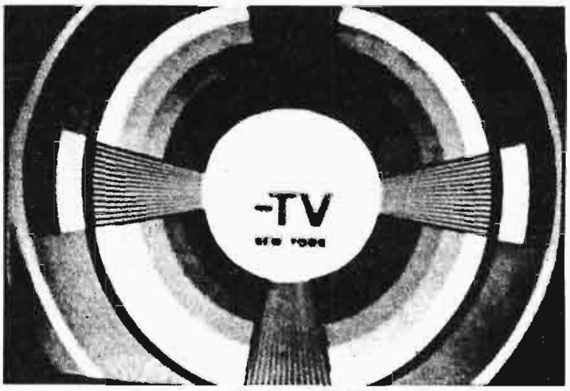

Fig. 97. Low resolution—roll-off from 1 mc.

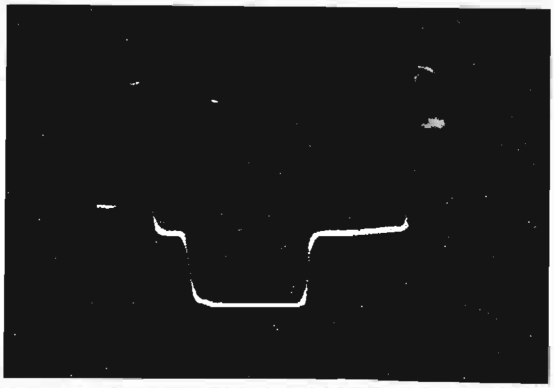

Fig. 98. Low resolution—roll-off from 1 mc—expanded horizontal.

Overshoots (Figs. 95, 96)

In a television signal, an overshoot is an excessive response to a sudden change in signal. A sharp overshoot is commonly referred to as a spike. An overshoot is generally caused by excess gain at high frequencies.

Following Whites or Blacks (Fig. 95). Overshoots within the picture area result in impairments to the picture called following white or black (edge effect). These appear as a black outline to the right of white objects and a white outline to the right of black objects. In Fig. 95, this is most evident as a white edge following the man's head. A black edge follows the white of the handkerchief.

Overshoot on Back Porch. An overshoot of the trailing edge of the sync pulse is called a "positive spike on the back porch." If this extends above black level, it may be visible in the picture as a gray vertical bar due to illuminating portions of the horizontal return traces. Fig. 96 illustrates a slight overshoot on the back porch.

Overshoot on Front Porch. An overshoot of the transition from picture to blanking is called a "negative spike on the front porch." Since this is below black level, it will not be visible in the picture. However, if the overshoot is of sufficient magnitude, it can cause premature triggering of stabilizing amplifiers, monitors or clampers, resulting in serious tearing or complete loss of picture. A slight overshoot on the front porch is shown in Fig. 96.

Resolution (Figs. 97-99)

Resolution is the ability to reproduce detail in a transmitted picture. Resolution is measured in lines, as discussed under the descriptions of the EIA and broadcasters' test patterns. Horizontal resolution is a function of bandwidth and also can be affected by the size of camera and receiver scanning beams. A rule of thumb is that 1.0 MHz of bandwidth corresponds to 80 lines of resolution. For maximum resolution within a given bandwidth, a flat amplitude and linear phase characteristic up to the point of cutoff would be desired. Too sharp a cutoff will produce ringing transients. However, in a transmission system having the same pass band, but with gradual frequency roll-off, and resultant reduced transients, the resolution will become poorer as

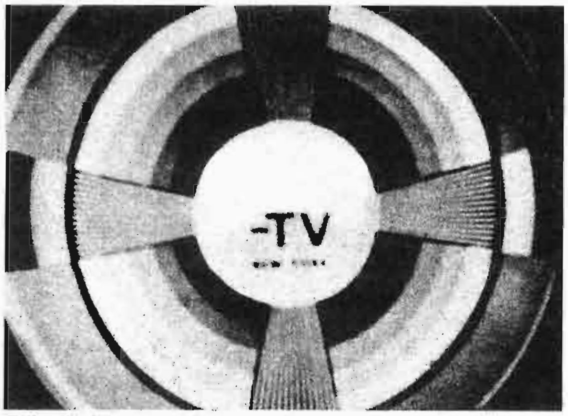

Fig. 99. Low resolution—receiver scanning spot too large.

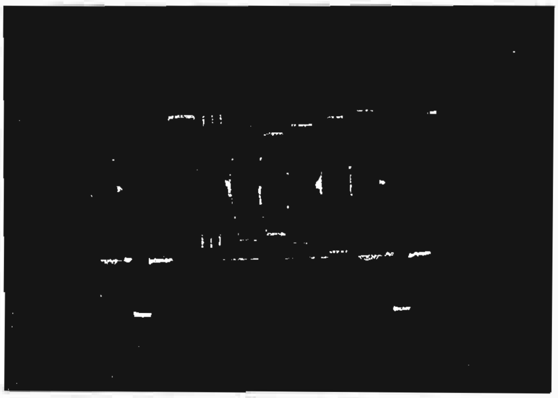

Fig. 100. Hour glass effect.

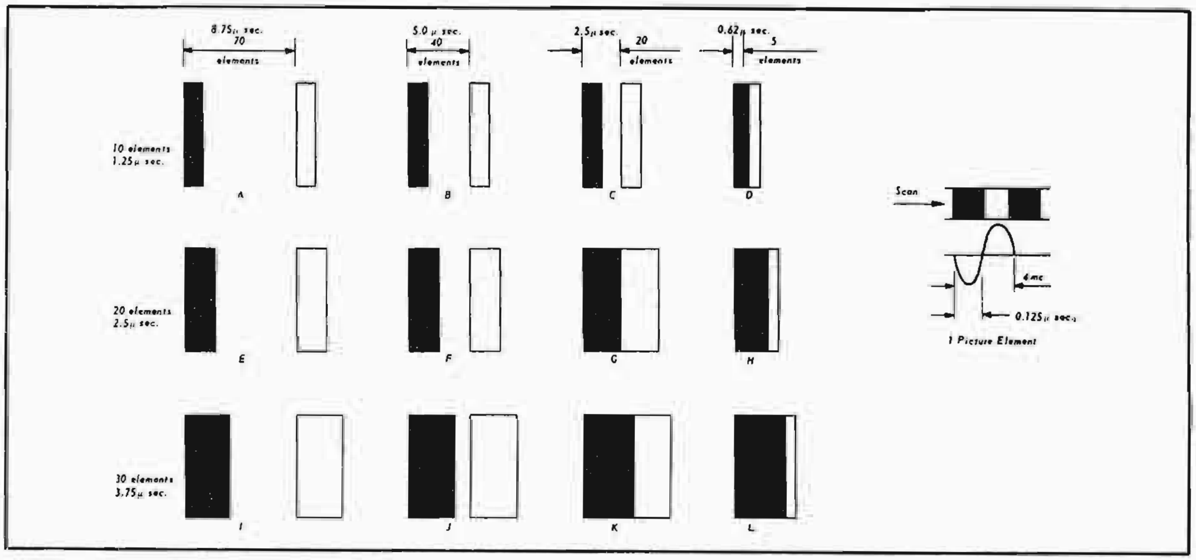

Fig. 101. Echo impairment effect versus image size and echo displacement.

lower and lower frequencies are selected as the start of the roll-off. The actual shape of a pass band is a compromise between transient effects in the region of cutoff and the loss of resolution introduced by the extent and shape of the roll-off.

In addition, excessive noise can mask fine picture detail exhibited by apparent loss of resolution.

Figs. 97 and 98 show test pattern transmissions when the high frequencies are strongly rolled off starting at about 1 MHz. The A-scope expanded presentation shows loss of sharpness at transition points. Fig. 99 illustrates loss of both horizontal and vertical resolution caused by too large a receiver scanning spot.

Hour Glass (Fig. 100)

When multiburst signals are transmitted over a video facility having an amplitude-frequency response characteristic such that the middle frequencies are attenuated with respect to both the lower and higher frequencies, the resulting A-scope presentation of the multiburst test signal is referred to as the "hour glass" effect. This frequency characteristic usually results from partial equalization, such as would occur when compensating for a facility having a gradually increasing loss with frequency, using an equalizer effective only in the upper portion of the frequency band.

Echoes (Figs. 101-111)

An echo signal, or ghost, is defined as a duplicate of the original video signal displaced horizontally from the original signal. A complete reproduction of the original signal is called a ghost, while a partial reproduction is called an echo or reflection. Ghosts and echoes are due to impairments in the transmission path which cause the signal pulses to reach the viewer at two or more discrete times. Generally, the echo signal is weaker than the original signal. When two or more echo patterns are present, one pattern usually predominates and the others are relatively weak.

The impairment effect of the echo picture not only varies with echo signal strength but also with the time offset and the nature of the original video signal. Fig. 101 attempts to illustrate this by showing bar patterns and their echoes. The bar patterns are of three different widths, corresponding to 10, 20, and 30 picture elements. The reference picture element is the smallest bit of picture information horizontally resoluble in a 4 MHz system; as illustrated, this is 0.125 microseconds wide. The bars are arranged in three horizontal rows, each row shows four different echo spacings from the same pattern. Thus, A, B, C, and D illustrate echo spacing corresponding to 70, 40, 20, and 5 elements (8.75, 5.0, 2.5, and 0.62 microseconds) from a bar 10 elements in width.

Vertically the echo spacing is identical; thus, A, E, and I represent echo spacing corresponding to 70 elements (8.75 microseconds) from bars 10, 20, and 30 elements in width. With regard to echo spacing, the top row (A, B, C, and D) illustrates the impairment resulting from different spacing of the same echo. The impairment at D, for instance, is less than that at A, where the echo is considerably displaced from the original image. Conversely, for the same degree of impairment, the echo would be of greater magnitude for the spacing at D than the spacing at A. With regard to the video material, the same echo spacing for three different original images is shown at C, G, and K. The impairment here is less for K than for C, and this is a consequence of the size of the original bar pattern.

With regard to echo amplitude, it is apparent that where the echo can be clearly distinguished from the main image (A, E, I, and wider spacings), the degree of the resulting impairment is mostly controlled by its amplitude. These three factors are difficult to relate mathematically and as a practical matter, have been evaluated on the basis of experience and observations. Consequently, the concepts may be subject to some change. The present thinking on this can best be summarized by reference to a complete picture rather than the simple patterns and components considered so far.

The echo will be a weak duplicate of the picture superimposed and displaced laterally in the time scale proportional to the delay. Where this displacement is fairly large (long delay), the resulting impairment is largely independent of the spacing and is mostly a matter of the level of the echo picture (echo amplitude). For spacing less than this (short delay), the picture and echo are close together and the impairment resulting from a fixed echo level may be expected to vary with the spacing and to decrease as the spacing decreases. This leads to separate considerations of the impairments resulting from widely and closely spaced echoes, and in turn, to separate limits on fine and coarse deviations in the parameters of the transmission medium (fine and coarse structures). For fine structure variations in attenuation and phase with the resultant widely spaced echoes, the echo amplitude is, therefore, controlling and must be held to a value that makes the echo picture practically invisible.

The value generally used as a system requirement is 40 dB below a 1.0 volt peak-to-peak video signal. For coarse structure variations, both the echo amplitude and echo spacing are controlling and the limit is set on the envelope delay deviation. This results in a permissible echo amplitude that varies inversely with the spacing.

As a practical matter, echo signals are generally not a true reproduction of the original signal, since the conditions that give rise to echo signals are usually not linear throughout the band. This adds still another variable factor, since distorted echo signals result in a lesser picture impairment effect than undistorted echo signals. Echoes may be either leading or lagging, and they may be either positive (same tonal range) or negative (reverse tonal range). Figs. 102 to 108 show positive lagging echoes; Figs. 109 to 111 show negative lagging echoes.

The usual cause of ghosts and echoes seen on home receivers is two transmission paths from the broadcast station to the receiving location—the direct path and a second path produced by a reflection from some tall building or high point of terrain. The ghost is offset to the right of the direct image by an amount of time equivalent to the difference in length of transmission time of the two paths. Transmission over the reflected path is generally attenuated, as compared with the the direct path, so the ghost appears weaker than the direct signal. When FM radio signals are used, as in radio relay systems, an impairment from a reflected path generally does not result in a television picture with a distinct echo, since its echo-producing signal would be smothered by the FM capture feature of the radio relay receivers.

Ghosts and echoes may also be produced in transmission facilities due to troubles or unsatisfactory adjustments. A trouble such as impedance irregularity in a cable section or an improperly terminated cable will produce electrical reflections which are delayed in transmission compared with the original signal, and thus produce ghosts or echoes. Ghosts will be produced if the irregularity affects substantially the

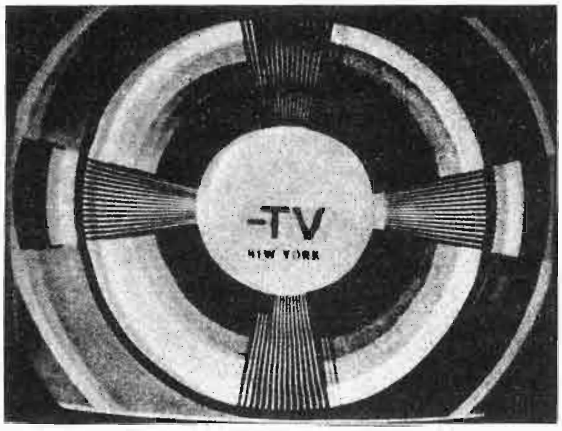

Fig. 102. Positive echo—test pattern.

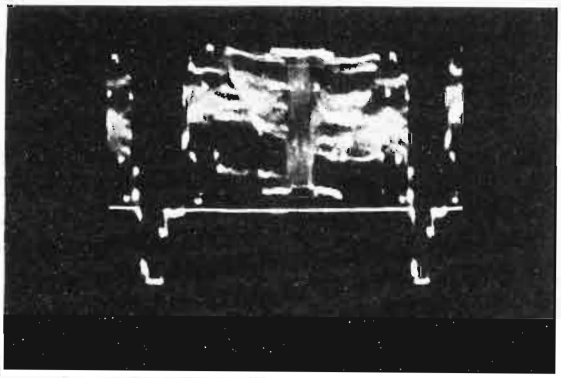

Fig. 103. Positive echo—test pattern—horizontal.

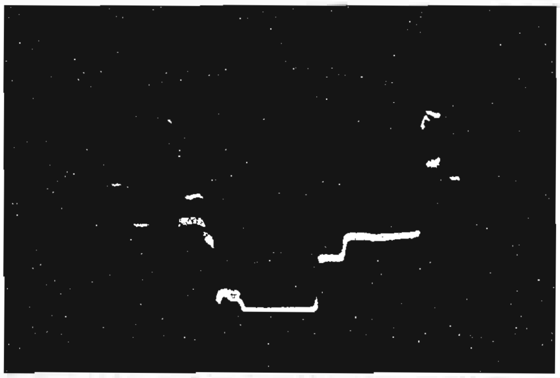

Fig. 104. Positive echo—test pattern—expanded horizontal.

whole video frequency band, and echoes when only a part of the frequency band is affected.

The same effects can also be caused by non-uniformity of gain- and delay-frequency characteristics. In particular, a gain-frequency characteristic having periodic peaks and valleys across the frequency band will act the same as an impedance irregularity on cable, affecting a broad band of frequencies.

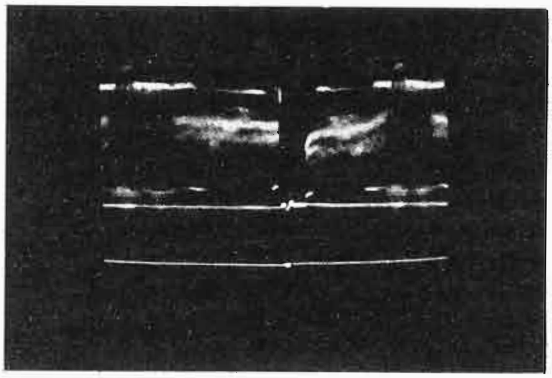

Fig. 105. Positive echo—test pattern—vertical.

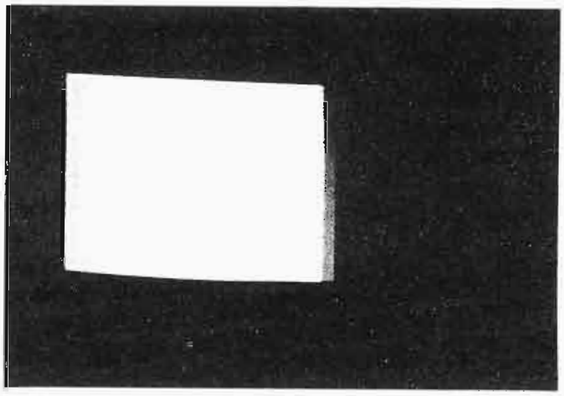

Fig. 106. Positive echo—window signal.

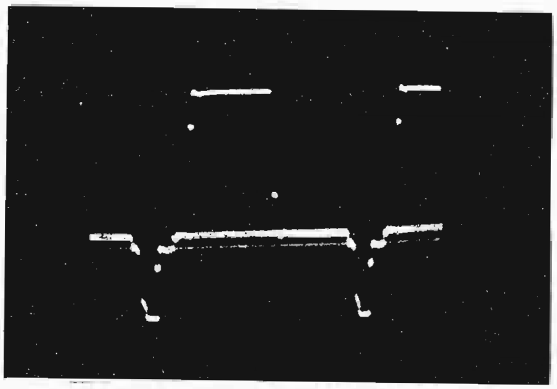

Fig. 107. Positive echo—window signal—horizontal.

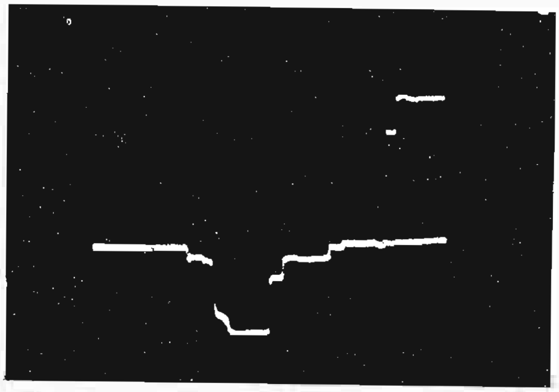

Fig. 108. Positive echo—window signal—expanded horizontal.

The spacing of the reflected image or images from the original object and from each other is determined by the location of the irregularity in the frequency spectrum and usually may be calculated by the relationship that the reflection displacement in seconds is equal to the reciprocal of the frequency in cycles at which the irregularity occurs. For example, an irregularity occurring at 500 kHz will produce reflections displaced from the original and from each other by 2 microseconds. Remembering that one line in a television picture (exclusive of blanking) is equal to about 53 microseconds, we can see that in this case, the reflections will be displaced by a fraction of the total picture width equal to 2/53. This equates to about 7/16 and 5/8 of an inch for 12 and 17 inch monitors, respectively. Where carrier type facilities are involved, it should be remembered that this is a video frequency calculation, and that further conversion to carrier frequencies may be required. The number of reflections is dependent upon the sharpness of the irregularity, being only one for a broad irregularity and increasing in number with irregularity sharpness.

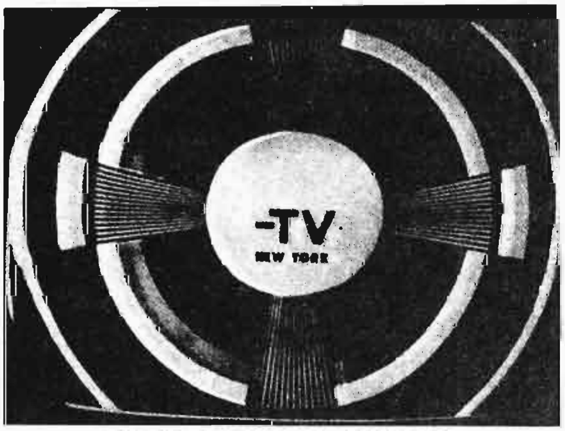

Fig. 109. Negative echo—test pattern.

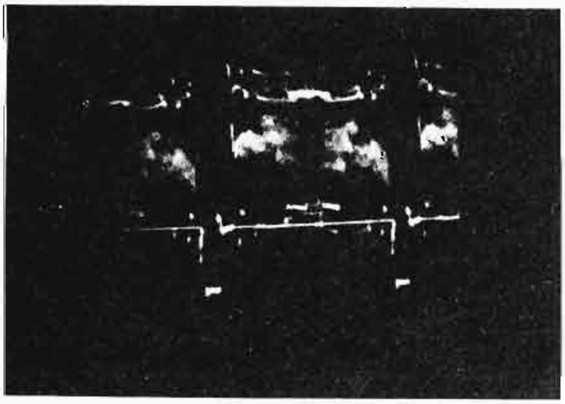

Fig. 110. Negative echo—test pattern—horizontal.

Interference

General

Interference is the introduction of extraneous signals into the desired signal. In the case of television transmission, the resulting picture impairments may be in the form of bars, moving spots, salt-and-pepper effect or erratic synchronizing. One form of interference is called noise, this term being used generally to describe natural phenomena such as thermal noise in electronic components; whereas, "interference" generally refers to man-made signals, such as extraneous single frequency voltages, crosstalk from another video channel, and the like. The term "noise" is a carryover from audio work. In television the effects are visual rather than aural.

Interference can be simply added into the path of the desired signal, or it can modulate the signal itself. Signal modulation by interference may occur in nonlinear circuit elements such as vacuum tubes, and results in the whole picture signal amplitude changing at the interfering rate. The two types of interference are difficult to distinguish in a television picture. Treatments that will minimize additive interference, such as filtering, use of clamper-amplifiers for low-frequency interference, etc., will not affect modulation products. Additive interference is the case discussed and illustrated in this section.

Single-Frequency Interference

The appearance in a television picture of extraneous regularly spaced bars or lines indicates the presence of an interfering frequency. At low levels of interference the amount of single frequency interference that can be tolerated varies quite widely, depending on the part of the spectrum in which it is operative.

Low-Frequency Interference (Figs. 112-119). A particularly sensitive portion of the spectrum

Fig. 111. Negative echo—test pattern—expanded horizontal.

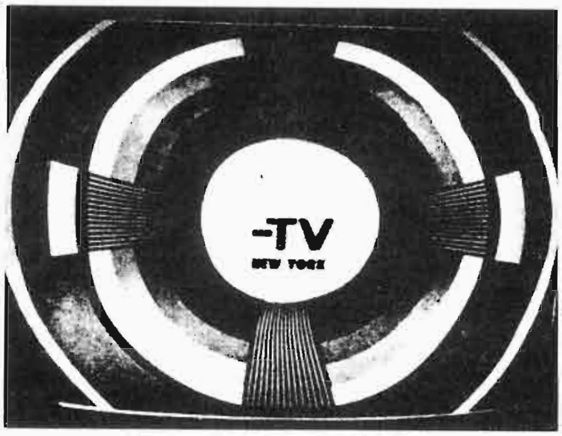

Fig. 112. Interference—120 Hz.

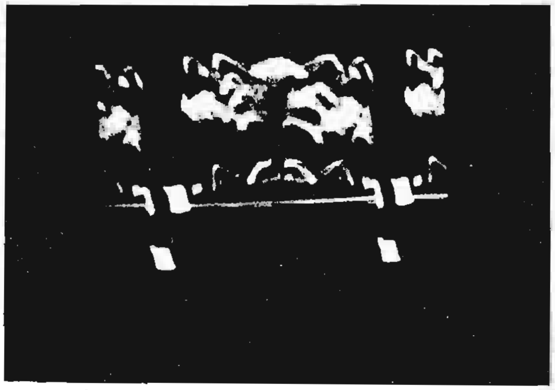

Fig. 113. Interference—120 Hz—horizontal.

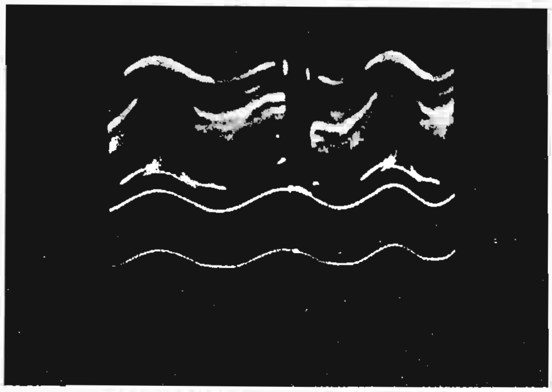

Fig. 114. Interference—120 Hz—vertical.

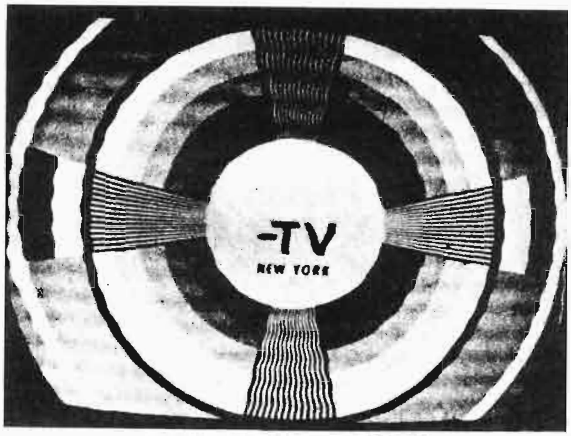

Fig. 115. Interference—1000 Hz.

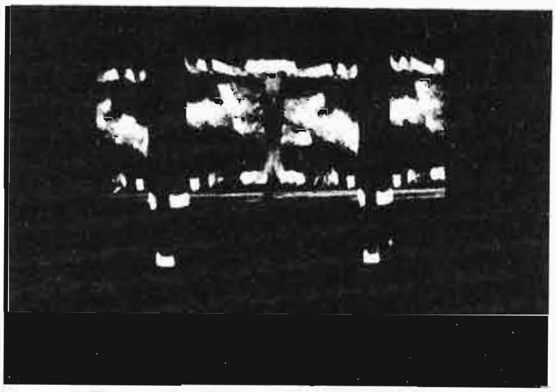

Fig. 116. Interference—1000 Hz—horizontal.

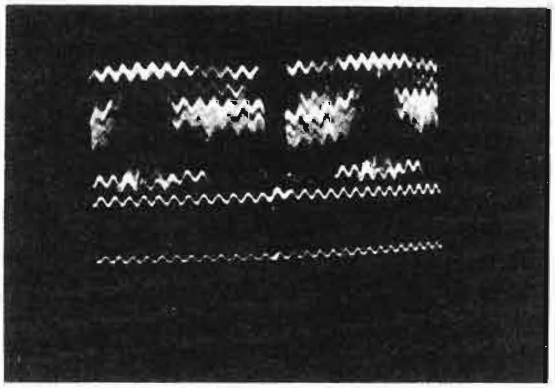

Fig. 117. Interference—1000 Hz—vertical.

is the immediate region of the field rate, 60 Hertz. It has been found that as the level of such an extraneous frequency is increased from a very low value, flicker is much more objectionable than the brightness distortion corresponding to a broad bar pattern. The flicker effect is accordingly controlling in this region. The tolerable level of interference varies with the flicker frequency (difference between the extraneous and field frequencies), a flicker rate of about 5 Hz being the most objectionable. This holds for frequencies either side of the field rate; that is, the most critical frequencies are 55 and 65 Hz. To be tolerated, the peak-to-peak amplitude of these interfering frequencies has to be about 54 dB less than the peak-to-peak amplitude of the television signal.

Figs. 112 and 115 are cases of 120-Hz and approximately 1000-Hz interference. For low-frequency interference which is an exact multiple

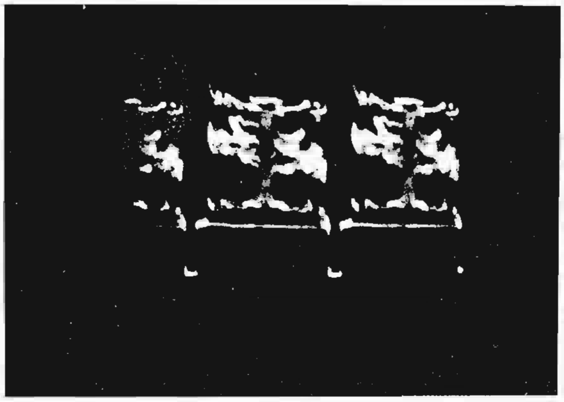

Fig. 118. Interference—clamped—120 Hz—horizontal.

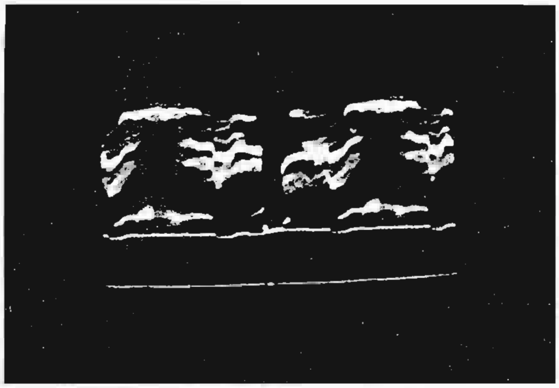

Fig. 119. Interference—clamped—120 Hz—vertical.

of the field rate (60 Hz), the extraneous bars will be horizontal and will remain stationary. The interfering frequency may be determined by multiplying 60 Hz by the number of white or the number of dark bars observed. Two horizontal white bars may be distinguished in the first instance, and sixteen or seventeen for the 1000-Hz picture. When the extraneous frequency differs slightly from the 60-Hz field rate or its multiples, the bars will remain horizontal but will move vertically through the picture, the rate of motion increasing with the difference in frequency. Interference at 60 Hz and its first few harmonics is frequently called "hum" as it is often caused by defects in power supplies—similar to the audio case.

Low-frequency interference shows on the A-scope horizontal presentation as thickened horizontal lines, the thickness indicating the relative amplitude of the interference, as in Figs. 113 and 116 for the 120- and 1000-Hz cases, respectively. The vertical presentation shows no thickening of the trace. The interference may appear as a wave form on the blanking line, horizontal sync tips and sometimes the picture signal, as in Figs. 114 and 117 for the same two examples.

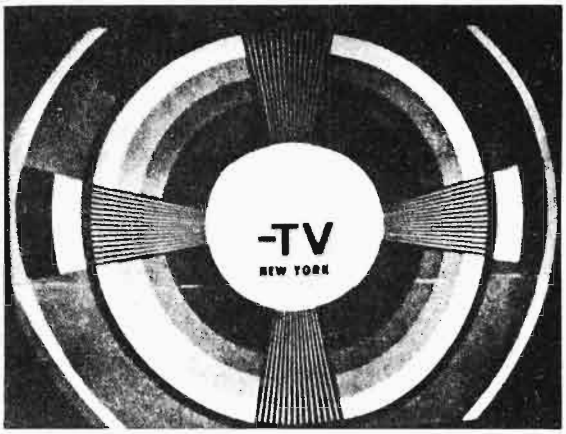

Fig. 120. Glitch.

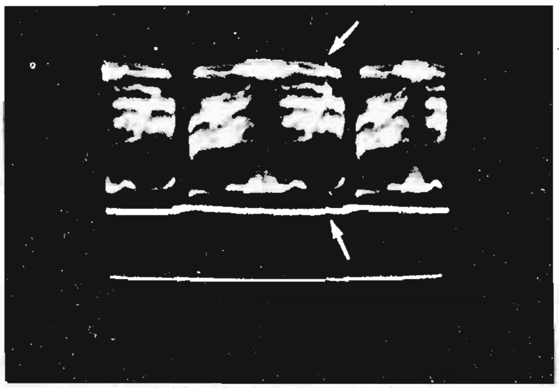

Fig. 121. Glitch—vertical.

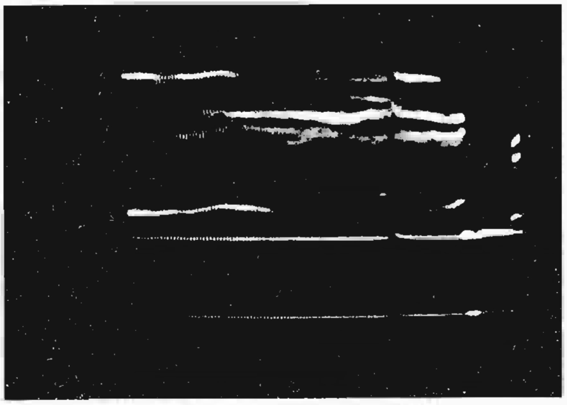

Fig. 122. Glitch—expanded vertical.

Clamper-amplifiers effectively reduce interference at 60 Hz by about 33 dB. This figure reduces progressively as the interfering frequency is increased and the clamper is not effective on interference above about 2 kHz. (This varies somewhat with the clamper time constant.) Figs. 118 and 119 show the 120-Hz interference of Figs. 113 and 114 after passing through a clamper-amplifier. No impairment is visible in the pictures.

Glitch (Figs. 120-122). A type of low-frequency interference, which has been commonly referred to by the broadcasters as a "glitch," is observed as a narrow horizontal bar moving through the picture (Fig. 120). Simultaneous observation of the A-scope at field or frame rate will indicate one or more extraneous voltage pips moving along the signal at approximately reference black level. The pip in Fig. 121 was moving rapidly from right to left.

This may be present in the signal from the customer's pickup, as a result of a difference in frequency between a remote camera power supply and the customer's local 60-Hz power supply. When using some types of radio relay equipment, the impairment also may result from spiking on the positive and negative sine-wave peaks of commercial power supplies. The speed of movement of the dark bar depends on the difference between the frequency of the picture field rate and the frequency of the commercial power supply. Such spiking may be introduced by gaseous or solid state rectifiers or similar systems feeding back voltage pips at a 60-Hz rate into the commercial power supply. Thus, this is not pure single frequency interference, but has many similar characteristics. It is possible to observe this spiking from such power supplies through use of an oscilloscope bridged on the power line. Effects are eliminated through filtering, either at the source of interference or at the point of connection to the radio relay equipment.

High-Frequency Interference (Figs. 123-134). In the region above the line rate, 15,750 Hz,

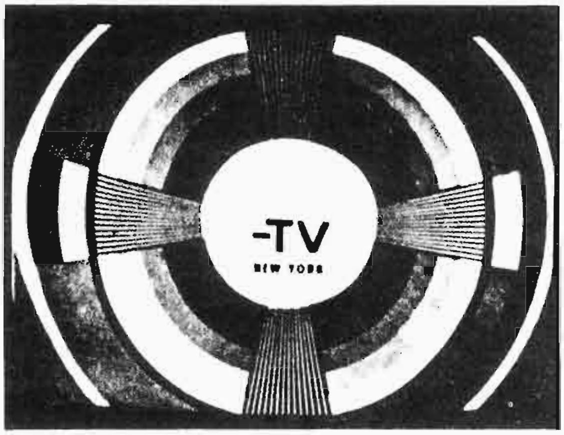

Fig. 123. Interference—31.5 kHz.

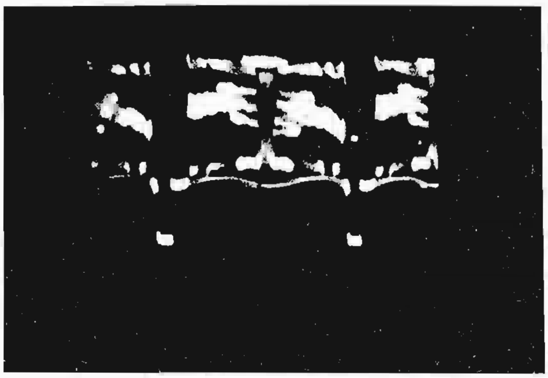

Fig. 124. Interference—31.5 kHz—horizontal.

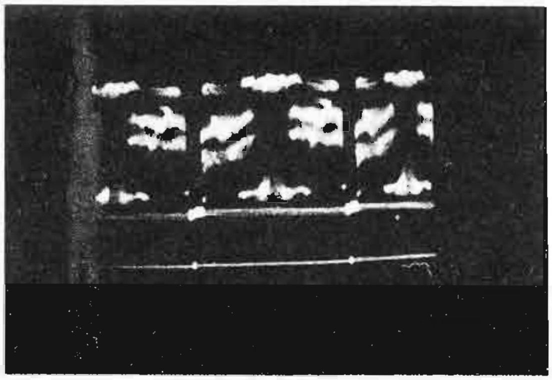

Fig. 125. Interference—31.5 kHz—vertical.

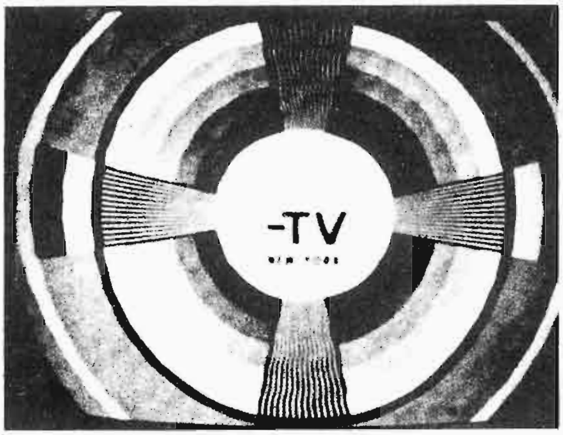

Fig. 126. Interference—311 kHz.

the most critical frequency is found to be in the 1/2 to 1/3 megaHertz range. The maximum tolerable interference level at this point in the spectrum is about 65 dB below the signal. High-frequency interference will appear as regularly spaced diagonal or vertical bars which become finer as the frequency increases. If this frequency is an exact multiple of the line rate, the pattern will be stationary and vertical. The interfering frequency may be determined by multiplying the line rate by the number of white or the number of dark bars observed cutting a horizontal cross section of the picture. Figs. 123, 126, 129, and 132 are samples, respectively, of 31.5 kHz, 311 kHz, 1.0 MHz, and 3.6 MHz interference. The first picture contains light vertical areas just to the left of center and on the right side of the pattern, which are difficult to distinguish. The bar

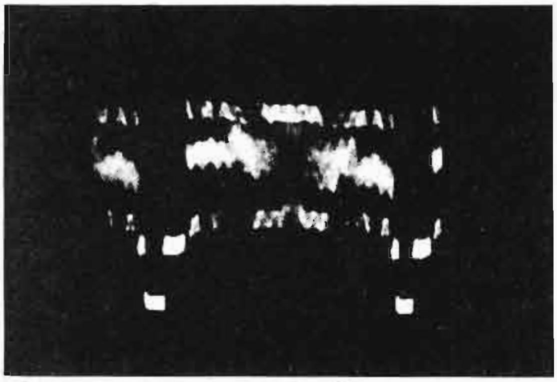

Fig. 127. Interference—311 kHz—horizontal.

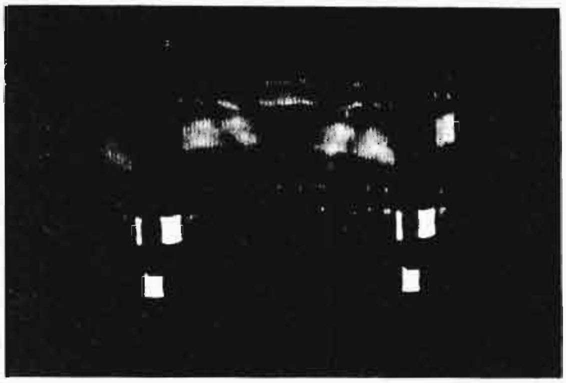

Fig. 130. Interference—1 MHz—horizontal.

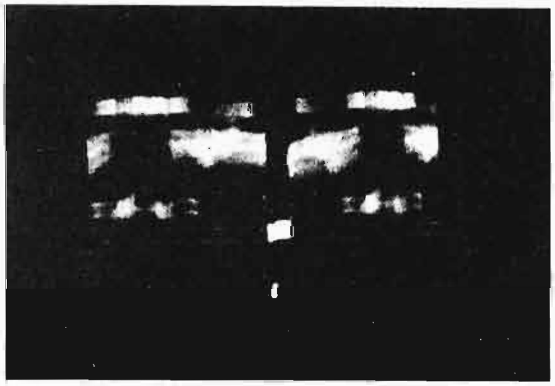

Fig. 128. Interference—311 kHz—vertical.

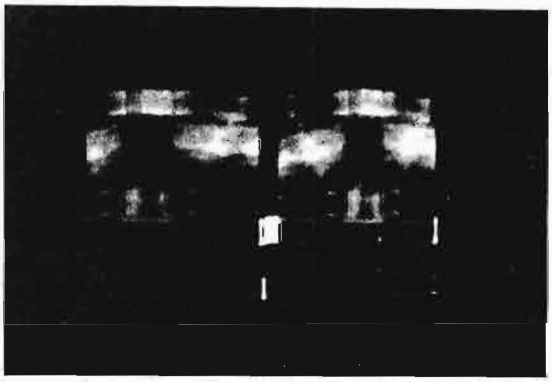

Fig. 131. Interference—1 MHz—vertical.

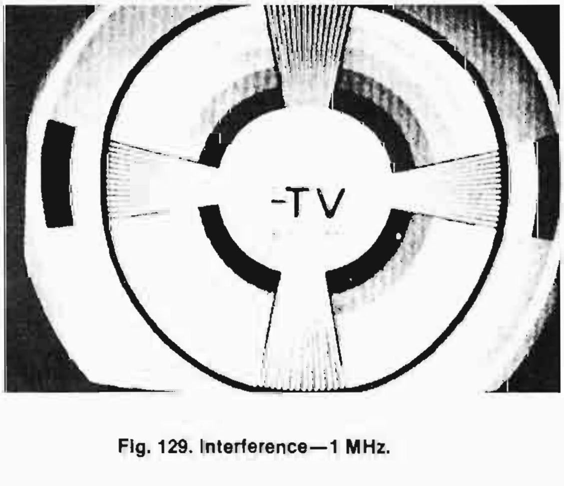

Fig. 129. Interference—1 MHz.

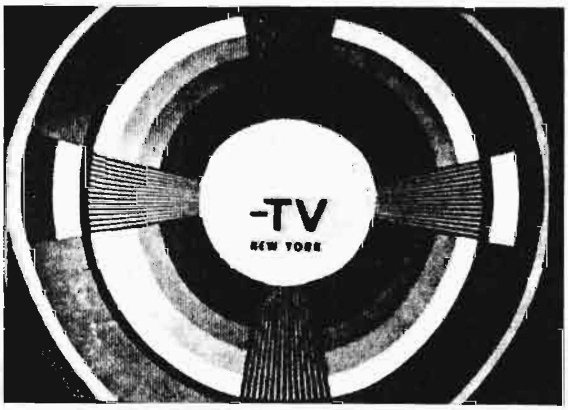

Fig. 132. Interference—3.6 MHz.

patterns on the other three pictures are quite evident and a count of the bars will give the interfering frequency quite accurately.

The A-scope presentations are shown by Figs. 124, 127, 130, and 133 at horizontal rate, and Figs. 125, 128, 131, and 134 at vertical rate, respectively. It will be noted that, on the horizontal display, the interference shows as a wave whose frequency may be determined by counting the Hertz appearing in the scanning interval. If the frequency is very high, expanding the scope presentation may be necessary to resolve the individual wave shapes. The vertical trace shows thickening as illustrated.

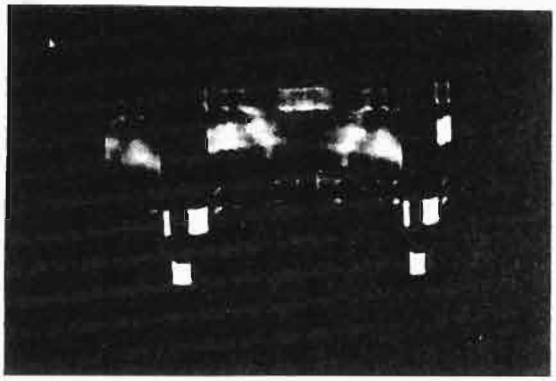

Fig. 133. Interference—3.6 MHz—horizontal.

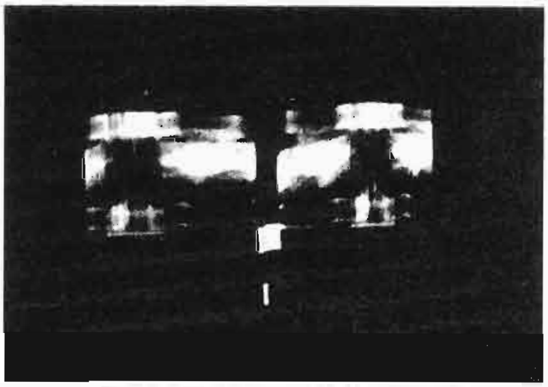

Fig. 134. Interference—3.6 MHz—vertical.

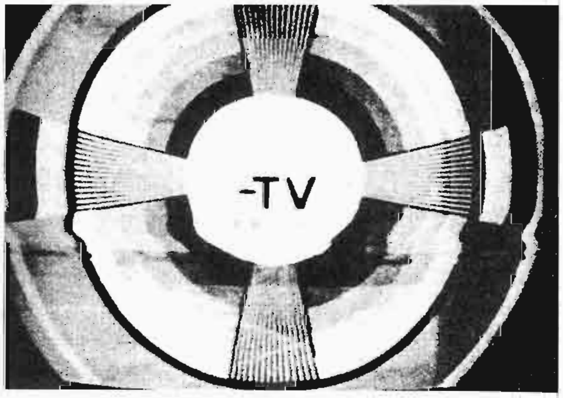

Fig. 135. Interference—crosstalk.

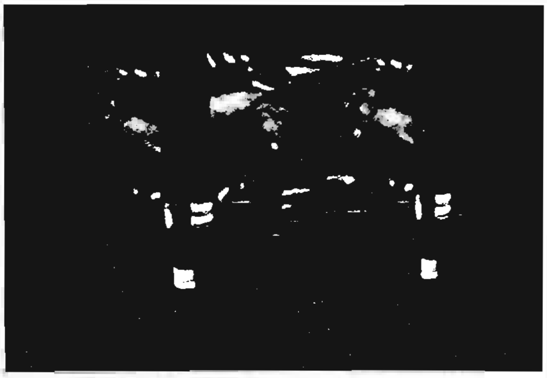

Fig. 136. Interference—crosstalk—horizontal.

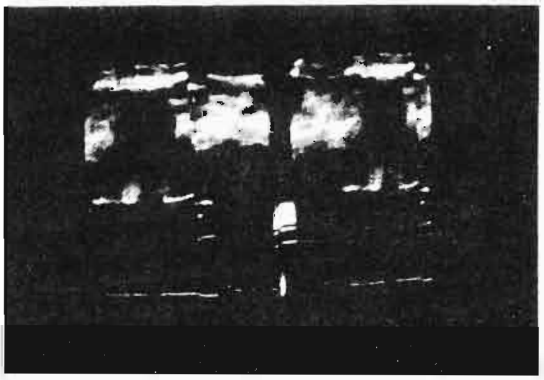

Fig. 137. Interference—crosstalk—vertical.

Crosstalk (Figs. 135-137)

Crosstalk, as considered herein, is the effect of undesired coupling between two television signal paths. If the coupling is strong enough, the result is a weak extraneous image, usually somewhat distorted, superimposed on the main image similar to Fig. 135. Since different video systems normally are not exactly synchronized, rather violent horizontal motion of the crosstalking image can occur. Vertical motion is not likely to be so violent, since the field rates usually will be closer together than the line rates.

The most prominent features of the crosstalking image will be the line and field blanking intervals. These are, of course, blacker-than-black and they effectively frame the crosstalking image. As crosstalk coupling is reduced, the crosstalking image is no longer visible but the horizontal interval which appears as a wide black vertical bar, and the vertical interval which appears as a wide black horizontal bar, will be visible moving through the picture. The rate of horizontal and vertical motion will vary with the differences between the sync rates of the two signals. The horizontal interval is usually the most disturbing since it extends the whole height of the raster as a wide black bar, with appreciable motion. The vertical interval is usually less noticeable.

Depending upon the strength of the unwanted signal, the interference may or may not be seen on the A-scope. In the example used, it was necessary for photographic reasons to introduce the crosstalking signal only about 10 dB below the desired signal. Therefore, the interfering signal is evident as modulation on both the horizontal and vertical presentations (Figs. 136 and 137).

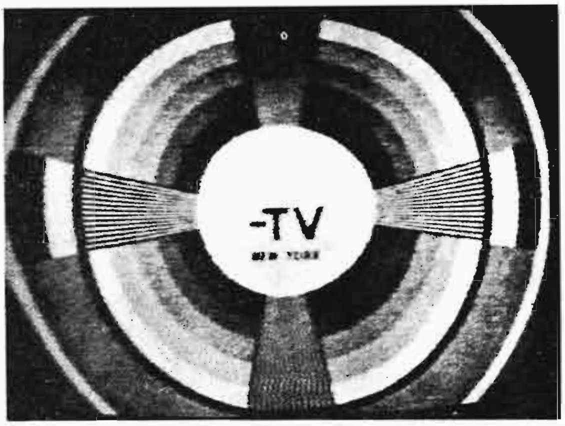

Fig. 138. Random noise.

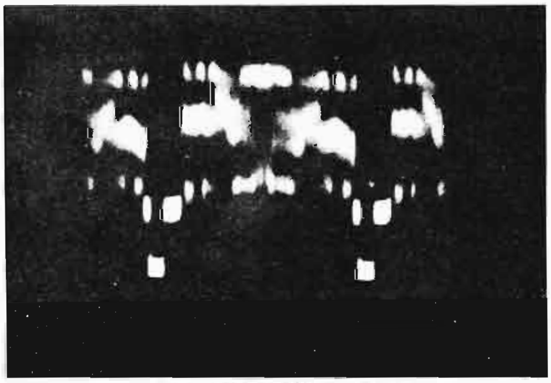

Fig. 139. Random noise—horizontal.

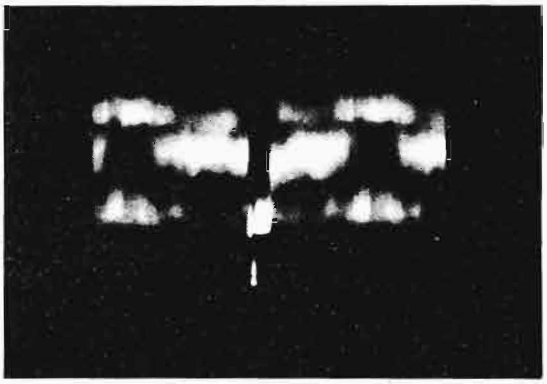

Fig. 140. Random noise—vertical.

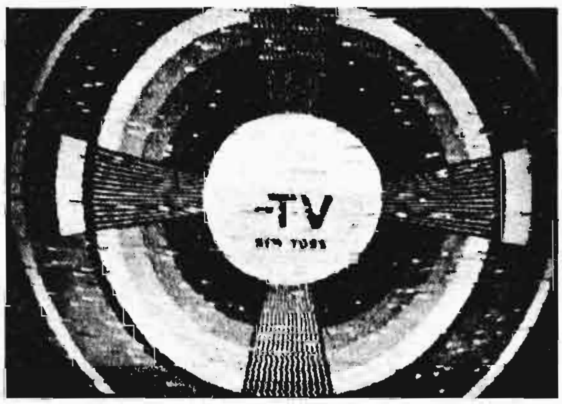

Fig. 141. Impulse noise.

Random Noise (Figs. 138-140)

This type of noise is of the general type obtained by amplification of thermal noise, but is not necessarily confined to that source. It covers a wide band of frequencies without too much energy variation. The overall rms amplitude is reasonably stable over time intervals corresponding to one line scan. Experience indicates that, assuming noise peaks about three times the rms value, peak random noise should be limited to approximately 30 dB below the picture signal for a 4 MHz bandwidth system. This 30 dB limit applies to the entire length of circuit involved, including everything from the camera to the home receiver. Accordingly, any part of the transmission circuitry would necessarily be limited to a much lower noise level in order to meet the overall limit. For quantitative measurements of noise it is necessary to eliminate energy in the frequency spectrum outside the video band.

The visual effect of random noise is that the picture acquires a pronounced graininess. When noise is strong enough, this may be called "snow" as shown in Fig. 138. Thickening of the blanking lines and tips of sync pulses is usually evident, as in Figs. 139 and 140 which show the horizontal and vertical scanning intervals of the picture of Fig. 138. Proper measurement of noise, however, is made by expanding the blanking lines in the vertical interval and observing them on a single line basis. These three illustrations are of noise caused by introducing a low level radio signal into a microwave repeater and restoring the radio signal to normal amplitude, thus amplifying the thermal noise in the equipment.

Another type of random noise is the result of a microwave message channel having a large number of busy circuits interfering with the picture channel.

Light random noise, visible only in the background of the picture, has been referred to sometimes as "busy background," since variations in intensity of the noise peaks usually cause the appearance of movement of the gray background, with minor thickening of the A-scope traces. This term is used with a different meaning by other groups connected with television and theatrical work, and its use is not recommended for description of television signal impairments. "Light noise" or "light high-frequency noise" are preferred terms.

Impulse Noise (Fig. 141)

The effect of impulse noise, which is composed usually of intermittent bursts or pulses, is difficult to evaluate. Assuming noise peaks at one per minute, one objective thought to be reasonable is to limit the peak noise to 20 dB below the signal level. The division between impulse noise and random noise is not sharp; as the rate of occurrence of noise pulses increases, the more nearly it approaches random noise. Picture impairments resulting from impulse noise, as shown in Fig. 141 are sometimes called "pigeons," since the spots seem to fly across the picture. Unless observation is made of the A-scope at the time of occurrence of the noise pulse, or unless the pulses occur frequently, thickening of blanking lines or other signal indications will not be observed.

Radar interference is one type of impulse noise which is seen occasionally. Radar, as observed on a picture monitor, consists of intermittent groups of pulses, or "pigeons," falling into a pattern on the screen. This pattern may move or be stationary and will vary greatly depending on the length of the pulse and the rate at which it recurs. Another characteristic of radar is the way it will usually fade and reappear at regular intervals. This is due to the rotation of the radar antenna, so the rate of reappearance is determined by the speed of rotation. Although there may be a wide variation, the usual rate is every six to ten seconds.

Microphonics (Figs. 142-144)

When some electron tubes are physically disturbed by vibrations due to nearby machinery, shocks from installation operations, or even by loud noises, their elements may vibrate, usually at a rate below 15,750 Hz. The varying tube characteristics will cause any signal being handled to be modulated at the vibration rate. Since this may be considered as low-frequency interference, the effect on pictures is to add a series of horizontal bars, usually moving and changing in size in accordance with the amplitude and frequency of the vibration. Note that in the A-scope pictures, Figs. 143 and 144, the sync portion of the signal is not varying with the microphonics in the picture information. These microphonics were found in a camera, with the sync information added later. Had the microphonics occurred in a transmission system, the sync would have been affected as well. In this case, the sync portion would look similar to Figs. 116 and 117.

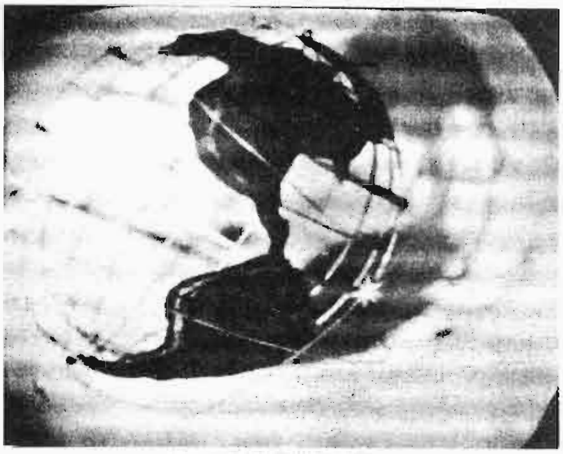

Fig. 142. Microphonics.

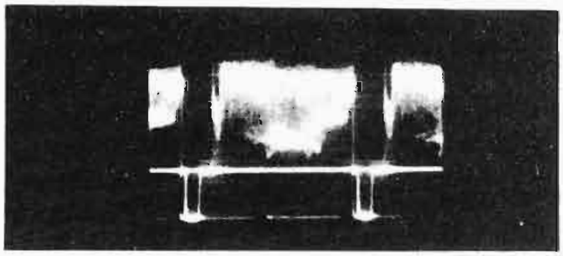

Fig. 143. Microphonics—horizontal.

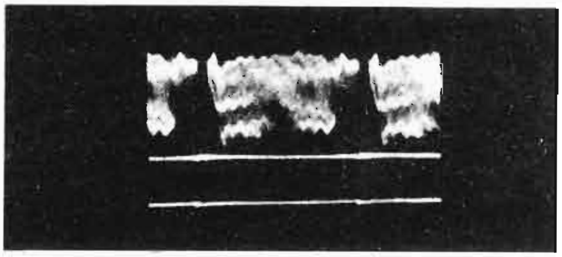

Fig. 144. Microphonics—vertical.

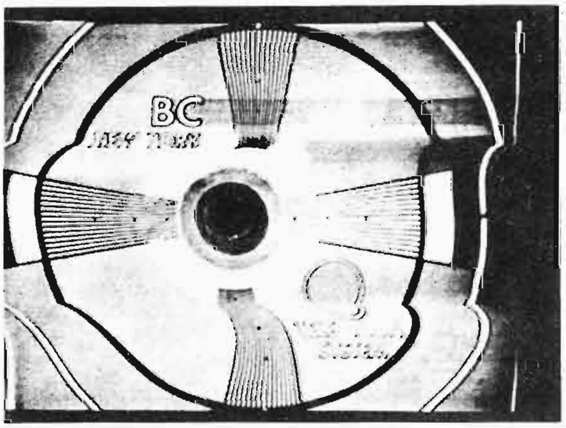

Fig. 145. Clamping failure.

Miscellaneous

Clamping

The effect on a composite video signal of low-frequency distortion is the same as though a low-frequency signal were added to the video signal. Thus low-frequency interference and low-frequency transmission deviations produce similar distortions of the video wave form. Clamping is a process whereby the effects of low-frequency interference and low-frequency transmission deviations are removed from the video signal. Telephone company clampers are designed so that a correcting bias voltage is added to the signal at the start of each horizontal synchronizing pulse, the magnitude and polarity of this correcting voltage being sufficient to keep the tips of the horizontal sync pulses at a fixed reference level.

Since the back porch immediately follows the tip of the synchronizing pulse which has been adjusted to a fixed reference voltage, it is subjected to approximately the full clamper correction. The front porch, however, occurs at the end of a line signal, and its level is displaced by the overall frequency distortion change during the preceding line interval. Since the clamper is triggered by the leading edge of the sync pulse, the front porch is unaffected by any subsequent correction that is applied by the clamper. Therefore, if the levels of the front and back porches would be equal except for the low-frequency impairment experienced, the correcting voltage supplied by the clamper would be equal to the difference in the level of the two porches. However, porches are frequently displaced due to other causes, such as transmission over a vestigial sideband carrier system where front porch level may vary depending upon the signal level at the end of each scanning line. In general, therefore, porch displacement should not be depended upon as a measure of clamper correction voltage, except under known conditions.

Absence of Clamping (Figs. 145-151). Loss of clamping results when the output level of the clamper drops to such a low level as to exceed the range of the clamper and thus make the clamping action ineffective. Figs. 145-151 show the result of loss of clamping due to low level. Loss of clamping also may be caused by defective tubes or other defective components. Erratic or no clamping action may also result from an overshoot on the leading edge of the front porch sufficiently large to cause the clamper to be falsely triggered, resulting in complete tearing of the picture. In the examples, only a few lines of tearing are visible at the top of the pictures; however, the A-scope reveals an erratic horizontal interval and serious distortion of the vertical blanking interval.

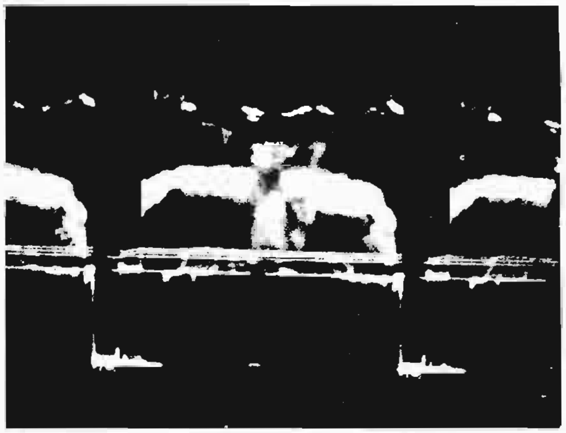

Fig. 146. Clamping failure—horizontal.

Fig. 147. Clamping failure—expanded horizontal.

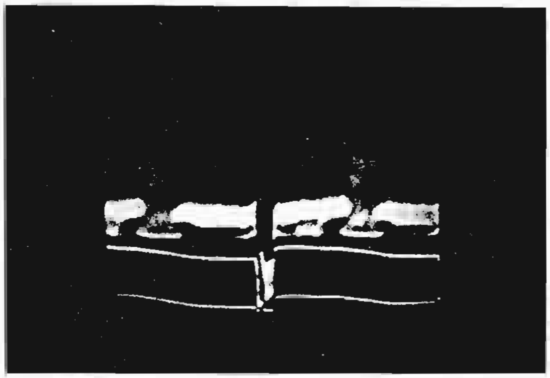

Fig. 148. Clamping failure—vertical.

Absence of clamper action is illustrated in Figs. 150 and 151. As previously discussed, the impairments observed due to low-frequency distortion are the same as though a low-frequency interfering signal were introduced and, therefore, will vary depending upon the nature and amount of low-frequency impairment present in the signal being observed. This is shown on the

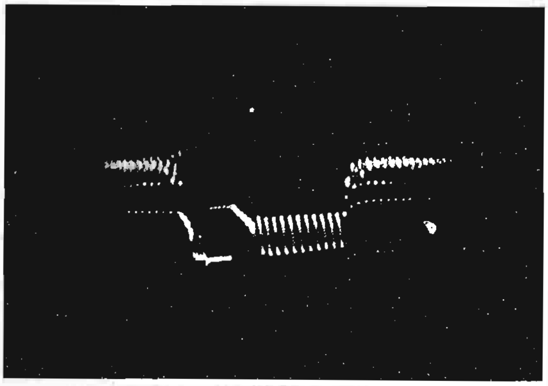

Fig. 149. Clamping failure—expanded vertical.

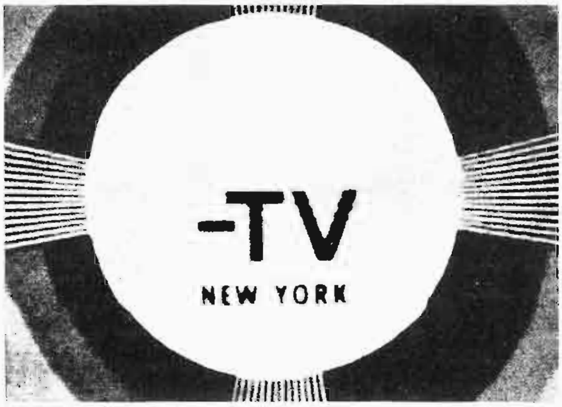

Fig. 152. Serrations.

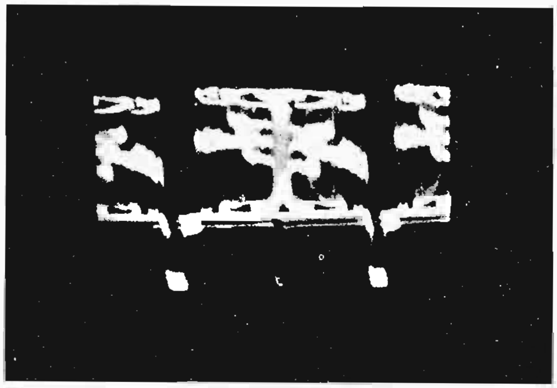

Fig. 150. Absence of clamping—horizontal.

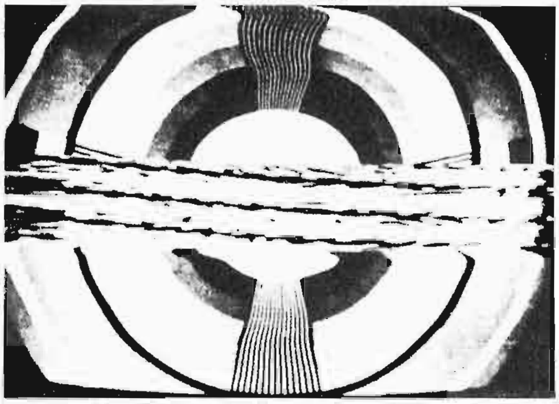

Fig. 153. Tearing.

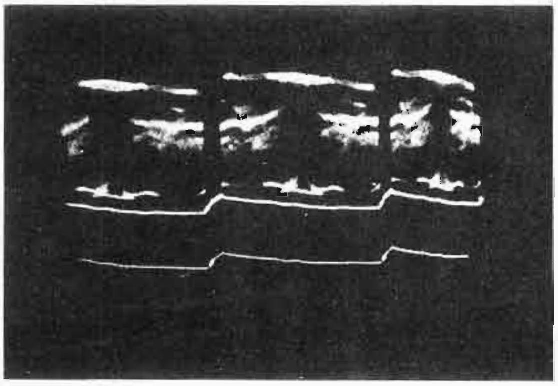

Fig. 151. Absence of clamping—vertical.

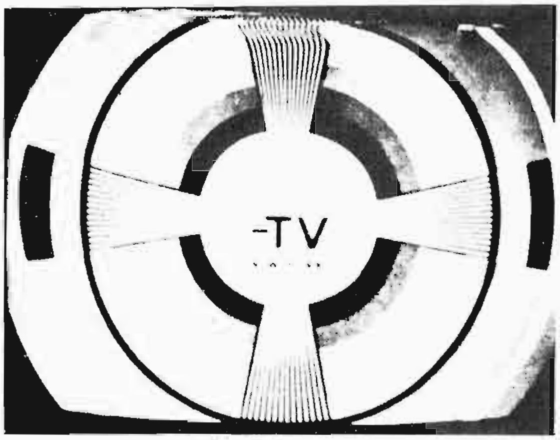

Fig. 154. Tearing.

horizontal presentation (Fig. 150) by the thickening of the traces, and in the vertical presentation (Fig. 151) by the varying tilts during vertical blanking and picture intervals.

Serrations (Fig. 152)

Serrations are jaggedness in the vertical and diagonal structure of images as seen in a picture monitor. They result from horizontal displacement of some of the scanning lines due to nonuniformity in the triggering time of the horizontal sweep oscillator. This condition may be caused by a distortion of the leading edge of the sync pulse as a result of interference, streaking, etc. Fig. 152 shows serrations of vertical and diagonal lines in the center of the test pattern.

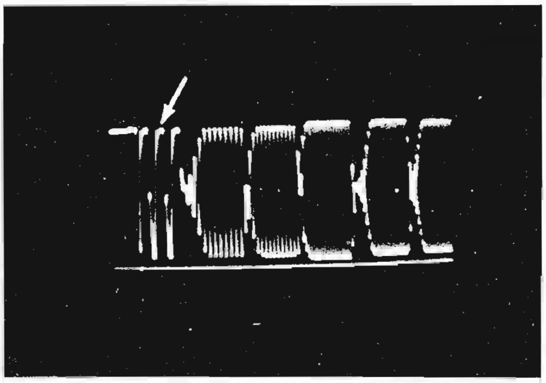

Fig. 155. Harmonic distortion—500 kHz.

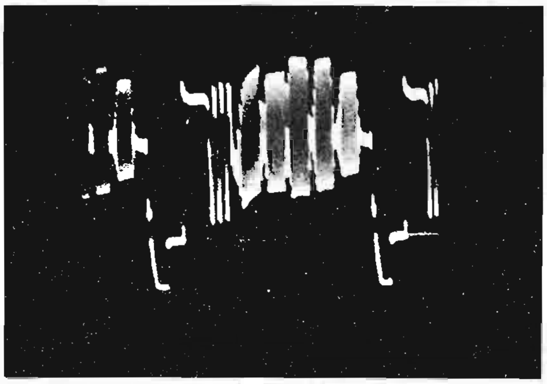

Fig. 156. Axis shift.

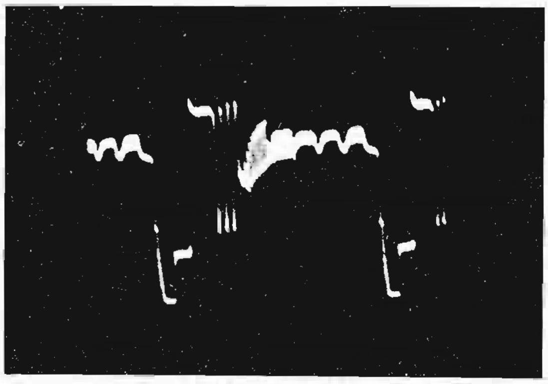

Fig. 157. Axis shift—through low pass filter.

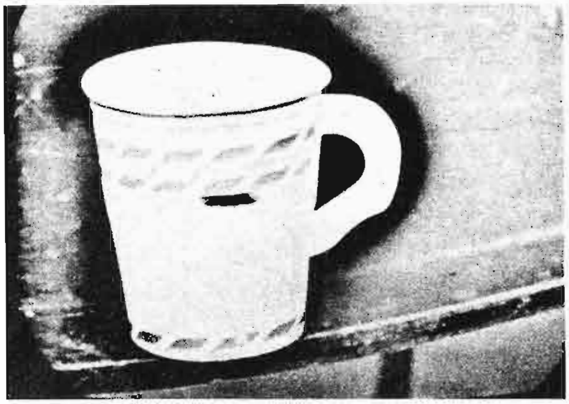

Fig. 158. Halo.

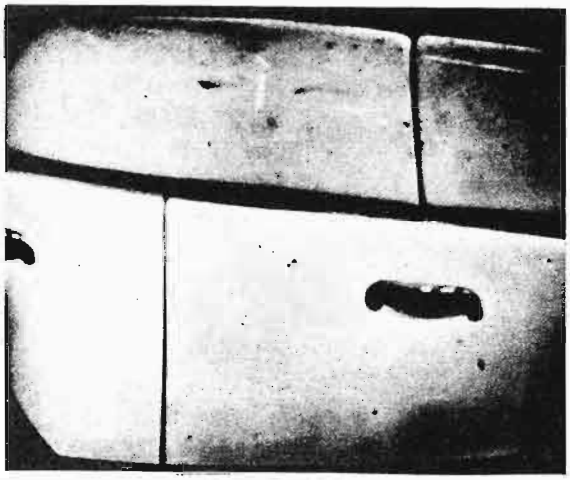

Fig. 159. Moiré.

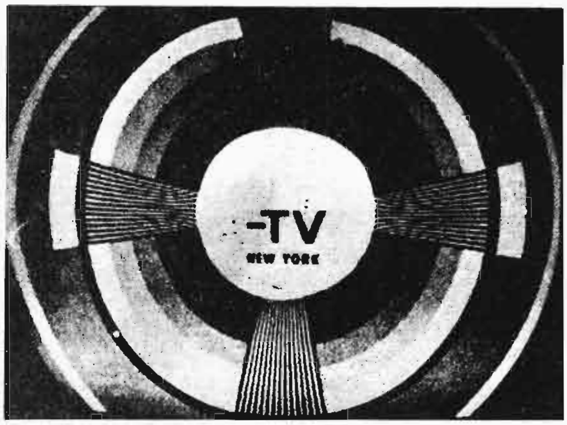

Fig. 160. Moiré.

Tearing (Figs. 153, 154)

Tearing is a horizontal displacement of the scanning lines to the extent that the picture appears torn. Tearing of the picture on the receiver or monitor may be caused by distortion or lack of horizontal sync pulses. It also may be caused by video black peaks or spikes which drop below blanking level near the horizontal sync pulse. Any other form of interference whose amplitude is such as to cause false triggering of the horizontal scanning circuit of a receiver or monitor will give similar effects. One illustration of such tearing is shown in Fig. 153.

Tearing at only the top of a picture, as in Fig. 154, is usually caused by impairment or loss of some equalizing pulses. This may be due to sync generator trouble, improper clamping action, or improper levels.

Nonlinearity (Figs. 155-157)

The requirement in most transmission circuits and amplifiers that the output be directly proportional to the input over the working range of voltages or power means that these circuits must be "linear." Operation outside the range of linearity may occur when exceeding ratings of equipment, when maladjustments occur, or when components such as vacuum tubes age. The departure from linearity that can be tolerated varies over wide ranges. For example, sync expansion circuits have been built into some telephone company clamper-amplifiers to deliberately "expand" the sync part of the video signal relative to the picture signal to compensate for unwanted compression which may accumulate in transmission. This illustrates that the results of nonlinearity may be either "compression," which is the more usual, or "expansion."

As discussed in the section on Level Irregularities, it is possible to compress either the negative or the positive peaks of a signal passing through an amplifier. The resulting video signal will contain either "black compression" or "white compression." In analyzing the effects of compression on a sive wave, it can be shown that the compressed signal, in addition to containing the fundamental sine wave, may include a dc component due to rectification, and other components made up of harmonics of the original sine wave frequency. When all of these components can be transmitted, the received wave is distorted and limited, as in Fig. 155, showing harmonic distortion on the 500 kHz burst of a multiburst test signal. Other examples of compression effects are shown in the section of this chapter dealing with level variations such as blooming, bleeding whites, etc. When compression becomes severe, it sometimes is called "clipping" and is observed as a sharp line of demarcation in level beyond which no signal is found.

If the nonlinearity is not equal for different impressed frequencies, combinations of effects may result which may be difficult to analyze. Such unequal distortions may occur in feedback amplifiers, where the feedback is a function of frequency in order to maintain overall flatness, or in circuits such as those of video cable amplifiers, where the high frequencies are transmitted at somewhat greater levels than the lows, in order to partially compensate for succeeding cable loss. Compression of higher frequency components of a signal compared to the lows has been noted fairly frequently.

The multiburst test signal has proved to be a good indicator for this selective type of compression, and may sometimes detect this condition when differential gain measurements indicate no trouble. When this distortion is present, close observation of the higher frequency burst will reveal that the axes of some or all of these bursts are shifted vertically by varying amounts, as in Fig. 156. As mentioned above, the distorted wave contains a dc, or, in the case of a video type signal, because of the horizontal scanning frequency, a 15,750-Hz component, and harmonics of the distorted burst. For frequencies above about 2.5-3.0 MHz, most transmission facilities cut out the burst harmonics leaving only the 15,750-Hz component and the fundamental frequency. This 15,750-Hz component will shift the axis of the multiburst through the burst in question. For frequencies whose second or higher harmonics are passed by the system, the axis shift is not so pronounced, but an expansion of the wave will show distortion, as on the 500 kHz burst illustrated in Fig. 155. This shifting of the axis of the bursts has sometimes been called "rectification," because of the production of the effective dc component. Fig. 157 is the same signal as Fig. 156, but in this case the signal has been put through a low-pass filter which effectively eliminates the higher frequency bursts and makes the axis shift more evident.

Halo (Fig. 158)

Halo usually is the appearance of a black border around unusually bright objects in a televised scene. As shown in Fig. 158, the border may be irregular in size and shape but is easily distinguished from streaking and smearing. It is caused by overloading of the pickup tube in scanning bright objects. While the accompanying figure indicates halo around an object occupying a large part of the viewing screen, it also is commonly noticed when stage lights are reflected from jewelry, eyeglasses and other small objects. With certain camera tube operating adjustments, a white area may surround dark objects.

Moiré (Figs. 159, 160)

Meshbeat or moiré effect is the appearance of vertical or diagonal lines on a picture, which resemble high-frequency interference. In Fig. 159, these lines are most noticeable across the top and bottom of the kitchen cabinet close-up. This difficulty may be caused by image-orthicon cameras where a beat is obtained between the scanning signal and the screen, or mesh, associated with the target plate.

Moiré pattern is also a natural optical effect when scanning closely spaced picture lines which are almost horizontal. It is evident on the horizontal wedges of the test pattern shown in Fig. 160.

Burned-In Image (Figs. 161, 162)

A burned-in image is one which persists in the camera output signal when the camera has been focused on another scene. Fig. 161 illustrates the case of a camera having been shifted to one side of a cue card, with the original image still visible to the right of the new one. Fig. 161 shows a burned-in image of the EIA test pattern, originally being viewed, superimposed on a close-up of a stove top and grillwork. This phenomenon is associated with orthicon camera tubes where the persistence of the burned-in image depends upon the length of time that the camera is focused on the original scene, and the brightness of the scene. It may last as long as several minutes in extreme cases.

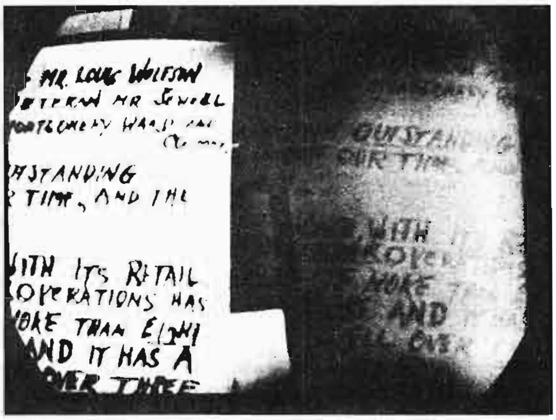

Fig. 161. Burned-in image.

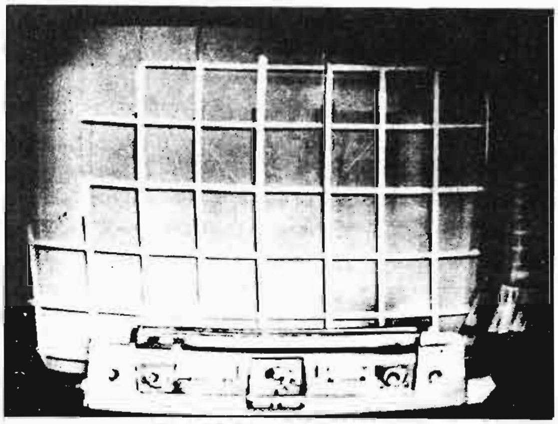

Fig. 162. Burned-in image.

Color Signal Impairments

In general, color television signals are subject to the same impairments as monochrome transmissions. However, color television signals may be impaired seriously by additional conditions that might not affect a monochrome picture adversely.

High or Low Chrominance Signal Level (Figs. 163, 164)

When the chrominance signal component of a color television signal is received at too high a level, colors will increase in saturation; when this component is received at too low a level, colors will tend to wash out. As long as overloading or differential gain is not evident, the proper relationship in saturation between various hues will be maintained.

A high or low chrominance signal level occurring when luminance signal levels are normal would result from excess gain or loss at the upper portion of the video signal frequency spectrum.

Since the color burst has the same frequency as the color subcarrier, any transmission characteristic affecting the amplitude of the chrominance signal will usually also affect the amplitude of the color burst (Figs. 163, 164). For rapid location of large deviations it is possible, using an A-scope with a wide band characteristic, to observe the color signal wave form for comparison of color burst and sync pulse amplitudes, which should be the same. However, a comparative measurement of color burst amplitudes is necessary for more precise locations.

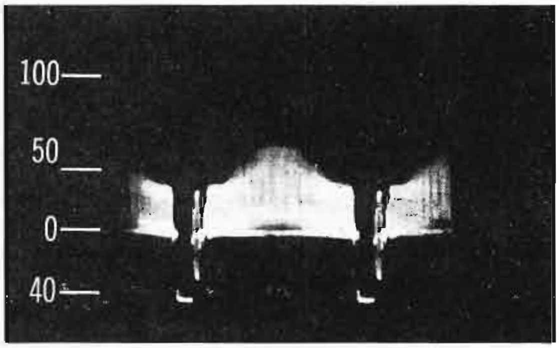

Fig. 163. High level chrominance signal—horizontal.

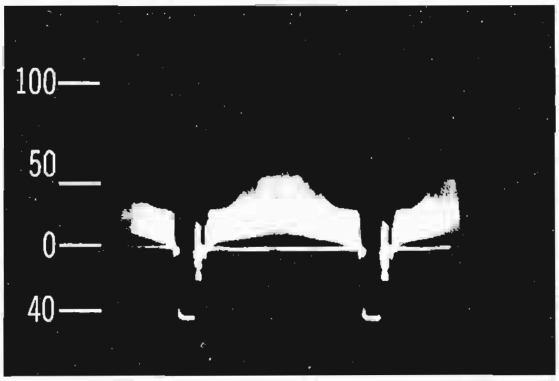

Fig. 164. Low level chrominance signal—horizontal.

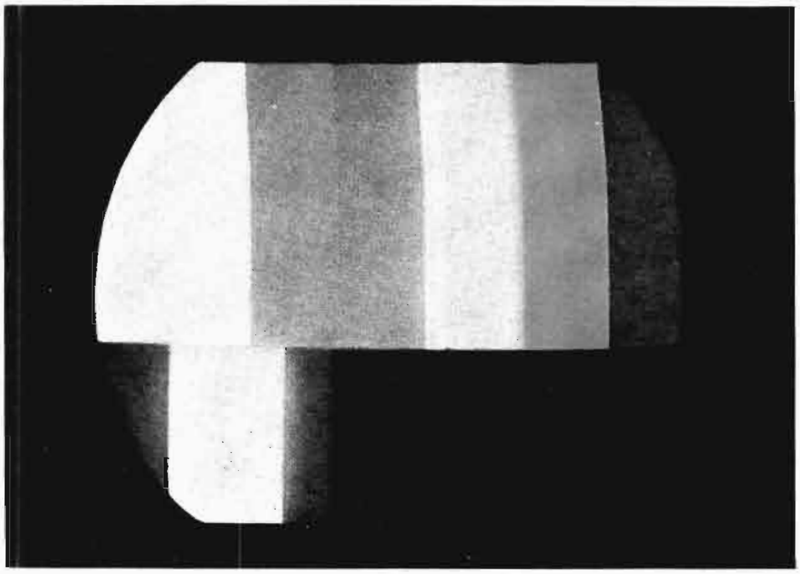

Fig. 165. Color bar signal—normal phase.

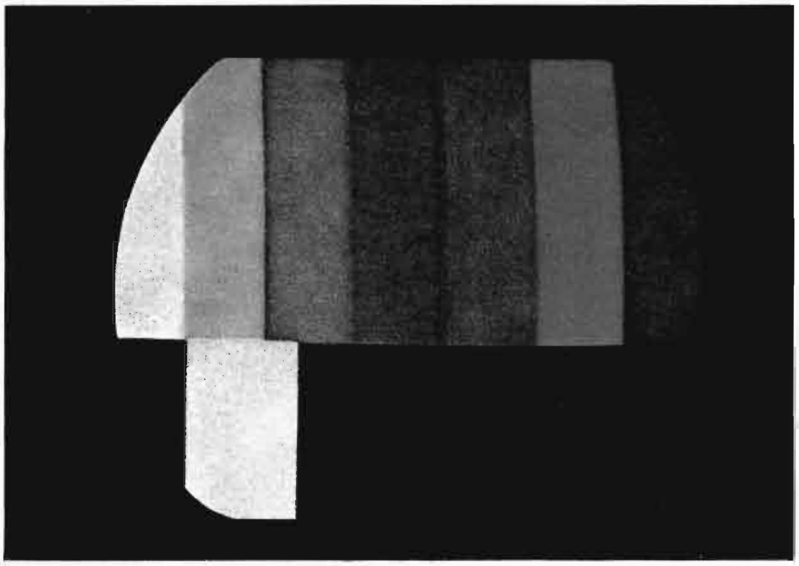

Fig. 166. Color bar signal—yellow shifted toward red.

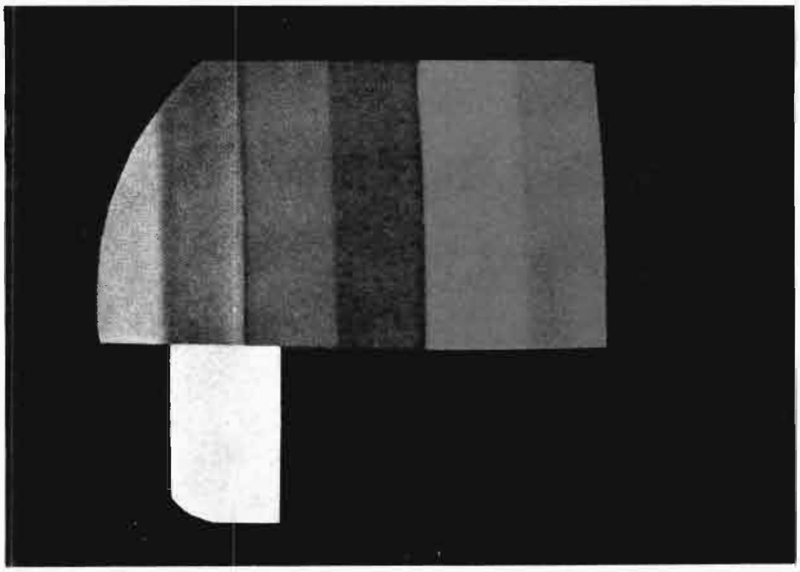

Fig. 167. Color bar signal—yellow shifted toward green.

Because results can be expressed quantitatively, A-scope location of impairments can usually be made more accurately and rapidly than would be possible using color monitors, although color monitors may also be used for verification.

Loss of Color

In the general case, this is caused by very low chrominance signal level. However, such a condition has occurred with an apparently normal color burst, as viewed on an A-scope. In this case, the frequency of the apparent color burst had been shifted from the normal 3.6 MHz value. Color monitors are required for quick location in such cases.

Differential Phase (Figs. 165-167)

Differential phase is the change in phase of the 3.6 MHz color subcarrier as the level of the luminance signal on which it rides is varied from blanking to white. It causes error in portrayal of hues. Figs. 166 and 167 illustrate large amounts of differential phase of opposite signs, as compared to Fig. 165 which is a "normal" picture.

In FM radio relay systems, this distortion is usually caused by a nonuniform delay-frequency characteristic in the IF equipment, where varying amplitudes of input signal are represented by varying frequencies. The color burst is always at blanking level, and therefore, will always swing about the same frequency on the radio relay system. Color components of the signal generally are not at blanking level; therefore, the FM swing will be about a different frequency and any difference in delay between the two results in differential phase. In telephone company systems, delay equalizers in IF paths are used to correct differential phase.

In addition to FM radio systems, differential phase distortion may be experienced in any equipment having transmission paths that vary in phase with level. Hue impairments are observable in color picture monitors, but are not apparent in either monochrome picture monitors or in A-scopes. Color monitors are neither sufficiently precise nor stable to use as a basis for correction of differential phase, and it is, therefore, necessary to release facilities from service in order to make differential phase measurements. The 47A Transmission Measuring System is used by the telephone company for proper adjustment of differential phase equalizers, while the broadcasters usually use a modulated stairstep signal for measuring differential phase.

Differential Gain

In color television transmission, differential gain is the change in gain of the 3.6 MHz color subcarrier as the level of the luminance signal on which it rides is varied from blanking to white. It causes error in color saturation of the received picture.

Differential gain is generally observed as signal compression as luminance levels are increased, although expansion can be experienced. The effects of differential gain may be observable in color monitors, depending upon degree. Severe cases of such signal impairment should be evidenced in the A-scope presentation of a color bar test signal as an overloading or expansion condition of the chrominance components. Other than for severe conditions of this type, the facility or equipment to be tested must be released from service for differential gain tests to enable location of causative facility sections.

When excess differential gain is experienced, the first step is to assure that proper amplitude levels have been maintained. Further investigation would include location of the portions of the layout or piece of equipment contributing appreciably to this condition. Clearance is then generally accomplished by replacement of tubes or other defective components.

Leading or Lagging Chrominance

When the chrominance signal is not received at the same time as the luminance signal, colors will appear in the color picture monitor either to one side or the other of the image. For example, a blob of red may occur at lip level on either side of the mouth. This is often called "funny paper" effect. A shift to the left results from leading chrominance information. When severe, this impairment might be observed as edge effect on monochrome pictures transmitted over the same facility.

This condition can result from improper delay relationship between the lower and the upper portions of the frequency spectrum over transmission facilities or through equipment. Therefore, envelope delay characteristics of television layouts in color condition should be checked, should leading or lagging chrominance be experienced.

GLOSSARY OF TELEVISION TERMS

General

This section defines various terms presently used in the line-up, operation and maintenance of video transmission systems. Experience in providing video service has indicated that a common understanding and use of the terms outlined in this section by the telephone companies and the broadcasting companies is desirable. Because these terms are intended for practical use by operating personnel, they may differ somewhat in wording from published standards which are not as well suited for the intended purpose.

Terms and Definitions

Aspect Ratio: The numerical ratio of picture width to height.

Back Porch: That portion of the composite picture signal which lies between the trailing edge of the horizontal sync pulse and the trailing edge of the corresponding blanking pulse.

Back Porch Tilt: The slope of the back porch from its normal horizontal position. Positive or negative refers, respectively, to upward or downward tilt to the right.

Bandwidth: The number of Hertzs expressing the difference between the limiting frequencies of a frequency band. For example, the 2.5-3.5 MHz band has a width of 1 MHz.

Black Compression: Amplitude compression of the signals corresponding to the black regions of the picture, thus modifying the tonal gradient.

Black Peak: The maximum excursion of the picture signal in the black direction at the time of observation.

Blacker-than-Black: The amplitude region of the composite video signal below reference black level in the direction of the synchronizing pulses.

Blanking (Picture): The portion of the composite video signal whose instantaneous amplitude makes the vertical and horizontal retrace invisible.

Blanking Level: The level of the front and back porches of the composite video signal.

Bleeding Whites: An overloading condition in which white areas appear to flow irregularly into black areas.

Blooming: The defocusing of regions of the picture where the brightness is at an excessive level, due to enlargement of spot size and halation of the fluorescent screen of the cathode-ray picture tube.

Bounce: An unnatural sudden variation in the brightness of the picture.

Breathing: Amplitude variations similar to "bounce" but at a slow regular rate.

Breezeway: In NTSC color, that portion of the back porch between the trailing edge of the sync pulse and the start of the color burst.

Burned-In Image: An image which persists in a fixed position in the output signal of a camera tube after the camera has been turned to a different scene.

Camera Tube: See Pickup Tube.

Cathode-Ray Tube: An electron tube assembly containing an electron gun arranged to direct a beam upon a fluorescent screen. Scanning by the beam can produce light at all points in the scanned raster.

Chrominance Signal: That portion of the NTSC color television signal which contains the color information.

Clamper: A device which functions during the horizontal blanking or sync interval to fix the level of the picture signal at some predetermined reference level at the beginning of each scanning line.

Clamping: The process that establishes a fixed level for the picture signal at the beginning of each scanning line.

Clipping: The shearing off of the peaks of a signal. For a picture signal, this may affect either the positive (white) or negative (black) peaks. For a composite video signal, the sync signal may be affected.

Color Burst: In NTSC color, normally refers to a burst of approximately 9 Hz of 3.6 MHz subcarrier on the back porch of the composite video signal. This serves as a color synchronizing signal to establish a frequency and phase reference for the chrominance signal.

Color Subcarrier: In NTSC color, the carrier whose modulation sidebands are added to the monochrome signal to convey color information, i.e., 3.6 MHz (3.579545 MHz).

Color Transmission: The transmission of a signal which represents both the brightness values and the color (chrominance) values in a picture.

Composite Video Signal: The complete video signal. For monochrome, it consists of the picture signal and the blanking and synchronizing signals. For color, additional color synchronizing signals and color picture information are added.

Compression: An undesired decrease in amplitude of a portion of the composite video signal relative to that of another portion. Also, a less than proportional change in output of a circuit for a change in input level. For example, compression of the sync pulse means a decrease in the percentage of sync during transmission.

Contrast: The range of light and dark values in a picture, or the ratio between the maximum and minimum brightness values. For example, in a high contrast picture there would be intense blacks and whites, whereas a low contrast picture would contain only various shades of gray.

CRO: Cathode ray oscilloscope.

Crosstalk: An undesired signal interfering with the desired signal.

Cutoff Frequency: That frequency beyond which no appreciable energy is transmitted. It may refer to either an upper or lower limit of a frequency band.

Damped Oscillation: Oscillation which, because the driving force has been removed, gradually dies out, each swing being smaller than the preceding in smooth regular decay.

Deemphasis: See Restorer.

Definition: See Resolution—(Horizontal) and (Vertical).

Delay Distortion: Distortion resulting from nonuniform speed of transmission of the various frequency components of a signal; i.e., the various frequency components of the signal have different times of travel (delay) between the input and the output of a circuit.

Detail: Refers to the most minute elements in a picture which are distinct and recognizable. Similar to definition or resolution.

Differential Gain: The amplitude change, usually of the 3.6 MHz color subcarrier, introduced by the overall circuit, measured in dB or percent, as the picture signal on which it rides is varied from blanking to white level.

Differential Phase: The phase change of the 3.6 MHz color subcarrier introduced by the overall circuit, measured in degrees, as the picture signal on which it rides is varied from blanking to white level.

Displacement of Porches: Refers to any difference between the level of the front porch and the level of the back porch.

Distortion: The departure, during transmission or amplification, of the received signal wave form from that of the original transmitted wave form.

Driving Signals: Signals that time the scanning at the pickup device.

Echo (or Reflection): A wave which has been reflected at one or more points in the transmission medium, with sufficient magnitude and time difference to be perceived in some manner as a wave distinct from that of the main or primary transmission. Echoes may be either leading or lagging the primary wave and appear in the picture monitor as reflections or "ghosts."

Edge Effect: See Following or Leading White and Following or Leading Black.

EIA: Abbreviation for Electronic Industries Association.

Equalizing Pulses: Pulses of one half the width of the horizontal sync pulses which are transmitted at twice the rate of the horizontal sync pulses during the blanking intervals immediately preceding and following the vertical sync pulses. The action of these pulses causes the vertical deflection to start at the same time in each interval, and also serves to keep the horizontal sweep circuits in step during the vertical blanking intervals immediately preceding and following the vertical sync pulse.

Expansion: An undesired increase in amplitude of a portion of the composite video signal relative to that of another portion. Also, a greater than proportional change in the output of a circuit for a change in input level. For example, expansion of the sync pulse means an increase in the percentage of sync during transmission.

Field: One half of a complete picture (or frame) interval, containing all of the odd or even scanning lines of the picture.

Field Frequency: The rate at which a complete field is scanned, nominally 60 times a second.

Flash: Momentary interference to the picture of a duration of approximately one field or less, and of sufficient magnitude to totally distort the picture information. In general, this term is used alone when the impairment is of such short duration that the basic impairment cannot be recognized. Sometimes called "hit."

Fly-Back: See Horizontal Retrace.

Following (or Trailing) Blacks: A term used to describe a picture condition in which the edge following a white object is overshaded toward black. The object appears to have a trailing black border. Also called "trailing reversal."

Following (or Trailing) Whites: A term used to describe a picture condition in which the edge following a black or dark gray object is shaded toward white. The object appears to have a trailing white border. Also called "trailing reversal."

Frame: One complete picture consisting of two fields of interlaced scanning lines.

Frame Frequency: The rate at which a complete frame is scanned, nominally 30 frames per second.

Front Porch: That portion of the composite picture signal which lies between the leading edge of the horizontal blanking pulse, and the leading edge of the corresponding sync pulse.

Frame Roll: A momentary roll.

Gain-Frequency Distortion: Distortion which results when all of the frequency components of a signal are not transmitted with the same gain or loss. A departure from "flatness" in the gain-frequency characteristic of a circuit.

Ghost: A shadowy or weak image in the received picture, offset either to the left or right of the primary image, the result of transmission conditions which create secondary signals that are received earlier or later than the main or primary signal. A ghost displaced to the left of the primary image is designated as "leading" and one displaced to the right is designated as "following" (lagging). When the tonal variations of the ghost are the same as the primary image, it is designated as "positive" and when it is the reverse, it is designated as "negative."

Glitch: A form of low-frequency interference, appearing as a narrow horizontal bar moving vertically through the picture. This is also observed on an oscilloscope at field or frame rate as an extraneous voltage pip moving along the signal at approximately reference black level.

Halo: Most commonly, a dark area surrounding an unusually bright object, caused by overloading of the camera tube. Reflection of studio lights from a piece of jewelry, for example, might cause this effect. With certain camera tube operating adjustments, a white area may surround dark objects.

Height: The size of the picture in a vertical direction.

High-Frequency Distortion: Distortion effects which occur at high frequency. Generally considered as any frequency above the 15.75 kc line frequency.

High-Frequency Interference: Interference effects which occur at high frequency. Generally considered as any frequency below the 15.75 kHz line frequency.

Highlights: The maximum brightness of the picture, which occurs in regions of highest illumination.

Hit: See Flash.

Horizontal Blanking: The blanking signal at the end of each scanning line.

Horizontal Displacements: Describes a picture condition in which the scanning lines start at relatively different points during the horizontal scan. See Serrations and Jitter.

Horizontal Retrace: The return of the electron beam from the right to the left side of the raster after the scanning of one line.

Horizontal (Hum) Bars: Relatively broad horizontal bars, alternately black and white, which extend over the entire picture. They may be stationary, or may move up or down. Sometimes referred to as a "venetian blind" effect. Caused by approximate 60-Hz interfering frequency, or one of its harmonic frequencies.

Hue: Corresponds to "color" in everyday use; i.e., red, blue, etc. Black, white and gray do not have hue.

Iconoscope: A camera tube in which a high-velocity electron beam scans a photoemissive mosaic which has electrical storage capability.

Interference: In a signal transmission path, extraneous energy which tends to interfere with the reception of the desired signals.

Interlaced Scanning (Interlace): A scanning process in which each adjacent line belongs to the alternate field.

Ion: A charged atom, usually an atom of residual gas in an electron tube.

Ion Spot: A spot on the fluorescent surface of a cathode-ray tube, which is somewhat darker than the surrounding area because of bombardment by negative ions which reduce the sensitivity.

Ion Trap: An arrangement of magnetic fields and apertures which will allow an electron beam to pass through but will obstruct the passage of ions.

IRE: The Institute of Radio Engineers. This organization combined with the American Institute of Electrical Engineers effective January 1, 1963, to form the Institute of Electrical and Electronic Engineers.

IRE Roll-Off: The IRE standard oscilloscope frequency response characteristic for measurement of level. This characteristic is such that at 2 megacycles the response is approximately 8.5 dB below that in the flat (low-frequency) portion of the spectrum, and cuts off slowly. The latest standards for this roll-off were issued in 1958. It is not anticipated that the usage of the term "IRE Roll-Off" will be changed in any way.

IRE Scale: An oscilloscope scale in keeping with IRE Standard 50, IRE 23.S1 and the recommendations of the Joint Committee of TV Broadcasters and Manufacturers for Coordination of Video Levels.

Jitter: A tendency toward lack of synchronization of the picture. It may refer to individual lines in the picture or to the entire field of view.

Kinescope: Frequently used to mean picture tubes in general; however, this name has been copyrighted.

Kinescope Recording: A motion picture film recording of the presentation shown by a picture monitor. Also known as Television Recording (TVR), Vitapix, etc.

Leading Blacks: A term used to describe a picture condition in which the edge preceding a white object is overshaded toward black. The object appears to have a preceding or leading black border.

Leading Whites: A term used to describe a picture condition in which the edge preceding a black object is shaded toward white. The object appears to have a preceding or leading white border.

Line Frequency: The number of horizontal scans per second, nominally 15,750 times per second.

Low-Frequency Distortion: Distortion effects which occur at low frequency. Generally considered as any frequency below the 15.75 kHz line frequency.

Low-Frequency Interference: Interference effects which occur at low frequency. Generally considered as any frequency below the 15.75 kHz line frequency.

Luminance Signal: That portion of the NTSC color television signal which contains the luminance or brightness information.

Meshbeat: See Moiré.

Microphonics: In video transmission, refers to the mechanical vibration of the elements of an electron tube resulting in a spurious modulation of the normal signal. This usually results in erratically spaced horizontal bars in the picture.

Microsecond: One millionth of a second.

Moiré: A wavy or satiny effect produced by convergence of lines. Usually appears as a curving of the lines in the horizontal wedges of the test pattern and is most pronounced near the center where the lines forming the wedges converge. A moiré pattern is a natural optical effect when converging lines in the picture are nearly parallel to the scanning lines. This effect, to a degree, is sometimes due to the characteristics of color picture tubes and of image orthicon pickup tubes (in the latter termed "meshbeat").

Monochrome Transmission (Black and White): The transmission of a signal wave which represents the brightness values in the picture, but not the color (chrominance) values in the picture.

Multiple Blanking Lines: Evidenced by a thickening of the blanking line trace or by several distinct blanking lines as viewed on an oscilloscope. May be caused by hum.

Negative Image: Refers to a picture signal having a polarity which is opposite to normal polarity and which results in a picture in which the white areas appear as black and vice versa.

NTSC: National Television System Committee.

Noise: The word "noise" is a carryover from audio practice. Refers to random spurts of electrical energy or interference. May produce a "salt-and-pepper" pattern over the picture. Heavy noise sometimes is called "snow."

Orthicon (Conventional): A camera tube in which a low-velocity electron beam scans a photoemissive mosaic on which the image is focused optically and which has electrical storage capability.

Orthicon (Image): A camera tube in which the optical image falls on a photoemissive cathode which emits electrons that are focused on a target at high velocity. The target is scanned from the rear by a low-velocity electron beam. Return beam modulation is amplified by an electron multiplier to form an overall light-sensitive device.

Orthicon Effect: One or more of several image orthicon impairments that have been referred to as "Orthicon Effect" as follows:

1. Edge effect—usually a white outline of well defined objects.
2. Meshbeat or moiré.
3. Ghost—appears in connection with bright images and is not limited in position to leading or lagging the main image.
4. Halo.
5. Burned-in image.

It is obviously necessary to indicate specifically the effect or effects experienced and, therefore, it is recommended that use of this term be discontinued.

Overshoot: An excessive response to a unidirectional signal change. Sharp overshoots are sometimes referred to as "spikes."

Pairing: A partial or complete failure of interlace in which the scanning lines of alternate fields do not fall exactly between one another but tend to fall (in pairs) one on top of the other.

Peak-to-Peak: The amplitude (voltage) difference between the most positive and the most negative excursions (peaks) of an electrical signal.

Pedestal: This term is obsolete.

Pedestal Level: This term is obsolete; "blanking level" is preferred.

Percentage Sync: The ratio, expressed as a percentage, of the amplitude of the synchronizing signal to the peak-to-peak amplitude of the picture signal between blanking and reference white level.

Photoemissive: Emitting or capable of emitting electrons upon exposure to radiation in and near the visible region of the spectrum.

Pickup Tube: An electron-beam tube used in a television camera where an electron current or a charge-density image is formed from an optical image and scanned in a predetermined sequence to provide an electrical signal.

Picture Monitor: This refers to a cathode-ray tube and its associated circuits, arranged to view a television picture.

Picture Signal: That portion of the composite video signal which lies above the blanking level and contains the picture information.

Picture Tube: A cathode-ray tube used to produce an image by variation of the intensity of a scanning beam.

Pigeons: Noise observed on picture monitors as pulses or bursts of short duration, at a slow rate of occurrence—a type of impulse noise.

Polarity of Picture Signal: Refers to the polarity of the black portion of the picture signal with respect to the white portion of the picture signal. For example, in a "black negative" picture, the potential corresponding to the black areas of the picture is negative with respect to the potential corresponding to the white areas of the picture; while in a "black positive" picture the potential corresponding to the black areas of the picture is positive. The signal as observed at broadcasters' master control rooms and telephone company television operating centers is "black negative."

Preemphasis: A change in level of some frequency components of the signal with respect to the other frequency components at the input to a transmission system. The high-frequency portion of the band is usually transmitted at higher level than the low-frequency portion of the band.

Raster: The scanned (illuminated) area of the cathode-ray picture tube.

Reference Black Level: The level corresponding to the specified maximum excursion of the luminance signal in the black direction.

Reference Signals (Vertical Interval): Signals inserted into the vertical interval at the program source which are used to establish black and white levels. Such a signal might consist of five microseconds of reference black at 7.5 IRE divisions and five microseconds of reference white at 100 IRE divisions located near the end of lines 18 and 19 of the vertical interval.

Reference White Level: The level corresponding to the specified maximum excursion of the luminance signal in the white direction.

Reflections or Echoes: In video transmission this may refer either to a signal or to the picture produced.

1. Signal:

(a) Waves reflected from structures or other objects.

(b) Waves which are the result of impedance or other irregularities in the transmission medium.

2. Picture: "Echoes" observed in the picture produced by the reflected waves.

Resolution (Horizontal): The amount of resolvable detail in the horizontal direction in a picture. It is usually expressed as the number of distinct vertical lines, alternately black and white, which can be seen in three quarters of the width of the picture. This information usually is derived by observation of the vertical wedge of a test pattern. A picture which is sharp and clear and shows small details has good, or high, resolution. If the picture is soft and blurred and small details are indistinct it has poor, or low, resolution. Horizontal resolution depends upon the high-frequency amplitude and phase response of the pickup equipment, the transmission medium and the picture monitor, as well as the size of the scanning spots.

Resolution (Vertical): The amount of resolvable detail in the vertical direction in a picture. It is usually expressed as the number of distinct horizontal lines, alternately black and white, which can be seen in a test pattern. Vertical resolution is primarily fixed by the number of horizontal scanning lines per frame. Beyond this, vertical resolution depends on the size and shape of the scanning spots of the pickup equipment and picture monitor and does not depend upon the high-frequency response or bandwidth of the transmission medium or picture monitor.

Restorer: As used by the telephone company, a network designed to remove the effects of preemphasis, thereby resulting in an overall normal characteristic.

Retrace (Return Trace): See Horizontal and Vertical Retrace.

R-F Pattern: A term sometimes applied to describe a fine herringbone pattern in a picture. May also cause a slight horizontal displacement of scanning lines resulting in a rough or ragged vertical edge of the picture. Caused by high-frequency interference.

Ringing: An oscillatory transient occurring in the output of a system as a result of a sudden change in input. Results in close-spaced multiple reflections, particularly noticeable when observing test patterns, equivalent square waves, sine-squared signal, or any fixed objects whose reproduction requires frequency components approximating the cutoff frequency of the system.

Roll: A lack of vertical synchronization which causes the picture as observed on the picture monitor to move upward or downward.

Roll-Off: A gradual attenuation of gain-frequency response at either or both ends of the transmission pass band.

Saturation (Color): The "vividness" of a color described by such terms as pale, deep, pastel, etc. The greater the amplitude of the chrominance signal, the greater the saturation.

Scanning: The process of breaking down an image into a series of elements or groups of elements representing light values and transmitting this information in time sequence.

Scanning Line: A single continuous narrow strip of the picture area containing highlights, shadows, and half-tones, determined by the process of scanning.

Scanning Spot: Refers to the cross section of an electron beam at the point of incidence in a camera tube or picture tube.

Serrated Pulses: A series of equally spaced pulses within a pulse signal. For example, the vertical sync pulse is serrated in order to keep the horizontal sweep circuits in step during the vertical sync pulse interval.

Serrations: This is a term used to describe a picture condition in which vertical or nearly vertical lines have a saw-tooth appearance. The result of scanning lines starting at relatively different points during the horizontal scan.

Setup: The separation in level between blanking and reference black levels.

Smear: A term used to describe a picture condition in which objects appear to be extended horizontally beyond their normal boundaries in a blurred or "smeared" manner.

Snow: Heavy random noise.

Spike: See Overshoot.

Streaking: A term used to describe a picture condition in which objects appear to be extended horizontally beyond their normal boundaries. This will be more apparent at vertical edges of objects when there is a large transition from black to white or white to black. The change in luminance is carried beyond the transition, and may be either negative or positive. For example, if the tonal degradation is an opposite shade to the original figure (white following black), the streaking is called negative; however, if the shade is the same as the original figure (white following white), the streaking is called positive. Long streaking may extend to the right edge of the picture, and in extreme cases of low-frequency distortion, can extend over a whole line interval.

Synchronization: The maintenance of one operation in step with another.

Sync: An abbreviation for the words "synchronization," "synchronizing," etc. Applies to the synchronization signals, or timing pulses, which lock the electron beam of the picture monitors in step, both horizontally and vertically, with the electron beam of the pickup tube. The color sync signal (NTSC) is known as the color burst.

Sync Compression: The reduction in the amplitude of the sync signal, with respect to the picture signal, occurring between two points of a circuit.

Sync Level: The level of the tips of the synchronizing pulses.

Tearing: A term used to describe a picture condition in which groups of horizontal lines are displaced in an irregular manner. Caused by lack of horizontal synchronization.

Television Recording (TVR): See Kinescope Recording.

Transients: Signals which endure for a brief time prior to the attainment of a steady state condition. These may include overshoots, damped sinusoidal waves, etc., and therefore, additional qualifying information is necessary.

Vertical Blanking: Refers to the blanking signals which occur at the end of each field.

Vertical Retrace: The return of the electron beam from the bottom to the top of the raster after completion of each field.

Vestigial Sideband Transmission: A system of transmission wherein the sideband on one side of the carrier is transmitted only in part.

Video: A term pertaining to the bandwidth and spectrum position of the signal which results from television scanning and which is used to reproduce a picture.

Video Band: The frequency band utilized to transmit a composite video signal.

Video-in-Black: A term used to describe a condition as seen on the wave-form monitor when the black peaks extend through reference black level.

Video Tape Recording (VTR): A magnetic tape recording of the composite video signal.

Waveform Monitor: This refers to a cathode-ray oscilloscope used to view the form of the composite video signal for wave-form analysis. Sometimes called "A-scope."

White Compression: Amplitude compression of the signals corresponding to the white regions of the picture, thus modifying the tonal gradient.

White Peak: The maximum excursion of the picture signal in the white direction at the time of observation.

Width: The size of the picture in a horizontal direction.

Degrees of Impairments

Television picture impairments may be present in varying degrees. In the case of oscilloscope presentations, most impairments can best be described to remote points by indicating the IRE scale readings of the various signal components. In the case of picture monitor presentations, however, impairments generally must be described in qualitative terms rather than quantitative terms, and the exchange of intelligence between remote observers is more complicated. The following descriptive terms, without a sharp line of demarcation being possible, are in common usage for indicating the magnitude of impairments:

Detectable: Impairment is not readily noticeable in a normal picture or oscilloscope display, but can be discerned by a minute inspection of the signal, it sometimes being necessary to vary picture monitor brightness or expand oscilloscope presentations.

Noticeable: Impairment is readily observed.

Objectionable: Impairment interferes with the viewing of the picture.

Unfit for Broadcast (UFB): Impairment is present to such degree that the program or portion of the program is not used.

23

Color System

FUNDAMENTALS

Color is a dimension that has been added skillfully to black-and-white television. To the engineering fraternity as a whole it signifies one of the most dramatic technological achievements of this age.

Nearly every branch of science including chemistry and psychology contributes in some way to the reality of color television. Through chemistry, improved phosphors are continually being found for use in color-picture tubes. Psychology enters into the selection of lighting arrangements and picture composition to obtain desirable interpretations by the viewer. But physics plays the leading role with intense application in optics and illumination as well as in the design of electronic circuitry and components for the complete television system.

Two specialized branches of physics, namely, radio and television engineering, are responsible for the electronic techniques which make color television "compatible" with black-and-white, or monochrome, television, marking what is probably the greatest technical advance in television in the past decade.

Compatibility

The compatible color system offers tremendous economic advantages to the home viewer as well as to the television broadcaster. Because of compatibility, color telecasts can be seen (in monochrome) on black and white television receivers without any changes or added devices. Also, color receivers can receive monochrome as well as color telecasts. Since compatible color is transmitted over the same channels as monochrome and within the same framework of standards, the television broadcaster can utilize his monochrome system as the transmitting nucleus when installing equipment to broadcast color. Moreover, he can utilize his color equipment to produce monochrome telecasts.

Another important advantage of the compatible color system is the part it plays in the conservation of the radio-frequency spectrum. Compatible color requires no additional space in the spectrum. However, it employs techniques which make much more efficient use of the standards originally set up for monochrome television.

A brief review of the fundamentals of monochrome television, particularly the areas wherein specialized color methods are employed, is presented in the next few paragraphs as an aid in describing the basic color concepts.[1]

Television—A System of Communications

Basically, television is a system of communications consisting of the television station at one end of the system and the television receiver at the other. As such, it is actually one of the highest capacity systems in use today, being able to transmit from station to receiver more than five million "bits" of picture information every second.

Very simply, the function of the television station is to divide and subdivide the optical image into over 200,000 picture elements, each of different light intensity; convert these light elements to electrical equivalents; and transmit them in orderly sequence over a radio-frequency carrier to the television receiver.

Reversing this process at the receiver, these electrical signals are each converted to light of corresponding brightness and reassembled to produce the transmitted image on the face of the picture tube.

Scanning

Picture elements to be transmitted in sequence are selected by a process of image scanning which takes place in the television camera focused on the studio scene at the station. Within the camera, an electron beam in a pickup tube scans a sensitive surface containing an "electrical image" of the scene of action. The electron beam successively scans the image at great velocity, beginning at the upper left corner and continuing from left to right in a series of paral-

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[1]For detailed information on the theory and operation of monochrome television broadcast equipment, reference should be made to the RCA "Manual for Television Technical Training," Form No. 2J 8172.

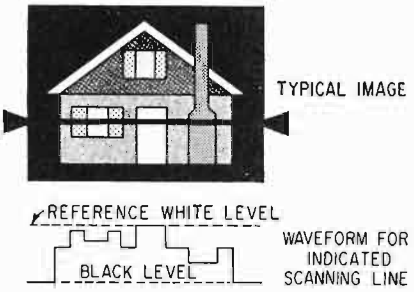

Fig. 1. Typical image and camera output waveform produced by light and dark areas during one scan along line indicated by arrows.

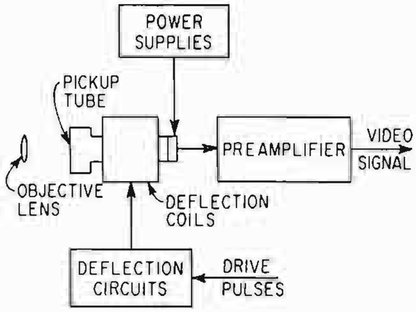

Fig. 2. Block diagram of monochrome-camera circuits.

lel lines to scan the image completely. Movement of the electron beam, which can be controlled magnetically by vertical- and horizontal-deflection coils surrounding the tube, is analogous to that of the eye in reading a printed page. The speed of movement is such, however, that 30 complete image frames of approximately 500 lines each are scanned every second. Of course, at the receiver, an electron beam in the kinescope, or picture tube, moves with the same speed and in synchronism with the camera-tube beam so that the corresponding picture elements appear in the proper relative position on the television screen.

Owing to "persistence of vision" and the speed of scanning, these elements appear to be seen all at once as a complete image rather than individually. Thus, the impression is one of continuous illumination of the screen and direct vision.

Scanning standards have been established in this country to assure that all television receivers are capable of receiving programs broadcast by any television station within range. The scanning pattern adhered to by manufacturers in the design of television receivers and broadcast equipment consists of 525 lines with odd-line interlaced scanning. Interlaced scanning, effective in eliminating perceptible flicker, is a method whereby the electron beam scans alternate rather than successive lines. For example, the beam begins by scanning the odd-numbered lines (1, 3, 5, 7, etc.) until it reaches the bottom of the image, whereupon it returns to the top of the image to scan the even-numbered lines (2, 4, 6, 8, etc.). Thus, each scan, or field, comprises only half the total number of scanning lines, and two fields are required to produce the 525-line frame. Each field is completed in one-half the frame time. The vertical scanning frequency is 2 X 30 or 60 Hz, and the horizontal scanning frequency is 30 × 525 or 15,750 Hz.

Resolution and Bandwidth

The degree of resolution, or fine detail, that can be seen in a televised image depends upon the number of scanning lines used and the bandwidth of the transmitting and receiving system.

The relationship between resolution and bandwidth can be seen by considering the number of picture elements that can be transmitted each second.

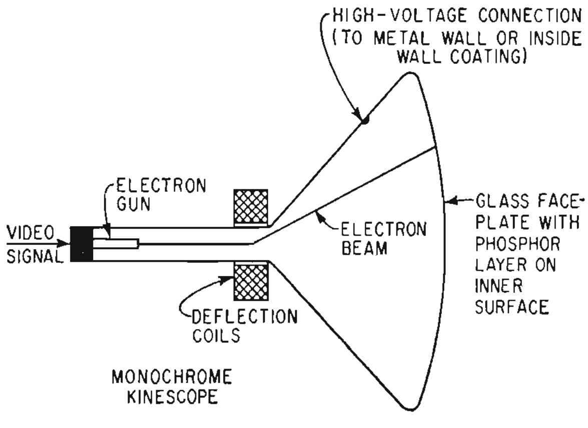

Fig. 3. Diagram showing principal elements of the monochrome kinescope picture tube.

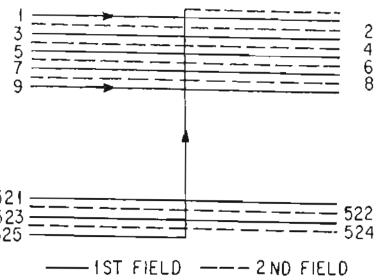

Fig. 4. Diagram showing paths of the electron beam in both the pickup tube and kinescope to produce the interlaced scanning pattern.

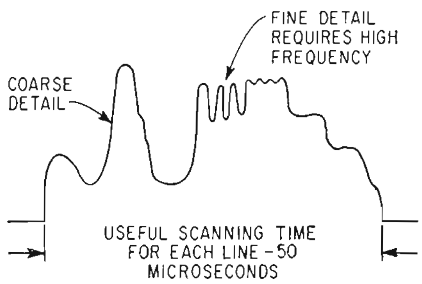

Fig. 5. Diagram illustrating the relationship between picture detail and signal bandwidth.

The standard 6-MHz broadcast channel provides a video bandwidth of approximately 4.1 MHz (the remaining bandwidth being required for a vestigial sideband plus the sound signal). Since each cycle of a sine wave is capable of conveying two picture elements (one black and one white), the maximum rate at which picture elements can be transmitted is 4,100,000 X 2, or 8,200,000 per second. Since 30 complete frames are transmitted per second, the number of picture elements per frame would be 8,200,000 ÷ 30, or 273,333, if it were not for the retrace blanking problem, which requires interruption of the picture signal periodically by blanking pulses. Since the combination of horizontal and vertical blanking pulses requires nominally 25 percent of the total time, the maximum number of picture elements per frame is reduced in practice to 0.75 X 273,333, or approximately 205,000.

Synchronizing

In addition to the picture information, or video signals, blanking and synchronizing signals are transmitted by the television station to control the intensity and movement of the scanning beam in the kinescope of the television receiver. Both these signals are in the form of rectangular pulses. Moreover, their polarity and amplitude are such that they are received as "black" signals and therefore do not appear on the receiver screen.

Blanking pulses eliminate the "retrace" lines which would otherwise appear between scanning lines and at the end of each field from the bottom of the picture to the top. Horizontal blanking pulses, transmitted at the end of each line, or at intervals of 1/15,750 sec, blank the beam during retrace periods between lines. Vertical blanking pulses, transmitted at the end of each field, or at intervals of 1/60 sec, blank the beam during the time required for its return to the top of the picture. Because the vertical retrace is much slower than the horizontal, the vertical blanking periods are longer than the horizontal blanking periods. Vertical blanking pulses are about 20 lines duration, while horizontal blanking pulses have a duration of only a small fraction of a line.

Synchronizing signals keep the scanning beam of the kinescope in step with that of the camera tube. These signals consist of horizontal and vertical pulses which are transmitted within the respective blanking periods. Although the sync pulses are of the same polarity as the blanking pulses, they are of greater amplitude ("blacker than black") and thus easily separated in the receiver and fed to the deflection circuits of the kinescope.

Since the vertical sync pulses are quite long compared with the horizontal sync pulses and the two are of the same amplitude, separation at the receiver is accomplished through frequency discrimination. Serrations, or slots in the vertical pulses, prevent loss of horizontal sync during the vertical blanking period.

The Monochrome Television System

The major equipment in a typical television station consists of the aural and visual units illustrated in the block diagram of Fig. 6. In the visual channel, the video signal leaving the camera is passed through processing equipment which inserts the blanking and synchronizing signals and performs other functions such as aperture compensation and gamma correction. From the processing chain, the video signal is fed to a switching system which provides for selection from a number of video sources. The selected signal is then sent to the visual transmitter through coaxial cable or over a microwave relay link, depending upon the distance between the television studio and transmitter. In the transmitter, the composite video signal amplitude-modulates a carrier in the VHF or UHF range, which is radiated by the television antenna.

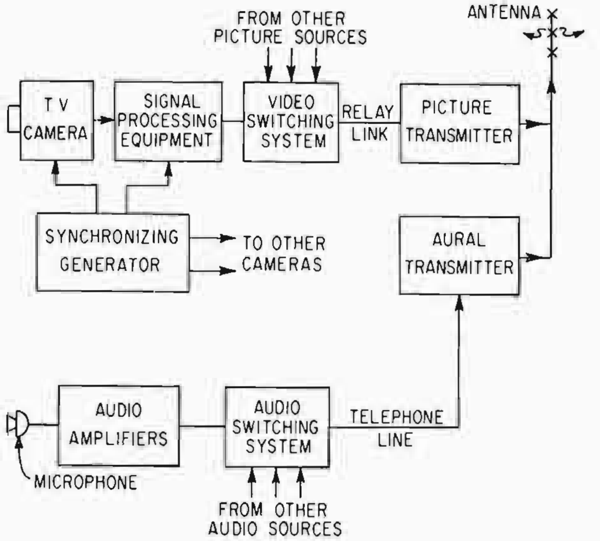

Fig. 6. Simplified block diagram of the monochrome-television station.

In the aural channel, the audio signal is fed from the microphone or other sound source through the switching system and to the aural transmitter. Frequency-modulated output from the aural transmitter is combined with the visual output and radiated from the same antenna.

The Radiated Picture Signal

Amplitude relationships between the synchronizing pulses and the tonal gradations from white to black in the picture are represented in the waveform of the radiated picture signal. From the illustration, it can be seen that modulation takes place in such a way that an increase in the brightness of the picture causes a decrease in carrier output power. Note that the reference-white line indicated on the sketch is relatively close to zero carrier level. Also, the synchronizing pulses are in the "blacker than black" region, representing maximum carrier power. Use of a widely different range of amplitude for the sync pulses makes it possible for home receivers to separate them by a simple clipping technique.

Receiver

The basic elements of the television receiving system are illustrated in the block diagram of the television receiver. The radiated television signal is picked up by an antenna and fed to a tuner which selects the desired channel for viewing. Output from the tuner is passed through an intermediate-frequency amplifier which provides the major selectivity and voltage gain for the receiver. A second detector then recovers a video signal which is essentially the same as that fed to the visual transmitter.

The sound signal is usually taken off at the picture second detector in the form of a frequency-modulated beat between the picture and sound carriers. The sound signal is further amplified in a special IF stage, detected by a discriminator or ratio detector, and applied to the speaker through an audio amplifier.

Picture output from the second detector is fed to two independent channels. One of these is the video amplifier which drives the electron beam in the kinescope, and the other is the sync separator, or clipper, which separates the sync pulses from the picture information. The separated pulses are then used to control the timing of the horizontal and vertical deflection circuits. The high-voltage supply, which is closely associated with the horizontal deflection circuit, provides accelerating potential for the electron beam.

The Three Variables of Color

Color is the combination of those properties of light which control the visual sensations known as brightness, hue, and saturation. Brightness is that characteristic of a color which enables it to be placed in a scale ranging from black to white or from dark to light. Hue, the second variable of a color, is that characteristic which enables a color to be described as red, yellow, blue, or green. Saturation refers to the extent to which a color departs from white, or the "neutral" condition. Pale colors, or pastels, are low in saturation, while strong or vivid colors are high in saturation.

The monochrome system is limited to the transmission of images that vary with respect to brightness alone. Thus, brightness is the only

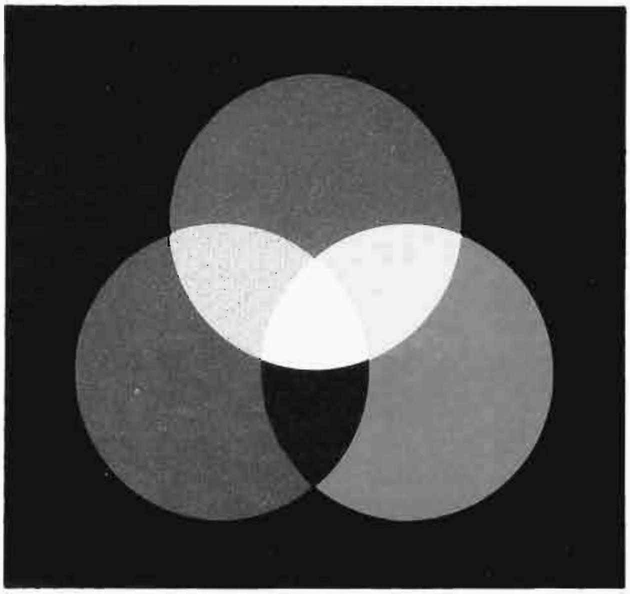

Fig. 9. The primary colors of television are red, green, and blue. Virtually any color can be matched by combining proper amounts of these primaries. White is produced by a combination of all three.

Fig. 10. Illustrating how a typical color image (upper left corner) can be separated by optical means into red, green, and blue counterparts.

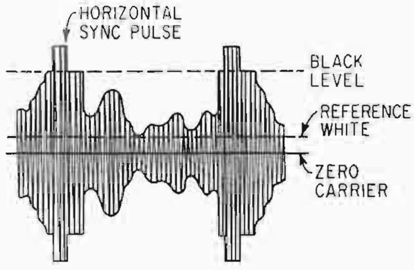

Fig. 7. Waveform and radiated picture signal.

attribute of a color which is transmitted over a monochrome-television system. To produce a color image, therefore, provision must be made for the transmission of additional information pertaining to all three of the variables of color. However, since the primary-color process can be employed, it is not necessary to transmit information in exactly the form expressed by the three variables.

Primary Colors in Television

Experiments have proved conclusively that virtually any color can be matched by the proper combination of no more than three primary colors. While other colors could be used as primaries, red, green, and blue have been selected as the most practical for color-television use. A few of the many colors that can be made by mixing lights of red, green, and blue are illustrated in Fig. 9 (see page between 688-689). Red and green combined produce yellow, red plus blue gives purple, and green plus blue gives cyan or blue-green. The proper combination of all three of the primary colors produces white, or neutral, as shown at the center of the illustration. By relatively simple optical means, it is possible to separate any color image into red, green, and blue, or RGB components, as shown by Fig. 10.

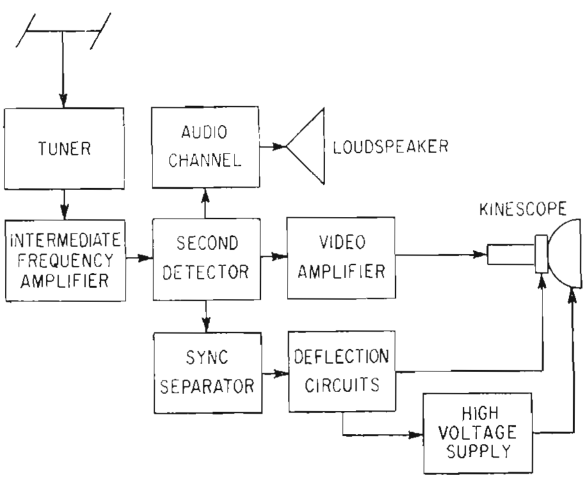

Fig. 8. Block diagram of monochrome-television receiver.

Generating RGB Signals

Major components of a color-television camera may have the block-diagram form shown in Fig. 11. Whereas the monochrome camera contains only one pickup tube, the color camera usually contains three separate pickup tubes mounted in three separate deflection-coil assemblies. An objective lens at the front of the camera forms a real image within a condenser lens which is located where the pickup tube is usually mounted in a monochrome camera. A relay lens transfers this real image to a system of dichroic (color separating) mirrors which shunt the red and blue light to the red and blue pickup tubes and permit the green to pass straight through to the green tube. In this manner, the three pickup tubes produce three separate images corresponding to the RGB components of the original scene. These images are scanned in the conventional manner by common deflection circuits.

A single scanning line through the typical color image at the point shown (Fig. 18) produces three separate waveforms. It is important to note the correlation between these waveforms and the image at the top. The yellow shutters in the image, for example, must be produced by a mixture of red and green, and the blue signal is not required. Thus, at this interval of scanning, the red and green signals are both at full value and the blue signal is at zero. The white door utilizes all three color signals. Of course, similar correlations can be seen for other parts of the image along the scanning line.

Displaying RGB Signals

RGB signals are displayed in color by the tricolor kinescope, the basic components of which are shown in the diagram of Fig. 12. Three electron guns produce three beams which are independently controlled in intensity by the red, green, and blue signals. These three beams are all made to scan in unison by deflection coils around the neck of the tube. The three beams converge at the screen owing to the magnetic field produced by a convergence yoke.

The phosphor screen of the color kinescope consists of an array of very small primary-color dots. Approximately 1/2 in. behind the phosphor screen is an aperture mask which has one very small opening for each group of red, green, and blue phosphors. Alignment of this aperture mask and screen is such that each beam is permitted to strike phosphor dots of only one color. For example, all the electrons emitted by the red gun must strike red phosphor dots on the aper-

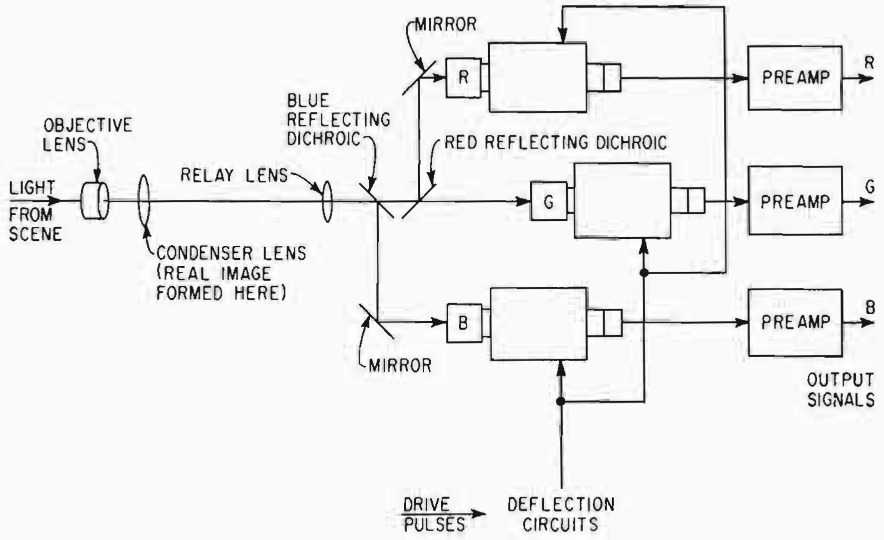

Fig. 11. Simplified block diagram of the optical and electrical components of the color camera.

ture mask; they cannot strike either the green or blue dots because of the "shadow" effect of the mask. Likewise, the beams emanating from the other two guns strike only green or blue dots.

In this way, three separate primary-color images are produced on the screen of the tricolor tube. But since these images are formed by closely intermingled dots too small to be resolved at the normal viewing distance, the observer sees a full-color image of the scene being televised.

ELECTRONIC ASPECTS OF COMPATIBLE COLOR TELEVISION

To achieve compatibility with monochrome television, color-television signals must be processed in such a way that they can be transmitted through the same channels used for monochrome signals, and they must also be capable of producing good monochrome pictures on monochrome receivers. Since color television involves three variables instead of the single variable (i.e., brightness) of monochrome television, an encoding process is required to permit all three to be transmitted over the one available channel. Likewise, a decoding process is required in the color receiver to recover the independent RGB signals for control of the electron guns in the color kinescope. Moreover, the process used must enable existing monochrome receivers to produce a monochrome picture from the color information.

Encoding and decoding processes used in compatible color television are based on four electronic techniques known as matrixing, band shaping, two-phase modulation, and frequency interlace. It is these processes which make the color system compatible with monochrome and enable the color system to occupy the existing 6-MHz channel.

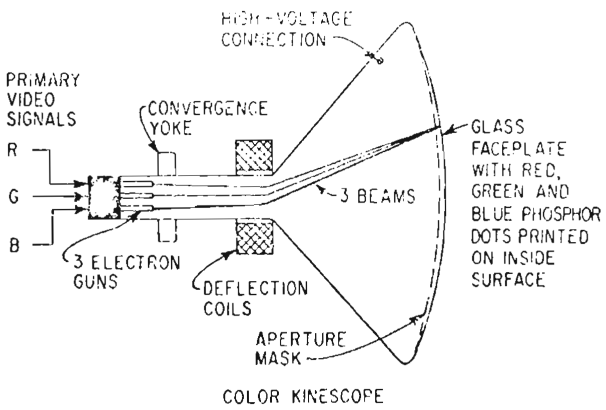

Fig. 12. Diagram showing components of the three-gun kinescope picture tube.

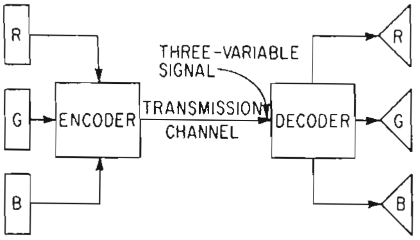

Fig. 13. Encoding of the RGB signals provides a three-variable signal which can be transmitted over existing monochrome channels.

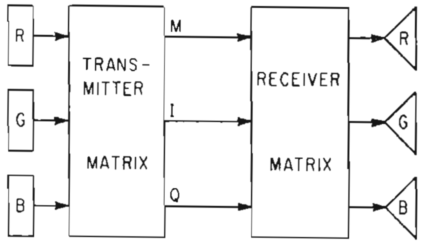

Fig. 14. A part of the encoding process is the matrixing of R, G, and B signals to provide M, I, Q signals.

Matrixing

Matrixing is a process for "repackaging" the information contained in the red, green, and blue output signals from a color camera to permit more efficient use of the transmission channel. The matrix circuits which perform this function consist of simple linear cross-mixing circuits. They produce these signals, commonly designated M, I, and Q, each of which is a different linear combination of the original red, green, and blue signals. Specific values for these signals have been established by FCC standards.

The M-signal component, or *luminance* signal, corresponds very closely to the signal produced by a monochrome camera, and therefore is capable of rendering excellent service to monochrome receivers. The M component is obtained by combining red, green, and blue signals in a simple resistor network (Fig. 15) designed to produce a signal consisting of 30 percent red, 59 percent green, and 11 percent blue.

The I and Q signals are *chrominance* signals which convey information as to how the colors in the scene differ from the monochrome, or "neutral," condition. The component I is defined as a signal consisting of 60 percent red, −28 percent green, and −32 percent blue. Minus values are easily achieved in the matrix circuits by use of phase inverters to reverse the signal polarity (see Figs. 16 and 17). The Q signal is defined as 21 percent red, −52 percent green, and 31 percent blue.

It can be seen that the quantities are related so that when red, green, and blue are equal, corresponding to a neutral condition, both I and Q go to zero. Thus, when the color camera is focused on an object having no color information, such as a monochrome test chart, the I- and Q-signal components are absent, leaving only the M component, or monochrome signal.

The matrix circuits, therefore, produce a new set of waveforms corresponding to the M, I, and Q components of the image. A comparison of the MIQ and RGB waveforms (Figs. 18 and 19, see page of color illustrations between pages 688-689) obtained from the image illustrates

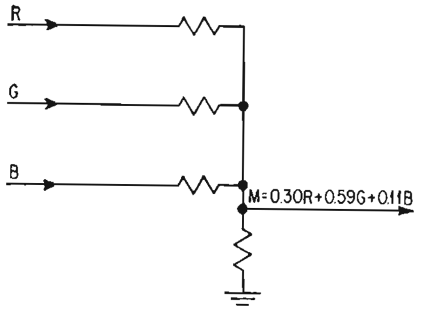

Fig. 15. Diagram of resistance matrix circuit used to produce the M luminance signal.

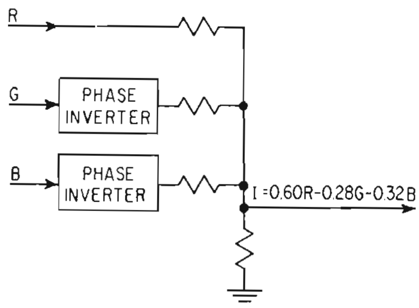

Fig. 16. Diagram of I matrix showing phase inverters to produce minus green and blue quantities.

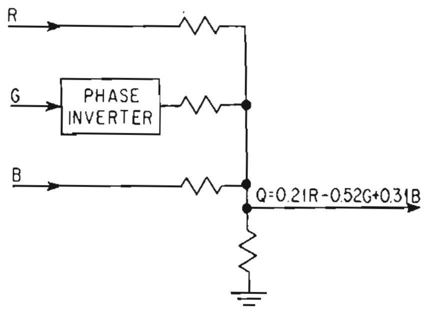

Fig. 17. Diagram of the Q matrix showing phase inverter to produce required minus green signal.

the correlation among the types of signals. It will be seen that the M signal remains in the region between black level and reference white. The I and Q signals, on the other hand, swing positive and negative around a zero axis.

Band Shaping

The eye has substantially less acuity in detecting variations in chrominance than it has for resolving differences in brightness. This important characteristic of human vision was considered in setting up the I and Q equations because it permitted a significant reduction in the bandwidth of these signals through use of low-pass filters. A bandwidth of approximately 1.5 MHz was found to be satisfactory for the I signal, which corresponds to color transitions in the range extending from orange to blue-green. For color transitions in the range from green to purple, as represented by the Q signal, the eye has even less acuity and the bandwidth was restricted to only 0.5 MHz. The M-signal component, which conveys the fine details, must be transmitted with the standard 4-MHz bandwidth.

Two-Phase Modulation—Generation of Color Subcarrier

Two-phase modulation is a technique by which the I and Q signals can be combined into a two-variable signal for transmission over a single channel. This is accomplished by adding the sidebands obtained through modulation of two 3.6-MHz carriers separated in phase by 90°. The resultant waveform is the vector sum of the components. Elements of the transmitting and receiving system are shown in Fig. 20. The two carriers, which are derived from the same oscillator, are suppressed by the balanced modulators. Thus, only the two amplitude-modulated sidebands, 90° out of phase, are transmitted. At the receiving end of the system, the I and Q signals are recovered by heterodyning the two-phase wave against two locally generated carriers of the same frequency but with a 90° phase separation and applying the resultant signals through low-pass filters to the matrix circuits. Typical signal waveforms are illustrated in Fig. 21.

The 3.6-MHz oscillator at the receiver must be accurately synchronized in frequency and in phase with the master oscillator at the transmitter. The synchronizing information consists of 3.6-MHz, "bursts" of at least 8-Hz duration transmitted during the "back-porch" interval following each horizontal sync pulse. The bursts are generated at the transmitter by a gating circuit which is turned "on" by burst keying pulses derived from the synchronizing generator. At the receiver, the two-phase modulated signal is applied to another gating circuit, known as a burst separator, which is keyed "on" by pulses derived from the horizontal deflection circuit. The separated bursts are compared in a phase detector with the output of the local 3.6-MHz oscillator. Any error voltage developed is applied through a smoothing filter to a conventional reactance tube which corrects the phase of the local oscillator.

FCC Standard phase relationships between the I and Q signals and the color synchronizing

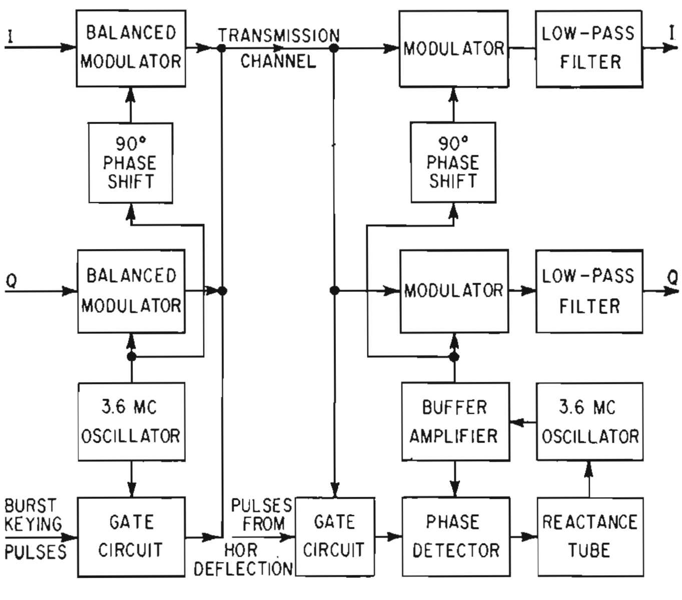

Fig. 20. Simplified block diagram showing elements for transmitting and receiving the I, Q, and burst signals.

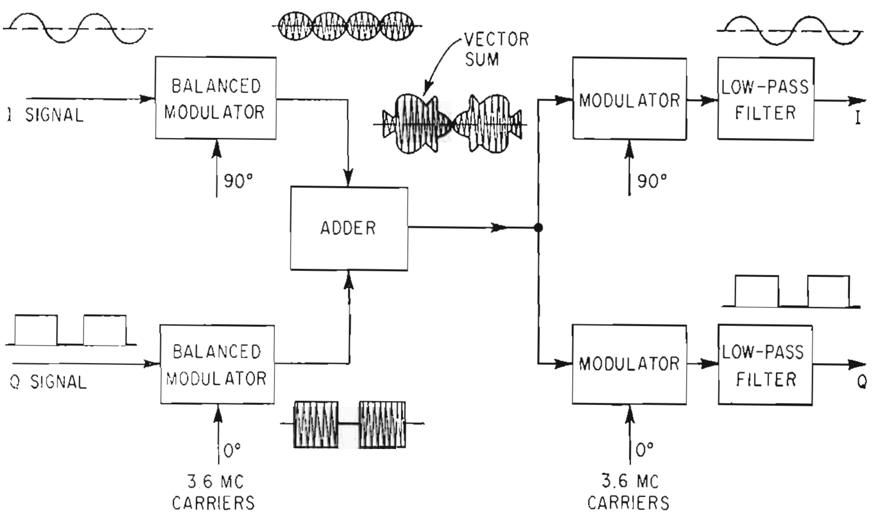

Fig. 21. Representative waveforms of the separate I, Q signals and the vector sum of the suppressed carrier sidebands at the modulator output. Original I and Q signals are recovered by beterodyning in balanced modulators at receiver.

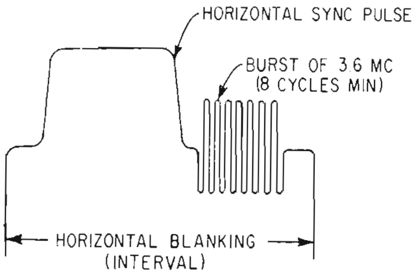

Fig. 22. Diagram showing position of subcarrier burst during horizontal blanking interval.

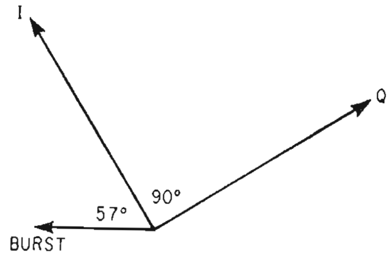

Fig. 23. Diagram showing phase relationship of I, Q, and burst signals.

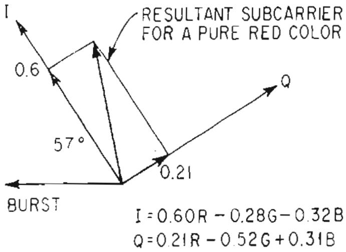

Fig. 24. Vector diagram showing phase and amplitude of subcarrier for a pure red signal.

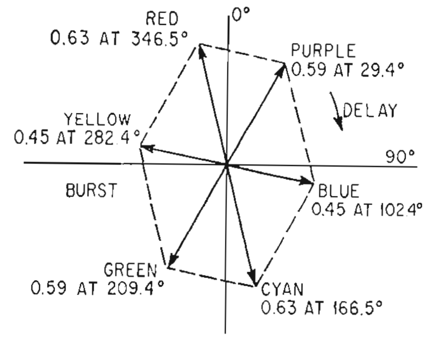

Fig. 25. Composite vector diagram showing subcarrier phase and amplitude for each of six colors.

burst are shown in the vector diagram of Fig. 23. The I and Q signals are transmitted in phase quadrature, and the color burst is transmitted with an arbitrary 57° phase lead over the I signal.

Several interesting properties of the two-phase modulated signal are illustrated by the vector diagrams which represent the resultant signal under known transmission conditions. For example, when a pure red color of maximum amplitude is being transmitted, the green and blue components are at zero and the I and Q signals have levels of 60 and 21 percent, respectively. When modulated upon their respective carrier, these signals produce the resultant shown in Fig. 24. The phase and amplitude shown are characteristic of pure red of maximum relative luminance. Fig. 25 is a composite vector diagram showing the phase and amplitude characteristics of the three primaries and their complementary colors. This composite diagram indicates that there is a direct relationship between the *phase* of the resultant two-phase modulated signal and the *hue* of the color being transmitted. There is also a relationship (although indirect) between the *amplitude* of the resultant signal and the saturation of the color being transmitted. If the phase of the resultant subcarrier and the level of the monochrome signal both remain constant, then a reduction in the amplitude of the subcarrier indicates a decrease in color saturation. The composite vector diagram also shows an interesting symmetry between complementary colors (colors are complementary if they produce a neutral when added together); the resultants for any two complementary colors are equal in amplitude but opposite in phase.

Frequency Interlace

Since the 3.6-MHz carriers, consisting of the I and Q sidebands, fall within the video passband as shown in the diagram of the television channel (Fig. 26), they become subcarriers and can be handled in many respects like unmodulated video signals. By use of *frequency interlace* it is possible to add the several components of the chrominance and monochrome signals together without causing objectionable mutual interference.

The significance of the straightforward addition of signal components made possible by frequency interlace may be brought out by a study

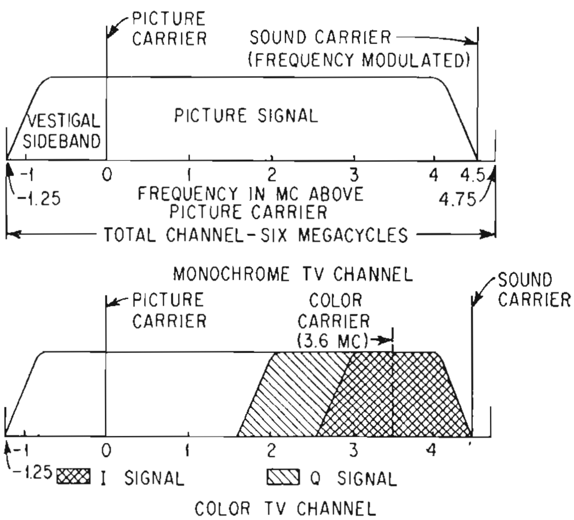

Fig. 26. Diagram of television channel showing portions occupied by color and monochrome signal components.

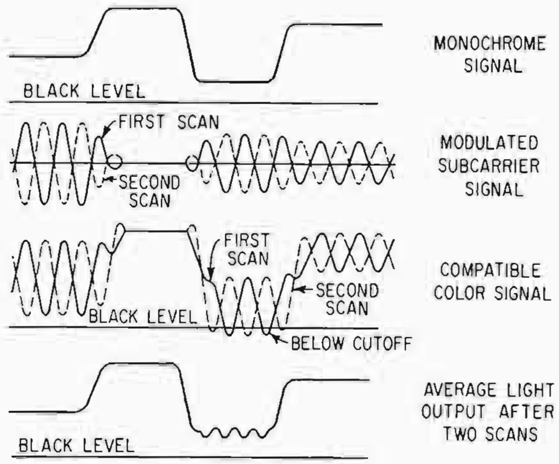

Fig. 29. Waveforms showing superposition of modulated subcarrier on scanning signals, compatible color signal, and effect of subcarrier on average light output.

of waveforms derived from a simple color image. Fig. 27 shows M, I, and Q signals after the latter two have been modulated upon 3.6-MHz subcarriers. Note that both the I- and Q-signal components are at zero during the scanning of the white door, a neutral area. Fig. 28 (see page of color illustrations between page 688 and 689) shows the vector sum of the I and Q signals and also the complete compatible color signal formed by adding together all the components, including synchronizing pulses and color-synchronizing bursts. The most significant fact about this signal is that it is still capable of providing good service to monochrome receivers, even though a modulated wave has been added to the monochrome-signal component. Although the modulated wave is clearly a spurious signal with respect to the operation of the kinescope in a monochrome receiver, its interference effects are not objectionable because of the application of the frequency-interlace principle.

The frequency-interlace technique is based on two factors—a precise choice of the color subcarrier frequency and the familiar "persistence-of-vision" effect. If the color subcarrier is made an *odd multiple of one-half the line frequency,* its apparent polarity can be made to reverse between successive scans of the same area in the picture. Since the eye responds to the average stimulation after two or more scans, the interference effect of the color subcarrier tends to be self-canceling, owing to the periodic polarity reversals (see Fig. 29).

Color-Frequency Standards

The relationships among the various frequencies used in a compatible color system are illustrated in the block diagram of Fig. 29. The

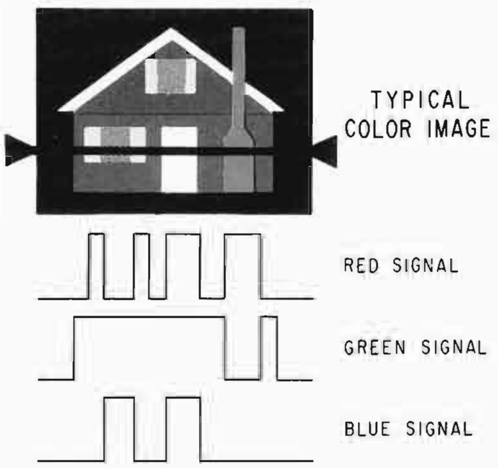

Fig. 18. Typical color image and RGB waveforms.

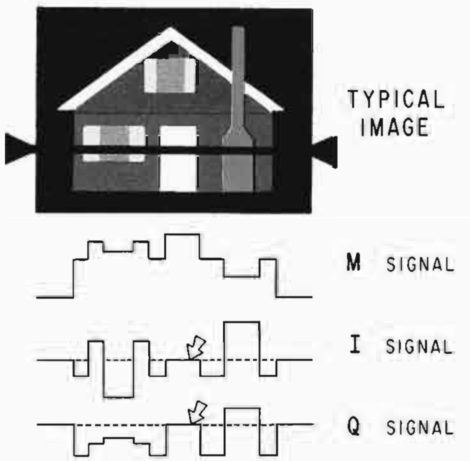

Fig. 19. Typical color image and MIQ wafeforms.

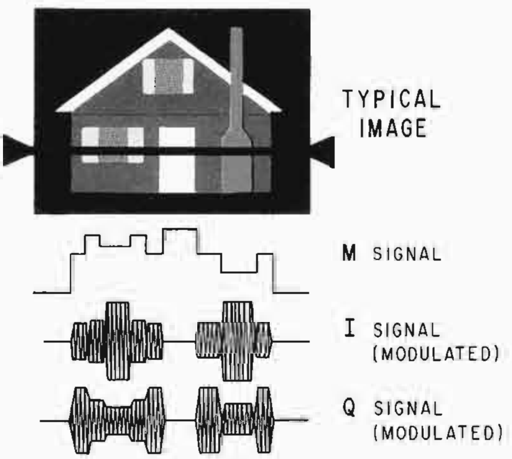

Fig. 27. Typical color image and waveforms of the M signal and modulated I and Q signals.

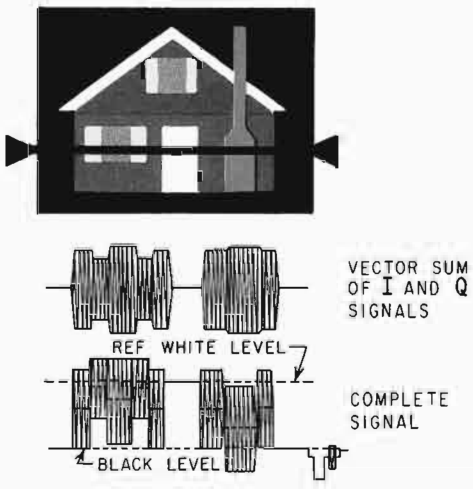

Fig. 28. Typical color image.

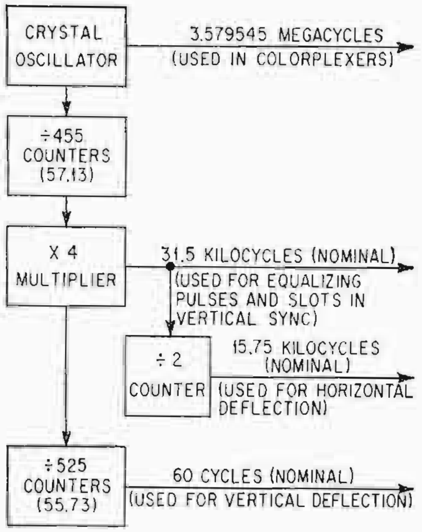

Fig. 30. Block diagram showing relationship between various frequencies used in color-television station.

actual frequency of the color subcarrier, which has been referred to as 3.6 MHz is specified by FCC Standards as 3.579545 MHz or exactly 455 multiplied by 1/2 the line frequency.

In broadcast practice, the frequency of the color subcarrier provides a frequency standard for operation of the entire system. A crystal oscillator at the specified frequency provides the basic control information for all other frequencies. Counting stages and multipliers derive the basic frequencies needed in the color studio. A frequency of nominally 31.5 kHz required for the equalizing pulses which precede and follow each vertical sync pulse and for the serrations in the vertical sync pulse. A divide-by-2 counter controlled by the 31.5 kHz signal provides the line-frequency pulses at nominally 15.75 kHz needed to control the horizontal blanking and synchronizing waveforms. Another counter chain provides the 60-Hz pulses needed for control of the vertical blanking and synchronizing circuits.

The Overall Color System

The major functions performed in transmitting and receiving color are shown in the overall block diagrams of the transmitting and receiving systems (Figs. 31 and 32).

At the transmitting end, camera output signals corresponding to the red, green, and blue components of the scene being televised are passed through nonlinear amplifiers (the gamma correctors) which compensate for the nonlinearity of the kinescope elements at the receiving end. Gamma-corrected signals are then matrixed to produce the luminance signal M and two chrominance signals I and Q. The filter section establishes the bandwidth of these signals. The 4.1-MHz filter for the luminance channel is shown in dotted lines because in practice this band

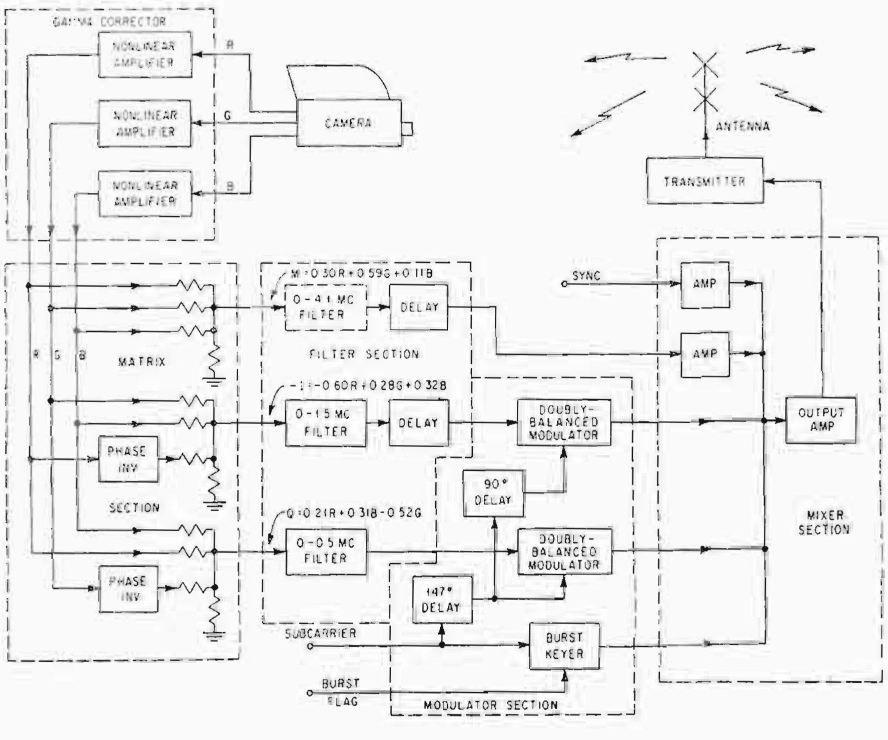

Fig. 31. Block diagram showing major functions of color-transmitting system.

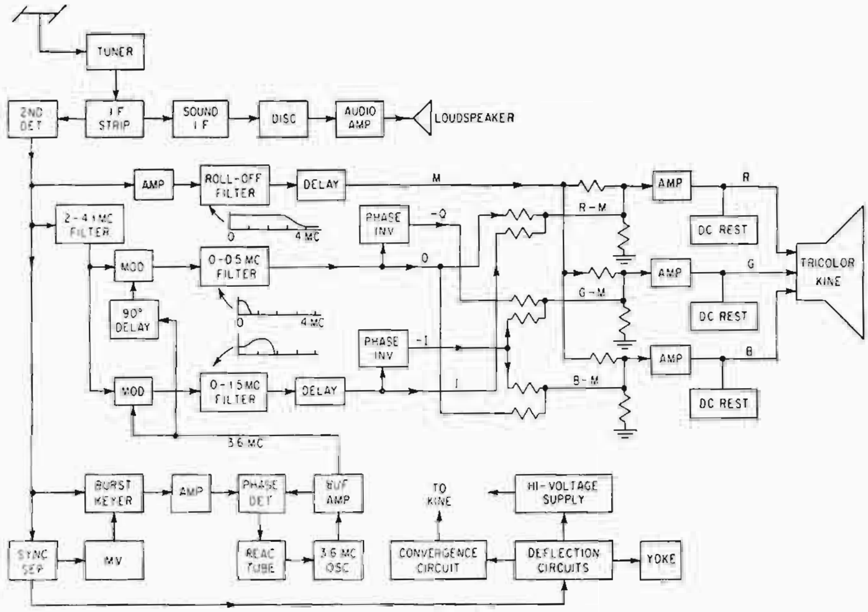

Fig. 32. Block diagram showing major functions of color-receiving systems.

shaping is usually achieved by the attenuation characteristics of the transmiter and the filter is not required.

The bandwidths of 1.5 and 0.5 MHz known for the I and Q channels, respectively, are nominal only—the required frequency-response characteristics are described in more detail in the complete FCC signal specifications. Delay compensation is needed in the filter section in order to permit all signal components to be transmitted in time coincidence. In general, the delay time for relatively simple filter circuits varies inversely with the bandwidth. The narrower the bandwidth, the greater the delay. Consequently, a delay network or a length of delay cable must be inserted in the I channel to provide the same delay introduced by the narrower band filter in the Q channel, and still more delay must be inserted in the M channel.

In the modulator section, the I and Q signals are modulated upon two subcarriers of the same frequency but 90° apart in phase. The modulators employed should be of the doubly balanced type, so that both the carriers and the original I and Q signals are suppressed, leaving only the sidebands. Some sort of keying circuit must be provided to produce the color-synchronizing bursts during the horizontal blanking intervals. To comply with the FCC signal specifications, the phase of the burst should be 57° ahead of the I component (which leads the Q component by 90°). This phase position was chosen mainly because it permits certain simplifications in receiver designs. Timing information for "keying in" the burst can be obtained from a "burst flag generator," which is a simple arrangement of multivibrators controlled by horizontal and vertical drive pulses.

In the mixer section, the M signal, the two subcarriers modulated by the I and Q chrominance signals, and the color-synchronizing bursts are all added together. Provision is also made for the addition of standard synchronizing pulses, so that the output of mixer section is a complete color-television signal containing both picture and synchronizing information. This signal can then be put "on the air" by means of a standard television transmitter, which must be modified only to the extent necessary to assure performance within the reduced tolerance limits required by the color signal. (Since the color signal places more information in the channel than a black-and-white signal, the requirements for frequency response, amplitude linearity, and uniformity of delay time are stricter.)

The Color-Receiving System

In a compatible color receiver, the antenna, RF tuner, IF strip, and second detector serve the same functions as the corresponding components of a black-and-white receiver. Thus, up to the second detector, the color receiver is no different from a black-and-white receiver except that the tolerance limits on performance are somewhat tighter.

The signal from the second detector is utilized in four circuit branches. One circuit branch directs the complete signal toward the color kinescope, where it is used to control luminance by being applied to all kinescope guns in equal proportions. In the second circuit branch, a bandpass filter separates the high-frequency components of the signal (roughly 2.0 to 4.1 MHz) consisting mainly of the two-phase modulated subcarrier signal. This signal is applied to a pair of modulators which operate as synchronous detectors to recover the original I and Q signals. It should be noted that those frequency components of the luminance signal falling between about 2 and 4.1 MHz are also applied to the modulators and are heterodyned down to lower frequencies. These frequency components do not cause objectionable interference, however, because they are frequency-interlaced and tend to cancel out through persistence of vision.

The remaining two circuit branches at the output of the second detector make use of the timing or synchronizing information in the signal. A conventional sync separator is used to produce the pulses needed to control the horizontal- and vertical-deflection circuits which are also conventional. The high-voltage supply for the kinescope can be obtained either from a "flyback" supply associated with the horizontal deflection circuit or from an independent RF power supply. Many color kinescopes require convergence signals to enable the scanning beams to coincide at the screen in all parts of the picture area; the waveforms required for this purpose are readily derived from the deflection circuits.

The final branch at the output of the second detector is the burst gate, which is turned "on" only for a brief interval following each horizontal sync pulse by means of a keying pulse. This pulse may be derived from a multivibrator controlled by sync pulses, as illustrated, or it may be derived from the "flyback" pulse produced by the horizontal output stage. The separated bursts are amplified and compared with the output of a local oscillator in a phase detector. If there is a phase difference between the local signal and the bursts, an error voltage is developed by the phase detector. This error voltage restores the oscillator to the correct phase by means of a reactance tube connected in parallel with the turned circuit of the oscillator. This automatic-frequency-control circuit keeps the receiver oscillator in synchronism with the master subcarrier oscillator at the transmitter. The output of the oscillator provides the reference carriers for the two synchronous detectors; a 90° phase shifter is necessary to delay the phase of the Q modulator by 90° relative to the I modulator.

There is a "filter section" in a color receiver that is rather similar to the filter section of the transmitting equipment. The M, I, and Q signals must all be passed through filters in order to separate the desired signals from other frequency components which, if unimpeded, might cause spurious effects. The I and Q signals are passed through filters of nominally 1.5- and 0.5-MHz bandwidth, respectively, just as at the transmitting end. A step-type characteristic is theoretically required for the I filter, as indicated in Fig. 26, to compensate for the loss of one sideband for all frequency components above about 0.5 MHz. Actually, this requirement is ignored in many practical receiver designs, resulting in only a slight loss in sharpness in the I channel. A roll-off filter is desirable in the M channel to attenuate the subcarrier signal before it reaches the kinescope. The subcarrier would tend to dilute the colors on the screen if it were permitted to appear on the kinescope grids at full amplitude. Delay networks are needed to compensate for the different inherent delays of the three filters, as explained previously.

Following the filter section in the receiver there is a matrix section in which the M, I, and Q signals are cross-mixed to recreate the original R, G, and B signals. The R, G, and B signals at the receiver are not identical with those at the transmitter because the higher frequency components are mixed and are common to all three channels. This mixing is justifiable because the eye cannot perceive the fine detail (conveyed by the high-frequency components) in color. There are many possible types of matrixing circuits. The resistance mixers shown provide one simple and reliable approach. For ease of analysis, the matrix operations at the receiver can be considered in two stages. The I and Q signals are first cross-mixed to produce R-M, G-M, and B-M signals (note that *negative* I and Q signals are required in some cases), which are, in turn, added to M to produce R, G, and B.

In the output section of the receiver, the signals are amplified to the level necessary to drive the kinescope and the dc component is restored. The image which appears on the color kinescope screen is a high-quality full-color image of the scene before the color camera.

It should be made clear that the block diagram of Fig. 32 is intended only to illustrate the principles used in color receivers and does not represent any specific model now on the market. Design engineers of color receivers have shown great ingenuity in simplifying circuits, in combining functions, and in devising subtle variations in the basic process which have made possible significant cost reductions while maintaining excellent picture fidelity. The principles of compatible color television are firmly established, and it is to be expected that steady progress will be made in the practical application of those principles.

COLOR FIDELITY

"Color fidelity," as used herein, is the property of a color-television system to reproduce colors which are realistic and pleasing to the average viewer.

Although perhaps not apparent at first, color fidelity is analogous to "high fidelity" as applied to sound reproduction. Just as a high-fidelity audio system faithfully reproduces sounds reaching the microphone, the color-television system is capable of faithfully reproducing colors as seen by the television cameraman. In fact, the color television system is capable of reproducing colors more accurately than techniques presently used in color printing and color photography.

Tests have shown, however, that color-television pictures are generally more pleasing to the viewer when deliberate modifications are made in the reproduced colors to compensate for the surroundings in which they are reproduced. The situation is similar to that experienced in the art of sound reproduction in the case of a symphony orchestra recorded at high sound levels in a large hall and reproduced at lower sound levels in a small room. In this case, a more pleasing effect is obtained if the ear's new environment is taken into consideration and the reproduction modified accordingly. Similarly, in color television, the changed environment of the eye must be considered and the reproduced colors modified accordingly.

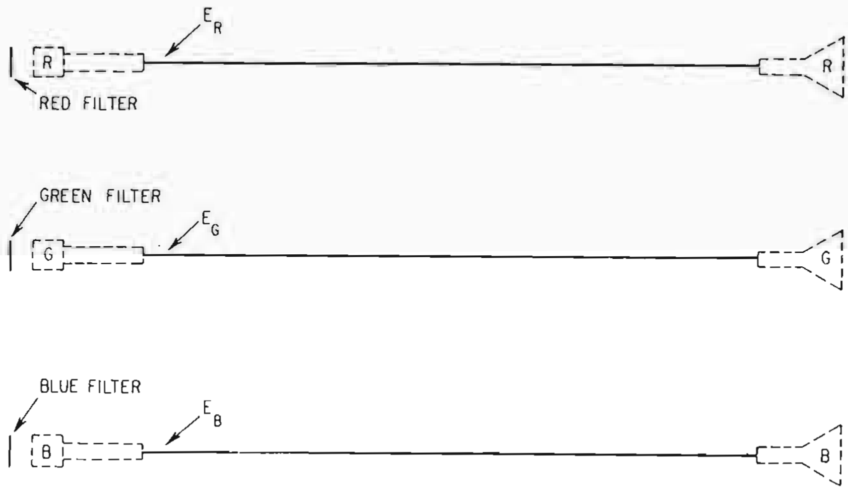

Fig. 33. Diagram of a theoretical color system showing linear RGB pickup tubes and kinescopes interconnected by wire.

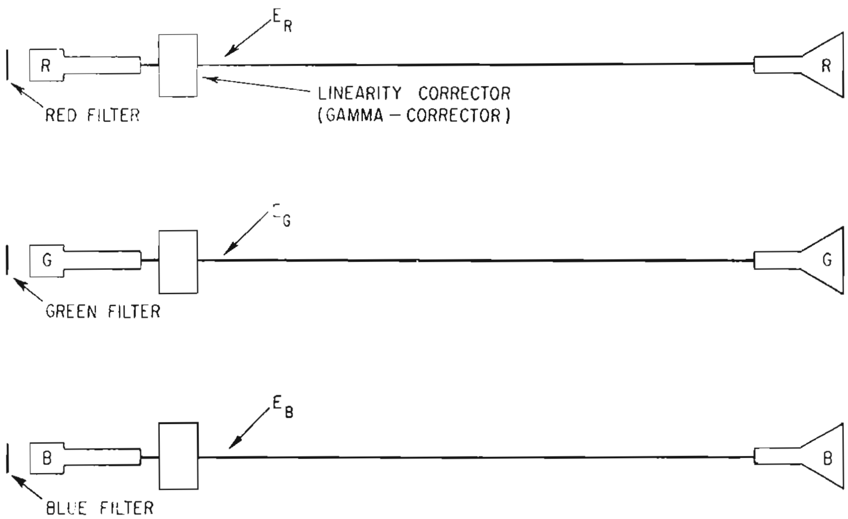

Fig. 34. The basic color system shown with necessary linearity correctors to compensate for color errors introduced by the nonlinear transducers.

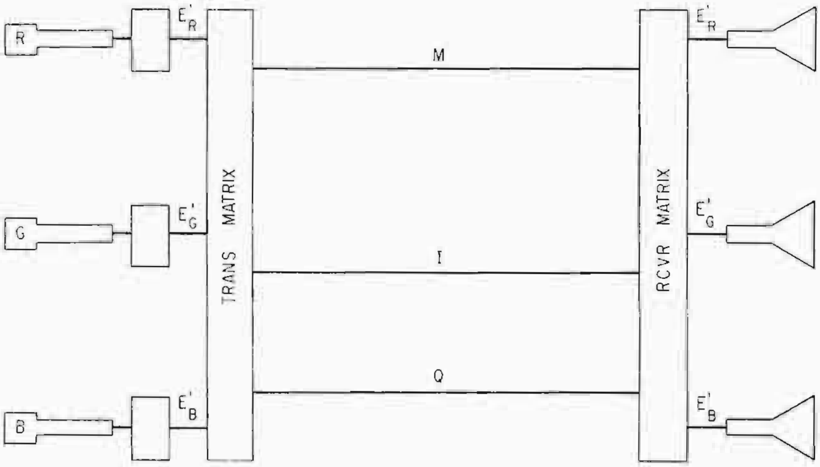

Fig. 35. Diagram showing transmitter and receiver matrix functions in the color system.

Color fidelity, therefore, is a term used to indicate a color reproduction which pleases the viewer aesthetically and persuades him that he is viewing a faithful reproduction of the original colors in the scene being televised.[2]

The following describes possible distortions in the color system and their effect on the picture and prescribes amounts or degrees of distortion that can be tolerated without adverse effects on picture quality.

Color-System Analysis

Individual elements or areas of the complete color system are discussed in the following paragraphs with the aid of the diagrams shown in Figs. 33 through 37.

Fig. 33 is a theoretical color system in that it assumes linear camera tubes and a linear kinescope interconnected by a distortionless wire system. The only distortion that can result from this system is a flaw in colorimetry.

Fig. 34 introduces linearity correctors to compensate for color errors produced by nonlinearities in the transducers.

Figs. 35, 36, and 37 successively introduce the complexities of matrixing, band limiting, delay compensation, and the transmission system (shown dotted in Fig. 37). These diagrams, each representing a possible color system, introduce techniques used in compatible color television and permit the study of color distortions peculiar to each technique.

The systems diagrammed in Figs. 33 and 34 are described under Possible Distortions in Transducers, and those in Figs. 35, 36, and 37 under Possible Distortions in Encoding and Decoding Processes. The system shown in Fig. 37 is discussed under Distortions in the Transmission System.

[2]A detailed discussion of colorimetry and perception, and how these factors affect the viewer, is presented in "Color Television Engineering" by John W. Wentworth, McGraw-Hill Book Company, Inc., New York, 1955.

Characteristics of the Eye

To appreciate fully the significance of color fidelity, it is helpful to consider some of the characteristics of the eye associated with color perception and to analyze such terms as color adaptation, reference white, and primary colors and determine their relationship to a color-television system.

Color Adaptation

One amazing characteristic of the eye is the phenomenon known as color adaptation. It is this adaptation which enables one to describe accurately the color of an object under "white" light while viewing it in nonwhite light. That is to say, recognition of color is surprisingly independent of the illumination under which an object is viewed. For example, if sunlight at high noon on a cloudless day is taken as "white" light, then, by comparison, the illumination from a typical 100-watt incandescent bulb is very yellow light. Yet it is known that an object viewed under sunlight looks very little if any different when viewed under incandescent light. Moreover, it is obvious to the observer, after a very few minutes in a room illuminated with incandescent lights, that the light is not yellow at all; it is really "white."

It is apparent, then, that the color seen by an observer is dependent upon the illumination to which that observer has been exposed for the past several minutes. This ambient illumination

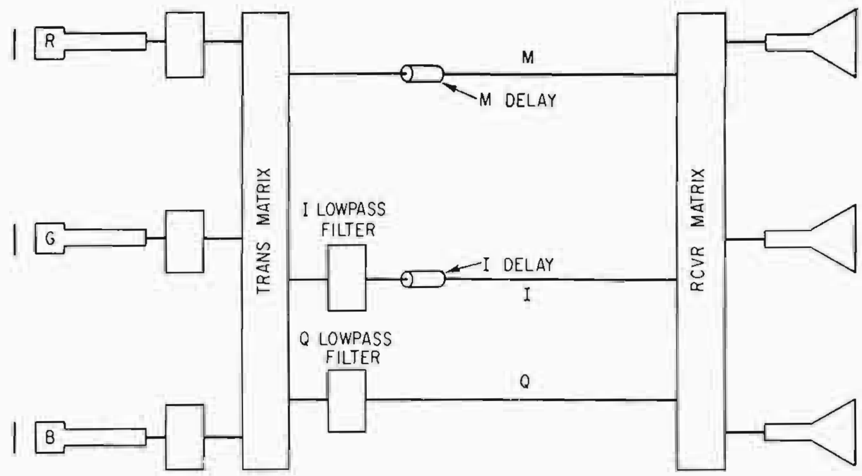

Fig. 36. Basic color system with band limiting and delay compensation.

will have a marked effect on his choice of what color he is going to call "white."

This phenomenon can cause a loss of color fidelity under certain conditions. Consider, for example, a theoretically perfect color system with camera viewing an outdoor scene under a midday sun while the reproduced picture is being viewed in a semidarkened room, with what little light is in the room also being derived from the midday sun. Under these conditions, the ambient illuminations at both camera and receiver are identical, so a man standing alongside the camera and a man viewing the receiver would both see the same colors. Now, if a change in the weather at the camera location should cause a cloud to cover the sun, the ambient illumination at the camera location would shift toward a bluer color. This shift would not disturb the viewer standing alongside the camera, because his eyes, bathed in the new ambient light, would rapidly adapt to the new viewing conditions and he would perceive the scene as being unchanged.

The man viewing the receiver would not be so fortunate. Assuming that he is far enough away that this same cloud would not affect his ambient, he would observe that everything on his screen had suddenly and inexplicably taken on a bluish cast, which he would certainly find most disturbing.

Such errors in color fidelity can be corrected by making the camera imitate the human eye in adaptation. The eye adapts to changes in ambient illumination by changing its sensitivity to a certain color. For example, if a light source changes from white to blue-white (as in the above example), the eye reduces its blue sensitivity until the light again appears to be white to the observer. Likewise, a camera operator can cor-

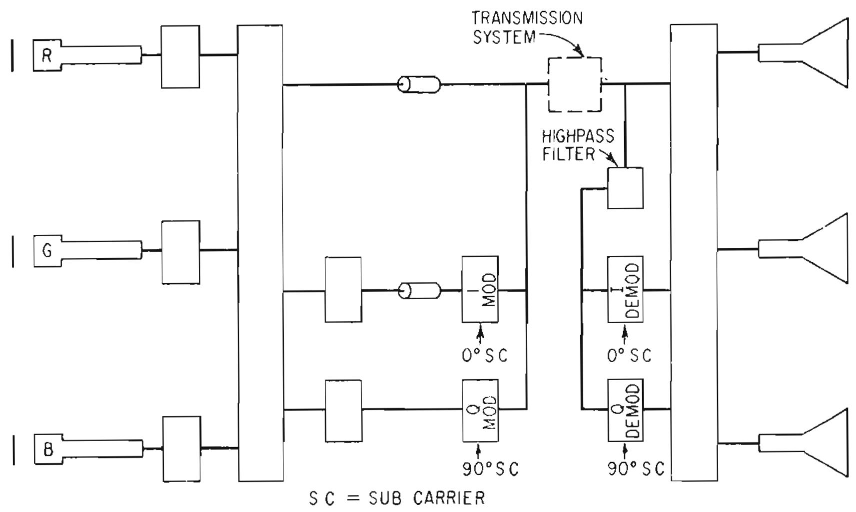

Fig. 37. Basic color system showing all major elements, including the transmission system.

rect for the same situation by decreasing the gain of the blue channel of the camera or by attenuating the light reaching the blue camera tube. In this way, the camera is made to "color-adapt," and the reproduced picture on a receiver loses its bluish cast.

Reference White

Although color adaptation can generate a problem such as the one just described, it also simplifies certain requirements. Specifically, it eases the requirement that white be transmitted as a definite, absolute color, for there clearly can be no absolute white when almost any color can be made to appear subjectively white by making it the color of the ambient illumination to which an observer's eye has adapted.

In color television, we take advantage of this characteristic in the following manner: A surface in the studio which is known by common experience to be white, for example, the EIA Gray-Scale Chart or a piece of Neutracor white paper, is selected to be reproduced as white on a home receiver. The relative sensitivities of the three-color channels of the camera are then adjusted so that the camera "adapts" to this white regardless of the studio illumination. The home receiver can then be adjusted to reproduce the surface as any "white' which the home viewer prefers, depending upon his surroundings.

It has already been mentioned that the eye adapts readily to the illumination that surround conditions of an overcast day. This representative standard illumination has been adopted internationally as a base for the specification of the color of objects when they are viewed outdoors. This standard (Illuminant C) has been chosen to be the "standard-viewing-white" of the receiver. A slightly different illuminant has been proposed as (Illuminant D) more accurately representative of outdoor illumination and may replace Illuminant C in the near future.

The change in reference white between studio and home will inevitably produce errors in all reproduced colors, but the errors are small and, more important, tend to be subjectively self-correcting, so that any given object will tend to produce the same color sensation whether viewed in relation to the studio reference white or the home reference white.

Consequently, a viewer may become familiar with an object such as a sponsor's packaged product and will recognize it on his television screen, under the fluorescent lighting of his supermarket, or under the incandescent lighting of his home and, furthermore, will note little difference in the colorimetric values of the package under the three conditions, even though the absolute colorimetric values would be appreciably different in the three situations.

Primary Colors

Of all the characteristics of the eye, there is perhaps none more fundamental to practical color television than that characteristic which allows us to choose certain colors called primary colors, and from these synthesize almost any other desired color by adding together the proper proportions of the primary colors. If it were not for this characteristic, each hue in a color system would have to be transmitted over a separate channel; such a system would be too awkward to be practical. Because of the eye's acceptance of synthesized colors, it is possible to provide excellent color rendition by transmitting only the three primary colors in their proper proportions.

Possible Errors in Transducers

The block diagram of Fig. 33 shows a fundamental color-television system using red, green, and blue primaries and three independent transmission channels. The camera tubes and kinescopes are shown dotted to indicate that any inherent nonlinearities in these devices are to be disregarded, for the moment, in order to simplify the discussion of the colorimetry of the system.

The general plan in a system such as that of Fig. 33 is to provide the three kinescopes with red, green, and blue phosphors, respectively, and to allow the corresponding camera tubes to view the scene through an appropriate set of red, green, and blue filters. If a phosphor and a filter have the same dominant wavelength, that is, if they appear to the eye to be the same color, it might be mistakenly supposed that they would be colorimetrically suited to be used as a filter and phosphor set for the channel handling that color. Actually, the basis for choosing filters and phosphors is much more complex and is based on the shape of the response curve of the filter, plotted against wavelength, and the shape of the light-output curve of the phosphor, also plotted against wavelength. The following paragraphs will discuss briefly a technique which might be used to determine the required relationship between the phosphor curves and the filter curves.

The color characteristics of the phosphor are generally less easily changed than are filter characteristics; for this reason characteristics of phosphors are taken as the starting point, and characteristics of the filters are determined from them. A laboratory setup which could be used to determine these characteristics is shown in Fig. 38. In this figure, an observer (who must have "normal" vision) is viewing simultaneously two adjacent areas, one of which is illuminated by a source of single-wavelength light which can select any wavelength in the visible spectrum, the other of which is illuminated by a red kine-

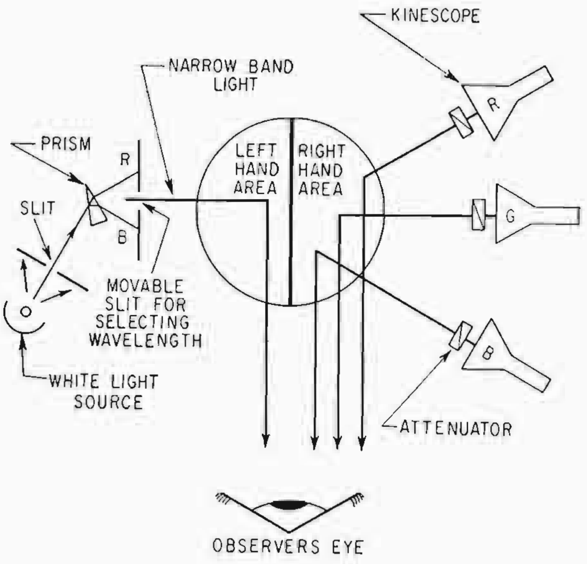

Fig. 38. Diagram showing laboratory setup arranged to compare narrow-band light source and R, G, and B light produced by kinescopes to determine proper camera-filter color characteristics.

scope, a green kinescope, and a blue kinescope. The phosphors of these kinescopes are the phosphors which are to be used in the color system. Starting at, say, the red end of the spectrum, a single-wavelength red is selected to illuminate the left-hand area, and the light from each of the three phosphors is varied until a color match is obtained between the left-hand and right-hand areas. The respective amounts of red, green, and blue lights needed to accomplish this match are recorded. Then another wavelength is chosen, the kinescope outputs varied to produce a match, and the new amounts of red, green, and blue needed for a match are recorded. Similarly, points are obtained throughout the entire spectrum, and a graph is plotted showing the various required outputs versus wavelength. The shapes of these three curves—one for red, one for green, and one for blue—are the required shapes for the three camera-filter response curves. The resulting curves would in general resemble Fig. 38.

(To simplify the above discussion it was assumed that the camera tubes responded equally well to all wavelengths. In practice, camera tubes show higher output at certain wavelengths than at others. The filter-response curves derived by the above technique would have to be modified so that the combined response of filter and camera would be correct.)

Certain practical difficulties could result in errors in the above procedure. For example, if the observer had any deviations from normality in his color-vision characteristics (as most people do), these deviations would result in "nonstandard" matches and, hence, improper camera-filter characteristics. Also, if the phosphors were contaminated in any way during their manufacturing process (as most phosphors are, at least to some small degree), the resulting phosphor characteristics would not be the proper ones and hence would give rise to improper camera-filter characteristics. The observer errors can be normalized out by standard colorimetric procedures, but phosphor errors represent a basic error which may possibly be present not only in the above experiment but also in varying degrees in a large number of receivers. Quality control of phosphor manufacture is sufficiently good, however, to make the net effect unnoticeable in home receivers.

A striking practical difficulty would also arise regardless of observer or phosphor errors. For most wavelengths, no combination of red, green, and blue kinescope outputs could be found which would produce a match. In order to obtain a match at these wavelengths, it would be necessary to move one or two of the kinescopes over to the other side so that they could add their light to the single-wavelength light being matched. This procedure can be described mathematically, for graphing purposes, by saying that adding light to the left-hand area is the same as subtracting that light from the right-hand area. Therefore, the amount of light added on the left would be considered as a negative quantity and would result in a point below the axis on the graph. Since this condition would be found to exist for several successive wavelengths, the resulting graph would show one or more minor lobes below the axis. These are called negative lobes.

These negative lobes represent a need for filters with negative light-transmission characteristics at certain wavelengths. Simple attenuating filters cannot yield such a characteristic, much more elaborate means would be required.

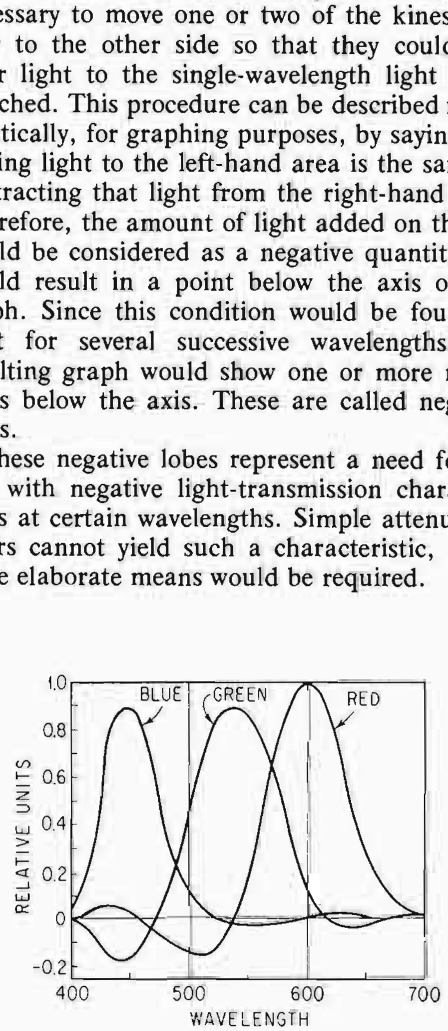

Fig. 39. Curves showing relative quantities in camera output required to produce correct kinescope colors over the visible spectrum.

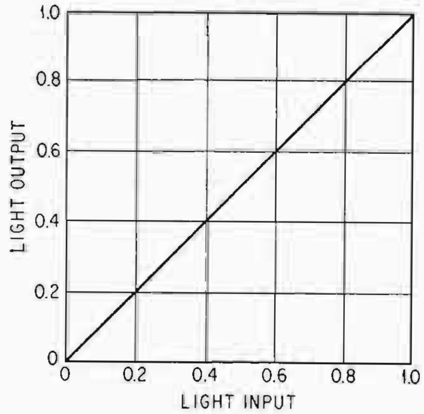

Fig. 40. Curve showing light-transfer characteristics of a perfectly transparent piece of window glass.

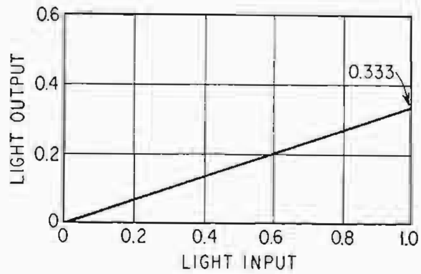

Fig. 41. Curve showing transfer characteristic of a neutral density filter with 3-to-1 light attenuation.

It is theoretically possible to achieve these negative lobes with added camera complexity but it has been shown that excellent color fidelity can be obtained by ignoring the negative lobes and using filters which yield the positive lobes only. Positive-lobe processes such as color photography have gained wide acceptance for years. Masking techniques which employ electrical matrixing have been introduced which can modify the spectrum characteristics of a color camera. These techniques can be used to help compensate for deficiencies in the color fidelity such as the lack of negative lobes.

Transfer Characteristics

A piece of window glass is perhaps the nearest approach to a perfect video system. For a piece of glass, the light output (to the viewer) is essentially identical with the light input (from the scene). This fact is shown graphically in Fig. 40. This plot could be called the "transfer characteristic" of a piece of glass, since it describes the way that light is transferred through the system.

If the window glass is replaced by a neutral-density filter which attenuates light 3 to 1, the transfer characteristic will then be given by Fig. 40. The difference between Figs. 40 and 41 can be described by these simple relationships:

For the glass:

$$\text{Light output} = \text{light input}$$

For the neutral-density filter:

$$\text{Light output} = k \times \text{light input}$$

where $k = 1/3$ in this case.

Both systems are linear; that is, doubling the light input of either will double its light output; tripling input will triple output; etc. A nonlinear system does not exhibit this simple proportionality. For example, consider a system described by

$$\text{Light output} = k \times (\text{light input})^2$$

Doubling the input to this system will quadruple its output; a threefold increase in input will result in a ninefold increase in output; etc. The transfer characteristic for this type of system is shown in Fig. 42. Note that the characteristic is definitely nonlinear; that is, it is not a straight line as were Figs. 39 and 40.

In television and photography, nonlinearity is more common than linearity. For example, an ordinary kinescope is a nonlinear device, having a transfer characteristic which can be approximated by the expression

$$\text{Light output} = k\,(\text{voltage input})^{2.2}$$

Camera tubes can be linear or nonlinear devices. For example, the characteristic of a vidicon is approximately

$$\text{Current input} = k\,(\text{light input})^{0.65}$$

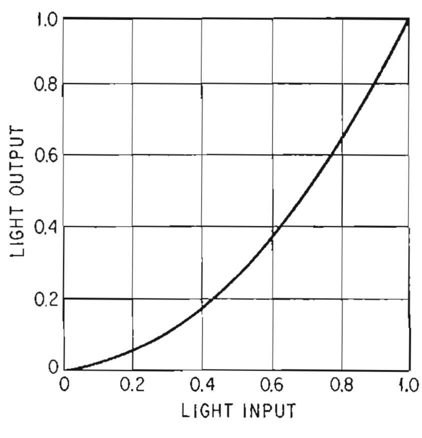

Fig. 42. Curve showing a nonlinear transfer characteristic.

The general expression for nonlinear transfer characteristic can be given approximately as

$$\text{Output} = \delta\ (\text{input})\,\gamma$$

where the exponent is the Greek letter gamma.

Graphical Displays of Transfer Characteristics

Linear Plots

The first reaction of any person asked to display two variables (like light input and light output) on a set of XY coordinates is to divide X and Y coordinates into equal increments and plot the variables in this manner. A typical result of such a plot has already been described (Figs. 40 and 41). Such a plot has the advantage of showing at a glance the linearity of the device described by the variables. If the plot is a straight line, we say the device is linear; if curved, we say the device is nonlinear. Moreover, the slope of the line describes the attenuation (or gain) of the device. If the slope is unity (which occurs when the plot makes a 45° angle with the X axis), there is no attenuation; we are dealing with a very good piece of glass. For the neutral-density filter described above, which has the equation (light output) = 1/3 (light input), the line has a slope of one-third (see Fig. 41).

Such are the advantages of plotting transfer characteristics with equal-increment divisions of the X and Y axis. However, other advantages—very important ones—can be obtained by dividing up the X and Y coordinates logarithmically. Such a plot is called a log-log plot.

Log-Log Plots

Consider a system which has a transfer characteristic given by $L_0 = (L_{in})^{2.2}$. If this equation is plotted on axes which are divided logarithmically, the resulting plot is the same as though the logarithm of both sides of the equation were plotted on equal-increment axes. Taking the logarithm of both sides, we obtain

$$\log L_0 = \log (L_{in})^{2.2}$$

Since $\log (L_{in})^{2.2}$ is the same as $2.2 \log (L_{in})$, then

$$\log L_o = 2.2 \log L_{in}$$

Comparing the form of this equation with an earlier equation, light output = 1/3 light input, we can see that just as the attenuation, 1/3, was the slope of the earlier equation, so 2.2, the exponent, is the slope of the latter equation. We see, then, that the use of logarithmically divided coordinates yields a plot in which the exponent is given by the slope of the line. Therefore, this plot will show at a glance the magnitude of the exponent and will also show whether or not the exponent of the system is constant for all light levels. It also is advantageous in showing the effects of stray light.

Figs. 43a and 43b compare the two types of plotting for three types of transfer characteristics.

The Effect of a Nonlinear Transfer Characteristic on Color Signals

Effect of Identical Nonlinearities in Each Channel

In monochrome television, some degree of nonlinearity can be tolerated, but such is not the case for a color-television system. It can be shown that a system exponent different from unity must inevitably cause a loss of color fidelity. For an example, consider a situation in which signals are being applied through linear amplifiers to the red and green guns of a perfectly linear (theoretical) kinescope. The green ampli-

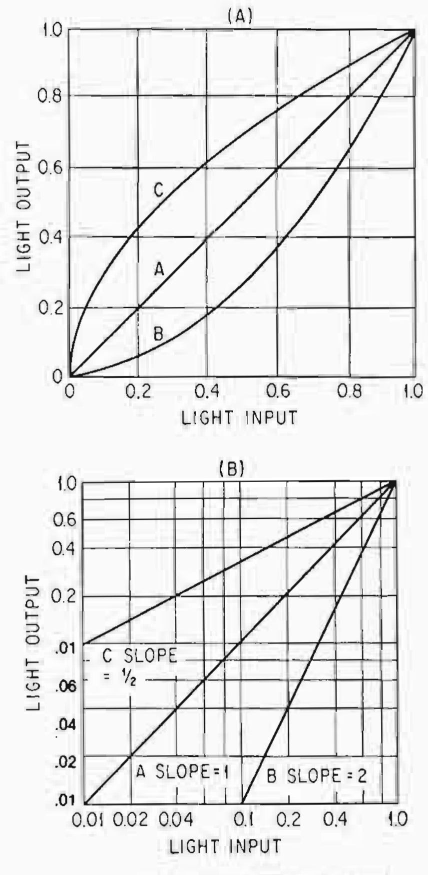

Fig. 43. Graphs showing the curves obtained by plotting A, B, and C types of transfer characteristics on linear coordinated (A) and on log-log coordinates (B).

fier is receiving 1.0 volt; the red amplifier, 0.5 volt. If everything is perfectly linear, the proportions of the light output should be 1.0G + 0.5R = a greenish yellow. However, if the kinescope has an exponent of 2.0, the light output will be $(1.0)^2G + (0.5)^2R = 1.0G + 0.25R$ = greenish yellow with an excess of green.

From the above specific case, it may be correctly inferred that in general, a system exponent greater than 1 will cause all hues made of the combination of two or more primaries to shift toward the larger or largest primary of the combination. Conversely, a system exponent less than 1 will shift all hues away from the largest primary of the combination.

In the above example, an exponent of 0.5 would yield $(1.0)^{0.5}G + (0.5)^{0.5}R = 1.0G + 0.707R$ = a greenish yellow which is just a shade off pure yellow.

In addition, the reader can correctly conclude that white or gray areas, in which all the primaries are equal, will not be shifted in hue by a nonunity exponent.

Effect of Differing Exponents in Each Channel

The preceding discussion assumed that all three channels (in Fig. 33) have the same exponent, whether unity or not. In practical systems, however, there is always the possibility that the exponents of the channels may differ from one another. This situation will produce intolerable color errors if the differences become even moderately large. In general, the requirements for "tracking" among the light-transfer characteristics of the individual channels are even more stringent than the requirement for unity exponent.

Figs. 44a, 44b, 44c, and 44d show graphically the effects of unequal exponents in the three channels. In all four figures, the red and blue exponents are taken as unity; in Figs. 44a and 44b the green exponent is taken as less than 1, and in Figs. 44c and 44d, as greater than 1. In Fig. 44a, the transfer characteristics are shown for the system adjusted to produce peak white properly. It can be seen that the bowed characteristic of the green channel will cause all whites of less than peak value to have too much green. A gray-scale step tablet before the camera would be reproduced properly only at peak white; the gray steps would all have a greenish tinge. Relative channel gains could be readjusted to reproduce one of the gray steps properly (Fig. 43b), but then all highlight steps would be purplish while lowlight steps would still be greenish.

A green-channel exponent greater than unity would reverse the above results (Figs. 44c and 44d). With gains adjusted to reproduce peak white properly (Fig. 44c), lowlights would be purplish; with gains readjusted to provide proper reproduction for one of the lower steps (Fig. 44d), highlights would be green and lowlights purple.

The Effect of Stray Light

If a kinescope is viewed in a lighted room, there will always be some illumination on the faceplate. Therefore, the eye will always receive some "light output" from the kinescope, regardless of the magnitude of the signal input voltage. Under this condition, a true black is impossible to obtain.

This condition is reflected in the transfer characteristic of the system. If, for example, the stray light were 5 percent of the peak highlight brightness of the picture, a linear plot of light output versus light input would have the entire transfer characteristic shifted upward by 5 percent. However, the most interesting change is found in the log-log plot, where, as seen in Fig. 45, the stray light causes a change in the slope in the lowlight regions. Since the slope is equal to the exponent, this change shows that stray

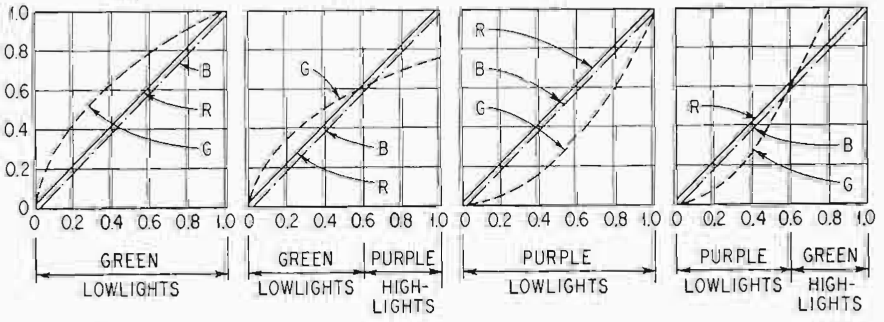

Fig. 44. Linear plots showing graphically the effect of unequal exponents in the R, G, and B channels. In all four graphs the R and B exponents are taken as unity. In (A) and (B) the green exponent is taken as less than 1, and in (C) and (D), as greater than 1.

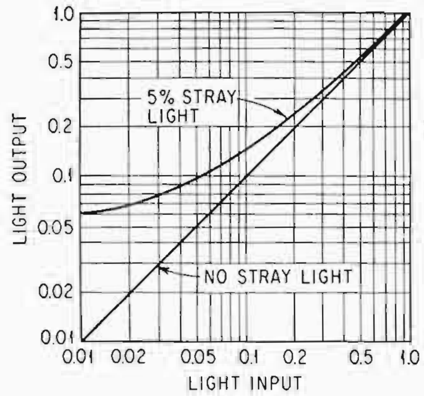

Fig. 45. Log-log plot of system with stray light, illustrating change of slope in the low-light regions.

light causes an effective exponent error in the lowlight regions of the picture and hence will cause color-fidelity errors which will be most marked in the lowlight regions.

These errors will be noted by an observer as improper hues and saturations, with the saturation errors—a "washing out" of the more saturated lowlight areas—being the more objectionable to a viewer.

Stray light is not the only cause of errors of this type. Similar effects will be noted whenever the kinescope bias ("brightness") is set too high. If camera pedestal is set too high, or if stray light enters the camera (whether through lens flare or any other source). In general, any condition which prevents the light output of the system from becoming zero when the light input is zero will cause errors similar to those caused by stray light.

Linearizing a System

It can be shown that a system using a vidicon with an exponent of 0.65 to drive a kinescope with an exponent of 2.2 will have an overall exponent given by the product $0.65 \times 2.2 = 1.43$, assuming that all devices in the system are linear. In general, the overall exponent of a system is the product of the exponents of the cascaded elements.

This knowledge provides an excellent tool for linearizing a system. For example, a system with an overall exponent of 1.43 could be linearized by inserting somewhere (in a video path) an amplifier having an exponent of $1/1.43$ ($= 0.7$) so that the product becomes unity: $1.43 \times 1/1.43 = 1$.

In Fig. 34, a nonlinear amplifier, or gamma corrector, is shown inserted in each of the three paths.

Possible Encoding and Decoding Distortions

The second of the two systems discussed in the preceding section bordered on being a practical system but still required three independent 4-MHz channels. A fortunate characteristic of the human eye—the inability to see colored fine detail—allows us to modify this requirement to one 4-MHz channel for monochrome fine detail and two much narrower channels for color information. Before this modification can be made, the red, green, and blue signals must be combined to form three other signals, usually called M, I, and Q, such that the M signal alone requires a 4-MHz channel, and the I and Q channels, which contain the color information, are confined to narrower channels. This rearrangement of red, green, and blue to form M, I, and Q is called matrixing and was described in the previous part. A system which uses a matrix is block-diagramed in Fig. 35. The illustration also shows that to recover the original red, green, and blue signals at the receiving end, a "rearranging" device is needed. This device is usually called the receiver matrix.

Matrixing alone offers no advantage unless steps are taken actually to limit the I-signal and Q-signal channels to the narrow bandwidths allowed. Fig. 36 shows a system employing such band shaping. The band-shaping filters themselves always introduce delay, which must be compensated for by placing delay lines in the wider band channels, as shown in the diagram.

To put both color and monochrome information in the spectrum space normally occupied by monochrome only requires that the color information overlap the monochrome. This overlap can be allowed for both I and Q signals, without incurring visible cross talk, if two techniques, known as frequency interlace and two-phase modulation are employed. A system using these techniques, which were described in the section on Electronic Aspects of Compatible Color Television, is block-diagramed in Fig. 37.

Possible Errors in the Matrixing Process

The entire matrixing process can be summed up in two sets of equations, the first set describing how the transmitter matrix takes in red, green, and blue and turns out M, I, and Q:

$$M = 0.30R + 0.59G + 0.11B$$
$$I = 0.60R - 0.28G - 0.32B$$
$$Q = 0.21R - 0.52G + 0.31B$$

and the second set describing how the receiver matrix takes in M, I, and Q and recreates red, green, and blue:

$$R = 0.94I + 0.62Q + M$$
$$G = 0.27I + 0.65Q + M$$
$$B = 1.11I + 1.7Q + M$$

Both matrices can therefore be considered as analogue computers which continuously compute the desired output from the given input. The coefficients in the above six equations are usually determined in the "computers" by precision resistors or, in the case of negative numbers, by precision resistors and signal-inverting amplifiers. The basic error that can occur, therefore, is a change in a resistor value or an amplifier gain, resulting in a change in one or more coefficients. In general, the resulting picture error resembles cross talk among the primary colors.

More specifically, the transmitter matrix can have two distinct types of errors. The first type involves the coefficients of the equation for M; the second type, the coefficients for I and Q. An error in an M coefficient will brighten or darken certain areas. In a monochrome reproduction of a color signal, such an error, if small, would not be noticed; if large, it would still probably be tolerated by the average viewer. In a color reproduction, however, even a small error would be objectionable. For example, a reduction of the red coefficient from 0.3 to 0.2 would cause a human face to be reproduced with an unnatural ruddy complexion and dark red lips.

Note that the sum of the M coefficients is 1. An error in one coefficient would change this sum, so that peak white would no longer occur at 1 volt. An operator could mistake this condition for a gain error and adjust either M gain or overall gain in an effort to obtain the correct peak-white voltage. Changing M gain would cause errors to occur in all M coefficients; changing overall gain would put errors in all coefficients. Although such an error is rare in well-engineered equipment, it is a possible source of color error which can be compounded by misdirected attempts at correction.

Note that the sums of the Q and I coefficients are each zero, which means that when $R = G = B$ (the condition for white or gray), Q and I both equal zero. An error in a Q or I coefficient would cause color to appear in white or gray areas and, in addition, would cause general errors in colored areas resembling cross talk among the primaries. Controls are usually provided in the Q and I matrices, called Q white balance and I white balance, respectively, which allow the operator to adjust the sum of the Q or I coefficients by changing the value of one of the coefficients. If the coefficient controlled is the one in error, adjusting white balance restores proper operation. If the controlled coefficient is not the one in error, then adjusting white balance restores the condition that the sum of the coefficients is zero, that is, it removes the color from white and gray objects, but it does so by giving the controlled coefficient an error which just counteracts the error of a nonadjustable coefficient, so that two coefficients are wrong instead of one. Again, such an error is rare in well-engineered equipment, for the adjustable coefficient is usually the one in error. However, the possibility of an error compounded by adjustment should be kept in mind.

A far more likely cause of white-balance error is an error in input level, that is, a discrepancy between the peak white levels of input red, green, or blue. In such a case, an operator can still achieve white balance (Q and $I = 0$ for white input) but the entire system will be in error. The starting point for all investigations of the cause of white-balance errors should be the levels of the red, green, and blue colorplexer inputs.

In the receiver matrix, only one general type of error can occur instead of two as in the case of the transmitter matrix. This type of error, a general coefficient error, results in cross talk among the primary colors. For example, a change in the I coefficient for the red equation from 0.94 to 0.84 would yield about a 7 percent reduction in the peak red output available and would also result in unwanted red light output in green or blue areas at about 3-1/2 percent of the green or blue level.

Gain Stability of M, I, and Q Transmission Paths

In the system of Fig. 35, every gain device or attenuating device in the three transmission paths must maintain a constant ratio between its input and output in order to maintain the proper ratios among the levels of M, I, and Q at the input to the receiver matrix. A variation in the gain of one of these paths will result in a loss in color fidelity.

For example, a reduction in M gain must obviously cause a reduction in the viewer's sensation of brightness. Not quite so obvious are the effects of I and Q gain. Since these are color signals, their amplitude would be expected to influence the sensation of saturation, but the manner of this influence is not intuitively obvious until the factors which influenced the selection of I and Q compositions are recalled. It previously was pointed out that the eye has the greatest need for color detail in the color range from orange to blue-green (cyan) and the least in the range from green to purple. Hence I, the wider band signal, conveys mainly orange and cyan information, and Q, the narrower band signal, conveys principally the greens and purples. Therefore, a reduction in I gain could be expected to reduce the saturation sensation for colors in the orange and cyan gamut, leaving the greens and purples virtually unaffected. Conversely, Q gain will influence the greens and purples without causing much change in the appearance of orange and cyan objects.

Modulation and Demodulation

The system of Fig. 35, which introduced bandwidth limiting of the I and Q signals in accordance with the capabilities of the eye to see colored fine detail, is a fairly practical and economical system, except for the fact that three individual transmission channels are employed. If we are to have a compatible system, however, these three channels must be reduced to one through some multiplexing technique. The technique used has already been described, and a system employing this technique is block-diagramed in Fig. 37.

Possible Errors in Modulation

Burst Phase Error

Perhaps the most fundamental error in the multiplexing process would be an error in the phase of the main timing reference, burst. Since the entire system is based on burst phase, an error in burst phase will appear as an opposite error in every phase except burst, because the circuits will insist that burst phase cannot be wrong. The general result will be an overall hue error in the reproduced picture. This effect can be better visualized by referring to Fig. 46.

A phase error in burst produces the same result as holding burst phase stationary and allowing all other phases to slip around the circle an equal amount (but in a direction opposite to the burst-phase error). Each color "vector" then represents a hue other than the one intended.

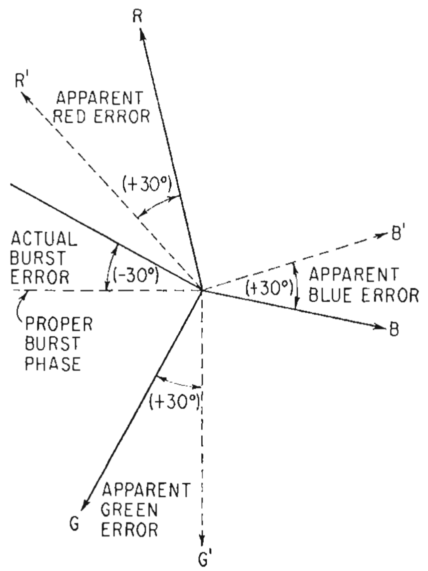

Fig. 46. Vector diagram showing how error in subcarrier phase becomes an opposite error in all other phases.

Burst Amplitude Error

In theory, the receiver circuits which extract timing information from the burst are insensitive to variations in burst amplitude as long as the burst is large enough to maintain a respectable signal-to-noise ratio and not so large that some type of clipping or rectification upsets the burst circuitry. But practical receivers always exhibit some degree of sensitivity to burst amplitude, the amount of this sensitivity depending mainly upon the error in the subcarrier oscillator in the receiver. If the free-running frequency of the receiver oscillator is very different from burst frequency—particularly if the difference is so great that the burst is in danger of losing control of the oscillator—then a fairly appreciable amplitude sensitivity will be noted. This sensitivity will take the form of a phase error, and the net result will be indistinguishable from a burst phase error, as discussed above.

Some receivers have a circuit which automatically adjusts the gain of the color-information channels so that the viewer always sees the proper saturations, regardless of errors which might tend either to "wash out" or to oversaturate the picture. Such a circuit, called an automatic chroma control (ACC), derives its control information from the amplitude of burst, which is presumed to bear a constant ratio to the amplitude of chroma. Transmission distortions, for example, might decrease the amplitude of both burst and chroma, but since the ratios of their amplitudes would be preserved, an ACC receiver could automatically modify its chroma-channel gain to compensate for the decreased chroma amplitude. However, if a colorplexer error should cause burst alone to decrease in amplitude, the ACC circuits would increase chroma gain just as in the above case, with the result that a viewer would receive an oversaturated picture.

Two-Phase Modulation Errors

The fidelity of color reproduction can be seriously affected if the phase separation of the Q and I subcarriers is not maintained at 90°. It can be shown that a "slip" in the angular position of the Q axis, for example, will result in cross talk of Q and I. The final result will be the same as cross talk among all the primary colors.

Likewise, in a receiver, the phase relationship between the reference subcarriers must be maintained to avoid a similar error. Any deviation from the proper phase relationship will have a result similar to the above, that is, cross talk of I into Q or Q into I, with the net picture result resembling cross talk among all the primary colors.

Carrier Unbalance

In a properly operating doubly balanced modulator, the carrier component of the signal is suppressed in the modulator circuit. If some error in components or operation causes this suppression to be imperfect, the carrier will appear in the output. This condition is known as carrier unbalance.

The effect of carrier unbalance can be evaluated by considering the unwanted carrier as a vector of constant amplitude which adds itself vectorially to every vector present in the colorplexer output. In general, such a vector will shift all vectors and hence all hues seen in the picture toward one end or the other of the color axis represented by the unbalanced modulator. For example, a positive unbalance in the I modulator would shift all colors toward the color represented by the positive I axis, that is, toward orange. A negative I unbalance would shift all colors toward cyan.

To visualize this effect, refer to Fig. 47, in which has been added to each color vector a small positive vector which is parallel to the I axis. This small vector represents the amount of carrier unbalance. The resultant vectors will all be rotated toward the positive I axis and changed in amplitude as well. Such changes represent errors in both hue and saturation.

Another error from carrier unbalance occurs in white and gray areas of the picture. In a normally operating colorplexer, a white (or gray) area in the scene causes the Q and I signals to become zero and thereby causes the modulator outputs to become zero. Hence, a white or gray area will normally appear in the signal as an interval of zero subcarrier amplitude. If one of the modulators begins to produce a carrier-unbalance vector, however, a white or gray area will become colored because of the subcarrier which will be added in this interval. Moreover, certain areas which are normally colored may have their subcarrier canceled by the carrier-unbalance vector and become white. Such white-to-color and color-to-white errors are very objectionable.

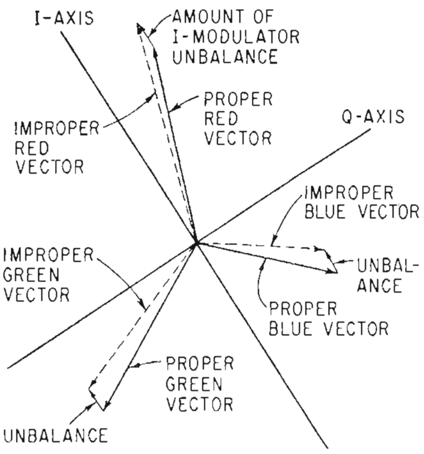

Fig. 47. Vector diagram of subcarrier phase and amplitude with positive vectors added to represent carrier unbalance in the I modulator.

Video Unbalance

A doubly balanced modulator derives its name from the fact that it balances out or suppresses both the carrier (as described above) and the modulating video (Q or I). If, for any reason, the video suppression becomes less than perfect, the resulting condition is called video unbalance.

Video unbalance will cause unwanted Q or I video to appear in the modulator output, in addition to the desired sideband outputs. This unwanted video signal will be added to the luminance signal, thereby distorting the gray scale of the picture. For example, a slight positive unbalance in the Q modulator would slightly brighten reds and blues and slightly darken greens. A negative unbalance would have the opposite effect.

Subcarrier-Frequency Error

The color subcarrier frequency is specified by the Federal Communications Commission to be 3.579545 MHz $\pm$ 10 Hz. Deviations within this specified limit are of no consequence (provided they are slow deviations). Large deviations, however, can affect color fidelity. The effect does not usually become serious within the possible frequency range of a good crystal-controlled subcarrier source driving a properly designed receiver.

In receivers, the subcarrier timing information is extracted from the burst on the back porch and used to control the frequency of a subcarrier-frequency oscillator in the receiver. As long as the unlocked frequencies of the burst and the receiver oscillator remain the same, the locked phase relationship between the two will remain the same. But if either the burst frequency or the receiver-oscillator frequency becomes different (and the difference between them is not so large that lockup is impossible), then the locked error, which obviously cannot be a frequency error, manifests itself as a phase error. This error can become as large as $\pm 90°$ before the AFC circuit can no longer hold the receiver oscillator on frequency. The frequency range over which this phase shift occurs depends upon the receiver design.

Possible Distortions in the Transmission System

Preceding sections have described the processes involved in the generation and display of a color-television signal. Errors in these processes are not the only possible source of distortion; when the signal is transmitted over great distances, the transmission system itself may contribute errors. This section discusses parameters which specify the behavior of a transmission system and describes the effects that errors in these parameters can have on the reproduced picture.

This section is divided into two parts. The first relates to the parameters of a perfectly linear transmission system, while the second part discusses the additional parameters required to describe the nonlinearities that are inevitable in any practical system.

The Perfectly Linear Transmission System

A perfectly linear and noise-free transmission system can be described by its gain and phase characteristics plotted against frequency as the independent variable.[3] Typical plots are shown in Figs. 48 and 49, respectively. These two characteristics known, it is possible to predict accurately what effect the transmission system will have on a given signal.

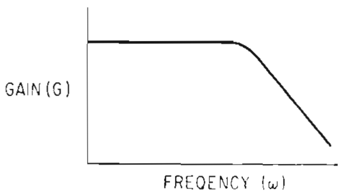

Fig. 48. Typical curve showing gain of a system plotted against frequency to determine its gain characteristic.

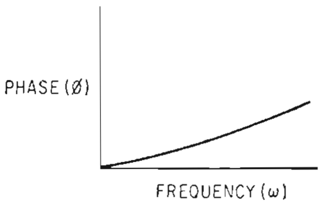

Fig. 49. Curve showing phase characteristic of a system plotted versus frequency.

[3] If the filters in the system are of the minimum-phase type, only one of the plots is needed, for either plot can be derived from the other for this type of filter. Almost all common interstage coupling networks are of the minimum-phase type.

Gain Characteristic

Fig. 48 is usually known as the frequency response or gain characteristic of the system. Ideally, it should be perfectly flat from zero to infinite frequency, but this, of course, is impossible to attain. An amplifier has a definite gain-bandwidth product, depending upon the transconductance of its active elements (tubes or transistors), the distributed capacity shunting these elements, and the types of compensation (peaking) employed. The bandwidth of a given combination of tubes, transistors, stray capacitances, and peaking networks can be increased only by decreasing its gain, or conversely, its gain can be increased only by decreasing its bandwidth. There is a limitation, therefore, to the actual bandwidth than can be obtained. For a given scanning standard, the bandwidth required in a monochrome-television system is determined by the desired ratio between the horizontal resolution and the vertical resolution. Although nominally a 4.0-MHz bandwidth is required for the monochrome standards, the requirement can be relaxed to the detriment of only the horizontal resolution. The subjective result is a "softening" of the picture in proportion to the narrowing of the bandwidth (neglecting the influence of the phase characteristic in the vicinity of the cutoff frequency). As pointed out in preceding sections, the entire chrominance information of the color system is located in the upper 1.5 MHz of the prescribed 4.0-MHz channel; hence, any loss of response in this part of the spectrum can have a marked effect on the color fidelity of the reproduced picture.

One of the most serious forms of distortion inflicted on a color picture by bandwidth limiting is loss of *saturation.* Consider a case in which the bandwidth is so narrow as to result in no gain at the color subcarrier frequency. The output signal then contains no color subcarrier and hence reaches the color receiver as a monochrome signal, producing zero saturation. Nearly as poor results can be expected from an amplifier with response such that the gain at 3.58 MHz is one-half the low-frequency gain. Since the saturation depends chiefly on the amplitude of the subcarrier, the saturation will be correspondingly reduced. The resultant color picture will have a "washed-out" look.

Loss of high-frequency response, which can be expected to contribute to loss of fidelity, is usually accompanied by phase disturbance, depending on the type of networks employed in the system.. The intent in this section, however, is to treat each variable separately. Therefore, discussions are based on the effects of varying only one parameter of a system. It is suggested that the reader can determine the combined

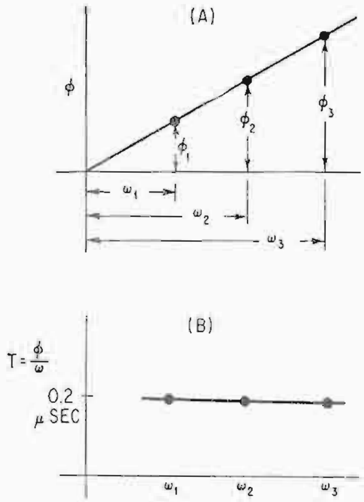

Fig. 50. Curves illustrating a system with linear phase characteristics, which will give the same time delay for signals of all frequencies.

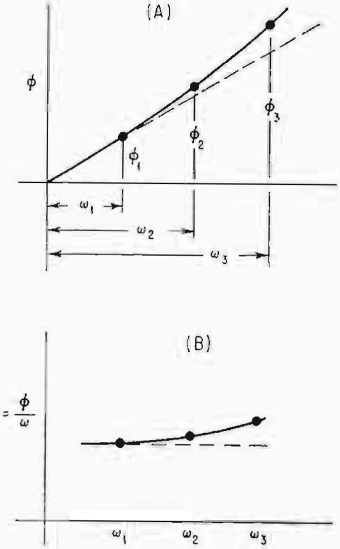

Fig. 51. Curves showing the effect of nonlinear phase characteristic on the time-delay characteristic.

effect of two or more variables by comparing the results shown for the individual variables.

Phase Characteristic

An ideal system has a *linear* phase characteristic, as in Fig. 50a. Such a characteristic implies that all frequencies of a signal have exactly the same *time* delay in passing through this system, since the time delay is given by the phase angle divided by the (radian) frequency. It can be seen in Fig. 50 that if three frequencies are chosen arbitrarily, then the corresponding phase angles must have values proportional to their corresponding frequencies (because of the geometric properties of a right triangle). To state it another way, if $\phi_1/\omega_1 = 0.2\,\mu$sec, then ϕ_2/ω_2 also equals $0.2\,\mu$ sec and ϕ_3/ω_3, too, is $0.2\,\mu$ sec. Plotting these three values and drawing a straight line through them as in Fig. 50a will show that the time delay for all frequencies is $0.2\,\mu$sec.

A signal is not distorted by delay as long as all parts of it are delayed by the same amount. However, when the phase characteristic is nonlinear (as in Fig. 51a), the time delays for all parts of the signal are no longer equal (see Fig. 51b). For example, if a complex waveform is made up of a 1-MHz sine wave and its third harmonic, these two components will suffer unequal delays in passing through a system having the characteristics of Fig. 50. The resultant distortion can be seen by comparing Figs. 52a, 52b, and 52c.

Such distortion is detrimental to both the luminance and chrominance of a composite signal. The luminance signal will have its edges and other important details *scattered*, or *dispersed*, in the final image. Such a transmission system is said to introduce *dispersion.* (Conversely, if a system does not scatter the edges and other high-frequency information, it is said to be dispersionless.) The effect of phase distortion on the chrominance information is of a rather special nature and can best be explained by introducing the concept of *envelope delay*.

Envelope Delay

In the preceding discussion, the time delays ϕ_1/ω_1, ϕ_2/ω_2, and ϕ_3/ω_3 were always determined by measuring the frequencies and the phases from $\omega = 0$ and $\phi = 0$. It might be said that the delay at zero frequency is commonly taken as the reference point for all other delays. This method is usually adequate for determining the performance of systems that do not carry any signals which have been modulated onto a carrier. But a carrier, with its family of associated sidebands (Fig. 53b), can be thought of as a method of transmitting signals in which the zero-frequency reference is translated to a carrier-frequency reference. This translation can be understood by referring to Figs. 53a and 53b. To calculate the delay of the carrier-borne signals *after* they have been demodulated, measurements of ϕ and ω must be referenced, not from zero frequency, but from *carrier* frequency.

In Fig. 54a, an impossible phase characteristic has been drawn to aid in further discussion of this subject. Such a characteristic, consisting of two perfectly straight lines, is never met in practice but makes a very simple system for developing the subject of envelope delay.

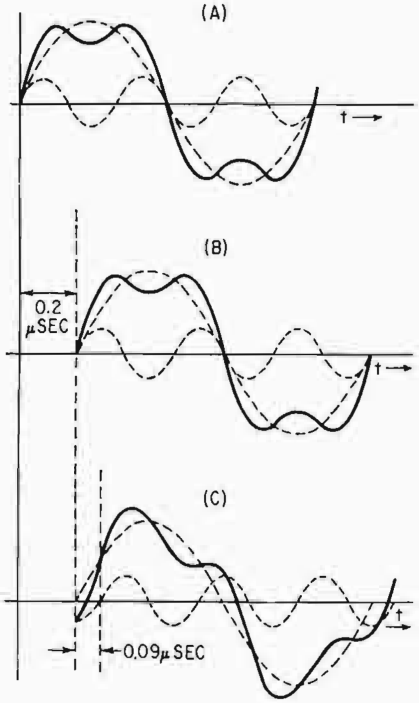

Fig. 52. Curves showing that a complex wave (A) is not distorted by time delay (B) when both components (shown dotted) are delayed by the same amount. Unequal delays (C), however, cause distortion.

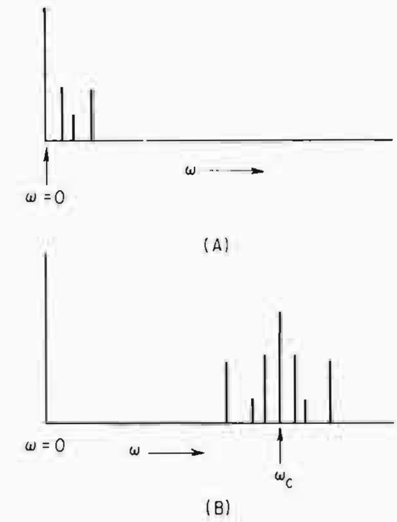

Fig. 53. Sketch showing how a group of frequencies near $\mu = 0$ [sec. (A)] can be translated by modulation onto a carrier to a group of sidebands near μ_c – α carrier frequency (B).

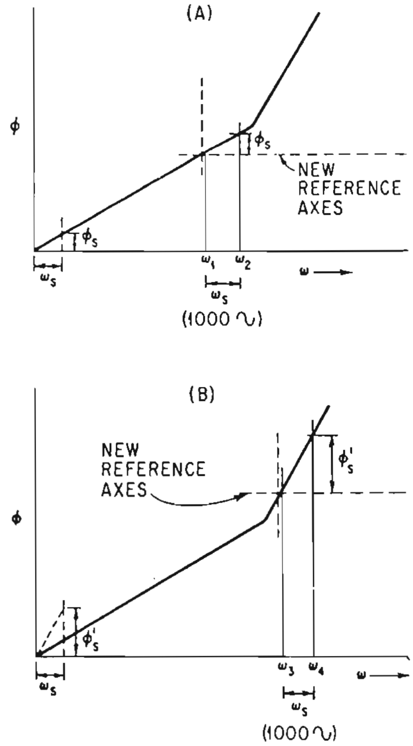

Fig. 54. Idealized straight-line phase characteristics showing how a carrierborne 1,000 Hz signal can be delayed excessively when the carrier and sideband fall on a steeper portion of the phase characteristic.

First, pass two frequencies ω_1 and ω_2 through this system. Let ω_1 be a carrier and ω_2 a sideband which might be, for example, 1,000 Hz higher. If ω_1 and ω_2 fall on the characteristic as shown in Fig. 54a, the delay which the 1,000 Hz will show after demodulation can be found putting new reference axes (shown dotted) with ω_1, the carrier, at zero on these new axes. Now, when ω_s and ϕ_s are measured as shown, the time delay after demodulation is ϕ_s/ω_s. In this case, the delay of the 1,000 Hz after demodulation is the same as it would have been had it been passed through the system directly.

Second, pass two other frequencies ω_3 and ω_4 through this system as redrawn in Fig. 54b. This time drawing in the new axes at ω_3, it can be seen that although ω_s is still 1,000 Hz, ϕ_s is larger than ϕ_s. Therefore, it can be concluded that the time delay ϕ_s'/ω_s for this second case is greater than for the first case. The 1,000 Hz, when demodulated, will show a considerable error in timing.

Stressing the phrase "delay in a demodulated wave" should not be taken to mean that the demodulation process produces this delay or even makes it apparent where it was previously not detectable. Any delay that a demodulated wave shows was also present when the wave existed as a carrier having an envelope. In short, the delay of the demodulated wave appears first as a delay of the envelope, hence the phrase "envelope delay."

Envelope delay does not constitute a distortion. If a system such as the one shown in Fig. 54a introduces a delay of 0.2 μsec to the 1,000-Hz wave (measured after demodulation), then the *envelope delay* of the system is 0.2 μsec. However, it was shown that a 1,000-Hz signal passed directly through the system (without first being modulated into a carrier) would also suffer a delay of 0.2 μsec. As long as the envelope delay ϕ_s/ω_s is the same as the time delay ϕ_1/ω_1, the envelope delay introduces no timing errors. But in the second system (Fig. 54b) the demodulated 1,000-Hz wave suffered a *larger* delay, say 0.29 μsec. A 1,000-Hz signal passed directly through this system, however, would still be delayed only 0.2 μsec. Therefore, the second system has an *envelope delay* of 0.29 μsec and an *envelope-delay distortion* of 0.09 μsec.

It is probably wise to point out that the time delay ϕ_3/ω_3 in Fig. 54b is considerably less than the 0.29 μsec estimated for the value of envelope delay. Although ϕ_3/ω_3 would be greater than 0.2 μsec (say, for example, that ϕ_3/ω_3 is 0.22 μsec), the value would be optimistic about the amount of timing error that would be shown by the demodulated 1,000-Hz signal. The need for a knowledge of the envelope delay ϕ_s/ω_s of the system is therefore obvious.

Effect of Envelope-Delay Distortion on a Color Picture

A transmission system which exhibits envelope-delay distortion will destroy the time coincidence between the chrominance and luminance portions of the signal. This will result in misregistration between the color and luminance components of the reproduced picture. The following paragraph explains briefly how envelope-delay distortion causes this error.

Any colored area in a reproduced picture is derived from two signals—a chrominance signal and a luminance signal. Since these two signals describe the same area in the scene, they begin and end at the same time. The chrominance signal arrives at the receiver as a modulated subcarrier; the luminance signal does not. Therefore, as shown above, the delay of the chrominance signal is determined principally by the envelope delay of the system and the delay of the luminance signal is determined principally by the ordinary time delay ϕ/ω. If the two delays are not identical (that is, if there is envelope-delay *distortion*), then the chrominance signal does not coincide with the luminance signal and the resultant picture suffers *color-luminance misregistration* in a horizontal direction.

For example, in a system having the characteristic of Fig. 54b, the luminance signal is delayed by 0.2 μsec but the chrominance signal is delayed by 0.29 μsec. The error in registration then amounts to 0.09 μsec, or about 0.2 percent of the horizontal dimension of the picture, which is about 0.3 in. on a 21-in. (diagonal) picture.

Although the subject of compatibility is outside the scope of this part, is is worth noting in passing that envelope-delay distortion adversely affects compatibility, since it causes wideband monochrome receivers to display a misregistered dot-crawl image in addition to the proper luminance image.

General Method for Envelope Delay

The specific cases described above (Figs. 54a and 54b) made use of simple, idealized straight-line approximations to develop the concept of envelope delay. Practical circuits are not so simple. For example, a simple *RC* network has a ϕ versus ω plot as i Fig. 55. Finding the envelope delay of this curved-line plot will clarify what is meant by envelope delay.

Referring back to the plots of Figs. 53a and 53b, it can be seen that the characteristic of the plot that determines the value of envelope delay is its *slope*. The larger envelope delay, which was suffered by the ω_3-ω_4 pair (Fig. 54b), was a result of their lying on the steeper slope. The envelope delay of *any* system is equal to the slope of the phase versus frequency characteristic. If this characteristic is a curved line (as for the *RC* network, Fig. 55), then the slope is different at every frequency and, therefore, the envelope delay is different at every frequency.

The slope of a curved line can be found by the methods of the differential calculus or to a good approximation by breaking up the line into a number of straight-line segments, as in Fig. 56. If the slope of each of these straight lines is then plotted against its corresponding frequency (that corresponding to the center of the line), the resulting curve will be approximately the envelope-delay characteristic.

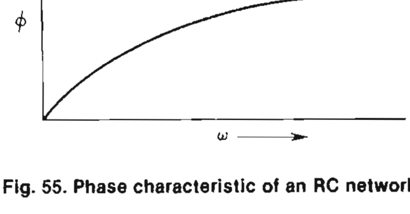

Fig. 55. Phase characteristic of an RC network.

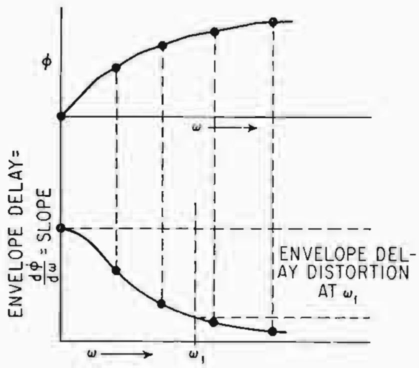

Fig. 56. Graphs showing how a series of straight-line segments can be used to approximate the smooth curve of Fig. 55 (top) and how the slopes of these segments may be plotted to approximate the envelope delay characteristics (bottom).

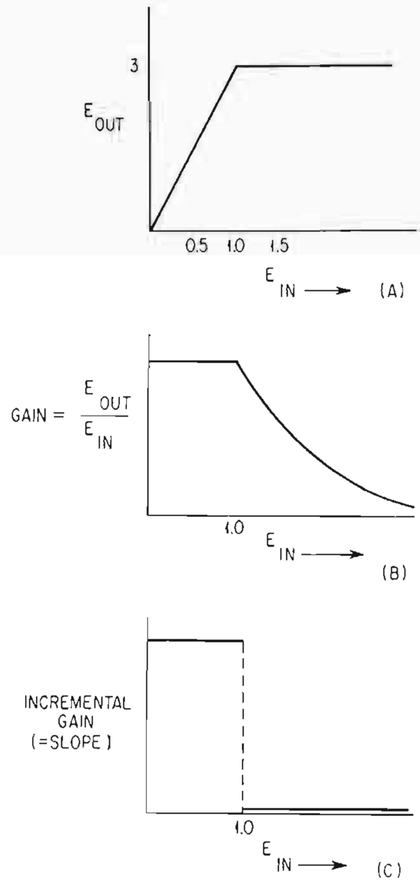

Fig. 57. Idealized straight-line plots showing (A) output voltage of an amplifier versus input voltage (B) gain of the amplifier versus input voltage and (C) incremental gain of the amplifier versus input voltage. Curve (C) is the slope of curve (A).

Nonlinearities of a Practical Transmission System

It is important to emphasize that the effect of nonlinearities in a color television system depends upon whether these nonlinearities precede or follow the matrixing and modulation sections of the system. Nonlinearities in transfer characteristics detract from color fidelity; the same degree of nonlinearity after matrixing and modulation also affects color fidelity although in a different way. The purpose of the following paragraphs is to discuss how a nonlinear transmission system affects a *composite* color signal. It is assumed that all other nonlinearities in the entire system either are negligible or have been canceled by use of nonlinear amplifiers such as gamma correctors.

The major sources of nonlinearity in a transmission system are its amplifying devices.[4] These devices—tubes and transistors—have a limited dynamic range. For example, if too much signal is supplied to them, an *overload* results. The transfer characteristic of such a system can be sketched as in Fig. 57a.

Such a nonlinearity is one of three types commonly encountered in video transmission systems. These three types are:

1. Incremental gain distortion
2. Differential gain
3. Differential phase

The paragraphs below will show that Type 2 is merely a special case of Type 1.

Incremental Gain

The concept of the slope of a plot, developed in the discussion of envelope delay, will be useful here as well. Consider a plot as in Fig. 57a which shows output voltage of an amplifier plotted against input voltage. Idealized straight-line plots are shown for simplicity. It can be seen that the amplifier has a maximum output of 3 volts for 1-volt input. Larger input voltages result in no more output; the amplifier *clips* or *compresses* when inputs larger than 1 volt are applied.

The gain of the amplifier is

$$\text{Gain} = \frac{E_0}{E_{in}} = \frac{3 \text{ volts}}{1 \text{ volt}} = 3$$

The gain is obviously constant below the clip point. For example, an input voltage of 0.5 volt gives

$$\text{Gain} = \frac{1.5 \text{ volts}}{0.5 \text{ volt}} = 3$$

But at an input of 1.5 volts, the output is still 3 volts, so the "gain" is only 2. (The word "gain" is of doubtful use here because of the

[4]FM systems can have nonlinearity as a result of *passive* networks, but this case is not considered here.

clipping involved.) The gain, defined as E_0/E_{in}, is plotted against E_{in} in Fig. 57b. It can be seen in this figure that the gain is constant only as long as the *slope* of Fig. 57a is constant.

It is useful, then, to establish a new term, called *incremental gain,* which will be defined as the *slope* of a plot such as Fig. 57a. For the particular plot of Fig. 57a, the slope is constant up to $E_{in} = 1$ volt and then suddenly becomes zero. The corresponding plot of slope versus E_{in} is shown in Fig. 57c.

The importance of incremental gain in color television can be assessed by applying the input signal shown in Fig. 57 to the distorting system of Fig. 57a. Before being applied to the distorting system, such a signal could be reproduced on a monochrome receiver as a vertical white bar and on a color receiver as a pastel-colored bar, say, for example, a pale green. After passing through the distorting system, the signal would still be reproduced as a white bar on the monochrome receiver with the only apparent error being a luminance distortion, that is, a slight reduction in brightness, which, for the magnitudes shown here, would probably pass unnoticed. The color receiver, however, would receive a signal completely devoid of any color information and would reproduce a white bar in place of the former pale-green one.

A less extreme case is shown in Fig. 59. For the system represented by this characteristic, the slope (incremental gain) does not become zero for inputs above 1 volt but instead falls to one-half its below-1-volt value. The color signal of Fig. 59 would not lose all color in passing through this system, but the amplitude of the subcarrier would become only one-half of its proper value. Since saturation is a function of subcarrier amplitude, the pale green of the undistorted reproduction would, in this case, become a *paler* green. The luminance distortion would also be less than in the extreme (clipping) case.

It can be seen, then, that unless the incremental gain of a system is constant, that system will introduce compression, which will distort the saturation and brightness of reproduced colors. Usually, the error is in the direction of *decreased* luminance and saturation. For certain systems, however, exceptions can be found. For example, the effect that the system represented by Fig. 59 will have on a signal depends on the polarity of the signal. For the signal as shown, the usual *decrease* in luminance and saturation is exhibited. For an inverted signal, however, the subcarrier amplitude would not be reduced, but the luminance signal would still be diminished. The subjective result of this distortion would be an *increase* in saturation. The unusual behavior of this particular system is attributable to its peculiar transfer characteristic, which was drawn with curvature at one end only to simplify the discussion. Most practical system-transfer characteristics exhibit curvature at both ends and therefore have an effect on the signal which is essentially independent of polarity.

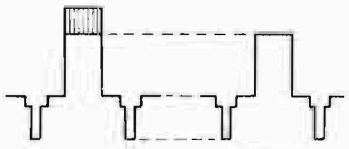

Fig. 58. Extreme case of distortion resulting from passing signal at left (A) through the amplifier represented by Fig. 57. The output (B) has no color information remaining.

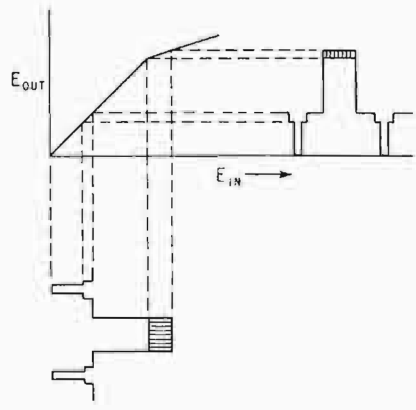

Fig. 59. Diagram showing effect of incremental gain distortion in reducing amplitude of color portion of signal.

Incremental gain can be measured in two ways, the first of which stems from its contribution to luminance distortion and the second, from its contribution to chrominance distortion.

In the first method, an equal-step staircase waveform such as shown in Fig. 60a is applied to the system to simulate a signal having equal luminance increments. If the system has constant incremental gain, the output will, of course, also have equal-step increments. But if the system does not have constant incremental gain, certain of the steps will be compressed, as in Fig. 60b. If the compression is as in the figure, the *incremental gain distortion* (IGD) is indicated by the distorted amplitude of the last step. Numerically, it can be stated as a percentage:

$$\mathrm{IGD} = 1 - \frac{S_{\text{distorted}}}{S_{\text{undistorted}}} \times 100\%$$

where S is a step amplitude.

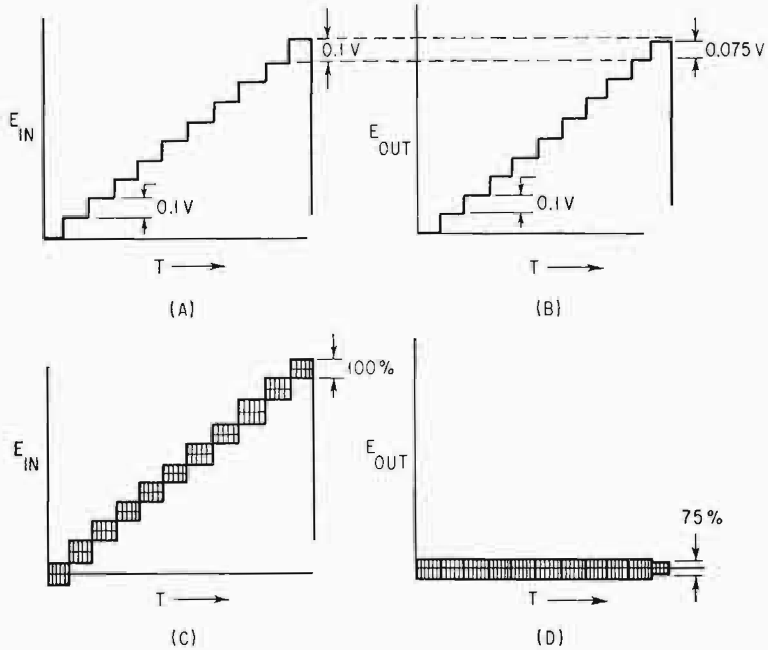

Fig. 60. Diagrams showing two methods of measuring incremental gain distortion, namely, in (A) and (B) by its contribution to luminance distortion and in (C) and (D) chrominance distortion.

For example, if an undistorted step is 0.1 volt and the distorted one is 0.075 volt, then the incremental gain distortion would be 25 percent.

Using the other (chrominance distortion) technique, an input signal consisting of the step wave plus a small, high-frequency sine wave, as shown in Fig. 60c, is applied to the system. After the signal has passed through the system, it is fed through a high-pass filter which removes the low-frequency staircase. The incremental gain distortion then is indicated by the differences in the amplitude of the high-frequency sine waves (see Fig. 60d). In this case, the high-frequency sine wave associated with the top step is shown as having 75 percent of the amplitude of the sine waves associated with the lower steps, which are assumed to be undistorted. Again, the incremental gain distortion is 25 percent.

A most important point must be made regarding the equivalence of these two techniques. Certain systems which show incremental gain distortion when tested by the luminance-step technique may or may not show the same distortion when tested by the high-frequency and high-pass-filter technique. Moreover, a system which shows distortion by the second technique may or may not show distortion by the first. In other words, the incremental gain distortion may be different for different frequencies. Such differences are frequently found in staggered amplifiers, feedback amplifiers, or amplifiers having separate parallel paths for high and low frequencies, such as might be found in stabilizing amplifiers.

A thorough test of a system, therefore, should include tests of its incremental gain by both techniques. The staircase-plus-high-frequency waveform can be used to provide *both* tests by observing the system output (for this test waveform input) first through a low-pass filter and then through a high-pass filter. The first test will show low-frequency distortions; the second, high-frequency distortions.

Differential Gain

On the basis of the above discussion of incremental gain distortion, the extremely important concept of *differential gain* can be presented merely as a simple definition. Differential gain is identical with incremental gain distortion when the latter is measured by observing ". . . the difference in the gain of the system for a small high-frequency sine-wave signal at two stated levels of a low-frequency signal upon which it is superimposed."[5] In other words, differential gain is a special form of incremental gain distortion which describes the IGD of a system for the superimposed high-frequency case only.

One of the reasons for selecting the high-frequency aspect of incremental gain distortion for the IRE definition of differential gain was applied in Fig. 58, when the ". . . high-frequency sine wave . . ." of the definition was made equal to color subcarrier. This special case of differen-

[5]From the definition of differential gain by IRE Subcommittee 23.4.

tial gain explores the system gain linearity in the vicinity of this particularly important frequency. The definition of differential gain was purposely made in the broad terms of a ". . . high-frequency sine wave . . ." to allow the greatest possible versatility in devising methods of measurement. In present color-television practice, however, the ". . . high-frequency sine wave . . ." is always color subcarrier and the low-frequency signal mentioned in the definition is a 15,750 Hz staircase, sine-wave, or sawtooth. The complete specifications for the signal presently used in this measurement will be found elsewhere in this article.

Another reason for emphasizing high-frequency IGD was implied previously by the sentence ". . . the signal . . . would . . . be reproduced . . . with the only apparent error being a luminance distortion . . . which, for the magnitudes shown ehre, would probably pass unnoticed." The magnitude shown was a 25 percent IGD, which is passing unnoticed, indicating that large incremental gain distortions usually cause no detectable luminance errors. Incremental gain distortion is almost too sensitive a tool to measure luminance distortions. For this purpose, simple gain distortion (compression) is more useful. Therefore, the luminance-distortion aspect of IGD was deliberately omitted from the definition of differential gain.

Incremental Phase and Differential Phase

The phase characteristic sketched in Fig. 49 indicates that the system described by this plot will introduce a certain amount of phase shift for any given frequency. For example, it might be found that a certain system would introduce a phase shift of 60° at 2 MHz. If the system in question were perfectly linear, this 60° phase shift would be produced regardless of how the 2-MHz signal might be applied to the system.

It can be shown, however, that some systems, when presented with a signal of the type shown in Fig. 61, will introduce a delay *different* from 60°, depending on where the zero axis of the sine wave falls on the transfer characteristic of the system. For the case sketched in the figure, a phase shift of 70° is drawn for the largest zero-axis displacement.

By analogy with the incremental gain and differential gain arguments above, it is possible to define three quantities which pertain to this type of distortion. These quantities are *incremental phase, incremental phase distortion,* and *differential phase.* It can also be shown that of the three, differential phase is the most important quantity.

Incremental phase is the least exact analogue, since it is not very similar in form to incremental

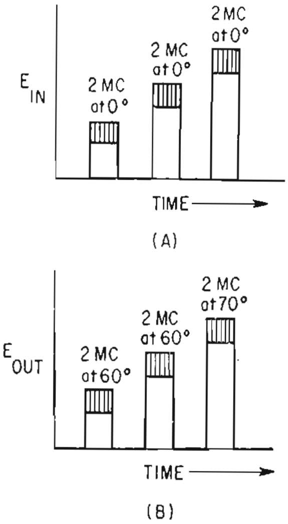

Fig. 61. Graphs illustrating how a signal (A) may undergo different phase shifts (B) depending upon where the zero axis at the sine wave falls on the system transfer characteristic. This distortion is called differential phase.

gain. Incremental *gain* is a *slope;* incremental phase is simply the absolute value of phase shift. In the above system, the incremental phase was 60° or 70° (or somewhere in between), depending upon the location of the zero axis.

Incremental phase distortion, like its analogue *incremental gain distortion,* depends upon the magnitude of the error. It should be zero for a perfect system. In the system of Fig. 61 the 2-MHz signal with 70° incremental phase would be said to have 10° incremental phase distortion, so it is clear that the difference between two phases (one of which is assumed to be "correct") gives the incremental phase distortion.

As previously stated, *differential gain* is identical with *incremental gain distortion* for the superimposed-high-frequency case only. Similarly, *differential phase* is identical with *incremental phase distortion,* but there is no need to limit the definition to the superimposed-high-frequency case, since there is no other case which is meaningful for phase distortion. Without the superimposed sine wave, no phase measurement is possible. Therefore, differential phase is identical with incremental phase distortion. In practical work, the first two terms are seldom used, for the last, differential phase, has been found completely adequate to describe this aspect of a system.

In summary, the differential phase of a system is "the difference in phase shift through the system for a small high-frequency sine-wave signal at two stated levels of a low-frequency signal on which it is superimposed.[6]

[6]From the definition of differential phase by IRE Subcommittee 23.4.

It is important that the phrases "differential phase *distortion*" and "differential gain *distortion*" be avoided because differential phase *is* distortion as is differential gain, since they are defined as being identical with incremental phase distortion and incremental gain distortion, respectively. To add the word *distortion* to either is redundant. A sample of proper usage is "this amplifier has a differential gain of 1.5 percent and a differential phase of 0.5°."

Effect of Differential Phase on a Color Picture

The phase of subcarrier in a composite signal carries information about the *hue* of the signal at that instant. If the signal passes through a system which introduces differential phase, the subcarrier phase (and hence, the hue) at the output will become dependent upon the amplitude of the luminance associated with the hue, since it is the luminance signal which determines the location of the zero axis of the subcarrier. For example, a system introducing 10° of differential phase might be adjusted to reproduce properly a low-luminance hue such as saturated blue or a high-luminance hue such as saturated yellow, but *not both.* One or the other would have to be in error.

State of the Art

The preceding portions of this part have discussed in general terms the possible sources of color errors in a color television system. In no practical system can any of these errors be reduced to zero; therefore, anyone working with practical systems should know how nearly perfect any given parameter should be to be considered acceptable according to the present state of the art.

System Colorimetry

Talking qualitatively about colorimetric accuracy is one thing; assigning numbers and magnitudes is quite another. For the practical purposes of this part, however, we are spared the need of digging deeply into the quantitative aspects of colorimetry by one simple fact: At the present time, color errors attributable to phosphor errors, filter errors, and other basic colorimetric errors are generally small in comparison with other sources of error.

System Exponent

At the present state of the art, adjusting a system to precompensate for a kinescope exponent of 2.2 is not enforced by the Federal Communications Commission, since this parameter is not yet well established. Adjusting the system to precompensate for this median value, however, can be done with precision. A gamma corrector which uses four or five diodes to make a series of straight-line approximations to a 0.7 exponent can be made so as to have a maximum error of less than 2 percent of the peak signal amplitude. The exponents of the three channels can be made to match within 1 percent of the peak signal amplitude.

Matrix Coefficients

A high-quality matrix, such as would be found in a well-engineered colorplexer or studio monitor, uses .5 percent precision resistors for all resistances which will influence the values of the coefficients, while inverters and amplifiers are either stabilized by feedback or made adjustable. Errors of greater than 1 percent are rare in such circuits.

White balance in the transmitter matrix, which is a special case of the subject of matrix coefficients, can usually be adjusted and held to a tolerance of the order of .5 percent of peak white.

Phase Accuracies

Adjustment of Q subcarrier, I subcarrier, and burst to within 1° of their proper relative phases is easily accomplished using standard commercial equipment and techniques. This accuracy is ten times that required by the Federal Communications Commission.

Subcarrier-Frequency Accuracy

Subcarrier frequency can be easily adjusted to within ±1 Hz the real limit on the accuracy of the adjustment being in the inherent accuracy of the standard used for frequency comparison. Long-term stability of well-engineered equipment should be easily within the required limits of ±10 Hz.

Transmission Characteristics

A single amplifier should have a gain characteristic with less than ±1/2-dB variation out to 8 MHz. Its envelope-delay error should be of the order of 0.001 μsec at 3.58 MHz, relative to 200 kHz. Differential gain of .5 percent and differential phase of 0.25° represent good performance.

Tolerable Color Errors

Sensitivity of the eye to color errors depends upon the manner in which two colors—the original and the reproduction—are compared. For example, if the two colors are placed side by side, the eye becomes a very sensitive indicator or color errors. However, if the comparison is made only by recollection or long term color memory, the eye is far more lenient in its requirements of perfect reproduction. Furthermore, if the reproduced color is one that the eye has not viewed before, the eye requires only that the color relayed to the brain be plausible, that is, that it be a reasonable color for the object.

Fortunately, side-by-side comparison of colors seldom, if ever, occurs in home viewing of color television. However, the system is frequently called upon to reproduce objects whose colors may be well known to the viewer, such as flesh tones or a sponsor's packaged product. Reproductions of these objects must be accurate enough to satisfy the viewer's recollection or color memory. If the system can satisfy the color memory of the viewer, the color-plausibility requirement will be easily met.

Investigations made to determine the sensitivity of the eye to color errors introduced by a deliberate shift of burst phase show that a shift of 10° or more produces perceptible change of hue. With color bar signals a burst phase shift of 3° can just be detected as a hue shift. With typical scenes a phase shift of 5° can be tolerated.

Tests have shown that the eye is much more tolerant of amplitude shifts in R, G, B components, which correspond to changes in color saturation, than it is of phase shifts or changes in hue.

One must distinguish between long-term adaptive errors in viewing a color television picture and short-term differential color errors. In the first case the eye is quite tolerant of changes or shifts in color balance providing that no direct side-by-side comparisons are involved. Thus a viewer is reasonably well satisfied with color pictures in which white is reproduced within the range of 3200°K to 9500°K. As soon as he views two color TV pictures side-by-side at two different white balance conditions, there will be a much more critical reaction to color fidelity.

For this reason, it is important that color monitors in a broadcasting control room be adjusted to have the same effective white balance, the same color phasing, and the same peak brightness. Since such monitors are usually arranged in a row adjacent to each, great care must be taken so that when the same picture signal is applied to all monitors, there is negligible difference in the color picture displays. Only then can the color monitors be useful in matching and comparing color balance of the various camera signal sources.

It is unusual to have more than one color receiver at a home viewing location at a given time. There the absolute color balance problem has little direct impact.

Control of short-term differential color errors is vitally important to the broadcaster. In any broadcast sequence, a given scene is generally viewed from different angles with several color cameras, at various magnifications, and the available video signals are selected from camera to camera to obtain program continuity. The eye views these color scenes in quick succession and is very critical of even small color differences, particularly with regard to skin tone rendition. Variations of the R, G, B or primary color components of 2 percent can be detected. Although the eye can easily adapt to any of the pictures in a few seconds, the viewer will find the abrupt color shifts very disturbing with switching transitions. Thus great care is taken with colorimetric tolerances in color cameras and with color-balancing procedures to provide color matching among cameras which will be precise.

A similar situation exists in the reproduction of color motion pictures. A feature movie having adequate color quality is usually shown in a sequence lasting 15 minutes or more, with the eye having adequate time to adapt to any discrepancies in color balance and skin tones. Commercials spliced into this feature program produce an instantaneous switch to a new and different skin tone balance without time for eye-adaptation. This transition to commercials and back to the feature can exhibit color mismatch in varying degrees, depending on the colorimetric control which has been exercised.

In fact, if the feature film is somewhat misbalanced, and intentionally "corrected" by appropriate use of R, G, B gains or "paint-pot" controls, the transition to the commercial will be more objectionable since the "correction" can then increase the misbalance, even for a "perfectly-balanced" commercial. Effort is going on in the industry to tighten up tolerances on skin tone rendition so that adequate performance can be obtained by purely routine operating methods.

Conclusion

This discussion of color errors indicates *possible* degradations in color fidelity and their probable sources. However, in a properly adjusted color TV system the picture quality is excellent. The various techniques now in development to improve picture quality within the framework of the NTSC system have assured a bright future for color TV.

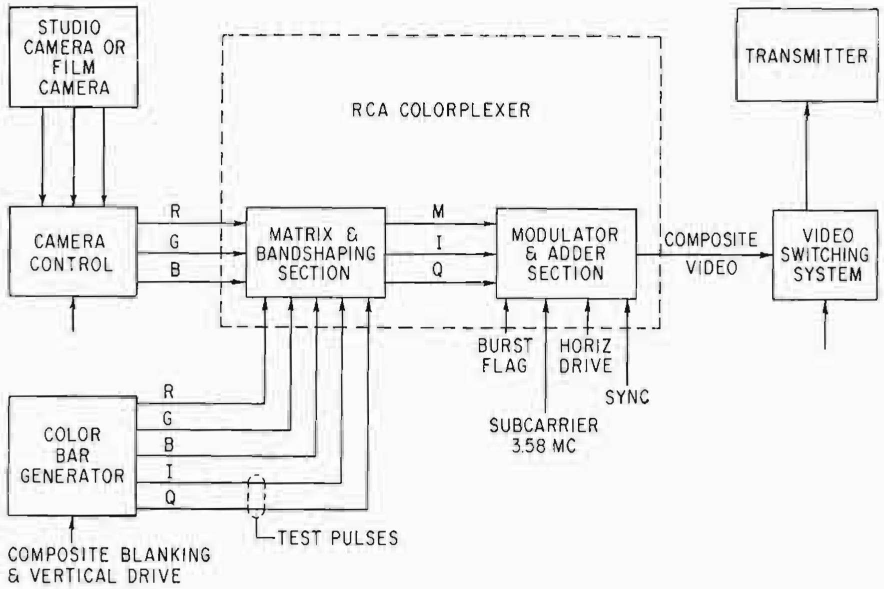

Fig. 62. Basic color-television system showing functions and major components of the colorplexer.

THE COLORPLEXER

The Colorplexer or encoder in the color television system performs the required encoding of the R, G, B signals from three-tube cameras or the R, G, B and Y (luminance) signals from four-tube cameras into a single color video signal conforming to FCC specifications. It is the heart of the modern color television system and represents a most ingenious application of many elements of communication circuit theory.

Fig. 62 shows a block schematic of a basic color television system indicating the functions and major components of the colorplexer.

A more detailed block diagram of the colorplexer showing the matrixing, bandwidth-limiting and quadrature modulation functions is shown in Figs. 36 and 37.

Basic Functions

The principal operations and functions performed by the colorplexer are:

1. Matrixing of R, G, B video signals to produce luminance and chrominance signals.
2. Filtering of the chrominance signals to obtain the required bandwidth.
3. Delay compensation to correct for bandlimiting time-delay.
4. Modulation of 3.58 MHz carriers by chrominance signals.
5. Insertion of color sync burst.
6. Addition of luminance and chrominance signal to form a complete color signal.
7. Optional addition of sync.

Design and system philosophy determines whether a colorplexer is a separate unit or an integral portion of a modular assembly. Present solidstate equipment design tends toward the modular concept since it is generally easier to maintain, repair, up-date and revise specific modular units or board assemblies without affecting the overall installation.

The electrical color bar generator which is generally provided for systems test and colorplexer alignment is available either as a separately contained unit or as a module in a complete operating assembly.

Colorplexers of modern solid-state design are inherently stable and require only routine verification or adjustment. Set-up of a colorplexer involves the use of color-bars which are electrically generated waveforms of high precision. A color bar generator is capable of producing on a color monitor all of the signal bars illustrated in Fig. 63.

Colors at the top of this display pattern are arranged from left to right as white, yellow, cyan, green, magenta, red and blue in their decreasing order of luminance. The lower portion of the pattern contains "I," "100% White," "Q," and black signal areas. The "I and "Q" signals simplify subcarrier phase adjustments in the colorplexer and the 100 percent white bar facilities white-balance adjustments. The specifications of the standard encoder color bar signal are given in EIA standard RS-189.

Waveforms

Fig. 64 shows the oscilloscope waveforms at a horizontal sweep rate of the color bar signals displayed on the television raster. Note that this is a composite representation of waveforms of

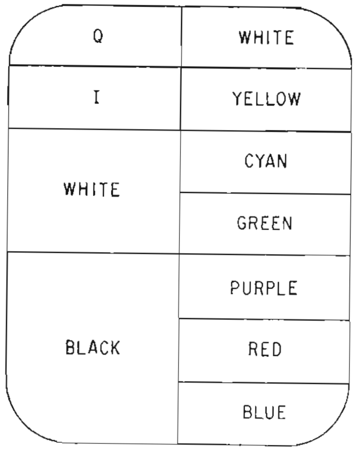

Fig. 63. Diagram showing color monitor display of color and test bars electronically produced by RCA color-bar generator.

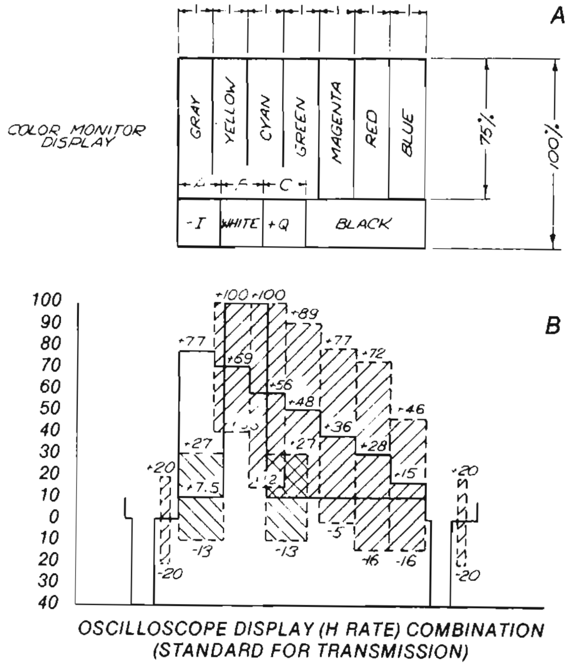

Fig. 64. (A) Color monitor display and (B) Oscilloscope display (H rate).

the top and the bottom areas of the raster. The color sync precedes the color bar pulse information.

Fig. 65 shows the various band-pass response characteristics of the luminance channel and of the "I" and "Q" channels of the colorplexer.

A colorplexer is set up and adjusted by using the calibrated color bars just described. The colorplexer luminance gain is adjusted by using the 75 percent white bar as a reference. By switching off the luminance channel the appropriate "I" and "Q" waveforms are available to set the proper peak amplitudes and the 90° phase separation. Either a wide-band oscilloscope or a vectorscope can be used for display in a variety of specialized set-up procedures. The vector relationship of chrominance components is shown in Fig. 66.

Aperture Compensation

Aperture compensation is used in television systems to correct for the decrease in signal out-

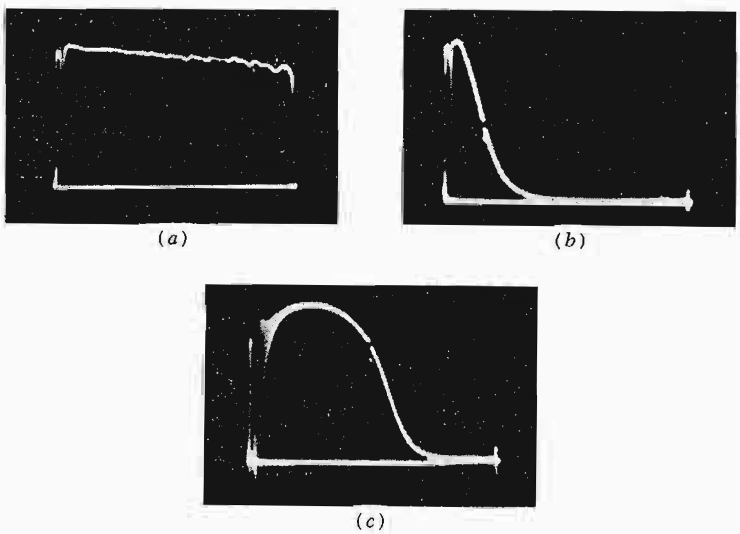

Fig. 65. Waveforms showing response characteristics of colorplexer monochrome, I and Q channels. (*a*) Response of monochrome channel without aperture correction, marker at 8.0 MHz; (*b*) output of I filter, marker at 2.0 MHz; (*c*) output of Q filter, marker at 500 kHz.

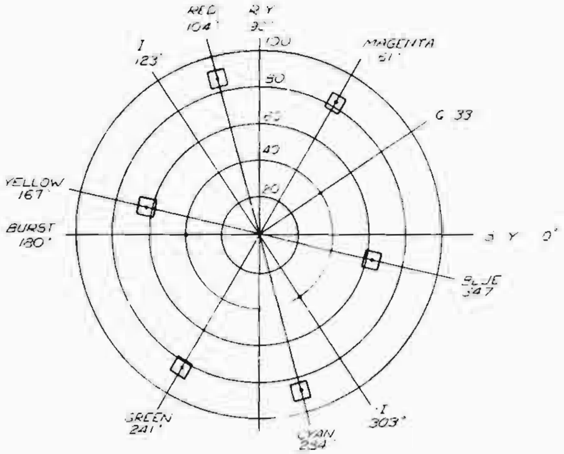

Fig. 66. Vector relationship among chrominance components.

put at high frequencies caused by the finite-size limitations of the scanning spot or of equivalent optical lens aperture response. If one considers abrupt or black to white square-wave transitions at 400 TV lines, corresponding to 5 MHz video components, the video signal amplitudes from a Plumbicon or vidicon pick-up tube may be only 30 to 40 percent of the amplitude of low frequency transitions at 40 TV lines or 0.5 MHz. If the signal-to-noise ratio of the output video is good, aperture compensation to give practically 100 percent flat response at 5 MHz can be applied, producing subjectively sharper pictures.

Horizontal aperture correction is done by comparing the amplitude response of a given picture element with that from adjacent elements by the use of differential amplifiers and electrical delay lines. This difference, suitably amplified and of correct polarity is added to the signal being corrected which increases the sharpness of the transition.

Vertical aperture response can also decrease with increased line number and can similarly be improved by comparing the response of picture elements on a given TV line with that of line elements preceding and following it. Differential amplifiers compare the video signals obtained from delay lines of a horizontal period (63.6 μsec) in duration with the picture elements of the TV line to be corrected.

Differences between these video responses are obtained from differential or comparison amplifiers amplified and suitably added to the main signal, to improve the vertical transition sharpness.

Judicious use of combined horizontal and vertical aperture correction or enhancement produces marked improvement in subjective picture sharpness. Since the luminance channel of a color system provides the sharpness information, it is generally used as the signal for aperture response improvement.

A block diagram of aperture compensation circuits is given in Fig. 67.

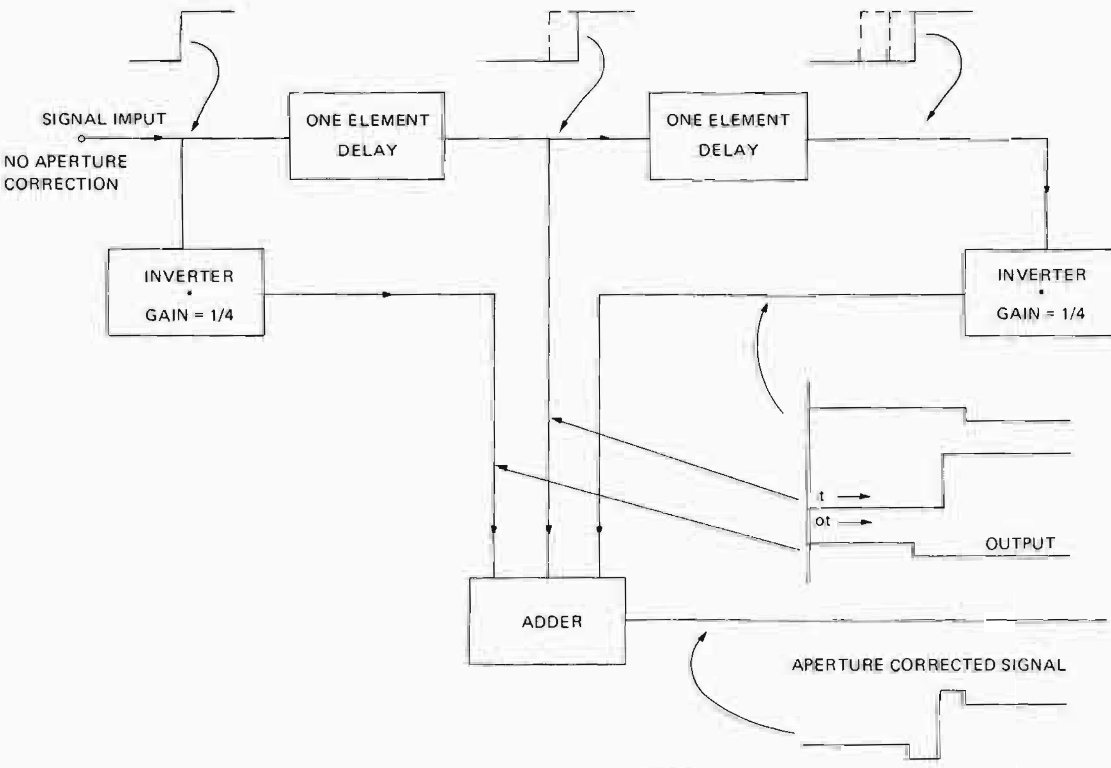

Fig. 67. Generalized aperture corrector.

Factors Affecting Color Camera Performance

The following general principles, which outline procedures for the proper alignment and operation of color cameras, are directed toward three-tube color camera models and are presented to assist the station engineer in understanding the effect that each adjustment can have on the composite color picture. No attempt is made to present a step-by-step alignment procedure which, while basically the same for all cameras, will vary in detail depending on the manufacturer and the type of camera.

CAMERA ALIGNMENT

It is important to point out that color camera alignment should be made by viewing the proper test charts for a given adjustment or procedure. Such charts are useful for direct indication of the required camera adjustments. The practice of making an indiscriminate adjustment during a scene to "paint" a pleasing picture should be avoided in any operational procedure. Such an adjustment is usually successful for only isolated conditions and may easily produce errors in subsequent scenes. It is also important to note that certain controls in the color cameras when improperly set may give a false indication that other controls are misaligned. Therefore, maximum effort should be given to logical rigorous routine alignment of the controls before program time.

During operation a properly aligned camera should require no more than exposure control using the lens iris as an operating control and an occasional adjustment of pedestal or black level setting.

The Three-Tube Concept

A three-tube camera consists basically of an optical system which "sees" the scene being televised through a dichroic mirror or prism assembly, suitably separated into its red, green, and blue image components. These three red, green, and blue images are focused on the photosensitive layer of the pickup tube in each color channel. By synchronous scanning of the three pickup tubes one obtains three independent video signals which differ only in their amplitude response to the three color images. Thus, we effectively obtain a red signal from the red tube, a green signal from the green tube and a blue signal from the blue tube. With the optical and electrical adjustments available, these three pictures are superimposed or registered on each other within an accuracy of a picture element. In order to carry out this registry process one has access to individual horizontal and vertical size and centering controls, as well as to mechanical rotation of the individual yokes and to "skew" which provides for orthogonal deflection by means of electrical cross-coupling between horizontal and vertical deflection. Thus, in principle one can obtain three independent R, G, B channels which are effectively superimposed in space at the pickup device and in time by virtue of the synchronous deflection process. One could apply these three signals to the red, green, and blue gun of the color kinescope to produce a replica of the scene being televised. However, certain procedures are necessary to obtain normalized and predictable camera behavior.

Signal-to-Noise and Sensitivity

One must set the gains of the individual video amplifiers in the R, G, B channels to a specific value. Then a given signal current from the Plumbicon will produce the required output level at the required signal-to-noise ratio. The Plumbicon signal-to-noise ratio depends almost entirely on the figure of merit of the external video amplifier. Nominal values of signal current are of the order of 300 to 400 nanoamps. These are obtained at exposures of approximately f:4 with 150 to 200 fc on an average scene. In contrast to the Image Orthicon camera where the signal-to-noise ratio is determined primarily by the signal-to-noise ratio of the image orthicon tube itself, there is a trade-off possible between sensitivity and signal-to-noise in the Plumbicon camera. Thus one can obtain twice "normal" sensitivity with a 6 dB decrease in signal-to-noise ratio or four times this sensitivity with a 12 dB decrease in signal-to-noise ratio. As long as the signal-to-noise ratio under standard conditions is excellent, in practice about 50 dB before gamma correction, one can tolerate such a degradation to obtain increased sensitivity and still achieve pictures which have adequate signal-to-noise.

Specular Highlights

The signal current magnitude is chosen so as to achieve a compromise between signal-to-noise ratio and the ability of the tube to discharge highlights. A standard procedure is to adjust for a factor of two reserve in the signal current by proper beam bias adjustments. In set-up, the normal scene lens exposure opening is deliberately increased by one f stop, doubling the light to the Plumbicons and the beam currents in the

R, G, B tubes are then adjusted to just discharge the picture highlights. The exposure is then restored to its "normal" setting. With this camera adjustment procedure any increase in peak brightness due to speculars or highlights in a scene which does not exceed this factor of two will be discharged effectively in the Plumbicon by the "available" beam current reserve which has been provided. If one attempts to use larger signal currents than 400 nanoamperes there may be limitations in the gun which cause loss of normal resolution and an inability to supply the required beam current reserve for satisfactory discharge of highlights.

When a camera is operated under conditions of specular highlights and there is motion in the scene, the presence of undischarged areas in the raster will give rise to false color halo effects, generally red, which are usually described as comet tails. This comet-tail effect on motion is called "puddling" by British broadcasters. The two-to-one highlight beam reserve usually controls the comet-tail effect satisfactorily.

Gamma Correction

Since the gamma of the Plumbicon tube is essentially unity, gamma correcting amplifiers must be used to produce a pleasing picture display using modern color kinescopes. The effective gamma characteristic of the color kinescope has approximately a 2.2 exponent; thus gamma correction of 1/2.2 or 0.45 is needed to obtain an overall gamma or transfer function of unity.

In order to obtain color "tracking" with changes of lighting or exposure, it is important that the transfer characteristics or gamma of the R, G, B channels be identical. This matching can be achieved by using techniques such as superpositioning of the transfer characteristics waveforms on a display oscilloscope, using a standard input sawtooth, and adjusting the individual gamma circuits for the same power law and the individual black levels or capped lens references for zero. A direct check for transfer characteristic adjustment is to use the neutral EIA logarithmic gray scale chart[7] placed directly in the scene viewed by the camera. When the tube and gamma circuits are correctly adjusted to an overall gamma, which is the same for all three channels, and a 0.45 slope value is maintained, the color picture display of the EIA chart on the kinescope will be observed as neutral or shades of gray with no apparent color misbalance over the entire gray scale range.

[7]Electronic Industries Association.

Aperture Correction

The aperture response of Plumbicon tubes of the 30 mm variety generally used for color TV broadcast is approximately 35 to 45 percent at 400 TV lines or 5 MHz as compared to a 100 percent reference response for low line-number transitions. For this reason it has been almost universal practice to aperture-correct or crispen the picture both horizontally and vertically by the use of omnidirectional aperture correction circuits. The response can be made effectively 100 percent of the time within the 5 MHz TV channel without noticeably deteriorating the signal-to-noise ratio. Such aperture correction techniques are described in the section on colorplexer and shown in Fig. 66. Clamping, blanking addition, and clipping of the processed signal, following accepted monochrome picture techniques, are performed on the three channels before they are ready to encode into the NTSC colorplexed form adopted for transmission.

Color Matching Techniques

In a color television operation the color-matching of the individual color cameras against each other is of prime importance. Ideally there should be *no* discernible color differences in the color TV pictures from all cameras when viewing the same subject. Experience has shown that by exercising tight control on the production tolerances of dichroic colorimetric components in the optical system and on the electronic components, one can achieve accurate color rendition from any cameras used on a given scene.

In practice each camera is aligned under normalized video gain conditions so as to obtain the required signal-to-noise performance and the same effective sensitivity. Then routine adjustment procedures to obtain the same gamma correction or transfer characteristic in the R, G, B are carried out.

The cameras now view an EIA logarithmic neutral gray scale under standard conditions. If the inputs to the colorplexer are standardized and cameras have been well aligned, the gray scales will be reproduced on a color monitor over the complete brightness range as a neutral picture, since the subcarrier amplitude everywhere in the scene should be zero. Such a chart is a very sensitive indicator of small misadjustments and is generally used as a tool for vernier balancing of a color camera.

Any minor discrepancies in color rendition of the cameras used in a studio are corrected by very small changes in either R, B, or G gain provided by "paint pots."

Operationally it has been found that one camera control operator, using a single color monitor, can match four cameras more rapidly and accurately than four operators working independently.

Electronic masking devices such as the RCA Chromacomp and the CBS Color Masking Processor permits color matching cameras to any degree of precision without upsetting white balance.

Flare in Pickup Tubes

Under certain conditions of scene content, an unwanted lift of black level or pedestal can occur in one or more of the color pickup tubes. The effect is due to light scattering in the photoconductive layer of the tube itself and is strongest in the red channel. Thus, for example, if a scene which is predominantly red is viewed by the camera, the red pedestal will rise by 3 or 4 percent producing a red cast in the picture. This can be corrected by manually resetting the red tube black-level control. Automatic circuits which are duty-cycle sensitive are often used to provide a good approximation to black level with changes in scene content without any operator attention. Flare in green is much less than in red and is quite negligible in the blue channel. Light scattering in optical components and lenses will also cause artificial lift of black level.

In a well-designed and well-aligned camera, color balance and color tracking are obtained automatically over a wide range of scene content and exposure.

A special opaque test pattern developed by BBC uses a "super-black" enclosure hole as a reference for black level setting in addition to the usual logarithmic gray scale for gamma checks. American broadcasters often use a square of clean black velvet as a "super-black" for flare-compensation circuit test and adjustment and as a solid black-level reference.

Lighting on the Scene

With Plumbicon cameras the incident lighting required for studio-quality signal-to-noise picture performance generally approaches 250 fc for a lens opening of f:4. The contrast of the scene which the color camera must handle is the product of the incident light and the reflectance of the subject matter. Technically, uniform or flat lighting is easiest to handle since this limits the range to the reflectance of the scene components, generally restricted to a highest white of 60 percent reflectance and a lowlight of 2 to 3 percent, giving a range of 20 or 30 to 1 at most. The rendition in monochrome TV is as important as the rendition in color since many of the TV viewers still look at the picture in monochrome. It is therefore important to select scene materials and surfaces so as to obtain good monochrome separation in the gray scale as well as to provide colorful rendition in the final color picture. Flat lighting, as mentioned previously, is easiest to carry out, but becomes monotonous and boring from the standpoint of the producer. Any departures from flat lighting must be executed with caution. It is necessary to "fill-in" holes and deep shadows in lighting the scene to obtain results which are pleasing from the standpoint of signal-to-noise, range, and lag.

Specular or mirror reflections can be controlled by positioning of lighting and cameras or by "dull-spraying" of the surfaces responsible. Dimming is not an acceptable method of controlling scene lighting, since skin tone balance, which is the key to good performance, is very susceptible to changes in illuminant color temperature. Changes in scene lighting are generally provided by changing the total number of fixtures illuminating the set. Where skin tones are not involved, some liberty can be taken in dimming or fading.

Outdoor Broadcast Pickup

When color cameras view outdoor scenes, such as football and baseball games and other outdoor events, the subject matter and the illumination on the scene are no longer under the direct control of the broadcaster. Thus, for example, in the sunlight and in the shadows the incident illumination can vary 10 to 1, thereby increasing the effective scene range from 200 to 1 or more for a reflectance gamut of 20 to 1. In this case the broadcaster has an option of exposing for proper rendition of detail in the lowlights and compressing the highlights or adjusting for proper highlight exposure and crushing the dark portions of the scene. Fortunately, with multiple-camera pickups used in sporting events, one can attempt to provide correct exposure for a camera scene with minimal overlap into underexposed or overexposed areas.

Specular Reflections

An annoying problem frequently met in outdoor pickup is specular reflection from shiny surfaces which can effectively direct an image of a light source or the sun itself into the pickup tube. Under such conditions there will be "tailing," "puddling," or "comet-tail" effects during motion due to the fact that it is impractical in standard cameras to provide sufficient beam current to completely discharge such specular highlights. Usual practice is to provide a minimum of twice the normal peak signal reserve for beam current to take care of such specular highlights. The signals themselves, of course, are clipped electrically in the video circuits so as to avoid overload problems in transmission. New developments now underway show promise of providing relief from "comet-tail" effects by providing a very high current discharge beam during horizontal retrace time.

Low-Light Pickup

A frequent color camera problem is the case of providing satisfactory results with insufficient or minimal light on the scene. In this case one trades signal-to-noise ratio in the camera for increased sensitivity. For example, with a reduction of 6 dB in signal-to-noise ratio, an effective gain of 2 in sensitivity can be obtained. Even a factor of 4 gain in sensitivity is quite possible with acceptable signal-to-noise performance. However, at low values of scene lighting, lag on motion becomes a limiting factor in obtaining satisfactory performance. Under these conditions "bias lighting" has been used experimentally in color cameras to provide increased sensitivity with reduced differential color lag on motion. A uniform "light level" applied to the red, green, and blue photocathodes of the Plumbicon tubes so as to increase the dark current to about 8 nanoamperes provides a noteworthy improvement in build-up and decay lag performance, under low-light operating conditions.

Color TV Film Chains

It is universal American practice to use photoconductive pickup tubes in the reproduction of color film. A powerful reason for this choice is that conventional high reliability intermittent pull-down motion picture film projectors for 16 and 35 mm film transport can be used. These are generally modified to convert the 24 frames per second motion picture standard to the 60 exposure fields per second required for nominal color TV standards, using the well-known 3-2 intermittent TV motion sequence. With a 3 to 2 intermittent film pull down, one motion picture frame is scanned by three television fields and the next picture frame is scanned by two television fields. Since each field lasts 1/60 second, the five fields take exactly 5/60 seconds or 1/12 second, which is exactly the same time as required to show two motion picture frames, 2/24 or 1/12 second. Thus we have automatically the 24 frames to 60 field conversion needed for TV.

The use of photoconductive tubes with storage such as the vidicon or the Plumbicon permits nonsynchronous system operation. The projector can be driven from the nominal 60 Hz house power supply even though the color TV field frequency is slightly less than 60 Hz. There is an effective tolerance of 1/4 to 1/2 Hz in the power supply frequency before any disturbing "application bar" effects can be noticed due to the nonsynchronous operation of the projector with respect to the vertical scan rate. Experience has shown that this tolerance is entirely adequate for well-stabilized electrical power systems used in America.

In addition to 16 mm and 35 mm color film, 2 X 2 in. slides are used for program announcements, commercials, and special tests. It is standard practice to provide as many as 3 or even 4 different optical inputs into the same color TV film chain by the use of moving-mirror or fixed-prism multiplexing techniques. Any one of these sources can be selected for color transmission thereby increasing the utilization of the equipment. Practically all modern color film chains use a field lens into which the image is projected. A typical film island is shown in Fig. 68 and a schematic of an optical multiplexer arrangement is shown in Fig. 69.

Network operations rely heavily on 35 mm color films for prime time programs. The local or regional stations use 16 mm color film and it is also used for news programs.

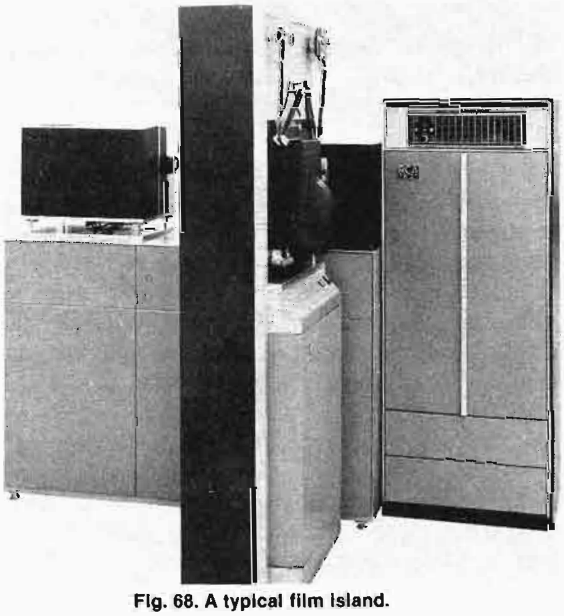

Fig. 68. A typical film island.

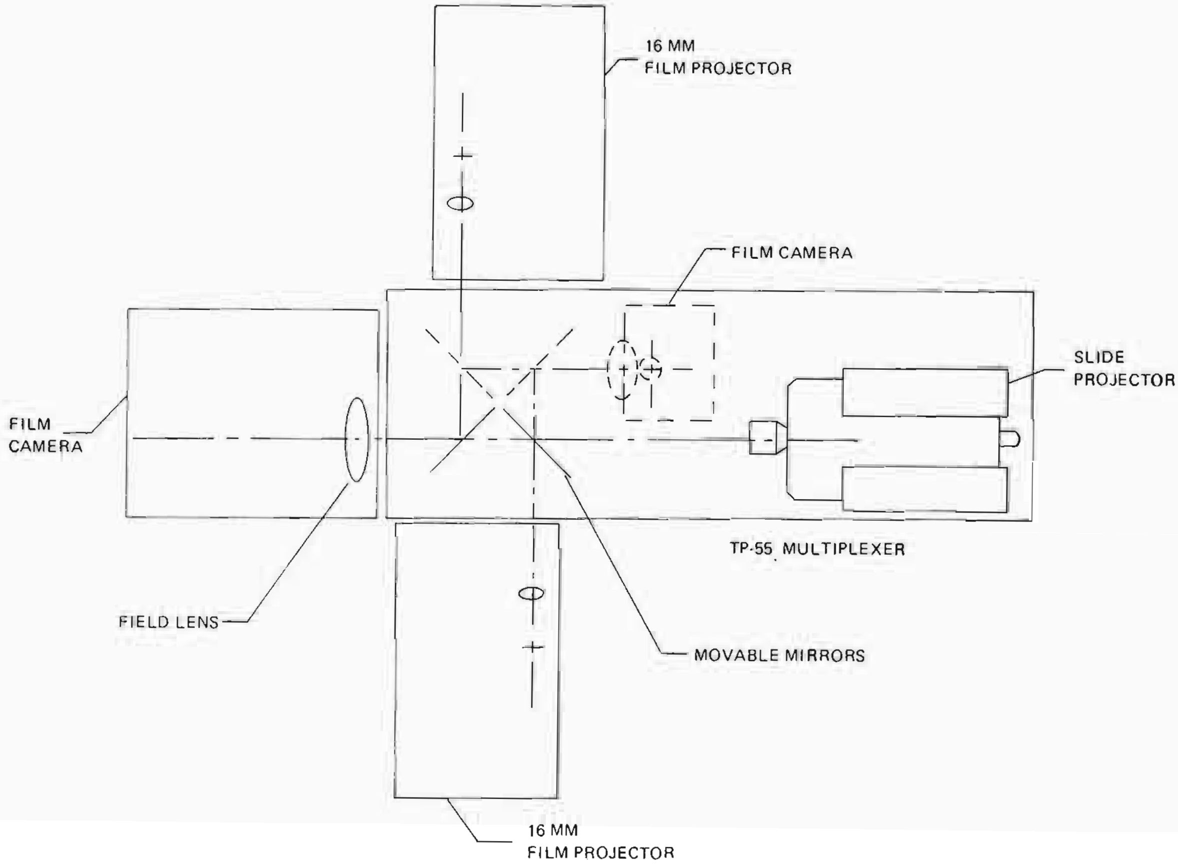

Fig. 69. Schematic of an optical multiplexer.

A recent publication titled, "Color Television" contains reprints of important color TV technical papers from the *Journal of SMPTE,* and is an important reference for the background of some of the fundamental developments in color TV theory, equipment design, and practice. It also provides a reference appendix listing current standards and recommended practices for TV and motion pictures, and a comprehensive bibliography of color television papers published in the SMPTE Journal.

COLOR TEST EQUIPMENT

The color television broadcast station relies heavily on specialized test and monitoring facilities in order to maintain adequate standards of performance and to ensure compliance with FCC regulations. In the early days of monochrome and color TV, the techniques and equipment were cumbersome and difficult to use on a routine basis. With the growth of the TV art the test signals especially developed have become more sophisticated and yield much more useful information on the performance of monochrome and color TV systems than was previously available with a series of isolated-functions measurement techniques.

A stable high-performance color monitor is an essential element of color test equipment. This, together with a vectorscope and a standard color bar generator for set-up and calibration, serves as a means of evaluating performance.

The color monitor, vectorscope, and color bar generator find utilization in rapid routine day-to-day check of the television system adjustments.

Additional test equipment needed for color TV performance evaluation falls into two categories: (1) equipment to evaluate studio performance and (2) equipment to evaluate microwave relay and transmitter performance.

The important electrical characteristics to be measured in either category are:

1. Linearity or differential gain;
2. Frequency response and differential phase performance;
3. Group delay characteristic;
4. Low frequency square-wave response.

Evolutionary developments have followed the requirement that specific test waveforms be made available which are compatible with normal television signal systems and can be introduced easily without disabling or upsetting normal operating conditions. Measurements of such test waveforms after passing through selected portions of the equipment or the complete system under evaluation will give the required differential gain, phase and group delay information.

Stair-Step Generator

A modulated stair-step generator waveform is shown in Fig. 70. The signal conforms to IEEE standad IEEE 206. It consists of five 20-IRE-unit risers with subcarrier modulation on each transition. The amplitude-linearity or differential gain response of an amplifier can be determined directly from oscilloscope measurements of the output wave display. By the use of a high-pass filter the differential gain characteristic can be displayed more graphically (Fig. 71, input); (Fig. 72, output) showing appreciable distortion. Differential phase measurements can be obtained by comparison of the subcarrier phase at each discrete level with phase of the color burst. Various oscillographic display techniques for precision phase measurements are available.

Sine-Squared Pulse and Bar

A second specialized waveform which is rapidly gaining popularity in color TV testing is the sine-squared pulse and bar with chrominance subcarrier modulation as shown in Fig. 73. It evolved from the monochrome sine-squared pulse and bar shown in Fig. 74. Use of this color test signal shows presence of differential gain distortions as in Fig. 75 and delay distortions as shown in Fig. 76. Operationally the elegance of the method is in the direct-display presentation where distortion limits may be checked by reticle overlay techniques.

Another frequently used waveform is the multi-burst signal, Fig. 77, which provides a series of selected frequency, constant-amplitude sine-wave electrical bursts of 0.5 MHz, 1, 2, 3, and 4 MHz at a horizontal line repetition rate. This, as in Fig. 78, is useful for check of amplifier and system frequency response. In principle it does not completely replace the continuous video

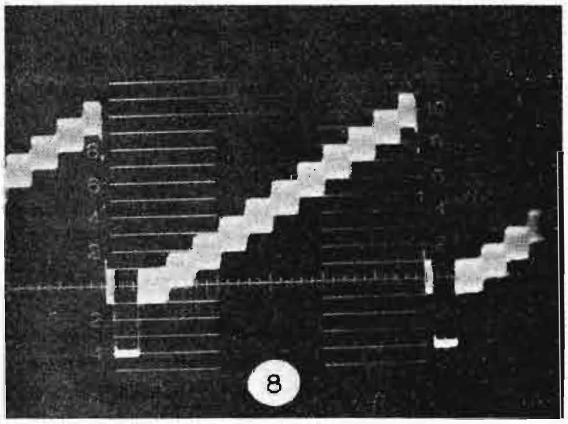

Fig. 70. Modulated stair-step generator waveform. (Picture courtesy of Marconi Instruments, Division of English Electric Corp.)

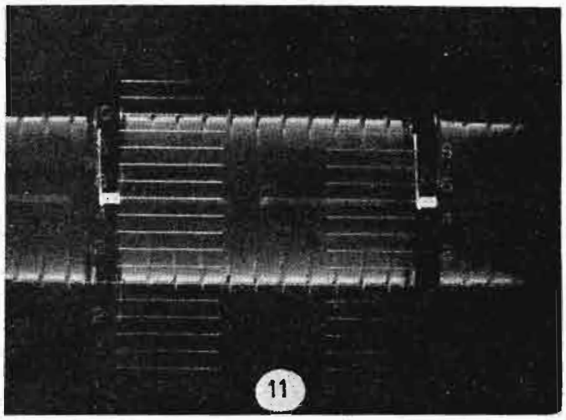

Fig. 71. High pass filter output with modulated stair-step waveform input. (Picture courtesy of Marconi Instruments, Division of English Electric Corp.)

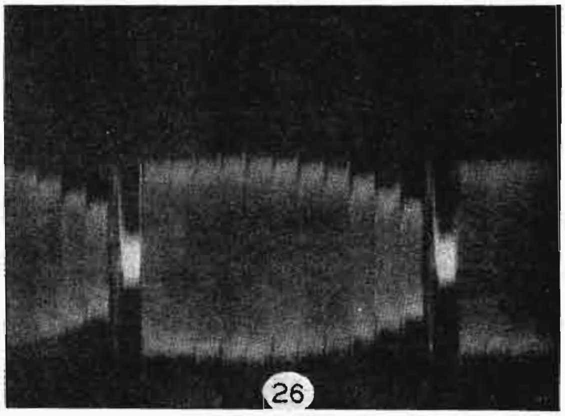

Fig. 72. High pass filter output of modulated stair-step waveform showing large amount of differential gain error in amplifier under test. (Picture courtesy of Marconi Instruments, Division of English Electric Corp.)

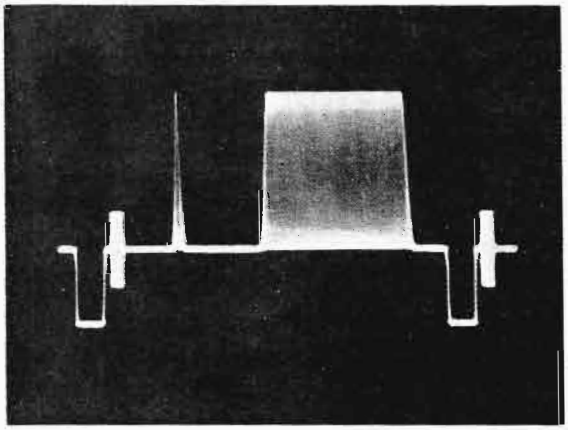

Fig. 73. Combined luminance and chrominance sine-squared pulse and bar. (Picture courtesy of Marconi Instruments, Division of English Electric Corp.)

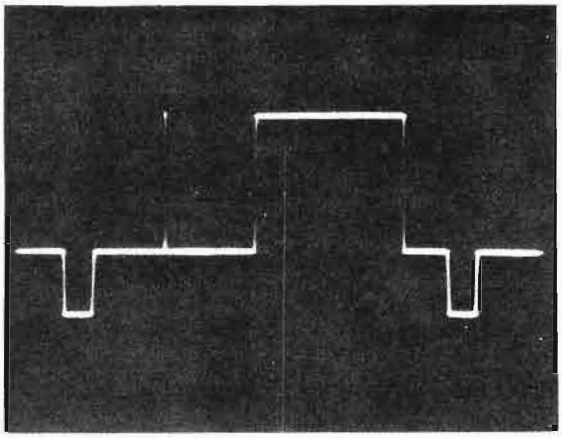

Fig. 74. Monochrome sine-squared pulse and bar. (Picture courtesy of Marconi Instruments, Division of English Electric Corp.)

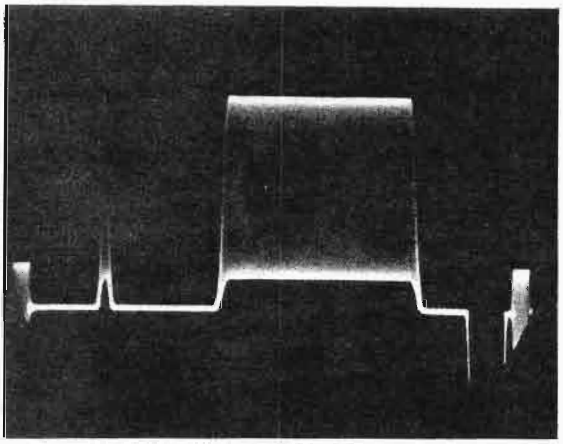

Fig. 75. Gain inequality indicated by combined luminance and chrominance sine-squared pulse and bar. Compare with waveforms of Fig. 73. (Picture courtesy of Marconi Instruments, Division of English Electric Corp.)

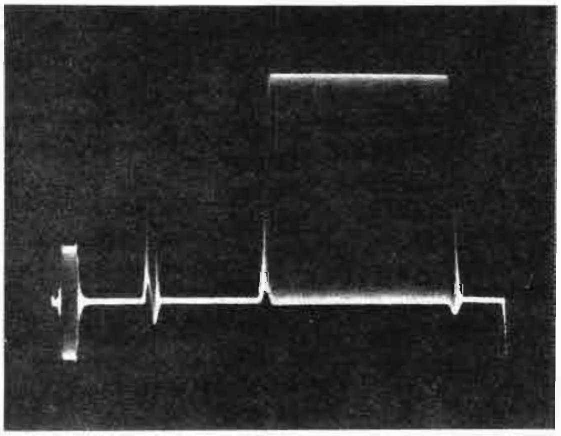

Fig. 76. Delay inequality indicated by the combined luminance and chrominance sine-squared pulse and bar. Compare with waveforms of Fig. 73. (Picture courtesy of Marconi Instruments, Division of English Electric Corp.)

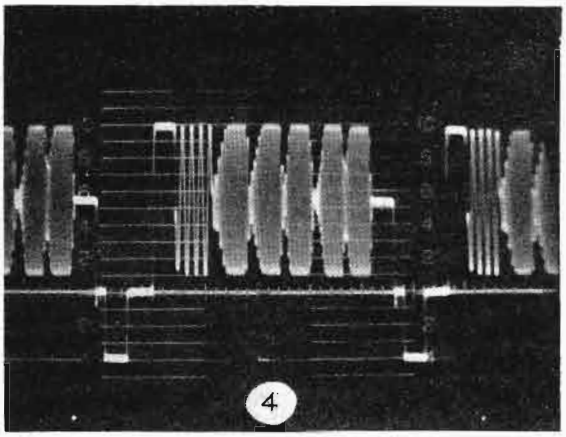

Fig. 77. Multiburst test signal with burst at 0.5 MHz, 1, 2, 3, and 4 MHz. (Picture courtesy of Marconi Instruments, Division of English Electric Corp.)

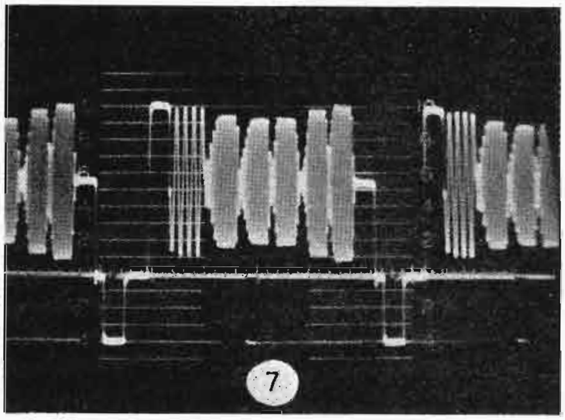

Fig. 78. Multiburst output signal from amplifier having distortion. Compare with Fig. 77. (Picture courtesy of Marconi Instruments, Division of English Electric Corp.)

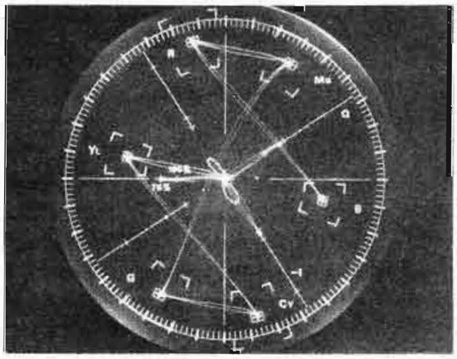

Fig. 79. Vector display. Split field color bars 75 percent amplitude 100 percent white reference, 10 percent set up. Conforms to EIA specification RS 189. (Picture courtesy of Tektronix, Inc.)

sweep signals which sequentially sample all frequencies in the video pass band. However, it is more convenient to use and to interpret in routine frequency response tests of broadcast equipment.

Vectorscope

The vectorscope[8] is a measurement instrument developed especially for color TV system test and monitoring. Its essential feature is the polar or vectorial display of chrominance information in which the radial deflection is proportional to saturation of a color and the angular position is equal to the phase angle of that color subcarrier with respect to the color burst. The 360° polar coordinate display corresponds to a complete cycle of color subcarrier or 280 nanoseconds in a time display. By convention, the color burst is normalized at 180°. If the color bar signal described in Fig. 64 and Fig. 66 is applied to the input to the vectorscope and the burst is normalized at 180°, the display shown in Fig. 79 is obtained on the graticule.

It is noted that for standard signal levels each color vector in the color bar sequence falls within its appropriately marked box on the graticule. The outer boxes define the FCC maximum permissible errors of $\pm$ 10° in phase and $\pm$20 percent in amplitude. The inner boxes correspond to $\pm$2.5° phase error and 2.5 percent amplitude error.

A feature of the vectorscope color bar technique is that it gives immediate reassurance on system performance with a color bar test signal display.

By alternating two signal sources at the input, one can obtain direct readings on differential phase and amplitude behavior of any selected picture sources.

Vertical Interval Reference and Test Signals

A development which has important long-range possibilities is the use of a special signal transmitted in a specific line of the vertical blanking interval. The Vertical Interval Reference "VIR" signal, consists of a chrominance bar having the same phase as color burst, together with an appropriate luminance pulse and a black level interval. The Vertical Interval Reference signal is added to the main video signal and is in fact a certification that at the time it is added all conditions are normal. If various distortions occur to this Vertical Interval Reference, it can be corrected, with the expectation that the main signal will also be corrected. Thus more rigorous control and compensation of system errors is possible. A "VIT" or Vertical Interval Test signal is used to verify transmission conditions using multiburst, sine-squared or stair-step test signals. Such signals can be used for continuous monitoring of TV system performance, and in the future will probably find application in automatic control or correction of color system performance.

Test Charts

There are available several pictorial charts which serve to optically generate special test signals useful for color camera alignment and system adjustment. These were developed by industry technical commitees and are available as opaques from EIA[9] or from equipment manufacturers for live cameras and as 2 X 2 in. slides from SMPTE for color TV film chains.

They are:

EIA Resolution Chart,
EIA Linear Gray Scale Chart,
EIA Logarithmic Gray Scale,
EIA Registration Chart,
RCA Multiburst Chart,
SMPTE Resolution Slide,
Registration Slide,
Linearity Slide.

The development of TV test signals and facilities is one which continually strives to increase the information to be obtained on systems performance, preferably on a continuous basis and without taking the system out of service. The "VITS" and "VIPS" concepts appear capable of providing a major step forward in test and measuring techniques.

[8]Tektronics Model 520 vectorscope is widely used for these measurements.

[9]EIA—Electronic Industries Association.

24

Planning and Costing of Radio and Television Facilities

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The information to follow should be used for general planning and cost estimating of facilities. Many factors determine the initial budget, as well as final cost figures at the time of actual completion. Proper planning and project coordination by the owner's representative is mandatory if a well-built, cost-effective facility is to be produced, by the date required. During nearly 30 years' experience, the writer has been involved with numerous large and small broadcast facility projects, all having one major thing in common: the fact that time begins to run out before you are really finished. This may not actually be so bad, as otherwise, what else could ever stop the additional requests and change-orders that keep on coming—broadcast personnel being what they are?

GENERAL PLANNING CONSIDERATIONS

The early planning of a broadcast facility usually involves a number of factors such as: consideration of the market to be served; site selection; radiated power; tower height; station policies; personnel; programming; hours of operation; and available capital. First and foremost of the decisions to be reached is whether the studio and transmitter are to be combined under one roof or are they to be in separate locations.

In the past few years there has been a trend toward combining the studio and transmitter rather than housing them in separate facilities. However, with the advent of remote control, there is a movement once again to separate the studio and transmitter.

It is generally agreed that wherever practical it is most economical to combine the studio and transmitter. The initial equipment requirements are less, but more important is the fact that the day-to-day operating expenses are lower. With the plant "all under one roof" there are savings in heating, air conditioning, building maintenance, travel time, and personnel. A combined operation, however, is not always possible.

When a combined operation is not practical, the second approach is of course to operate the transmitter by remote control from the studio. By utilizing remote control, a transmitter site can be selected that is most advantageous from a coverage standpoint, and the studio can then be placed in the most convenient location. The building requirements at the transmitter can be the very minimum, requiring only space for the equipment, a small work area, and a small heating unit. The studio then could contain both the programming and business functions.

Facility Planning

The initial step in station planning is to develop an outline of requirements that will form the basis upon which future decisions are made. Such an outline for broadcast facility planning may be developed as follows:

OUTLINE FOR BROADCASTING FACILITY PLANNING

1. Site Selection

a. Adequate space for immediate building needs plus anticipated expansion.

b. Adequate parking space for employees, guests, and studio audience (if latter is being considered).

c. Trucking access and adequate loading area—loading dock, if possible.

d. Accessibility from high speed or uncongested roads (mobile units, audience, convenience of employees).

e. Transmission—tower space or line-of-sight for microwave.

f. Zoning—use of towers, antennas, identification or advertising signs.

[1]Formerly Vice President of Engineering and Facilities, Metromedia, Inc.

g. Possible use of helicopters for news and traffic reporting.

h. Relation of site to environmental elements: (i) noise, (ii) weather, (iii) drainage.

2. Building Program (Space Arrangement)

a. Proper flow and/or separation of studios, related technical spaces, craft shops and storage, programming and engineering, talent and dressing, administrative offices and mobile units.

b. Entrance arrangements for employees, guests, VIPs, and audience.

c. Relation of studios to loading areas.

d. Relation of parking areas to employee and audience entrances.

e. Security—inside, outside.

3. Building Construction

a. Selection of structural system, taking into account local conditions, codes, availability of materials, flexibility for future changes, special loading conditions and spans, degree of fire resistance and effect on fire insurance rates. Careful study of fire code requirements.

b. Partitioning—types to afford relatively good sound isolation, yet flexible enough for ease of removal or relocation. Better to make rooms larger in beginning and subdivide later if necessary.

c. Ceilings—high degree of accessibility for multitude of communications wiring; good acoustical value; cleanability, ease of electronic repairs.

d. Wall materials—extreme durability in technical and production areas, due to frequent moving of equipment and supplies.

e. Floor materials—durable yet resistant to traffic sounds. (*Note:* Floor slabs for TV studios must be extremely level for proper camera movement.)

4. Engineering

a. Availability of incoming HV power service.

b. Separate unit substations for: (i) air-conditioning, air handling and other facility motor loads, (ii) general illumination, (iii) studio production lighting, (iv) technical loads.

c. Lighting in general—fluorescent, 100-foot candles in working areas, dimmer controlled incandescent in control rooms.

d. Studio production lighting system—dimmer racks, patch panels, control consoles, etc.

e. Cable trays—master control to studio control, studios, computer suite, etc.

f. Emergency generator to handle essential loads when normal power fails.

g. Miscellaneous systems—telephone (technical and commercial), public address, watchman's tour, door security, closed circuit TV and fire alarm.

h. Air conditioning—heavy studio loads (TV), low velocity for sound control, stand-by AC for master control rooms, separate exhaust system (air purging) for TV studios.

i. Compressed air system for video tape machines—cleaning, painting, etc.

5. Acoustics

a. Sound isolation within areas.

b. Sound transfer from area to area.

c. Quality of sound within spaces (room acoustics).

d. Special doors, viewing windows, wall, floor and ceiling treatments.

e. Low-velocity air and duct linings, sound traps.

f. Isolators for machinery and piping.

6. Security

a. Control of audiences (where received).

b. Control of all points of entry.

c. Closed circuit TV systems, watchman's tours.

d. Electrified gates and doors.

e. Separation of 9:00-5:00 areas from 24-hr. areas.

f. Night lighting.

AM/FM STUDIO FACILITIES[2] EQUIPMENT PLANNING

While the technical equipment required for an AM or FM radio facility is determined basically by station size, layout and programming, it should be remembered that the operating flexibility of the station depends to a great extent on the equipment selected.

An extra measure of versatility in the studio equipment may greatly promote program speed, accuracy and creativity, enhancing the station's audience and advertiser interest. Certainly, the transmitter plant with the highest efficiency and reliability will place the strongest and most consistent signal where the people are. More than just economy, therefore, each piece of equipment should offer all the added benefits of value and performance that modern technology allows.

Too many times the costly assumption is made that all broadcast equipments, if FCC type-approved, are basically the same "under the hood." So, all you have to do is to find the supplier with the lowest price. Several mismatched units and thousands of dollars later, however,

[2]Source material Radio Corporation of America.

price is very often found to be closely related to the quality and reliability of components, as well as the attention and service that can be expected from the manufacturer after the sale.

Audio Equipment

Since no two broadcast stations have the same operating requirements, the selection and arrangement of microphones, audio tape systems, turntables, consolettes, amplifiers and other equipment will differ for each installation. Many stations choose to have their control equipment tailor-made to the station's requirements.

Control Consoles

Usually the most important reason for the addition or replacement of a control console or consolette is the need for more input channels. This can be brought about by the addition of a new studio (and thus additional microphones) or by adding FM stereo facilities. It is convenient to be able to leave telephone lines connected to the "board," and thus as the number of remote programs increase, the telephone input requirements will increase. A consolette may also be added to a station in order to increase the flexibility of recording facilities. Many stations use a small board in a "production" control room where they make commercials and station promotion recordings. Another requirement for the addition of a small audio consolette is for the remote pickup of programs such as at sporting events, auditoriums, churches and nightclubs. In general, as a station increases its program variety and flexibility, its requirement for audio input facilities also increase.

Consolettes of the highest quality employ computer grade components throughout. In these equipments, components are selected for their long life and dependability. For example, the best consolettes use telephone type switches for their superiority over wafer types, and step attenuators rather than carbon pots. They are fully transistorized using the most advanced state-of-the-art circuitry. Plug-in modular design provides complete accessibility with interchangeability of subassemblies and quick, convenient servicing. Reliability of equipment is a priceless ingredient in the design of today's successful broadcast system in view of the increasing shortage of competent technical maintenance personnel.

Custom Audio Equipment

In addition to offering a comprehensive line of standard audio control equipment, leading equipment manufacturers specialize in custom designing and building complete speech input systems to meet individual needs of stations and networks. Their engineers have worked closely with the nation's leading broadcast engineers in the design, production and installation of many custom equipments. Studio control systems such as these are tailor-made, combining just the right facilities for the control of program operations and the reproduction of high-fidelity sound. This custom service is not limited to large stations and networks, it is available to everyone. Broadcast station engineers, in some cases, may wish to lay out and design the system themselves. In these instances, specifically built units or modified standard items can be supplied to meet these specifications. Or, as some stations may desire, a study of station requirements can be made with detailed layouts and specifications drawn up for the equipment needed.

Tape Recorders

Program material on magnetic tape provides extra flexibility in scheduling, simplifies program operations and reduces the cost of program production. Modern stations utilize every possibility offered by the medium—mono or stereo, cartridge and reel-to-reel, 2-track and 4-track stereo, manual and automatic equipment. Cartridge tape systems permit the immediate playback of recordings without cueing and threading. They provide precision timing of program segments, and the program material will be exactly the same every time a passage is repeated. They offer the most convenient storage medium and the quickest and easiest access to selected segments of material. The system of cue tones makes the equipment readily adaptable to automatic or semi-automatic systems. Multi-cartridge tape systems, designed essentially for the heavy traffic station, reduce the load on operating personnel by automatically handling a series of short (or long) program segments through start/stop and audio switching sequences in rapid errorless succession. Two hours of material can be programmed with one multi-cartridge unit, which can be teamed with as many other units as needed. Tape systems may be remotely controlled.

Reel-to-reel tape machines, on the other hand, take full advantage of the editing ease and speed that tape offers. Reel-to-reel machines can operate at various speeds so that the material can be tailored to program needs. Super thin tapes can be used to permit hours of programming on a single reel, and the equipment features portability for interviews and news stories. Manually operated and self-cueing versions are available.

Signal Processing Equipment

Audio signal processing equipment is available to automatically control audio peak and average levels into the transmitter, as required, to prevent overmodulation with consequent adjacent channel interference or even possible damage to the transmitter.

Automatic gain control (AGC) amplifiers, with their slower attack and recovery times, are used in control rooms and studios to maintain a constant average audio level. Peak limiters, with their faster attack times are normally used at the input of the transmitter because of their ability to limit the amplitude of high speed transient peaks.

In FM, however, a 75 μ sec pre-emphasis network normally installed at the transmitter input produces a high-frequency boost which tends to cause overmodulation. This overmodulation can be prevented by high-frequency rolloff, or by peak *clipping* after pre-emphasis or by a combination of both. Peak *limiting* after pre-emphasis is not usually desirable because the high frequency peaks will cause a serious reduction in gain and consequent lowering of the average modulation level. High-frequency rolloff, too, is obviously undesirable because of the degradation of the received signal. Peak clipping is the recommended method since it provides absolute protection against overmodulation without reducing signal gain and with no audible degradation of the signal. Signal processing units are used in tandem for stereo.

Tape Automation Systems

An audio tape programmer combining solid state and relay switching is available to automatically program multievent sequences from several different tape systems with an absolute minimum of attention from station personnel.

For use with both monaural and stereo systems, the device is designed to select from several audio sources and sequence them in any preset pattern as consecutive events. It is particularly advantageous to stations requiring separate programming for AM and FM. The operator who may be handling both programs can preset the system to sequence the FM events during times when live broadcasts or program changes must be made on AM.

Microphones[3]

Careful thought should go into the selection of type and quality of microphones for AM and FM facilities. Too often the microphones selected do not complement the quality of other equipment. This can seriously impair overall performance.

There is considerable overlap in the uses of available broadcast microphones, of the many types, but each has attributes for specific applications. High quality broadcast-type microphones have performance features that make them ideal for AM and FM use, such as smooth frequency response over the audio range, low distortion, high output levels, and well shielded (and sometimes shockmounted) output transformers to prevent hum and noise pickup. Certain types have selectable directional patterns useful in high noise areas. Public address microphones, on the other hand, are designed to offer additional economy. Frequency range and sensitivity are sacrificed to some extent for ruggedness and lower cost. Response limitations should always be considered when these microphones are used for broadcast applications.

[3]See separate section at the end of this chapter entitled "Microphones: Their Application and Operation."

RADIO STUDIOS—ON A LOW BUDGET

Considerations Involved in Building an AM or FM Station with Less Than an Optimum Budget

It would be easy to apply one set of standards for the construction of radio station facilities everywhere in the country. Unfortunately, the difference in cashflow of a 50,000-watt clear channel in a major market and a 250-watt daytime or Class A FM in a rural area dictate that the small market station is going to be quite different than its big city counterpart. In most cases, the selection of a studio site in a small market is dictated by what it costs to get the space. It is not unusual for space to be traded out in part or in full for advertising.

In many cases, the chief engineer will be presented with an existing suite of offices, a store front or even an older house that must be converted to a studio. The first thing to do in this situation is call a meeting of management, sales, and programming to see what they expect of the facility. If it is a typical small market station, it will fall within the following requirements.

1. Record shows—combo operation. Announcer playing records, taped commercials.
2. Direct airplay or recording beeper reports for later use in newscasts, farm reports, high school news.
3. Facility for picking up remotes from high school or college athletic events, church remotes.
4. Capacity of recording and dubbing commercials for later airplay.
5. Capacity for originating a live music program from your studio. (Quite often a church

will use a studio to do a small service rather than invest in phone lines and remote equipment!)

6. Delayed programming such as a telephone talk, call in forum or swap shop show.

7. Remote off-air pickup of other AM and FM stations for rebroadcasting regional networks.

8. Remote pickup of mobile units and portable transmitters for news actualities and other events.

If the station is a new or growing operation and cannot afford the equipment to do all of the above, at least consider what functions may be required at a future date. For this reason plan now for what might be needed in two years.

Physical Layout

This will depend largely on what is available. The bare bones minimum control room known to be used was 6 ft. wide by 7 ft. deep. There was barely enough room for an operator, two turntables, cartridge machines, and a console. *It worked.*

The operation was well constructed, well maintained and well utilized. The technical quality of the programming was as good as many large operations in major markets, so it can be accomplished *with small space.*

When laying out studio location, do the following:

1. Draw a sketch of the available floor space and existing walls.

2. Make a number of copies of this floor plan and start drawing in studios, offices, reception areas and the like. Make three or four.

3. The first items you want to place are the main studio and control room. In smaller operations these are one and the same. Naturally they must be quiet, so keep them away from noisy areas such as underneath heavily traveled stairways, air conditioners, and front windows opening on busy streets. The control room floor should be very solid. The most desirable material to use if you are building a studio is reinforced concrete. If you are stuck with a wooden floor try and select a location that does not bounce. People walking on such a floor will cause the floor to move. This motion is transmitted to the turntable cabinet to the tone arm where it is picked up and sent over the air. In extreme cases, a heavy person can cause the needle to jump out of the groove. Sandbags or bricks in the base of the turntable cabinet will sometimes improve a bad situation.

Another item that will determine placement of the control room is visibility of the meters on the transmitter and its associated monitoring equipment. FCC rules and regulations have recently changed regarding this requirement and undoubtedly will change in the future. Check the rules before you build. If you are fortunate enough to be putting in your own walls, stay away from designing perfectly square rooms. A room that is 8 by 8 by 8 ft. is going to have a very definite resonance. Strive for 6 by 8 by 10 ft. or dimensions in this proportion. Sound locks while desirable are not essential. Doors of solid construction with weatherstripping can be used effectively.

4. Measure some typical office furniture and cut out cardboard desks, file cabinets, counter tops and record cabinets to scale. Put in your furniture and see how it fits. Is there room for people to move around? Did you leave room for doors to open and close? Remember not to have doors open out into busy hallways where people will walk into them as they pass by. Doors come in all sizes. The average door in most stations is 3 ft. wide. If you get into a space problem this can be reduced by 6 inches or even a foot. But remember that you will be moving furniture and equipment in and out of that door and you should provide room for it to go in and out and be turned once it's in the room.

The narrowest hallways should be no less than 3 ft. 6 in., preferably 4 ft. Also be aware that hallways take up space. For every square foot of hallway you eliminate you get an equal amount of space that can be used for something productive.

Equipment

In a low-budget situation remember this rule of thumb, "Is what I am about to buy going to pay for itself and make the station money?"

The purchase of a $200 directional microphone to do a one time remote broadcast when being paid only $100 for the whole job is poor business.

Use this logic when equipping the station. As mentioned earlier, create a list of those functions you will have to perform, spend only what is needed to get on the air and function. However, do plan for the future. Design around a console with enough inputs to accommodate these anticipated needs. A four potentiometer board is not enough for most operations. Even the smallest stations should have six or eight pots. A four pot board will be satisfactory today but two years later it will not. If the station is a one studio operation, how will the console be replaced while on the air? It makes good sense to purchase the proper console in the beginning.

Do not forget the patch panel. There is a growing tendency among engineers today to eliminate this important switching center. All high level inputs and outputs should appear here. Even console inputs should show up. This also applies to all recorders, tuners, and other audio sources. This practice makes for a very versatile operation and can save the embarrassment of dead air time if the console should fail. If this happens, the recorder can be patched directly to the transmitter, bypassing the defective elements in the system.

Fig. 1 shows the audio flow in a typical small market radio station with the bare essentials. This was installed at WBME-AM in Belfast, Maine. It should be considered a minimum installation. One cartridge tape machine, one reel tape, audio processing equpment and a transmitter. This system can be expanded to include other program sources as the station's needs grow.

Figs. 2 and 3 show the audio flow and physical layout of a Class C FM station designed and built by McBee Laboratories, Inc., in Topeka, Kansas. Note the versatility here. The studio can be operated through the automation system as a source. In the event of an emergency, the announcer can remotely connect the output of the console to the STL, bypassing the automation system. In the event of an STL failure, the audio can be patched directly to the transmitter via the remote control system line.

In selecting equipment for a small station, one usually considers used equipment. U.S. made broadcast equipment is built to last. It is not unusual to see transmitters in regular use after 30 years. The same can apply for consoles, amplifiers, and some other audio equipment. However, if you purchase something this old, the chances are that the manufacturer will no longer be able to supply spare parts. Most equipment suppliers will maintain spares for 20 to 25 years. Do not get the impression that spare parts are no longer made, they just are not stocked by the equipment manufacturer. In many cases, it will be necessary to seek out the item wanted from the original component manufacturer.

Special items such as modulation and plate transformers can be rebuilt or fabricated; it can be costly but it can be done.

When buying a piece of used equipment, try and get the previous owner to throw in his spare tubes and other parts. Also obtain a history of the unit and where parts can be obtained. It is also advisable to find other owners of the same type of unit.

Before purchasing anything of this nature take a long hard look at it.

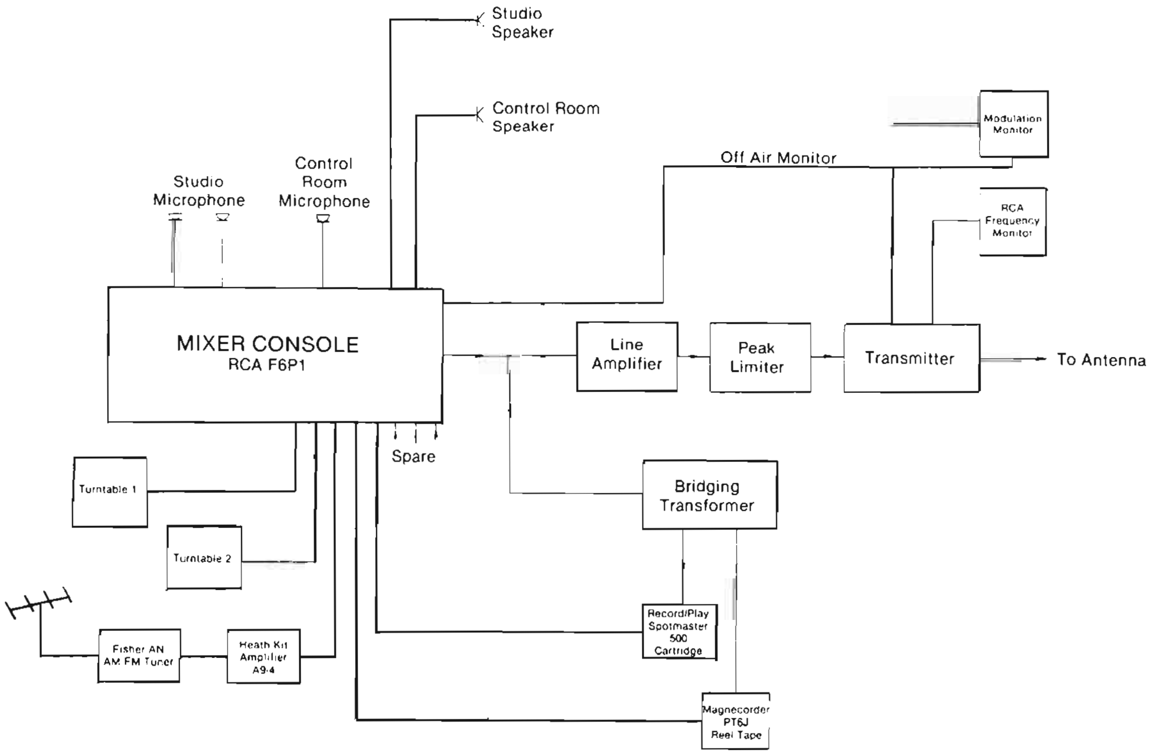


Fig. 1. Audio flow diagram from station WBME-AM.

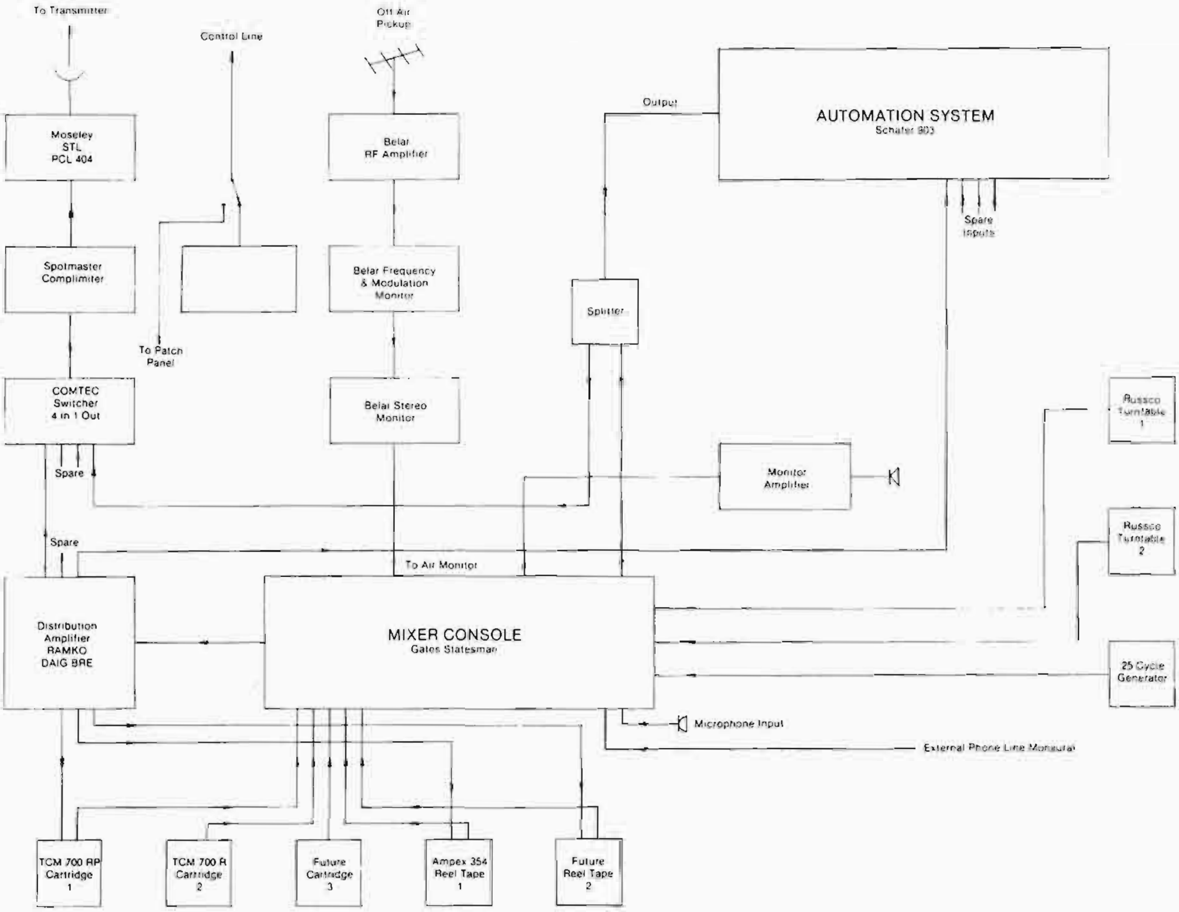


Fig. 2. Audio flow diagram from station KTPK-FM.

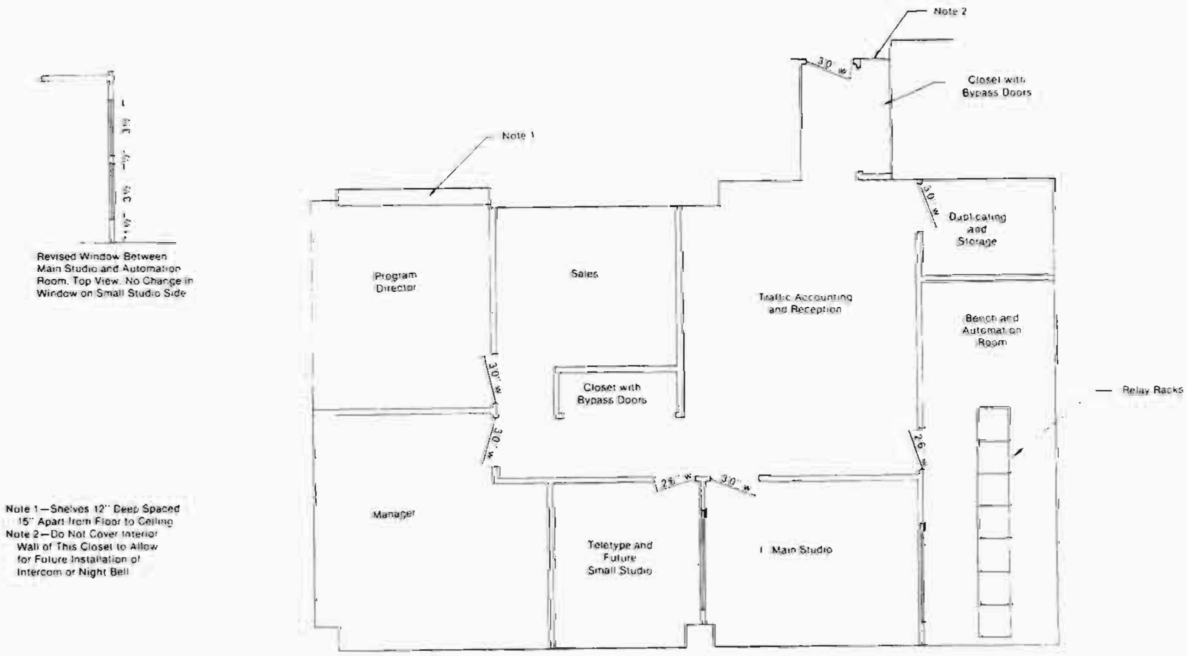


Fig. 3. Studio layout for station KTPK-FM, Topeka, Kansas.

Go through this checklist:

1. Is it clean, is there dirt on the inside of the insulators which are subject to high voltage? Does it appear that any insulators have started to break down?
2. Are any capacitors or potted transformers leaking? Look for discoloration due to heating.
3. Is the wiring brittle as though the unit has been poorly ventilated? Unit might require re-wiring.
4. Look at the tubes—are they still obtainable or will the unit require modifying to something still obtainable?
5. Is whatever you are buying still operating and if it is required, will it still meet equipment performance requirements of the FCC?
6. Is the unit still type approved or type accepted for licensing by the FCC?
7. If unit is a recorder what is condition of heads and motor? Are the belts flexible or dry and cracked? Do brakes appear worn?

Nothing will be 100 percent perfect, but if the equipment is examined carefully, it will be evident what problems to expect when putting it into operation.

It is important to remember that with used equipment there is no manufacturers guarantee and the buyer is on his own in making it work. The one consolation is that unlike much home consumer type equipment, broadcast gear is built to give many years of service and can be easily repaired.

There is yet another place to turn to for inexpensive equipment especially recorders and tuners. A broadcast type reel tape recorder costs between $900-$3,500. This is a healthy amount of money. A comparable home recorder, if connected to your system through the proper matching transformers, will give very good results for a lot less money, generally $100 to $300. Remember though that quite often these units are susceptable to RF pickup from the stations' transmitter. Also remember that many of these units have an unbalanced input or output at other than the standard 600-ohm impedance; so investigate before you buy.

This type of recorder will not last as long as the professional machine and spare parts may be difficult to obtain. When building a station, the judicious use of home high-fidelity equipment can substantially lower the cost of getting on the air.

The high-fidelity equipment store can also be a source of high quality used equipment such as equalizers, monitor amplifiers, speaker enclosures at a fraction of the cost of the same equipment from a broadcast supply house.

In conclusion, when a small market broadcast facility is under construction, it is sometimes necessary to cut costs to a minimum through the use of existing buildings not designed for that purpose. Such structures can, with minimum alterations, be made to function adequately as studios, transmitter locations, and offices.

It is possible to cut construction costs through the careful use of selected home high-fidelity products and used broadcast equipment. The reliability and life expectancy of the resulting installation will be less, but in many locations this is justified by the lower cost.

As mentioned previously in some instances, the licensee either has an available structure or wishes to take advantage of an existing structure to use as the nucleus of his broadcase facility. In such cases, the existing structure is usually a house or a desirable piece of property that can be easily expanded or converted into the studio/transmitter building.

An excellent example of this concept is station WNHV, White River Junction, Vermont, that expanded upon an existing building to develop a very efficient and workable broadcast facility. Fig. 4 depicts the changes which were made to the existing building with the resulting added floor space.

The nucleus of this building was a nondescript, small house which was ultimately camouflaged behind additions and beneath new materials. Much attention was given to sound conduction, natural and artificial lighting, and controlled ventilation. Aluminum was used extensively throughout in conformance to the licensees needs. The modification added a total of 1,120 sq. ft., compared to 864 sq. ft. in the existing structure.

Fig. 5 is a photograph showing the addition to the original structure. Note roof peak of old original house in the background.

The News, Broadcast and Production studios are depicted in Figs. 6, 7, and 8 and contain the following equipment:

News Studio

1 reel-to-reel deck;
1 four-channel board;
1 recording cartridge machine.

Broadcast Studio

2 12-in. turntables;
1 8-channel board;
3 playback cartridge machines;
1 control rack to meter and control transmitters and monitor modulation.

Production Studio

2 12-in. turntables;
1 5-channel board;
1 reel-to-reel deck;
1 playback cartridge machine;
1 recording cartridge machine.

Fig. 4. Additions and alterations to WNHV radio station, White River Junction, Vermont.

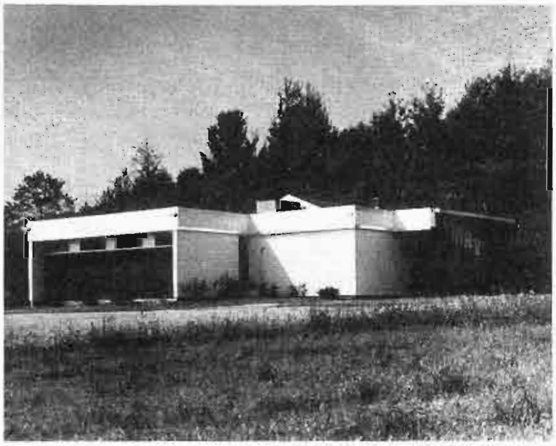


Fig. 5. View of remodeled station, WNHV in Vermont.

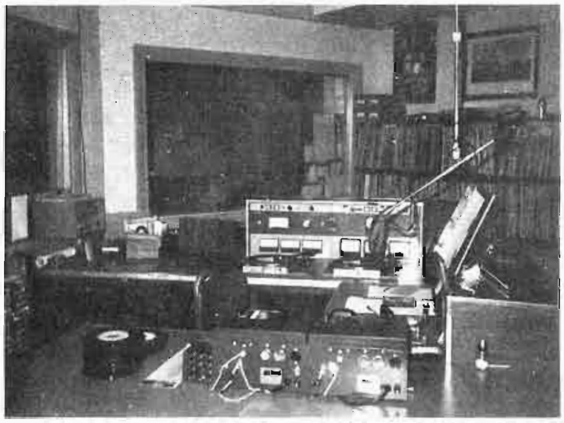


Fig. 7. Broadcast control room and announcing studio.

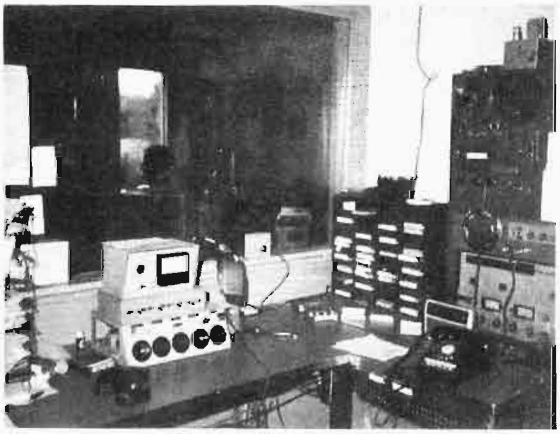


Fig. 6. News studio.

Fig. 8. Production studio.

BUILDING PLANS[3]

One of the prime requisites for a successful broadcast station is the careful layout of studio, production, and administrative areas to achieve maximum effectiveness of space and personnel. The following are four typical layouts depicting a small market minimum staff facility to an arrangement suitable for a large metropolitan operation employing a full complement of personnel. Each floor plan is handled differently according to the needs of different size stations.

Control room, studio, and production facilities for each station are in a centrally located CORE AREA. The suggested sizes of these areas should be considered as minimum from an operating standpoint with normal equipment complement. The layouts are presented as a guide for planning a modern, functional radio facility with considerations given to size of market, staff and programming requirements.

Plan One

With approximately 1,800 sq. ft., this floor plan provides adequate space for the small AM or FM station with a minimum staff. Since smaller staffs have several responsibilities, partitioned general office space is omitted in favor of a large news, transcription storage, and general-use area at the rear of the building.

The transmitter or workshop area is next to the control room, with a window recommended for a clear view of the transmitter meters. Alternate CORE AREA layouts are shown.

The building is of brick and plaster fascia, and includes a glass curtain wall. The building price will vary considerably depending on area construction costs; but a typical figure is $36,000. (See Fig. 9.)

Plan Two

In medium size stations, office space requirements for sales, promotion, and programming activities exceed the need for a substantially larger technical CORE AREA. This floor plan expands the "small station" layout to approximately 2,500 sq. ft., providing more room for the sales staff and clerical help, and an impressive office for the general manager. Studio and control room space is slightly larger in anticipation of more equipment and activities in these areas. The news director, transcription library, and chief enginner gain office space. Alternate CORE AREA layouts may be employed, and a few suggestions are indicated.

The building includes brick walls, weathering steel columns, and fascia, with dark glass entrance and glazing strips. Cost is approximately $55,000, but may vary considerably, depending on construction costs in your area. (See Fig. 10.)

Plan Three

In Plan 3, the technical CORE AREA is adequate for two full-size control rooms, each with a large associated studio. Control rooms are separated by the transmitter, automation, or workshop area. This floor plan includes approximately 3,150 sq. ft. and is suggested for stations planning both AM and FM operations. Additional office space is also allocated for the larger staff in this station. See alternate CORE AREA floor plans for additional layout ideas.

The mirror glass curtain wall building is set in a reflecting pool and costs approximately $70,000. *Note:* building cost may vary greatly, depending on the area in which it is built. (See Fig. 11.)

Plan Four

This 4,300 sq. ft. studio/office complex is an impressive broadcast center. Of primary importance is the location of all control room and studio space in the center of the building, eliminating the problem of outside traffic noise in a metropolitan area.

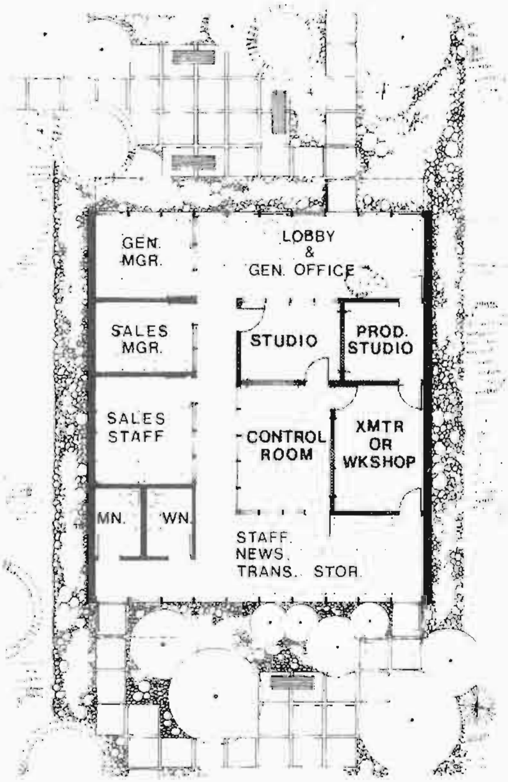
Operating personnel are assigned to the rear office areas, and the news room is strategically located near the control rooms and an outside exit to the newsmobiles.

The building is of exposed concrete, with a dark glass curtain wall. Building price is approximately $90,000, but may vary greatly from area to area, depending on material and labor costs. (See Fig. 12.)

CONTROL ROOM ANNOUNCE BOOTH DESIGN

Many present-day radio control rooms are not only used for this purpose but also act as announce booths where most of a station's announcing is carried on. In many cases the control room may be the only studio area in a station, and it will contain all the audio equipment of the station. Frequently, a transmitter and record library will also be located in the control room. This makes the problem of acoustics

[4]Plans courtesy of Harris Corporation, Quincy, Ill.
In the following plans, transmitting and antenna equipment are not listed since they vary with power and pattern.



SMALL MARKET MINIMUM STAFF

Fig. 9. Small size AM station equipment list (Plan One).

Studio equipment (monophonic):

1	8-Mixer Console, mono
2	12" Turntable
2	Integrated Circuit Equalized Preamplifier, mono
2	12" Tone Arm
2	Stereo Cartridges (Outputs connect in parallel for monaural operation)
3	8'' Loudspeaker
3	Speaker Matching Transformer
3	Wall cabinets for Speaker
1	Cardioid Microphone
2	Dynamic Omnidirectional Microphones
1	Boom Stand
1	Desk Stand
1	Clamp-on Mike Stand
4	Wall Receptacles for Microphone
4	Microphone Plugs
4	Connectors
100'	2-Conductor #20 Microphone Cable, jacketed
500'	Shielded Miniature Audio Cable
1	Headphone
1	Phone Plug for Headphone
2	Studio Clocks

Studio equipment options (stereophonic)

1	Stereo Console
2	Stereo Equalized Preamplifier

Remote Broadcast Equipment:

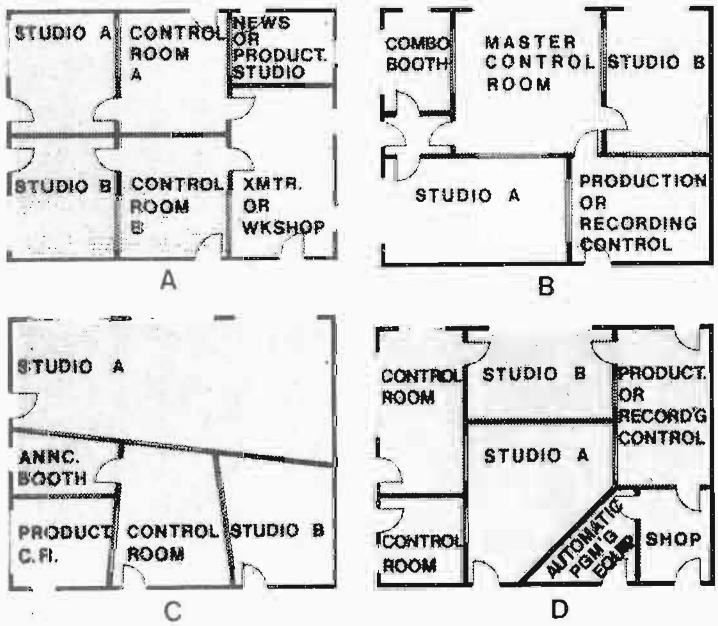
1	4-mixer Transistor Amplifier, Less Batteries
1	Battery Kit
1	Headphone
1	Plug for Headphone
1	Dynamic Microphone with 18 Ft. Cable
1	Plug for Microphone

Tape Recording Equipment:

1	Half-Track Portable Tape Recorder, 7½'' per sec.
2	Cartridge Playback, mono
1	Recording Amplifier for above, mono
24	Cartridges, 40 Sec.
24	Cartridges, 70 Sec.

Remote Control Equipment for Unattended Operation:

1	Remote Control System for unattended operation
1	RF Amplifier with Antenna
1	Rack Cabinet



alternate "core area" plans

MEDIUM MARKET NORMAL STAFF

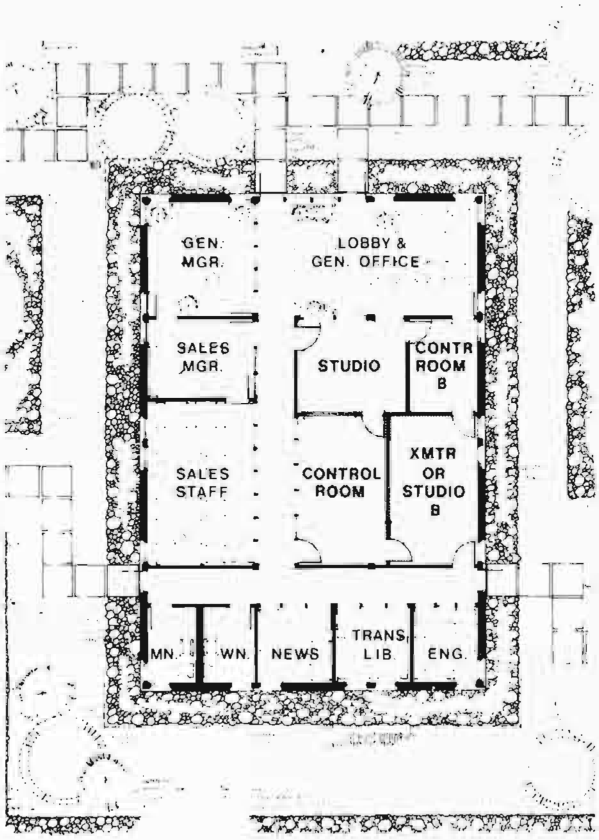


Fig. 10. Medium Size AM Station Equipment List (Plan Two).

Studio Equipment:

1	8-Mixer Console, Monaural
2	12'' Turntables
2	Integrated Circuit Turntable Preamplifier
2	12'' Tone Arm
2	Stereo Cartridge (Outputs connected in parallel for monaural operation)
3	8'' PM Type Loudspeaker
3	Speaker Matching Transformers
3	Wall Cabinets for Speakers
1	Cardioid Microphone
2	Dynamic Omnidirectional Microphones
1	Boom Stand
1	Desk Stand
1	Clamp-on Mike Stand
4	Wall Receptacles for Microphone
4	Microphone Plugs
4	Connectors
100'	2-Conductor #20 Microphone Cable, Jacketed
500'	Shielded Miniature Audio Cable
1	Headphone
1	Phone Plug for Headphone
2	Studio Clocks.

Remote Broadcast Equipment:

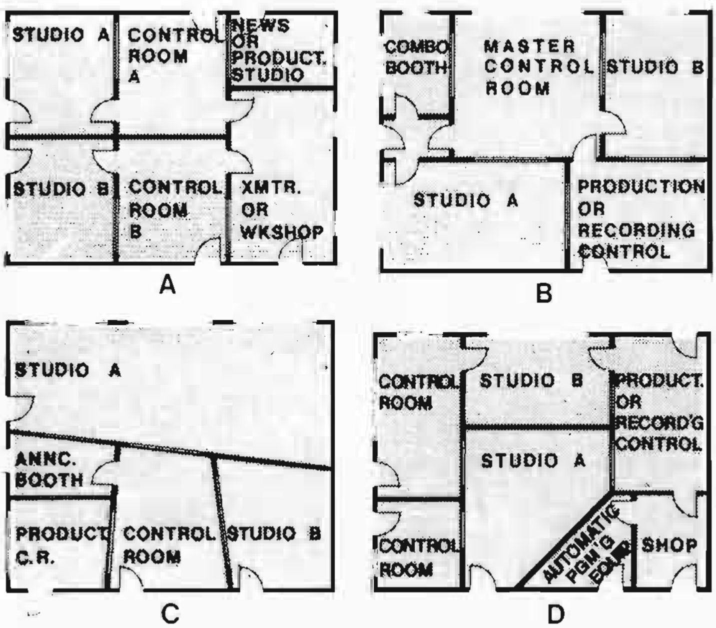
1	4-Mixer Transistor Amplifier, less batteries
1	Headphones
1	Phone plug
1	Omnidirectional Microphone

Tape Recording Equipment:

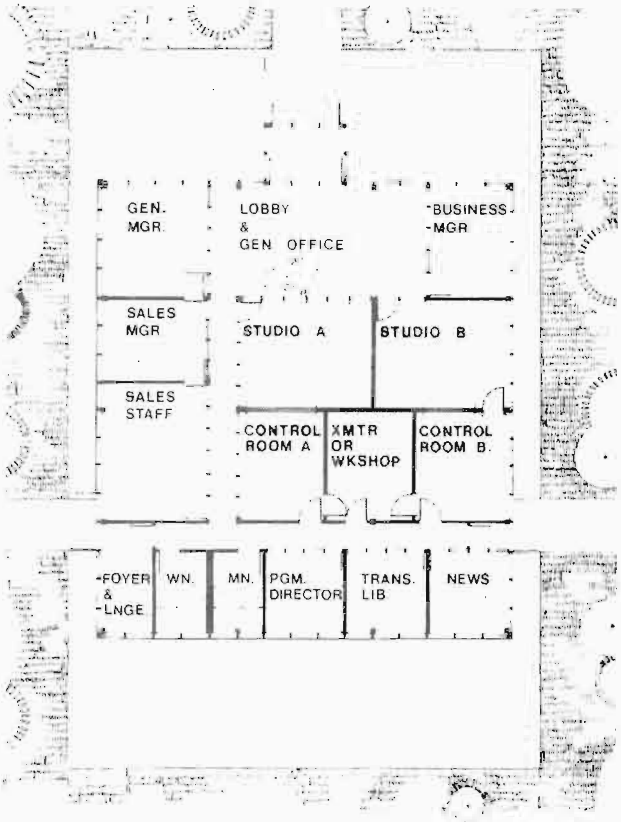
1	Half-track Portable Tape Recorder, 7½ in. per sec.
1	Cartridge Playback Unit and Recording Amplifier, one tone, desk mount
1	Cartridge Playback Unit, Desk Mount
24	40 Sec. Cartridges
24	70 Sec. Cartridges

Remote Control Equipment for Unattended Operation:

1	Remote Control System for unattended operation of transmitter
1	RF Amplifier with antenna
1	Rack Cabinet.



alternate "core area" plans



AM-FM OR DUAL CONTROL ROOM OPERATIONS

Fig. 11. AM/FM Dual Control Room Equipment List (Plan Three).

Transmitter Audio Equipment:

1	Rack Cabinet
1	AM Solid State Limiting Amplifier
1	FM Solid State Limiting Amplifier

Monitors:

1	AM Modulation Monitor, Solid State
1	EBS Monitor
1	FM Modulation Monitor

Studio Equipment

1	8-Mixer Console, Monaural
2	12'' Turntables
2	Integrated Circuit Turntable Preamplifier
2	12'' Tone Arm
2	Stereo Cartridge (Outputs connected in parallel for monaural operation)
3	8'' PM Type Loudspeaker
3	Speaker Matching Transformer
3	Wall Cabinets for Speakers
1	Cardioid Microphone
2	Dynamic Omnidirectional Microphones
1	Boom Stand
1	Desk Stand
1	Clamp-on Mike Stand
4	Wall Receptacles for Microphone
4	Microphone Plugs
4	Connectors
100'	2-Conductor #20 Microphone Cable, jacketed
500'	Shielded Miniature Audio Cable
1	Headphone
1	Headphone Plug
2	Studio Clocks.

Remote Broadcast Equipment

1	4-Mixer Transistor Amplifier, less batteries
1	Headphones
1	Phone Plug
1	Dynamic Omnidirectional Microphone

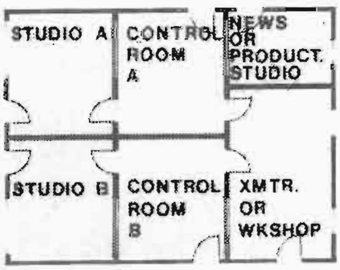
Tape Recording Equipment

1	Half-track Portable Tape Recorder, 7½ in. per sec.
1	Cartridge Playback Unit and Recording Amplifier, one tone, desk mount
1	80 Cartridge Playback Unit, Desk Mount
24	40 Sec. Cartridges
24	70 Sec. Cartridges

Remote Control Equipment for Unattended Operation

1	Remote Control System for unattended operation of transmitter.

alternate "core area" plans



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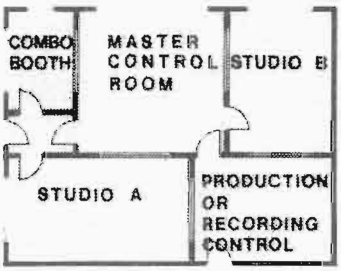

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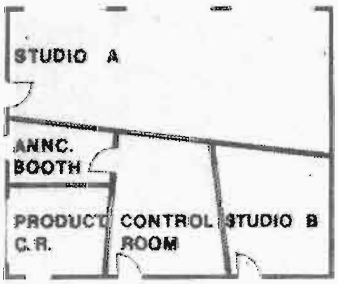

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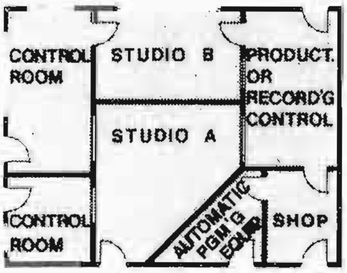
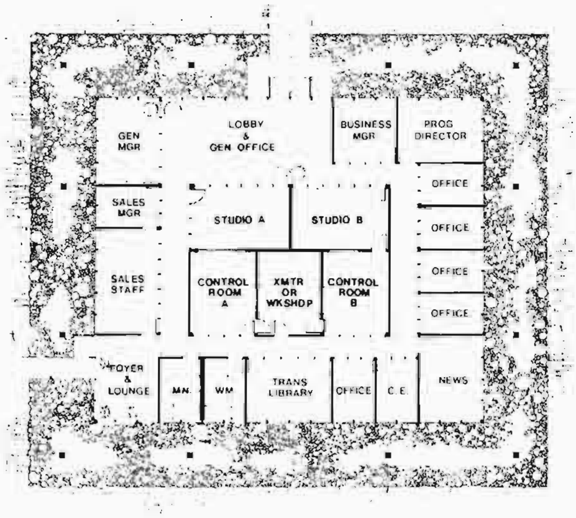


D

METROPOLITAN MARKET FULL STAFF

Fig. 12 Metropolitan Market Full Staff (Plan Four).



Transmitter Audio Equipment (monophonic)
- 1 Rack Cabinet
- 1 FM Solid State Limiter

Monitors
- 1 FM Frequency Measuring Unit
- 1 FM Modulation Monitor
- 1 EBS Monitor

Stereo Options
- 1 Stereo Generator
- 2 FM Solid State Limiters, matched
- 1 Stereo Modulation Monitor
- 1 19 kHz Pilot Frequency Comparator

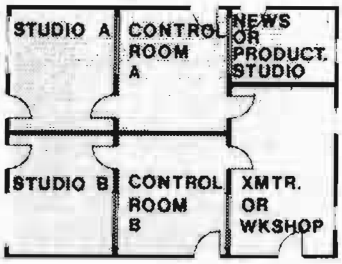
Studio Equipment (monophonic)
- 1 8-Mixer Console, mono
- 2 12'' Turntable
- 2 Equalized Preamplifier
- 2 12'' Tone Arm
- 2 Stereo Cartridge (Outputs connect in parallel for monaural operation)
- 3 8'' Loudspeaker
- 3 Speaker Matching Transformer
- 3 Wall Cabinets for Speaker
- 1 Cardioid Microphone
- 2 Dynamic Omnidirectional Microphones
- 1 Boom Stand
- 1 Desk Stand
- 1 Clamp-on Mike Stand
- 4 Wall Receptacle for Microphones
- 4 Microphone Plugs
- 4 Connectors
- 100' 2-Conductor #20 Microphone Cable, jacketed
- 500' Shielded Miniature Audio Cable
- 1 Headphone
- 1 Phone Plug for Headphone
- 2 Studio Clock

Studio Equipment Stereo Options
- 1 Stereo Console
- 2 Stereo I.C. Equalized Preamplifier

Remote Broadcast Equipment
- 1 4-mixer Transistor Amplifier, Less Batteries
- 1 Battery Kit
- 1 Headphone
- 1 Plug for Headphone
- 1 Dynamic Microphone with 18 Ft. Cable
- 1 Plug for Microphone

Tape Recording Equipment
- 1 Half-Track Portable Tape Recorder, 7½'' per sec.
- 2 Cartridge Playback, mono
- 1 Recording Amplifier for above, mono
- 24 Cartridges, 40 Sec.
- 24 Cartridges, 70 Sec.

Remote Control Equipment for Unattended Operation
- 1 Remote Control System for unattended operation
- 1 RF Amplifier with Antenna
- 1 7 Rack Cabinet



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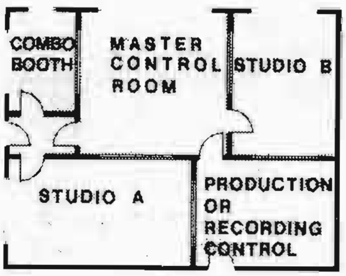

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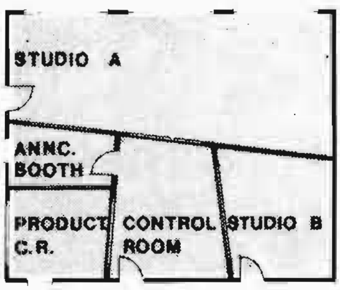

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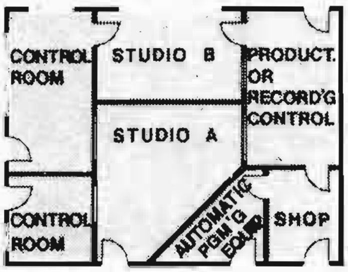

D

alternate "core area" plans

more complex, but since radio sells with sound, good acoustics are a must when the best sound possible is desired.

Design Factors

Combination control rooms are at best a compromise of the several design factors. In the design of this control room, consideration must be given to the following:

1. Location of the control room within the studio building;
2. Isolation—elimination of unwanted sound and noise, both internal and external;
3. Construction—dual wall, floating wall, single wall;
4. Reverberation control, elimination of unwanted reflections, and floor treatment;
5. Ventilation and air conditioning;
6. Size and arrangement of equipment.

Location

The combination control room must be located so that it is convenient to the office areas, but traffic in and out of the room should be minimized in order to reduce distractions to the announcer. The location selected must have as little external acoustical and electrical noise as possible. The control room should be located away from street noise or noise that may be generated in other parts of the building because it may become difficult and costly to reduce unwanted noise that enters through the floors and walls. Air-conditioning compressors and other rotating machinery should be well isolated and kept as far away from the control room as possible.

It is not wise to locate a control room next to a power-transformer vault or other large electrical equipment that may produce strong electrical fields. These strong electrical fields may cause noise problems in audio equipment. If the control room contains the transmitter, great care should be given to the grounding of all audio equipment, including equipment racks, consolettes, turntables, pickup arms, and other metal objects. In some cases, it may be desirable to shield the control room with copper screen to reduce noise generated from high-power RF fields of the nearby transmitters and antennas.

Isolation

Ideally, a control room should be a sound-isolated room within a room. Cost considerations in a small station may make such construction impractical, but it should be considered when possible. The floors and walls should be built from materials that will minimize the transfer of sound into the control room. Many new stations use concrete block walls and concrete slab floors that are isolated from the building walls with asphalt-impregnated glass fiberboard. This type of floor construction is very practical, since it reduces outside vibration in the control room floor. A stable floor will improve turntable operation by reducing vibration that enters the pickup system from external sources.

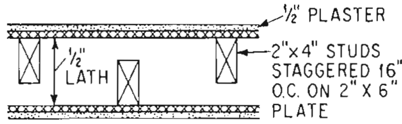

Fig. 13. A cross section of a sound-insulating partition. Wooden walls should be constructed in this manner to reduce external noise.

Construction

The ideal control-room wall would consist of either a dual masonry wall or a masonry wall with a sound-isolated floating inner wall. In the smaller stations, cost considerations usually preclude this type of construction. A single wall of masonry, cement, gypsum, or pumice block is a good compromise, which is completely satisfactory where external noise is reasonably low.

Wood-wall construction should not be used unless double walls are used. Staggered 2 by 4 in. studs can be set on 16 in. centers on a 2 by 6 in. plate for the double-wall construction (see Fig. 13). Rock-wool bats can be interlaced between the studs for additional sound isolation. There should be at least 2 in. of rock wool or other sound-absorbing material above the ceiling surface, and if external noise is of large magnitude, the ceiling should be sound isolated.

If care has been given to the location of the control room in a given building, the offices and other quiet areas surrounding the control room may screen it from unwanted sound. Control-room doors should be the heavy soundproof type (see Fig. 14), or double doors should be

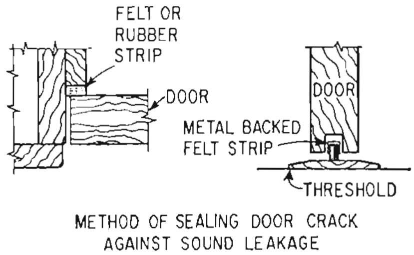

Fig. 14. Normal methods for sealing the control-room door. The door itself should be of a heavy type to improve isolation of the control room.

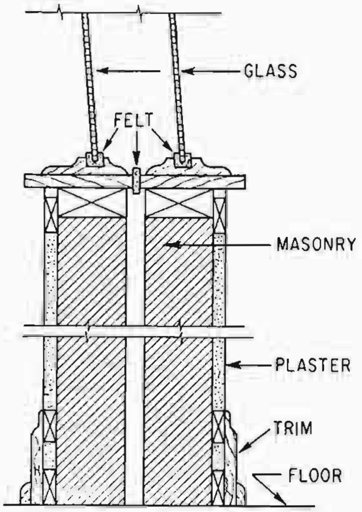

Fig. 15. Sound-insulating window construction showing structural separation of double wall. Glass windows in studios and control rooms should be off about 10°, and they should be mounted as shown on a double wall.

used. Observation windows should be kept to a minimum. Each such window should consist of two panes of heavy plate glass of different thicknesses to break up resonance conditions. The glass plates should be set in rubber or felt gaskets, and usually the glass plates are set about 10° off vertical (see Fig. 15).

Reverberation Control

Some form of reverberation control should be employed within the studio. If a studio has too long a reverberation period, the sound may blur and speech may lack intelligibility. Such sound characteristics are not pleasing to the listener. Generally a studio should have an approximate reverberation time of 0-4 sec. for a volume of 1,000 cu. ft. rising to 0.6 sec. for 10,000 cu. ft. (see Fig. 16). The reverberation time should be about the same from 100 to 5,000 Hertz, but it may rise slightly at 5,000 Hertz (see Fig. 17). This type of studio characteristic helps eliminate low-frequency boominess. An acoustical consultant should design the studio and supply the proper materials.

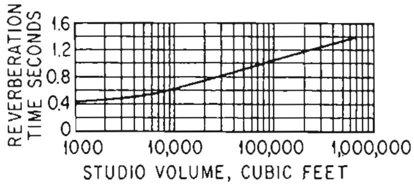

Fig. 16. Variations in reverberation time as the size of the room increases with a 512-Hz reference signal.

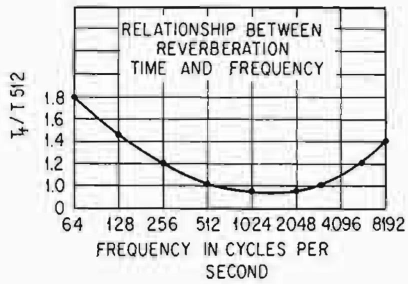

Fig. 17. Morris-Nixon curves showing the relationship between reverberation time and frequency. Reverberation time should remain fairly constant between 100 and 5,000 Hz.

Consideration should be given to all wall and equipment surfaces in the control room in order to eliminate unwanted reflections. Perforated hardboard or Transite can be used for wall coverings with rock or glass wool placed behind it for sound absorption (see Fig. 18). Hardboard may be painted, and it is easily maintained with occasional washing. The hardboard can be used for wall panels set at various small angles of 5 to 10° to produce greater diffusion of sound.

All glass surfaces should be set on an angle to reflect sound into the sound-absorbing surfaces of the ceiling. Glass surfaces should be kept to a minimum, and large corner areas of glass should be avoided. The floor covering should be of a soft material, such as cork or vinyl tile, to reduce surface noise. A rug may be necessary to produce the required deadening in control rooms having many glass surfaces and other reflecting areas. The surface of the operating table should be made of a soft material such as linoleum or vinyl. This will reduce table-top noise.

Microphone Requirements[5]

A good microphone with proper directional characteristics is important in the control room. A microphone operated in a unidirectional pattern has excellent properties. The distance between the speaker and the microphone will be determined by the acoustics of the control room; however, good microphone technique is important for all personnel if natural reproduction is desired.

Ventilation

To do a good selling job, an announcer must sound alive. It is important to provide air conditioning and ventilation so that announcers have a good environment in which to work. A central air-conditioning system is recommended. The

[5]See section entitled "Microphones: Their Application and Operation."

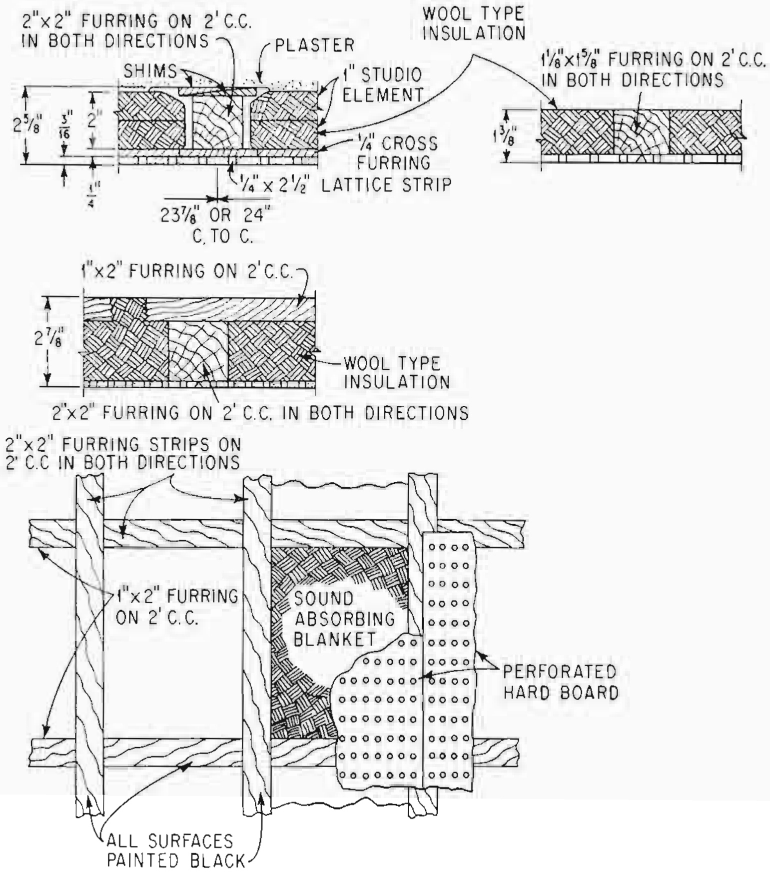

Fig. 18. Typical acoustical panels and how they are mounted. Excellent isolation can be obtained if this type of wall material is backed up with glass or rock wool.

air is brought in through ducts from the coolers. The air ducts should be lined with a sound-absorbing material for a distance at least twenty times the average width of the duct. A separate duct should be run to each studio and to each control room to avoid sound transfer through the ducts. Low-velocity air should be used to prevent air noise from the duct openings.

If the control room contains a transmitter, it is usually possible to exhaust hot transmitter air to the outside and to cool the transmitter with spent room air. If this is not possible, the transmitter should be partitioned off from the control room, and a separate source of air should be used to cool the transmitter. The transmitter can be remotely controlled if it is in another room some distance from the control operation. Such a procedure will save many dollars in construction costs and also eliminate a source of noise in the control room.

Equipment Arrangement

The equipment selected will, to a large extent, determine the physical aspects of the control room. The control room should be large enough to contain all required personnel and equipment. At the same time thought should be given to possible future expansion, and extra space should be provided with this in mind. A control room that is a little larger than necessary at the outset makes it easily expanded later. Furthermore, it is always more difficult to treat a small room acoustically than a large room.

Planning It Right

A good architect should be consulted when planning a studio-control room. After a general station plan is formulated and equipment selected, the architect and the consulting engineer should work out the specific construction details for the station. Careful acoustical planning combined with good equipment will enhance the sound of any station and make its sound sell more.

Exclusion of Noise

A studio with good acoustics has its walls insulated against the transmission of outside noises

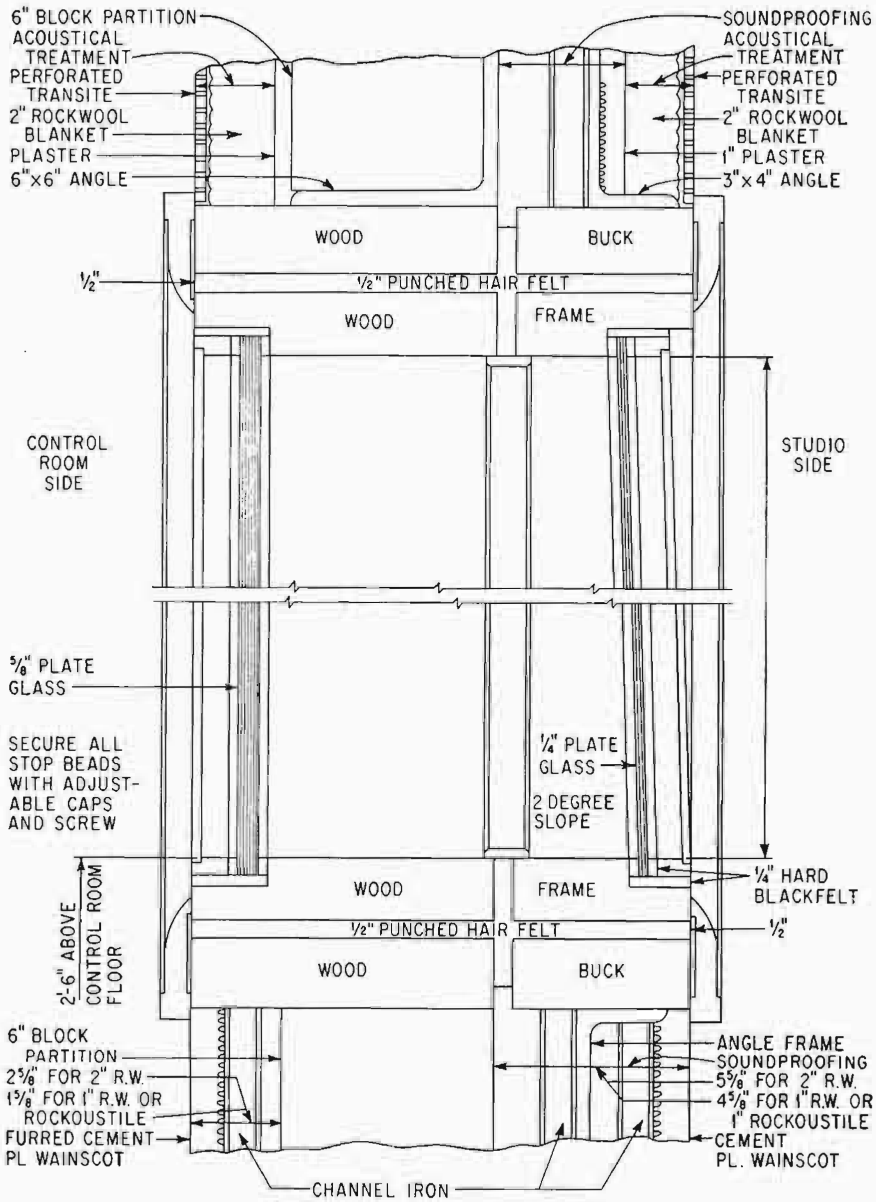

Fig. 19 Sound-insulated window.

into the studio. The transmission of sound is of two kinds: (1) aerial and (2) structural. Small openings due to doors, windows, etc., transmit sound to a great degree. Thus, all the joints between walls, doors, windows, etc., should be made as airtight as possible.

Likewise, transmission of sound through structures, such as the noise from vibrating motors and machinery, should be minimized by using massive walls and floors and by separating all vibrating bodies from their supporting structures by sound-insulating materials such as cork, lead, or rubber.

Massive walls are not always necessary to obtain sufficient sound insulation. A double wall of fairly light construction will give good sound insulation provided the two walls are not closely coupled mechanically by nails or cross members, that is, provided the walls are kept isolated or separated from each other.

A noise survey of the proposed studio site should be made by a qualified acoustical engineer before plans are drawn. From the viewpoint of excluding outside noises and building vibrations it is essential that during erection all joints and openings between panels, etc., shall be fully caulked to give a continuous and sealtight enclosure and furthermore that the entire wall structure shall be floated on cork, rubber, or other suitable material in order to isolate the

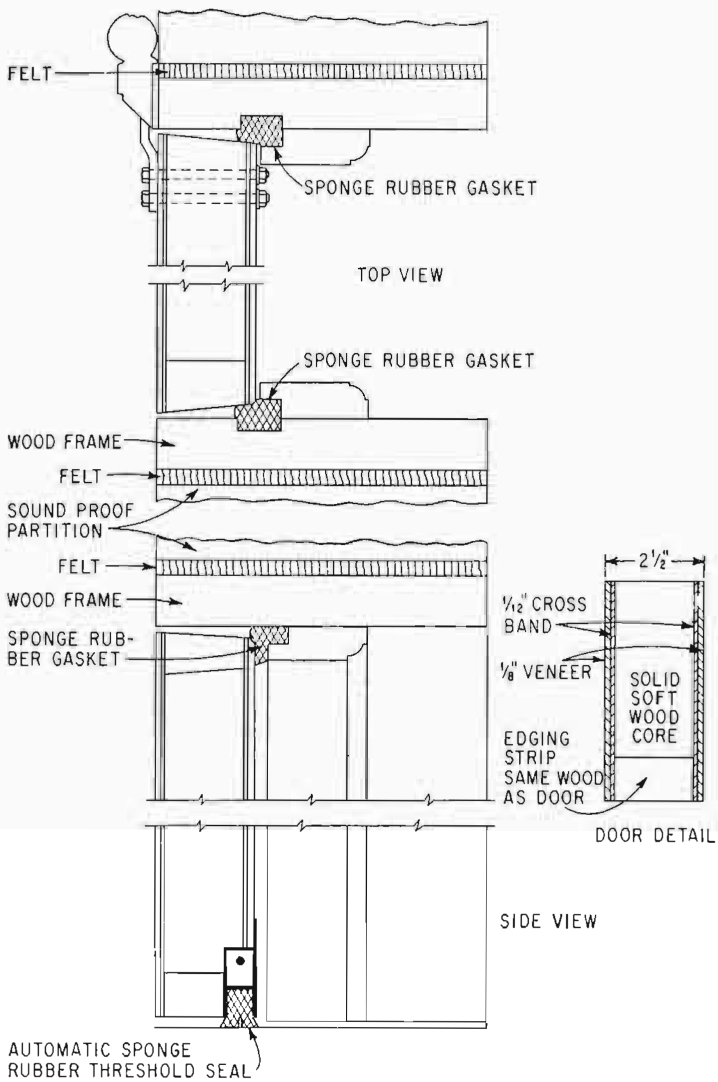

Fig. 20. Sound-retarding door.

walls completely from the main building structure. This precaution is extremely important, since a single mechanical bridge or solid connection between the inner and outer shells caused by nails, pipes, ducts, etc., can almost completely nullify the sound insulation by setting the inner structure into vibration. Any bracing between inner and outer walls which may be necessary for structural reasons should receive individual isolation treatment to break the continuous mechanical connection. The various methods employed in building practice and patented methods for vibration isoltion are too numerous to treat in these specifications. The underlying principle for preventing transmission through solids is to avoid a continuous medium (reinforced concrete, brick, etc.) or solid connection (wood, metal, etc.) by interposing a resilient or less dense material (cork, rubber, felt, air, etc.) in the link between the source of vibration and the reception point. In general the greater the number of such discontinuities (dense to less dense medium and vice versa), the greater the isolation effect. The ceiling and floor structure should receive similar caulking and vibration-isolation treatment.

Fig. 19 shows a cross section of a typical window of the sound-retarding type. Fig. 20 shows a cross section of typical sound-retarding door such as the Riverbank door used by broadcasting stations and other sound studios. Fig. 21 illustrates construction of a typical sound-insulating wall in accordance with principles stated by Bagenal and Wood in their book "Planning for Good Acoustics."

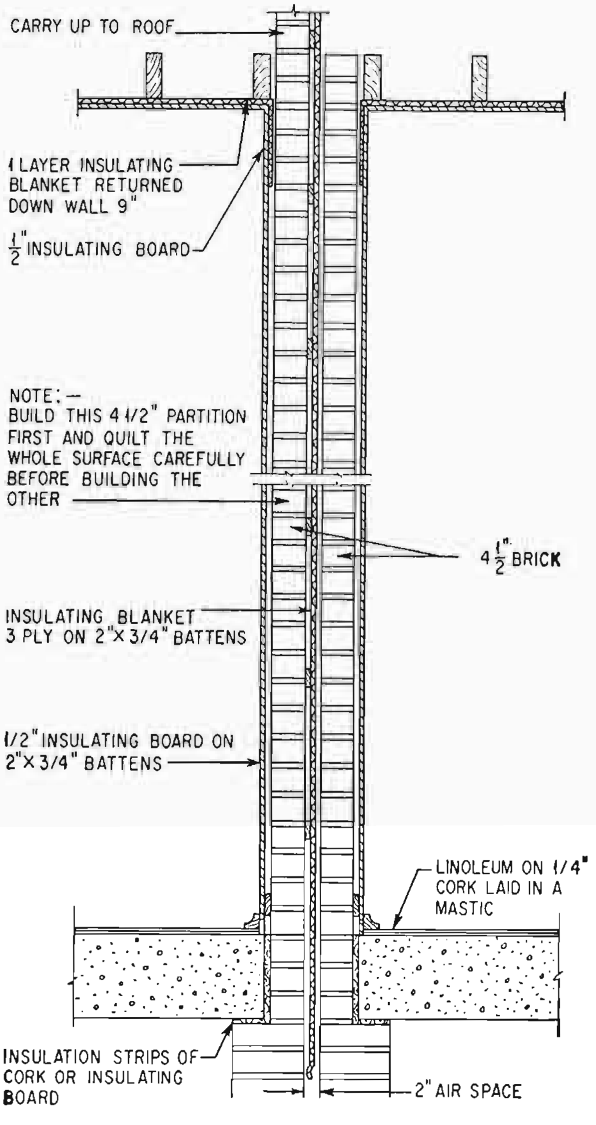

Fig. 21. Sound-insulating wall construction.

TV STUDIO FACILITIES—GENERAL

Staging and Production Areas Proper

Access to studios for vehicular and pedestrian traffic must be efficient for people and materials handling, since this is a final, live production point in the plant. Type of construction and materials will vary, depending upon local conditions, availability, and cost factors. A relation of costs of the various elements to one another should be established in order to facilitate the inevitable compromises that must be made. Dimensions will vary depending upon requirements; however, three typical sizes are as follows: 70 X 110/7700 sq. ft., 40 X 55/2200 sq. ft., and 20 X 35/700 sq. ft. Structural beam heights and lighting grid heights depend upon whether a new structure is built or an existing building is to be utilized. Maximum clearance is always desirable, with a lighting grid to floor minimum of 15 ft. and practical upper limit of 30 to 35 ft.

Types of finishes used on floors, walls, and ceilings can have much bearing on the production quality possible in a given facility. After many experiences, it has been determined that gray deck linoleum is a fine floor surface covering, having a good wear factor, low fatigue, good sound and color features. Wall and ceiling acoustic treatment is desirable; however, this must be determined by the scope of the operation and budget considerations. Air conditioning and ventilation must be afforded in the required amount and volume, yet without being an uncontrollable noise factor. Heating must not be overlooked as a necessity in climates where there is that temperature requirement.

Traffic flow in and out of the studios is an extremely important matter for efficient operation. Doorways should not be planned in more than one or two of the studio walls, as there is a direct reduction in the amount of usable staging space where entry ways reduce the floor and set areas. The space matter, notwithstanding proper recognition, must be given to fire exits and safety measures for the protection of employees and visitors.

A proper talent and preprogram checkout assembly area or room is needed outside the studios which are being prepared for use. This allows careful briefing of all parties prior to air or production starting times. Dressing rooms, prop areas, and security storage locations must be in appropriate proximity to the actual studio/staging locations. Depending on the scope of an operation, these areas may be more or less critical in nature.

Lighting

Studio stage-lighting grid systems are of two basic types: (1) long pipes that can be raised or lowered by counter-weighted rope arrangements; a number of lights are attached to each light and the whole unit is moved and (2) fixed grid systems of steel beams with a track attached (known as "unistrut"). In this system, each light can be moved horizontally in the track and raised or lowered by a hanging device known as a pantograph.

A lighting suspension system for an average size (40 X 60 ft.) studio should begin with a 1¾ in. or 2 in. pipe grid, spaced approximately 4 ft. apart, across the width of the studio. This type of grid seems to give the most flexibility as to hanging devices and fixture arrangement. The fixtures are usually hung on an adjustable pipe (ranging from 4 ft. off the floor to full grid height). This pipe is anchored to the grid by means of a pipe clamp. The use of pantographs as hanging devices are no longer popular because of their size, weight, and bulk. *Unistrut* material used for grids is novel but has definite disadvantages in their hanging and locking devices, which become increasingly difficult to actuate with age and use.

Lighting control systems today are made up basically in three units: (1) SCR dimmers and racks, (2) patch panel and cords, and (3) low-voltage control console. In studio planning it is not necessary to include the dimmer racks in the studio. They can be placed nearby in a convenient place for venting, thereby reducing the noise and temperature levels in the studio. The patch panel and control console should be part of the studio lighting design, although a second remote control console can be placed in the control rooms or at the video position. This gives the lighting director or technical director versatility in making on-air changes or adjustments. The control console should also be versatile enough to handle various presets and scene-to-scene changes. Of major importance is the evaluation of the total amount of wattage required for optimum studio versatility, that is, multiset lighting and major full studio production numbers.

TV lighting fixtures come in many shapes and sizes today but they are broken down into four basic types. Key lights are the main source of illumination on a subject. This is usually a focusing type lamp with a Fresnel lens, ranging in lens size from 6 in. to 20 in. In wattage, that would be 500 w, 750 w, 1,000 w, 2,000 w, 5,000 w, and 10,000 w. In most studios the 1,000 w, 2,000 w, and 5,000 w lamps are used as key lights. This type of lamp is used as backlite, which will be discussed later. Fill lights used exactly as their name implies, fill in the shadows created by the key lights. These fixtures are usually large lensless, diffused sources of illumination. Typical of this type of fixture is the scoop and cone lamp. Becoming increasingly popular is the line of reflected light sources known as soft or shadowless lamps. The fill lamps are usually 1,000 w or 2,000 w in the scoop-type lamps and up to 8,000 w in the shadowless reflected type fixtures. Effects or projection type lamps such as the elipsodials have a lens system and are used to project patterns or can function as a follow-spot. Its beam can also be cut to various shapes (by means of individual shutters) and sizes.

Last but not least are the cyclorama lights, which are used to illuminate the cyc-from-floor level. In cases where added versatility is needed, and/or high cycs, additional cyc strips are placed at grid height, illuminating the cyc from above. Usually these strips have two or three individual circuits. Colored glass frames are supplied with each circuit, thus offering numerous possibilities for colored cyclorama effects. A large amount of wattage is needed to successfully illuminate an average size cyc. Careful consideration should be given to this area of studio lighting.

In determining the types of bulbs to be used in the previously mentioned fixtures, serious consideration should be given the line of Tungsten-Halogen bulbs. Basically, the difference between the T-H bulbs and the incandescents is that the Halogen gases act as a catalyst to recycle the burned-off tungsten, thus maintaining a constant Kelvin temperature throughout the life of the bulb. The T-H bulb is now available in all the popular base configurations such as medium and mogule bipost, twist bayonet, screw mogule, etc.

In an effort to attain a pleasing and technically acceptable picture through lighting, several basic factors must be practiced. First of all, a light level of approximately 250-foot-candles must be maintained. Contrast ratios exceeding 2 to 1 should be avoided except in cases where highly dramatic effects are requested. Brightness ratios on sets, props, and wardrobe should not exceed 20 to 1. This can be maintained with the use of cutters, flags, dots, barndoors, etc., or better yet, careful set planning. Back lighting is used to give separation and dimension to a subject. It is difficult to set a definite level on this lamp; it should be set by looking at a monitor to avoid video clipping or polarization. An overall base light or fill light level should be used as often as possible at the suggested ratios. This base level tends to minimize video noise and assures the video operator of relatively flat pictures. It cannot be stressed strongly enough about the part played by the video operator and the lighting director working together in solving various problems. Communication between all participants is a must.

Sound Pickup

Four types of microphones are in general use:

a. The mike mounted on a large boom with the ability to roll the boom from place to place within the studio.

b. The desk or stand mike.

c. A small mike hung around the neck and resting against the chest.

d. The hand-held mike.

There are wireless mikes in use today but the quality of these units is inferior.

Storage of microphones is best accomplished in sectionalized cabinets or drawers lined with soft material. The mikes should be stored in or near the studio. It is convenient to keep the mike cables in the same cabinet.

Video Pickup

Television cameras are generally mounted on fixed bases with wheels. These are of a size that one man can move and steer the base and at the same time operate the camera. Recent technology has brought the zoom lens into wide use. This lens allows the operator to obtain a closer or wider picture (while remaining in focus) without moving the camera. If large dramatic productions are planned, a crane-type camera-mount may be needed. This is a two-man operation: one running the camera and one pushing or guiding the crane.

Accessory Devices

The connection of cameras, mikes, and cueing devices to control areas is best accomplished by fixed terminal connectors on the studio walls. Camera and mike cables can then be unpluged if needed elsewhere. The same applies to any picture monitors within the studio proper.

Clocks and cueing devices can be mounted on the base holding the movable picture monitor or on the studio walls. If the latter, be sure location is visible from all working areas of the studio.

If economy permits, automatic prompter devices should be included in the studio equipment. With these units, the talent may read previously typed scripts while looking almost directly into the camera lens. The readout unit is normally mounted on the camera (above or below the lens) and the reading speed selected by the talent or regulated by someone on the studio floor.

Projection Devices

Projection equipment used within the studio for onset effects (a filmed scene or chart appearing behind the talent, for example) can be purchased in a variety of configurations. The two basic designs are front projection and rear projection. Using these devices, a screen is placed behind the talent and scenes projected onto the screen. The camera then frames the talent and the scene projected. Care must be taken to allow room (particularly rear-screen projection) for the necessary equipment.

Audience Considerations

Provision should be made for audience seating. This can vary from foldout bleachers to standard, fixed theatre seats. Local fire codes generally specify arrangements and configurations permitted.

Acoustics

Care should be taken in planning the acoustics in the studios. The engineer planning the studios should specify the allowable sound transmission through walls, doors, and windows (measured in dB units), and the reverberation time (measured in tenths of seconds). If wall treatment is desired, it can be glued, tacked or sprayed onto studio walls. Studio ceilings are not usually treated, but hung battens may be needed to improve the reverberation characteristics.

Operational Control Facility

There are several possibilities concerning control-room location. If the engineering staff is limited in number, it is wise to have the air control room adjacent to the Master Control area. This will allow technicians responsible to Master Control observance to set up the control room and still be in view of transmission areas. A folding door can be installed and closed when quiet in the control room is necessary. This configuration requires that the control room be between the main studio and Master Control.

In a large operation it is desirable to have control rooms separate from Master Control and adjacent only to the studio. The advantage to this layout is that recording and production tasks do not go on in the same area as on-air tasks. This layout results in less confusion between the two operations.

If two studio/control areas are needed, the control rooms should be side-by-side and separated with a block wall and a medium decibel-rated door.

The ability to see from control room to studio is important and sound windows should be installed. Arguments can be made for "blind" operation or the use of closed circuit cameras, but these are generally unsatisfactory for the production personnel.

Access from control area to studio should be direct. This allows production people to enter the studio to discuss items with the talent or to give directions concerning set location, etc., to the operating personnel.

There seems to be little difference in operation between elevated or ground level control rooms. Budget and building layout will dictate the best choice.

Even though separate viewing rooms are planned, it is a wise idea to allow space within the control room for clients and VIPs. Special seating or counters should be constructed *behind* the operating personnel. If this is not done, these people will hang over and interfere with the director.

The majority of monitors in the control room can be small black-and-white units. It is wise to include a large color monitor with line, or off-air signal; one monitor for each source is preferable to any monitor switching arrangement in the control room. The proper number of video waveform monitors should also be allocated for level and balance checking. Location of the monitors (on the counter or over the window) is a matter of overall control room layout. It is not necessary to worry about the director's view being blocked by monitors provided he can see into the studio when standing.

Control counters can be purchased in modular metal form but custombuilt wood counters covered in formica are generally more attractive and lend themselves to flush mounting with clocks, intercom controls and mikes, and control switches. Construction should be sturdy, with 2 X 4 braces covered with back and end panels of formica-covered plywood. Be sure the panels are removable for wiring access.

The general finish of the room is important to the efficiency and quality of the production. Wall finish should be of sturdy wallboard up to 42 in. from the floor, and then acoustic tile to the ceiling. Industrial carpeting of a dark, patterned shade is desirable. Both wall and floor covering help with sound characteristics of the room. Room lighting should be of the incandescent type and adjustable as to intensity. Air conditioning should have a separate thermostat for the one or two control rooms. Avoid placing air-conditioning outlets over the heads of operating personnel. Use sufficient air-conditioning outlets within the room to avoid noise from air flow.

When purchasing items used by the operating personnel such as chairs, headsets, and timing clocks, spend what is necessary to get sturdy equipment that will take a beating and not break. These items are pushed, shoved, dropped, thrown, banged, and yelled at.

In deciding whether to place the audio operator at the same counter with video switching and the director or in a separate room, proposed program plans must be considered. If the operation is to be mainly from program sources sent in by others (films, videotapes) and if the programs recorded in the station are mainly discussion or light entertainment productions, no separate audio room is necessary or desirable. However, if classical music or large musical or dramatic productions are planned, a separate sound-treated room should be planned. Always include off-air audio monitoring in the audio control room.

The ideal configuration of counter and equipment layout for the audio operator is a U shape. Careful consideration should be given to location of each piece of equipment the operator will use. He should be able to reach the audio console controls comfortably, also the cartridge load slots, reel-to-reel tape recorder, record turntables, and intercom buttons. Avoid configurations using remote controls if the actual equipment to be loaded is to be placed out of reach. If something malfunctions, the operator can have great difficulty correcting the problem and still maintain control of the operation.

All equipment should be permanently mounted, if possible; roll-in turntables, etc., have a tendency to be broken and poorly maintained. Standard equipment racks, placed to the side or rear of the audio operator, should be used. Equipment requiring periodic service should be mounted on sliders. Leave 24 to 36 in. behind each rack to allow space for wiring and removing or service of the equipment. It is wise to leave 25 percent of the audio rack space unused for expansion purposes.

The location of audio equipment is very important. Drawings, mockups, and discussion with an experienced audio operator will help to insure the efficiency of the finished design.

Interconnection wiring of audio sources throughout the facility are dependent on budget and degree of backup and flexibility desired. Whatever the final audio routing arrangement may be, all sources should come to a designated position of the patch panel in the audio control racks. This allows for flexibility, both in audio source rerouting or emergency substitution. These panels are small and can generally be installed in the audio racks. It simplifies installation and servicing if the audio wiring is first brought to a terminal block on the rear of the rack and then to the front-mounted patch field.

If the audio operator is to be in a separate room, he must be able to view the director, the studio, and all preview picture monitors. Direct communication (not part of the overall intercom system) with the director is desirable. The audio room should have a separate clock, timing clock, and picture monitor. The monitor should be patchable to off-air and studio video sources.

Audio consoles generally have cue positions which allow the operator to preview audio sources without affecting air operations; however, these speakers are normally small and give poor quality. Installation of two high quality speakers in the audio room is recommended. One is connected to air or studio audio and the second switchable to preview the various audio sources within the station.

Space should be included for storage of cartridge and audio tapes. Allow space for seating of two extra people and/or some expansion space.

In considering viewing rooms, an evaluation must be made as to types of guests expected. If groups from the general public are to be invited, access to the viewing rooms should be as direct as possible from the main entrance for security reasons. In no case should guests walk through the studio or control areas to reach these rooms. Rest rooms and drinking fountain should be close, and, if possible, separate from station personnel facilities.

Wall coverings, floors, and furniture should be of durable materials and easily cleaned. Picture monitor and audio amp should be permanently mounted, with access to all controls except volume locked and to be adjusted only by station personnel. A phone to the receptionist should be installed.

It is generally advisable to have viewing rooms elevated and to install large windows with tempered glass starting about 24 in. from the floor. In many cases, children will be guests and the unbreakable glass may avoid injury. Include a large coat closet in the room if weather conditions of the location dictate.

It is possible that station people may wish to use the viewing room for clients or VIPs. If furniture used for general guests is removable, the room decoration can be upgraded by substituting lounge chairs and carpet for the special occasion guests.

Recorded Material Origination Area

Film/Motion Picture

In planning a television operation, a good deal of programming will originate on film. This film will be run on motion picture projectors, of which there are three basic types: 8 mm, 16 mm, and 35 mm. A standard television operation uses 16 mm projectors due to ease in shooting, processing, editing, screening, and storage of 16 mm film. In large operations, where major motion picture film is shown, special 35 mm projection equipment is used to a minimum. (8 mm film is rarely used in broadcast transmission, due to the nature of the film itself.) Since clarity or resolution in motion picture film is of utmost importance, normally 16 mm film will be used. In total, the philosophy and scope of a television operation will determine the projection equipment to be used.

When planning an area to house the projection equipment, careful layout must begin from the ground up. Basically it must begin with a well-constructed floor. Since most of the projection ear is so complex, a proper foundation will insure that the projection machines will remain stationary, allowing its parts to function normally. Picture alignment is also critical, thus firm foundation is essential.

Since space costs money, most television stations save space by installing multiplex units in their projection areas. The multiplexer is a device that houses a small television camera and a complex set of mirrors and prisms. By aligning as many as two film projectors and a single slide projector to this one unit, it is possible to program three separate film sources in any individual order one wishes. But whether a multiplex system is called for or separate motion-picture machines, the projection area must house a uniform audio and video monitor control panel. The control panel is the heart of the project area. Here, individual monitors will enable the projectionist to preview what film or slides he may have programmed on a particular film or slide machine. It is this same preview device that enables the projectionist to catch any errors in loading, which may have occurred before the film source is aired. A well-constructed preview control panel also enables the projectionist to roll or show his film from a sitting position. Thus, time and energy are saved. This same panel may also be wired for an automated film system, whereby a programmed master unit will roll or show slides via remote control. In a small operation, this is highly desirable, since the projectionist can load, double-check his work, and then be available to cover another position in the Master Control area.

With a well-planned projection area, the storage of film becomes an important factor. Only those films that are to be run each day should be placed in the operating area on a special rack. Loose standby films (varying in program length) should also be readily available, but not clutter the operations area. All other films in the station should be placed in a properly humidified and temperature-controlled room near the film shipping and film-editing rooms. Again, efficiency in handling film saves time and money.

Included in an efficient projection area are important miscellaneous items: (1) an air-hose gun with sufficient length and air pressure is needed to clean dirty film while it runs on the air; (2) both video and audio alignment films are needed to test the film equipment daily for possible malfunction. All equipment should be stored in a central working table which also contains the numerous slide trays; (3) small tools and spare projection lamps should also be stored in order to repair or replace needed items quickly.

Film/Still

In a television operation the projection area will also house another program source called a slide. A slide simply is a single still picture. This still picture is made with a special 35 mm-slide camera, the film is then developed, the individually selected pictures are then mounted and shown on a slide projection device. The device, normally called a slide drum (which may hold as many as 36 individual slides) is connected to a multiplex unit (see above). A special beam of light will pass through the slide/film and its image will be recorded by the small television camera in the multiplex system.

The slide is an important program source and can be used in television for many purposes. A series of similar slides tells a simple visual story. A single slide can either identify something or be used as a simple program transition device. Whatever the case, slides are important and must be shown correctly.

When planning your projection area, at least one slide projector should be attached to each film island containing a multiplexer unit, a film projector and slide projector. A film island may consist of as many as two slide projectors and one motion picture camera, or vice versa. When planning a film island, one also must keep in mind whether the system can be compatible, that is, able to be shown in both black and white, and in color.

Whether the station owns a film island or not, each slide projector should be connected to preview control panel. As in the case of the motion picture projectors, the preview panel will save time, mistakes, and money. For utmost operational efficiency, the slide projectors may be wired to the panel for automated commands. Once again, the projectionist may load a series of slides, preview them, reset for air, and walk away to cover another position in Master Control.

As important as slides are, they are of little use if they cannot be found readily. Within the projection area, slides should be kept in slide trays in a systemized order. The slide trays should frequently be examined for duplication, loss, and old program material. Part of this duty will lie with the promotion, commercial operations, and programming departments.

Keeping in mind what has been discussed regarding the projection area, a television station can find this area the simplest and most trouble-free area to work in.

Videotape

Generally speaking, the on-air tape center of a television station is best situated near the projection area in Master Control. Being housed in one large room, the Master Control technician may have complete command within a short walking distance of film or videotape areas. Depending upon the operational size of a station, a minimum of two machines should be used.

Careful consideration should be given to the positioning of such machines in the assigned area. Normally, a 2 in. videotape machine size is 4½ ft. by 6 ft. high and each machine is placed side by side. Plenty of room should be allowed, not only in the direct working area but also behind the machines themselves. Frequently a videotape technician must repair the machine from the rear and there is not sufficient space, thus necessitating moving a heavy, but very delicate instrument. Chances are that once you move a 2 in. tape machine, readjustments have to be made. In addition to providing ample work space around the 2 in. videotape machine, the general environment plays a major role in the efficiency of machine re: wear and operation. Due to the complex nature of a videotape machine, proper ventilation is needed to keep the machines running cool. Air ducts should be provided in the ceiling over the machines. But where there is ventilation there is dust. Dust is the major cause of wear on the life of a videotape head (the system that translates magnetic tape information from the tape itself to electronic impulses that, in turn, produce visual pictures and sound). With today's modern technology, special devices called "dust curtains" may be installed directly over the machine to reduce the amount of dust. Carpeting has also been found to be a deterrent to dust. Thus, it should firmly be considered in planning a videotape area. Environmental noise in the videotape area is another problem; proper ceiling and wall tile should always be considered in planning a videotape area. With less noise, there are generally less human mistakes made.

Thus far we have concentrated on the on-air videotape area. Little is normally mentioned concerning the videotape machines used for editing or screening. In large operations it is best to place these machines in an adjacent but ample size room. The reasons are many: videotape editing is a skillful but painstaking process. A minimum of two machines are normally required. If the video machines are not spacially separated, the tendency is to use the extra machine for air operations. This is fine, but when editing or screening of videotape material msut be done, there is no machine available and this costs the station money. Confusion may also exist between on-air or off-air videotape personnel if the machines are placed in one large area. Since the needs for a machine are so diferent (editing, screening, versus on-air playback), the space allocated should be different.

Although we have discussed the standard 2 in. videotape machine used in major television stations, we should note that there are two other types of machine available: 1 in. videotape plus cartridge videotape.

The 1-in. videotape machine is a baby unit. It is slightly larger than standard broadcast audiotape recorder, but quite versatile. Mainly, it can be used to store the same tape information found on 2 in., but in less space. Although it is not used for standard broadcast transmission, programmers and salesmen alike may delight in previewing and selling products stored on 1 in. tape. The operator may play back or even tape an event practically anywhere. The size alone speaks for itself.

The videotape cartridge machine, used for television, is another wonder of our age. The increasing trend in broadcasting toward short recorded messages on both tape and film (especially during station breaks) have created monstrous problems. With this new system, a short message may be recorded on a videotape cartridge and placed in the proper television log format. The machine is programmed automatically through Master Control, and all the station's tight commercial breaks are executed cleanly and on time. There is also less tape handling involved, less tape storage, and less chance for mistakes. Future station planning should seriously explore the purchase of the versatile videotape cartridge machine.

Master Timing, Transmission and Central Control

Master Control is the central control point for the entire plant and some consideration should be given to its location with relation to the other branches. If the broadcast facility's location is such that elevation permits the transmitter-antenna tower on the premises, then it is desirable to have the transmitter and its control area located in the Master Control area. This will minimize personnel requirements and make for better communication and coordination between the technical personnel involved. Obviously, if geographical and other considerations require the transmitter-antenna to be located some distance from the production area (in order to attain elevation for the transmitter and its antenna and ease of access to the production facility) then the above-mentioned desirable situation is unattainable.

Other factors in connection with Master Control location are its proximity to various production studios, studio control rooms, and their video-audio control points, recording areas (video and audio), and the maintenance or shop area for maintenance of the technical apparatus.

Location of the video control point in this area expedites the pinpointing of deficiency in video signal transmission, allowing corrective measures to be taken in a minimum of time. Also, it allows for more uniform cable lengths, which eases the burden of sync timing, cable equalization for high-frequency roll-off, etc.

The shop or maintenance area should be in close proximity to Master Control, for it is here that uniformity of transmission standards are determined; monitors and other measuring instruments must be periodically calibrated in order that all personnel involved with video and audio transmission may maintain the standard signal level. This close proximity to Master Control also permits sharing of the more expensive pieces of test equipment and makes for closer communication between Master Control personnel, who detect equipment deficiencies, and the maintenance personnel, who correct them. Also, the Master Control of a modern plant will have various special video waveform-generating devices which should be readily available at the shop facility.

There remains three other areas to be considered that should be located within Master Control area but are of secondary importance as to location in relation to areas mentioned above.

A videotape recording area is a must with a separate videotape recording area with facilities for reel-to-reel audiotape and facilities for live booth audio recording and audio cartridge recording. Also desirable in this area would be a simple video-audio switcher to handle a limited number of video and audio signals for making promotional spot announcements, film-to-tape transfers with slide titling information superimposed, editing, assembling, and duplicating videotape.

The location of this area in relation to Master Control is not critical except as regarding cable lengths and their high-frequency rolloff. Balancing this argument in favor of close proximity to Master Control is the noise factor that will be connected with this recording room facility. If utilized, it will be a noisier location than desired for Master Control.

If economics do not permit a separate recording facility in the plant, then it will be necessary to utilize the videotape playback area for recording. Also, if for the same reason the spot-announcement production cannot be incorporated, then it will be necessary to utilize the main production control facilities (audio and video mixing and switching) for this purpose.

The Studio Control location in relation to Master Control is not critical, assuming a good intercommunication system exists, since the only video cables routed to this area will be monitoring circuits for picture monitors. Assuming also that the audio control area is in, or adjacent to the video control area, no audio distribution problems should be encountered since these circuit lengths are not critical for practical distances and may be easily equalized if necessary. Actually, it should be located above Master Control level to allow it to be an observation point overlooking the studio floor, which should be on the same level as Master Control shop area to allow cameras to be wheeled into the shop area for servicing without encountering steps or needing elevators.

Illumination in Master Control should be balanced between sufficient light to read jackfield labels, monitoring apparatus control function designations, etc., and subdued enough to make the displays on picture monitors and waveform monitors stand out with clarity. Some operational positions in this area, such as video switchers where a program log or other instructions must be easily read, will require a higher level of illumination and may be provided the additional light by devices of the semispot variety.

Closely related to the illumination in the Master Control area is the finish on the racks, walls, and ceiling. These finishes should be a neutral, semimatte finish of medium reflectance.

Since a broadcast plant's product is metered by time, a good central time system is highly desirable. This should be a master clock, preferably located in Master Control (in order that technical personnel may periodically check it against the national time standard and correct it if necessary), for supplying drive pulses to slave clocks throughout the plant. This allows switching between various inplant (and out-of-plant) sources of program origination on a split-second basis.

Another timing factor in the production of video material is the synchronizing generator which should be in Master Control, along with the distribution facilities for its various timing signals. A common sync generator for all camera and other video generating systems makes for ease of timing, phasing, and mixing of these devices throughout the plant. The sync generator should have provision for locking on a color basis to a video signal generated remotely from the plant to allow for mixing of locally generated signals with remotely generated signals, thereby greatly expanding production potential. This sync generation, distribution, and phasing facility should be in close proximity to the proper monitoring facilities such as a good vectorscope and waveform monitor, unless the equipment used has provision for remoting these phasing functions in which case this test equipment could be shared with other monitoring functions.

A central video processing point is highly desirable, as well as its location in the Master Control area. This reduces the outlay for monitoring equipment and the stringent requirements of timing the various synchronizing and video signals to a common point and makes for simplification in camera substitutions and other patching requirements. A jackfield is also desirable in this area to facilitate patching and monitoring, as well as distribution of the video signals throughout the plant.

A well-layed-out jackfield of good design for video distribution is a must in a plant where maximum flexibility is to be achieved. Better still is a Master Control jackfield for the termination of all video switchers throughout the plant (as well as incoming out-of-plant signals) in conjunction with a jackfield adjacent to the in-plant video encoding and processing equipment. Assuming all video cable lengths and timing signals have been previously adjusted, this makes for great flexibility of camera and/or switcher substitutions and additionally gives the video control area control of in-plant signal levels, and the Master Control jackfield distribution and level control of in-plant and incoming out-of-plant signals.

In connection with video distribution and associated jackfields are the distribution amplifiers, which should be located near the jackfield and monitoring point, in order to standardize level adjustments. These distribution amplifiers should be of good design and preferably of modular plug-in construction, adding further to the flexibility of equipment substitution.

The video-mixing devices under the control of the studio control area should be located in Master Control to minimize cable lengths, as well as putting their maintenance adjustments in the technical personnel area. Location of these units near a jackfield monitoring point is desirable but not essential.

If automation is to be utilized in the plant, it should be located in Master Control and its video handling circuitry treated the same as a studio switcher. The audio inputs and outputs of this device should be routed through an audio jackfield, the location of which should be adjacent to the main audio distribution point. The audio jackfield location is not critical but should have communication and monitoring facilities nearby.

The control circuits for automation such as film and tape preroll, etc., being dc are not critical as to length or location. A degree of additional flexibility could be achieved by having the control circuits patchable, so that control pulses to the various machines could be routed to other machines to eliminate changing the input information to the automation device in case of a machine failure. If this is incorporated into the system, video and audio should be on the same patch cable, to minimize error.

A great number of audio feeds from any one source in a broadcast plant are required if maximum flexibility is to be achieved. Each source of program material, videotape, studio control area, etc., should be able to monitor what the other sources are doing, as well as the ability to switch into and integrate that source into the program being produced. This requires one or more distribution amplifiers for each source of audio material in the plant. The location of these distribution amplifiers is not critical except as noted previously as to jackfield and level monitoring.

One or more announce booths will be required, the location of which is not critical as long as there are good communications and monitoring facilities. Audio signals may be routed as any other audio source would.

While it is assumed that each audio control area will have its own reel-to-reel and cartridge tape facility, it is worthwhile to incorporate a cartridge machine with the automation device for various purposes, apologies, audio tags on spots, etc., to relieve the announce staff of these duties. Also, a reel-to-reel device in Master Control will be found to be valuable at times.

A good intercommunication system is a must for any effort that involves as many people as at many different locations whose actions must be synchronized to the degree called for in the production of a television program. In actuality, two such systems are desirable. One is a loudspeaker type for directions and cues to personnel in areas where considerable movement is required and wearing a headset would be tiring and cumbersome. The second type, of course, would be the headset type, which is necessary for cameramen and other studio personnel where the directions and cues would be picked up on the open studio microphones.

The loudspeaker system will require message routing buttons in order that person-to-person communication may be achieved without disturbing other personnel. The message routing function may be done with solid state matrix selection or relays, the solid state being preferred due to avoiding periodic cleaning of relay contacts to prevent failure.

The headset type has become standardized to such a degree that it makes interfacing within camera intercommunication circuitry very easy. The other stations that use headset type communications, as in the announcing booth, etc., could have selection of the control area to maintain station flexibility. This would require a communication line for each studio control area that announcers, studio floor manager, etc., could switch to at their respective stations. The video operators should be able to patch a camera's intercommunication circuit to any studio control area's communication line.

Location of the intercommunication system's common apparatus, amplifiers and switching matrix in the case of loudspeaker system and retard coils and patch points in the headset system, should be located in Master Control area accessible to technical personnel.

Rock layout in Master Control area will be dictated by access requirements of the various equipment. Also some operation positions in Master Control should have a countertop affixed to the rack at that position for program logs, cue sheets, etc. Video handling circuitry should be grouped as close together as feasible due to cable length and timing considerations previously cited. Jackfield racks should be located at points previously indicated. Audio equipment and devices whose adjustment functions can be remotely controlled, perhaps should be given a "back row seat," as long as monitoring of their performance is convenient. Besides video circuitry grouping and adjustment monitoring, the remaining consideration for a good rack layout is accessibility, front and rear. A minimum 4-ft. clearance is recommended.

Since the television art is such a rapidly advancing science, some consideration should be given to future modifications to an expansion of the plant facilities. There are miles of coaxial cable, shielded audio cable, and control circuit cable in a modern television plant. Provision must be made for routing this cable through the plant in a manner that will not obstruct operating personnel movement nor subject the cabling to abuse. Also, it should be easily installed, removed, or rerouted. Though possibly not as neat in appearance as floor trenches and wall ducts, the overhead tray method will be found to be very convenient if fulfilling the stated requirements. The cost factor and effort to reroute should also be less. Since the trench duct method must be incorporated in the design of the building, modification to it by unforeseen developments would be prohibitive from a cost standpoint.

Maintenance and Project Area

Due to the complexity of television equipment, it may be anticipated that considerable maintenance will be required to keep it in top condition. This maintenance may be divided into routine and emergency. Experience will show that the more of the former the less of the latter will arise. Most routine maintenance may be done with the equipment in its normal position by passing standard signals through it and observing departure from this standard. If monitoring facilities and the waveform generators mentioned earlier are incorporated into the plant, this routine checking can be easily done. Marginally, operating equipment may be detected and corrected in this way. There will be times, however, when there will be equipment that in circuit adjustments will not correct and equipment must be removed for more extensive checks in the shop to determine the nature of the failure. Maintenance logs should be kept on all the major equipment and routine maintenance results noted. These case histories can be of great value. Records should also be kept of consumable items of considerable expense, such as camera pickup tubes, videotape heads, etc. These will be of value in preparing engineering budget requirements, as well as catching items that are in the manufacturer's warranty, thus retrieving at least part of their cost.

A good shop facility should have a routine servicing procedure, starting with tagging the equipment received for repair, stating nature of trouble, location in plant from which removed, urgency of repair, etc. There should be available in the shop the standard waveform signals (mentioned earlier in connection with the synchronizing generator), a complete updated set of manufacturer's service manuals for the equipment, and the necessary test equipment to service any device in the station.

When a sufficient number of a certain device is used throughout the plant to justify its construction, a test-jig is a great convenience. This would include video distribution amplifiers, audio distribution amplifiers, etc., which require a separate power source that must be available for testing.

In addition to the aforementioned items, the shop should have on hand an ample supply of spare parts. Technical personnel get frustrated spending hours finding a defective component and then have to wait weeks to get a replacement. The records mentioned above will be of great value in determining frequency of failure and inventory required for various equipment parts.

A well-lighted shop, with sufficient floor space to wheel in a defective camera and still have room to walk around it, is desirable. The light should be controllable in intensity since certain television equipment maintenance is best done in subdued lighting conditions. This would include color picture monitor conveyance and oscilloscope waveform observation.

Any aggressive television station will find a need for some devices to make the task of producing a television program easier, which the broadcast equipment manufacturing industry did not anticipate. Development of these devices will be up to the Engineering Department of the plant. Due to the nonroutine nature of this, a special place should be allotted for this work where the parts and plans may be kept intact for the technical personnel involved.

News Center

Part of a television station's duty to its public is its ability to gather, assimilate, decipher, and report the news as accurately and quickly as possible. In order to do this, the news team must be given adequate facilities with which to work.

Basically, the written news is finally assembled in a newsroom. Proper planning would allow for a large newsroom, so that the reporters and writers may work informally together, but be near their producer, film editor, photographer, artist, and director. In order to accomplish this, the general news area should be situated adjacent to the film editing rooms, film library, the graphic department, and the film processing lab.

In addition, the newsroom can also serve as an instant news set. With proper planning, fast-breaking news may be reported on the spot. The key to this is a permanent set of hanging television lights, a full-time television camera, ready to go, and the reporter at hand to report what is happening now.

Finally, the newsroom should be equipped with adequate audio and video monitoring equipment for everyone to see and hear. If an event calls for a film crew, the assembling point is seconds away (a so-called hotline ready-room). The news cars are well equipped, and two-way communication is in full operational use. Thus, a properly planned news-gathering facility does bring extra dividends: (1) time saved, (2) money saved, (3) a high-working *esprit de corps,* (4) quality workmanship, and (5) possibly a greater listenership.

Program Screening and Rehearsal Rooms

Film and tape materials should be screened by station personnel before being broadcast. If economy dictates and machines are scheduled carefully, this can be done in the film and tape operations areas; however, a more efficient approach is to equip a room with film and tape viewing equipment separate from the broadcast equipment. Film projection and slide viewing equipment cost is nominal, but a videotape machine for this purpose may prove too expensive.

These programs should be checked for identification, quality, content, and accuracy of timing of segments. Some system of labeling with space for comments by the previewer should be implemented. This not only alerts the technician to possible trouble at air time, but gives the station a record of defects in films and tapes shipped in from other stations or sources.

A preshow meeting or conference room should be included near the studio. This room can be used for discussions prior to and during the rehearsal of the production. The room should be large enough to hold producers, directors, talent, technical people, and clients, and should be well ventilated.

Proper rehearsal requires the availability of all people involved in the production, all props and sets and all control room and studio facilities required during the actual production. Consideration must be given to rehearsal requirements in the design phase of a building if heavy production schedules are contemplated.

Traffic, Schedules, and Automation (Control Material Flow)

Location—Program Formats and Timing of Film and Tapes—Log Preparation, Automation and Special Feeds

The responsibility for preparation of schedules and logs generally falls to the Programming Department. One person is appointed to head up the Traffic Section and has perhaps the most difficult and important job in the station.

The coordination of films, tapes, slides, and live shows must be put on an operating log daily. Quality of the station's output and, in most cases, government regulation requires that the log be properly timed and accurate. Procedures must be set up to allow for late changes, including notification to the operating personnel of these changes.

Office space for the Traffic Department should be close to the operations area and the film and tape make-up area. The space can be a large room with a separate office for the traffic manager. Allowance should be made for large areas of counter working space. Film make-up and editing is a noisy operation; traffic operations require quiet areas for concentration on details. The two operations should not be in the same room but should be in close proximity.

A separate room should be assigned for receiving, shipping, and storing tapes and films. The handling of these materials is usually done by film editing personnel, but record keeping concerning the program flow may be done by traffic personnel if their work area is close to the Receiving Room. Because of the costs involved (film rental, videotape raw stock), accurate records of material in storage are essential. One of the major problems of material flow is timely discarding, erasing, or shipping program material no longer needed. This must be the responsibility of the Program Director.

Timing of programs (tape or film) is done by assistant or trainee directors. If editing to delete or change parts of the program becomes necessary, this information is given to the film or tape make-up people. The final times are then supplied to the Traffic Department for inclusion in the daily operating log. Films, tapes, or slides to be integrated within the program are selected by the Sales or Program Department and again entered on the log. This coordination of events of various times and sources leading to a finished program of stipulated length is put into effect by the Traffic Department.

The traffic people must also gather the various films, tapes, and slides, put them in orderly fashion, and deliver them to the operations people.

If automation of the air operations of the station is planned, the functions described above become more critical. If operations people are handling the various elements for broadcast, they may recognize and correct mistakes. This becomes more difficult with highly automated facilities. It should be noted, however, that once an automated broadcast operation is organized and working well, the on-air look is superior and the various facets of record keeping become more accurate. Automation puts an extra burden on the planning group but avoids the human errors in the implementation of those plans. A station considering automation will realize economies in the operational area but be prepared to respend some savings in additional programming, make-up, and traffic personnel.

MECHANICAL AND ELECTRICAL GUIDELINES

The following guidelines set forth the many mechanical and electrical considerations which should be considered when planning a broadcast facility:

Mechanical

A. General

1. Color television studios require special consideration in solving the many problems entailed in the mechanical design due to the high-lighting capacity, noise criteria, air distribution and emergency stand-by operation. Black and white, color television studios, and radio broadcasting facilities would require the same consideration, but some of the problems would not be as severe.

B. Design Conditions

1. The optimum summer and winter design conditions to be maintained by the air-conditioning system is 75°F dry bulb and 50 percent relative humidity. However, these conditions should be checked (in respective area with the owner's) since they may require slightly different criteria.

2. The outside design conditions are dependent upon the geographical location from data established by the US Weather Bureau.

C. Air-Conditioning Loads

1. Studio and production lighting for color television constitute the major portion of the heat gain and can exceed 75 percent of the total cooling load requirement. The unit lighting load requirement in the production area of the studio can equal 50-60 watts per square foot of floor area and in many cases this load can occur in any part of the studio since the production area and audience accommodations are flexible.
2. Transmission and solar heat gains are minimal since the exterior walls are well insulated and windowless.
3. Another contribution to the cooling load results from occupancy heat gain and the fresh air load. The fresh air requirement should be based on either 15 CFM per person, or the equivalent of one air change of fresh air, whichever is greater. It is also important to check and insure that the fresh air quantities conform with all code requirements.

D. Method of Air Distribution and Noise Control

1. Proper air distribution and air movement are of critical importance. Systems should be designed so that within a zone of 12 ft. above floor level, an air movement of 25 fpm is not exceeded. Air velocities exceeding the 25 fpm can cause movement of performer's hair, clothing, and stage props, which are usually highly expendable and flimsily built of thin canvas and light plywood.
2. The air supply should be introduced at a level above the movable lighting grid system to prevent interference with the closely spaced batten strips. Low-level return grilles located at the perimeter of the studio, in principle, would be desirable. However, due to the nature of studio operation, the grille could be blocked off by the cyclorama curtain or by studio props, which would result in an ineffective return air system. It could also be a possible source of noise generation. Locating the return air outlets at a level above the air supply will tend to relieve the neutral zone before it can heat the ceiling and radiate heat downward. Proper location of return air grilles and maintaining low velocities will eliminate any possible "short circuiting."
3. Noise criteria is of utmost importance and unless proper consideration is given to this problem, it can result in a nonproductive studio. Noise level should be within a range of NC 20 to NC 25, so as not to interfere with studio performance, particularly during scenes where there is no conversation and no background sound effects. Duct velocities should be designed for approximately 400 fpm within 10 ft. of diffuser or register opening, 525 fpm within 10-30 ft. from opening, 700 fpm within 30-50 ft. of opening, and 800 fpm within 70-90 ft. of opening.
4. All ductwork (supply and return) should be acoustically lined for sound attenuation and the sound power level of all outlets should be carefully checked to insure that it does not exceed the decibel rating at the end of the duct run, otherwise it will become additive (logarithmic) and negate a portion of the acoustically treated ductwork.
5. All piping should be insulated and all ductwork should be externally insulated to eliminate reflected sound in studios. Where ductwork and piping pass through walls or floor, the openings should be sealed with acoustical sound-deadening material. Ductwork and piping should be suspended from vibration isolators. Where ductwork and piping pass through studio walls, flexible pipe and flexible duct connections should be provided. Piping should be sized so that velocity of the medium transmitted is low enough to be inaudible.
6. Mechanical equipment should be located remotely from studio to eliminate transmission of sound and vibration. All equipment should be properly supported from vibration isolators. Sound traps for sound attenuation and flexible duct connections to prevent transmission of vibration should be provided for all air-handling apparatus.

E. Type of System and Control

1. Each studio should be served by its own air-handling apparatus and should consist of supply and return fans, filters, heating and cooling coils, sound traps and a purge exhaust system.
2. There are several schemes that can be utilized in the arrangement and selection of the component parts of the system, and this is somewhat dependent upon the economics, space conditions, and geographical location of the project. An "economizer" cycle utilizing 100 percent fresh air during intermediate season or a fixed percentage fresh air system can be used. The application of preheat coils is also dependent upon the percentage of fresh air and geographical location. Heating coils can be either steam or hot water type and cooling coils should be of the chilled water type. In areas where freezing outside temperatures are experienced, special conditions have to be considered to prevent possible "freeze-up" of preheating coils and chilled water coils.

3. A separate purge exhaust system should be provided to permit studio to be evacuated during periods when it is not in operation. During purge operation, the system should handle 100 percent outside air without attempting to maintain studio design conditions. Where an economizer-type cycle is provided, purging of the area can be accomplished by resetting controls to 100 percent outside air.

4. Control system should be arranged to control studio temperature, and where facilities are provided for audience participation, additional humidity control should be provided.

5. The installation of a Supervisory Data Center would provide operational supervision of the project and would include remote control for resetting of space temperatures and humidity, starting and stopping of air handling system, "read-out" of other pertinent air and water temperatures and alarm indication.

6. Pneumatic temperature control system should be provided with standby air compressor with automatic cut-in features.

F. Stand-By Operation

1. Due to the critical operation of the Master Control Room and Videotape Room, a separate air-handling system shall serve these areas with provisions for standby equipment in the event primary equipment fails. This can be accomplished by interconnecting the ductwork (properly dampered) with another air-handling system serving a noncritical area in the building (i.e., office areas), thereby permitting the Master Control Room and Videotape Room to be satisfied during an emergency period. Another desirable feature to be incorporated in the system is provision for handling 100 percent fresh air in the event refrigeration equipment becomes inoperative.

2. Multiple refrigeration equipment and boiler equipment should be provided so that in the event a single unit becomes inoperative, partial operation can maintain conditions in critical areas.

3. Compressed air system serving videotape machines should be provided with standby compressors to insure continuous operation. Compressors that are water cooled can operate off the chilled water system and arranged so that in the event there is a loss in chilled water pressure, the cooling system will automatically switch over to city water.

4. In the event of an electrical power failure, an emergency generator should start automatically to maintain operation of the boilers, heating pump, air-handling system serving the Master Control Room and Videotape Room, pneumatic temperature control air compressor and air compressor serving videotape machines.

Electrical

A. General

1. This outline description covers general electrical installations for large television broadcasting facilities.

B. Codes and Regulations

1. The complete electrical installations shall be provided in accordance with the latest revisions of the National Electrical Code and all other codes and regulatory agencies having jurisdiction. The installation shall be subject to the approval of the FIA.

C. Area Classification

1. All electrical installations, materials and equipment shall comply with the classification "General Purpose" except for hazardous areas which shall be designed for Class I, Group D, explosion-proof conditions.

D. Incoming Power Service and Metering

1. Incoming power service may be high voltage (4.16 kv or 13.8 kv) due to high load requirements.

2. Standby incoming service shall be provided with automatic transfer when normal service fails.

3. One point of primary metering shall be provided to obtain best possible utility rates.

E. Primary Distribution

1. Distribution within complex may be high voltage (4.16 kv or 13.2 kv) from a primary switchgear to unit substations located as close as possible to the center of the loads served.

2. Separate unit substations shall be provided for different type loads, as follows:

   a. With secondary 120/208 v to handle equipment and motor loads and all fluorescent lighting;

   b. With secondary 120/208 v to handle receptacle, incandescent lighting and small equipment loads;

   c. With secondary 120/208 v to handle studio production lighting only;

   d. With secondary 120/208 v to handle technical TV loads only.

3. Each unit substantion shall include components as follows:

   a. Primary compartment with Hv fused load break switch;

   b. Open dry type transformer with Hv primary delta and secondary 120/208 v or 277/480 v, 3 phase, 4 wire. Sound rating of transformer shall be best possible;

c. Voltmeter, ammeter, and selector switches;

d. Main secondary air circuit breaker;

e. Moulded case feeder circuit breakers and spares.

F. Secondary Distribution

1. Power shall be extended from unit substations with cable and conduit to automatic circuit breaker panels and motor control centers.
2. Motor control centers shall be Class I, Type B, with combination magnetic, full voltage starting, circuit-breaker-type motor starters or circuit breakers only for 480 v, 3-phase operation. Each starter shall have 3 thermal overloads.
3. Power panels shall be designed for 480 v, 3-phase, 3-wire service. Panels shall be of the dead front type with automatic circuit breakers of ampere rating as required.
4. Panels for receptacle and incandescent lighting loads shall be designed for 120/208 v, 3-phase, 4-wire service. Panels shall be of the dead front type with automatic circuit breakers of ampere rating as required.
5. Lighting panels shall be designed for 277/480 v., 3-phase, 4-wire service. Panels shall be of the dead front type with 20 ampere automatic branch circuit breakers. Panels shall be similar to Westinghouse Type NH1B-4.

G. Conduit

1. Rigid steel conduit asphaltum painted shall be used when installed in concrete slabs, below grade and outdoors above grade.
2. Rigid aluminum conduit shall be used for exposed installation in mechanical equipment rooms, damp locations and locations where exposed to mechanical damage.
3. Rigid aluminum or steel conduit shall be used for all feeder and subfeeder runs.
4. Steel EMT with compression weathertight fittings shall be used for all other branch circuit wiring indoors and above grade.

H. Wire

1. Hv cable shall be single conductor cross-linked polyethylene insulated and shielded.
2. Building wire shall be Type THW rated at 600 v-75 degrees C No. 12 AWG and smaller shall be solid copper. No. 8 AWG and larger shall be stranded.
3. Fixture wire shall be Type AF, 300 v insulation.
4. Minimum wire size shall be No. 12 AWG, except No. 14 AWG for control wires. Maximum wire size shall be No. 500 MCM.

I. Grounding

1. Electrical grounding shall be provided in accordance with the National Electric Code. Equipment enclosures, electrical service, transformer neutrals, outdoor lighting standards, and cable shielding shall be grounded.
2. Insulated bushings and double lock nuts shall be provided at all panel boards and pull boxes in feeder runs and pull boxes shall be bonded through with bare copper wire.
3. Separate technical equipment ground system shall be provided as required.

J. Switches, Wiring Devices, Wall Plates and Special Enclosures

1. Single pole switches shall be 20 amperes, 120/277 v, ac, quiet type.
2. Duplex receptacle shall be 20 amperes, 125 v, 2 pole plus U-slot ground.
3. Special outlet to be provided as required.
4. All wall plates for switch, receptacle, and telephone outlets shall be .06 in. stainless steel.

K. Telephone System

1. Two incoming underground services are required, one for technical use and one for commercial use.
2. Equipment room for the technical service shall be located close to Master Control and there shall be a cable-tray tie between the equipment room and Master Control.
3. The commercial system shall be complete, consisting of conduits from equipment room outlying telephone closets and interconnecting panels and thence to the various outlets as required. All installations shall be in accordance with the requirements of the local telephone company.
4. Interconnecting panels shall be of steel with plywood backboard, full opening door, latch, cylinder lock and trim.
5. Telephone closets shall be furnished with plywood backboard.
6. Conduits shall be ¾ in. minimum.
7. Telephone outlets shall be 4 in. sq. with bushed hole cover plate.
8. Equipment instruments and wiring shall be by the telephone company.
9. Some recent trends are for the broadcast station to actually own the telephone equipment. Should this be true, Items 1 through 7 are still to be used as a guide.

L. Public Address System

1. A complete PA system consisting of amplifiers, loudspeakers, and microphone shall be provided.

2. Loudspeakers shall be located in corridors throughout the complex and calls shall originate from the telephone operator's desk.

3. System shall be zoned as required.

M. Fire Alarm System

1. The fire alarm system shall be closed circuit zoned, consisting of control cabinet, gongs, manual stations and automatic fire detectors.

2. Manual stations shall be provided at each stair on each floor and at all ground level exterior doors.

3. Automatic thermal or smoke detector shall be provided in all areas except where sprinkler heads are installed.

4. Each sprinkler alarm valve shall indicate on the fire alarm panel zone annunciator as a separate zone when activated.

N. Video Cable Trays and Audio Signal Conduits

1. A system of cable trays and signal conduits originating from Master Control shall be provided to studio control rooms, studios, microwave rooms, electronic shop, program computers, etc.

2. In addition, a separate cable tray with antenna cables shall be provided from Master Control to all areas where antenna outlets would be required.

O. Studio Production Lighting System

1. Unit substation and dimmer board shall be located as close as possible to studio served.

2. Unit substantion shall include the following:

   a. Electrically operated main circuit breaker to permit remote control from studio floor.

   b. Transformer with 6-2½ percent taps, 3 above and 3 below rated primary voltage, to compensate for possible secondary voltage variations.

3. Other work shall be as follows:

   a. Wireway with wiring from load side of dimmers to studio floor patch panel.

   b. Studio grid wireways with load wiring to studio patch panel;

   c. Wiring under studio floor from studio floor "pockets" to studio patch panel;

   d. Control wiring from studio control console to dimmer board.

4. In sizing unit, substantions serving dimmer boards, a 50 percent demand factor may be applied to connect dimmer load.

5. An "on-air" studio warning light system be provided as required.

P. Security

1. The following security systems shall be provided:

   a. Supervision of all exterior doors on ground level, with control cabinet in guard room;

   b. Closed circuit TV cameras at key positions, with monitor in guard room;

   c. Manual nonwired watchman's tour stations located throughout complex;

   d. Electrically operated gates to control automobile traffic.

Q. Emergency System

1. Power for the emergency system shall be provided with a water-cooled diesel generator set with generator voltage 277/480 v, 3-phase, 4-w. The installation shall include all accessories such as automatic transfer switch, output switchboard, battery starting set, oil storage tank, fuel pump, mufflers, vibration isolators, etc.

2. Generator set shall automatically sense power failure or 80 percent undervoltage, start engine, attain and maintain speed, and transfer emergency load. Manual override of start and transfer of load controls should be provided.

3. Provide local transformer with primary delta 480 v, 3-phase and secondary 120/208 v, 3-phase, 4-wire to serve 120/208 v loads on emergency supply.

4. Loads on emergency supply shall include stair lights, exit signs, selected corridor lights, PA system and all technical lighting and heating, ventilating, and air conditioning loads required for transmission of live news programs and taped programs.

R. Lighting (277 v for Fluorescent, 120 v for Incandescent)

1. Lighting fixtures shall be completely installed with all required outlet boxes and accessories.

2. Lighting levels shall be in accordance with IES latest recommendations, with minimum 100 FC in working areas.

3. Fluorescent fixtures shall be used for general illumination. Fixtures shall be with 40 w RS lamps and HP factor ballast, with best sound rating. Fluorescent fixture types shall be as follows:

   a. Recessed with acrylic lens diffuser to be used in areas with hung ceiling;

   b. Surface or pendant mounted with wraparound acrylic lens diffuser to be used in stairs and other selected areas with exposed ceiling;

   c. Industrial RLM with porcelain reflector to be used in mechanical equipment rooms, storage rooms, etc.

4. Executive offices and conference rooms shall be provided with dimmer-controlled incandescent lighting using recessed fixtures.

5. Selected walls and art work shall be illuminated with recessed ceiling-mounted incandescent wall-washing fixtures.

6. Make-up room mirrors shall be illuminated with special bracket wall-mounted fluorescent fixtures. Dressing room mirrors shall be illuminated with special wall-mounted strips with incandescent bare lamps.

S. Outside Lighting

1. Outside lighting shall include illumination of audience concourses, entrances, parking lots, signs, building exteriors, planters, etc.

2. Lighting levels for all outside area illumination shall be strictly in accordance with IES latest recommendations.

T. Miscellaneous

1. Wall-mounted clocks operating on 120 v shall be provided complete with outlet in designated areas.

2. Clock system for technical use with master clock in Master Control and indicating clocks in studio control rooms, offices, etc., shall be provided as required.

3. Local office intercommunication systems shall be provided as required.

4. Local sound systems shall be provided for large conference rooms.

Cost Estimating

The following Checklist and Project Budget Form are designed for estimating the cost of station construction.

SUGGESTED CHECKLIST FOR COST ESTIMATING

Item

1. Land
2. Land tests
3. Site clearing
4. Architects' and engineers' fees
5. Permits
6. Special consulting fees (include interior decorator)

General Construction

1. Heating, ventilating and air conditioning
2. Plumbing
3. Electrical
4. Architectural
5. Special in-house cabling (TV, Music, PA)

Interior Finish

1. Wall covering (fabric or paint)
2. Floor covering
3. Special studio treatment

Furniture and Fixtures

1. Decorative office furniture
2. Standard office furniture
3. Office area built-ins
4. Working area counters, cabinets and built-ins
5. Draperies
6. Art work

Telephone

1. Broadcast line facilities
2. TWX or facsimile
3. Type of switchboard (owned or leased)
4. Office interconnection needs
5. Number of private lines
6. System—owned or leased

Miscellaneous Items (likely to be overlooked):

1. Xerox outlet (special power hookup)
2. Special ventilation for odor areas.
3. Building maintenance equipment closets.
4. Drinking fountains and vending machine areas.
5. Space for air conditioning subdistribution boxes, fans, etc.
6. Special waste water treatment for film darkroom processing, if local ordinances dictate.
7. Cable connection to roof for radio and television antenna system and two-way antenna.
8. Possible microwave antenna mounts.

PROJECT BUDGET FORM

Call Sign ____________________ Start Date ____________________

Service (Radio or TV) ____________________ Finish Date ____________________

Type of Facilities: (Check as applies)

Office ________ Studio ________ ____________________
Street address of project

Transmitter ________ Mobile ________

____
City, State and Zip

Item #	*Description*	*Estimate*	*Actual*
1.	Land purchase/lease	________	________
2.	Survey—property (and other)	________	________
3.	Title search/insurance	________	________
4.	Real estate broker/commission	________	________
5.	Architects/engineers—fees	________	________
6.	Permits and licenses (if separate)	________	________
7.	Consultants—acoustic structural, etc.	________	________
8.	Site preparation and demolition	________	________
9.	General construction and finish	________	________
10.	Optional construction items and finish	________	________
11.	Special construction and finish	________	________
12.	Furniture and fixtures	________	________
13.	Decoration—interior	________	________
14.	Landscape—exterior	________	________
15.	Special equipment—electronic (and other)	________	________
16.	Special equipment—installation of above	________	________
17.	Contingencies (including price increases)	________	________
18.	Other	________	________
19.	Other	________	________
20.	Other	________	________
	Totals	________	________

Prepared by ____________________ Checked by ____________________ Approved ________

CONSTRUCTION EXAMPLES

The five examples that follow illustrate three degrees of construction for radio facilities and two for TV stations. All stations are in large cities, with construction being completed between 1967 to 1973. Cost increases over the last few years have been continuous and are almost totally unpredictable in a general manner. They must be examined carefully by competent architects and construction engineers for the specific structure and area involved if there is to be any accuracy in budgeting the project.

Two major factors contributing to cost overrun on projects are inadequate initial plans and the resultant change orders during construction. Also, there must be an owner's supervisor highly involved in the project on a *daily* basis.

In each case, a general contractor was retained and coordination was handled by staff engineering personnel.

Electrical costs include power to all equipment, but not wages paid to staff technicians who installed the broadcast equipment.

Architectural and consulting fees are for outside help only. No attempt was made to estimate time spent by staff personnel in layout and planning.

Decoration fees include the services of an interior decorator and the cost of all decorative furniture (sofas, lounge chairs, etc.). This furniture was generally used in reception areas, conference rooms, and executive offices. The decoration costs also include the purchase and installation of carpet, the purchase (but not installation) of vinyl or paper wall coverings, and also draperies.

Special fees, permits and licenses are included in the general construction and architectural costs.

Cost of broadcast equipment is not included in the examples, but the "special woodwork, built-ins" section does cover the custom cabinetry and tables necessary to mount equipment such as audio mixers, video switchers, and producers' consoles.

Example I

This FM station, in Washington, D.C., had been a minimal facility. The decision was made to construct first-class office and studio space in the lower level of an existing six-year-old building. All furniture, fixtures, and equipment were to be new and an interior decorator was to coordinate colors and furniture in the office area.

The space selected had few existing partitions, but building air-conditioning was available. An additional 10-ton unit was added to serve the studios, Master Control, and the Newsroom, with both supplemental and emergency cooling.

The major part of the architectural layout and planning was done by engineering staff personnel. (This is why the architectural and consultant fees are relatively low.)

All equipment was new and installed by staff personnel. This station is a combo operation and no control rooms were necessary.

Cost figures are as follows:

Cost Figures

Total area	3,800 sq. ft.
Total cost of construction	$127,553
Cost per sq. ft.	$33.57

Component Costs		*Totals*	*Per sq. ft.*
I. General Construction			
a. Demolition	$ 543		
b. Concrete, masonry, plaster, and painting	3,850		
c. Partitions, doors, hardware	8,124		
d. Acoustical ceiling and studio wall acoustic	3,813		
e. Vinyl tile	764		
f. Carpentry, glass	4,727		
g. Contractor's labor, insurance, taxes	8,246		
h. Rental equipment & miscellaneous expense	6,882		
Total general construction		$36,949	$9.72
II. Electrical		30,017	7.90
III. Heating, ventilating & air conditioning		21,331	5.61
IV. Plumbing		4,500	1.18
V. Architect's fee		6,825	1.80
VI. Special woodwork, built-ins		4,712	1.24
VII. Decoration		11,572	3.04
VIII. Office furniture		11,647	3.07

Example II

This is an AM-FM station in Philadelphia, Pa. It was decided to completely remodel, rearrange and redecorate the entire station, in a 30-year old building. The studios, control rooms, Master Control, and the news operation were to be moved from the first floor to the third floor. It was necessary to construct six new studios (3 for AM, 3 for FM) in an area that was office space. This required demolition of the office areas and replacement with block-wall construction. Computer flooring was used in all studios, control rooms and in Master Control.

A complete new 35-ton air conditioning system was installed to serve the technical and studio areas and was designed for both supplemental and emergency use. Existing air conditioning was used for general offices.

In the office areas, about 15 percent of the partitions were removed, relocated, or built anew. New ceiling was installed throughout.

Most of the layou' and mechanical and electrical design work was done by an architectural firm. Decoration was done by an interior decorator and new furniture and fixtures were used throughout the building.

All studio and newsroom equipment were new and installed by staff technicians. The pulling of interconnecting wiring was done by electricians and is included in the electrical cost.

Cost figures for Example II are as follows:

Cost Figures

Total area	21,764 sq. ft.
Total cost of construction	$613,795
Cost per sq. ft.	$28.20

Component Costs		*Totals*	*Per sq. ft.*
I. General Construction			
a. Demolition	$20,121		
b. Concrete, masonry, plaster, ceramic, paint	53,929		
c. Partitions, doors	36,360		
d. Acoustical ceiling and studio wall acoustics	16,575		
e. Vinyl tile and floating floors	7,548		
f. Finish hardware & mis. metal	25,559		
g. Carpentry & millwork, glass	34,813		
h. Contractor's misc. expenses	6,841		
Total General Construction:		$201,746	$9.28
II. Electrical (large am't. already existing)		57,529	2.64
III. Heating, ventilating & air conditioning		117,709	5.41
IV. Plumbing		11,482	.53
V. Architect, electrical engineering, mechanical engineering		76,618	3.52
VI. Special woodwork & built-ins		12,825	.59
VII. Decoration		78,441	3.60
VIII. Office furniture		57,445	2.64

EXAMPLE III

This is an AM Radio facility in Oakland, California. The station was to be relocated in a completely different building to one floor of a newly rebuilt structure. Five studios were to be constructed (an allowance for growth of the station).

The existing floor was a shell. Building air conditioning was available but it was necessary to run all interior ductwork.

Dual wall studio construction was used. Computer floors were installed in Master Control and control rooms. To reduce solar heating and external noise problems, a peripheral isolation corridor was placed between studio and outside building walls. This also provided excellent traffic flow and good emergency exit measures.

All studio and newsroom equipment were new and installed by staff technicians. The pulling of interconnecting wiring was done by electricians and is included in the electrical cost.

Most of the layout and mechanical and electrical design work was done by an architectural firm. Decoration was done by an interior decorator and new furniture and fixtures were used throughout the building.

Cost figures for Example III are as follows:

Cost Figures

Total area	14,950 sq. ft.
Total cost of construction	$344,671
Cost per square foot	$23.07

Component Costs	*Totals*	*Per sq. ft.*
I. General construction	$126,176	$8.44
II. Electrical	71,549	4.79
III. Heating, ventilating, air conditioning	88,339	5.91
IV. Plumbing	21,322	1.43
V. Architect, electrical engineer, mechanical engineer	18,064	1.21
VI. Special woodwork and built-ins	19,221	1.29

Example IV

This is a UHF-TV station in San Francisco, California. The basic aim was to build an office and studio complex (two studios) for a reasonable cost. The station was not doing well economically and it was felt that live studio facilities might help to establish extra income.

A 20,000 sq. ft. former warehouse was leased. The first phase of construction was to remodel and decorate the small office area which had been a part of the former warehouse operation. All fixtures and furnishings were new.

An architect was retained on an hourly basis and much of the operation area layout work was done by staff engineering personnel.

The basic operating facility included total new construction in the open warehouse area of the two studios, one control room, Master Control, shop, newsroom and film-tape storage, and editing area. Future plans were to add a second control room and photo development area. The expansion area was left unfinished.

The warehouse had a minimum air conditioner for the office area, therefore, 40 tons of air conditioning was added for the studio and operations and office areas. This work was contracted for separately (not through a general contractor).

All equipment was installed by staff technicians, but electrical cost does include pulling of wiring for power to the equipment.

The cost figures do not include decorator items, furniture, or equipment.

Cost Figures

Total area	20,000 sq. ft.
Total cost of construction	$618,380
Cost per square foot	$30.92

Component Costs		*Total*	*Per sq. ft.*
I. A. General construction (walls, doors, floor, ceiling, glass, labor & materials, contractor's overhead & profit)	$189,334		
B. Painting & plaster	28,970		
C. Hardware	24,067		
D. Structural steel (includes lighting grid)	18,022	$260,393	$13.02
II. Electrical		152,026	7.60
III. Heating, ventilating, air conditioning		158,400	7.92
IV. Plumbing		16,000	.80
V. Architect, electrical engineering and mechanical engineering		24,468	1.22
VI. Special woodworking (built-ins and counters)		7,074	.36

Example V

This is a VHF-TV station in Los Angeles, California, completed in 1970. Construction here was a major project. Old buildings were removed, considerable site work was done, and a completely new and modern three-story structure was built. It is a good illustration of where we have utilized the "Suggested Checklist for Cost Estimating," illustrating the large number of items that must be considered in planning a project of this size. Also included here for this example is a night view photograph of the structure (Fig. 22) and plans for the three floors of the building (Figs. 23, 24, and 25).

Cost Figures

Total area	145,000 sq. ft.
Total cost of construction	$6,915,793
Cost per sq. ft.	$47.69

	Component Costs	*Totals*	*Per sq. ft.*
I.	Demolition, Site Work, Landscaping	$178,477	$1.23
II.	Structural	873,476	6.02
III.	General Construction	3,096,745	21.36
IV.	Electrical	367,900	2.54
V.	Heating, ventilating, air conditioning	930,125	6.41
VI.	Plumbing	209,829	1.45
VII.	Architect, electrical engineering, mechanical engineering, soil testing	497,695	3.43
VIII.	Special acoustical (including ceilings)	263,893	1.82
IX.	Special woodwork & built-ins	87,251	.60
X.	Decoration	267,233	1.84
XI.	Office furniture	143,169	.99

Fig. 22. Night View of KTTV.

TABLE 1
Comparison of Examples

	I	II	III	IV	V
	Move studios & remodel 21,764 sq. ft.	New station— from shell 14,950 sq. ft.	New station— from shell 3,800 sq. ft.	New station— from shell 20,000 sq. ft.	New building 145,000 sq. ft.
	Philadelphia	Oakland	Washington	San Francisco	Los Angeles
Demolition, site work, landscaping	—	—	—	—	$178,477/1.23
Structural	—	—	—	—	873,476/6.02
General construction	$201,746/9.28	$126,176/8.44	$36,949/9.72	$260,393/13.02	3,096,745/21.36
Decoration	78,441/3.60	—	11,572/3.04	—	267,233/1.84
Office furniture	57,445/2.64	—	11,647/3.07	—	143,169/.99
Heating, ventilating & air conditioning	117,709/5.41	88,339/5.91	21,331/5.61	158,400/7.92	930,125/6.41
Electrical	57,529/2.64	71,549/4.79	30,017/7.90	152,026/7.60	367,900/2.54
Plumbing	11,482/.53	21,322/1.43	4,500/1.18	16,000/.80	209,829/1.45
Architect, elec. & mech. engineering	76,618/3.52	18,064/1.21	6,825/1.80	24,468/1.22	497,695/3.43
Special woodwork & built-ins	12,825/.59	19,221/1.29	4,720/1.24	7,074/.36	87,251/.60
Special acoustical (including ceilings)	—	—	—	—	263,983/1.82
Totals per sq. ft. cost	$28.20	$23.07[a]	$33.57	$30.72[a]	$47.69

[a]These increase by approximately $6.00/sq. ft. if decorator and office furniture is added.

TABLE 2
Estimating Costs

Totals

New studios and offices (complete new structure)	$40 to $60/sq. ft.
Conversion for studios & offices (in existing structure)	$25 to $35/sq. ft.
Transmitter building (new structure)	$25 to $40/sq. ft.

Separate elements

Demolition and site work	$1.00 to $1.50/sq. ft.
Structural	$5.00 to $7.00/sq. ft.
General construction	$10.00 to $25/sq. ft.
Heating, ventilating and air. cond.	$5.00 to $8.00/sq. ft.
Electrical	$3.00 to $9.00/sq. ft.
Plumbing	$0.75 to $2.00/sq. ft.
Arch & engineering fees	$1.25 to $3.50/sq. ft.
Special acoustical	$1.50 to $2.50/sq. ft.
Woodwork and built-ins	$0.60 to $1.50/sq. ft.
Office furniture	$1.50 to $3.50/sq. ft.
Decoration	$2.00 to $3.50/sq. ft.

Note: Electronic equipment installation and wiring not covered by any of above. A good general rule is to allow 10 percent to 20 percent for this in addition to basic equipment cost. Variation is due to location, personnel, working rules, etc.

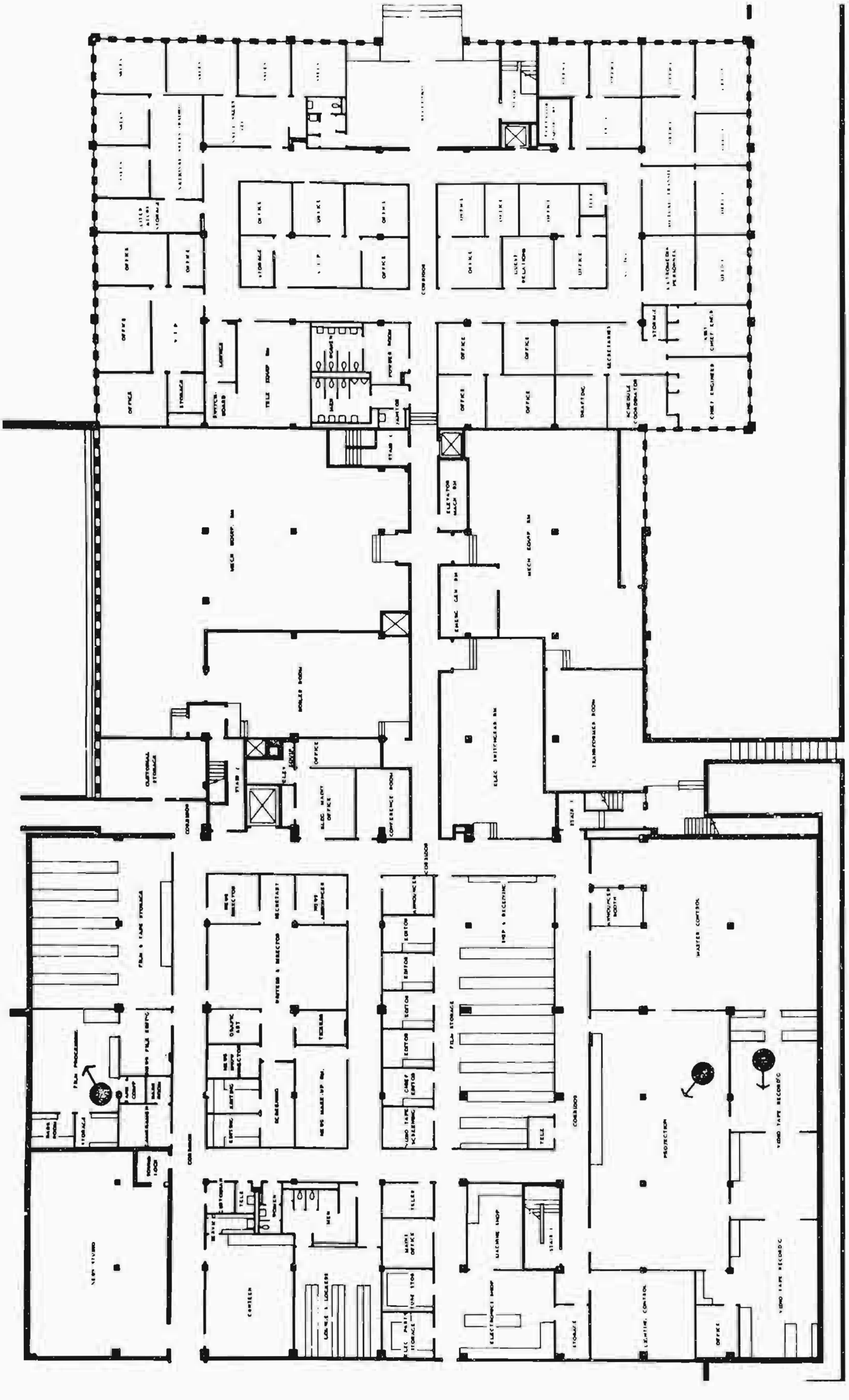

Fig. 23. First floor KTTV-TV.

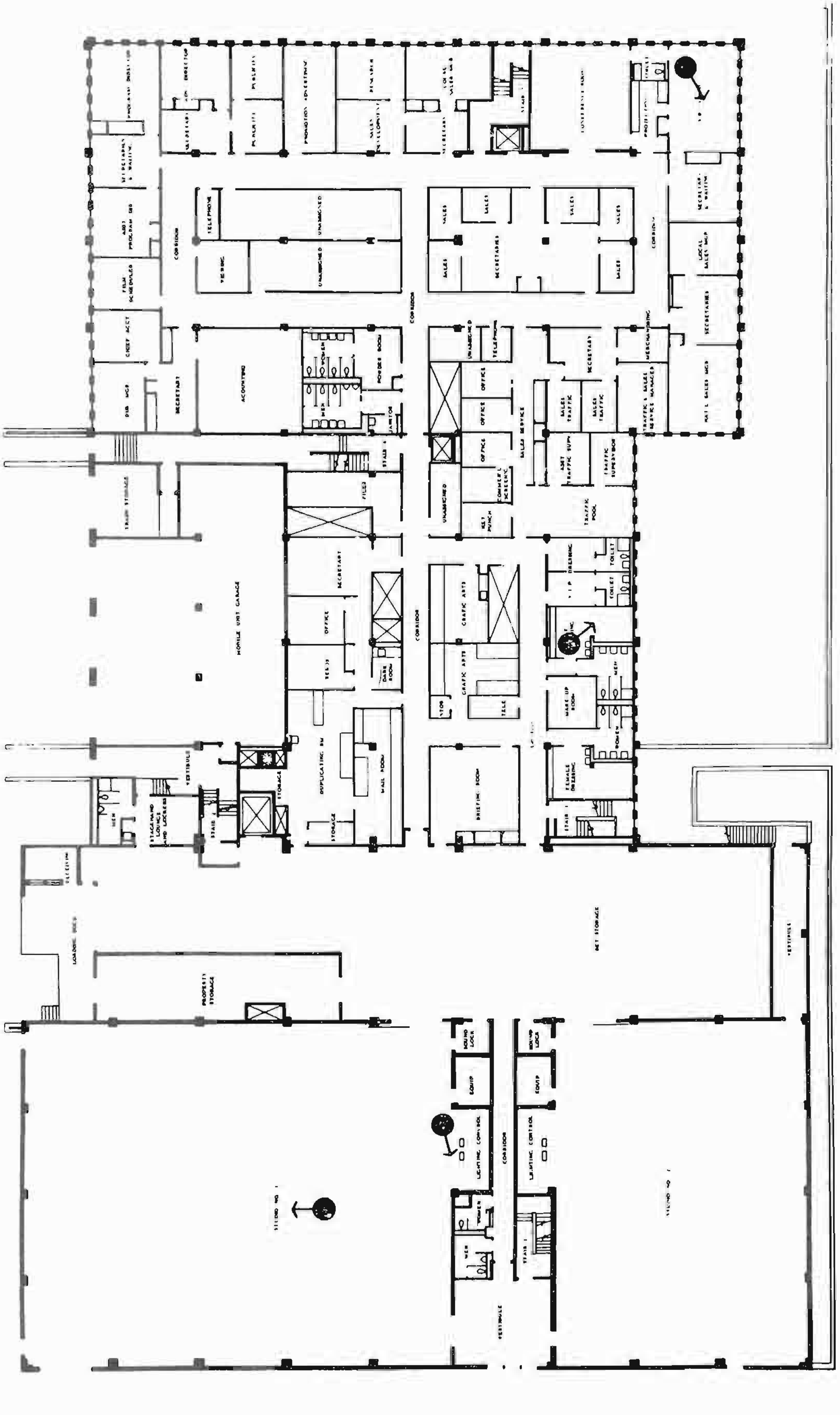

Fig. 24. Second Floor KTTV-TV.

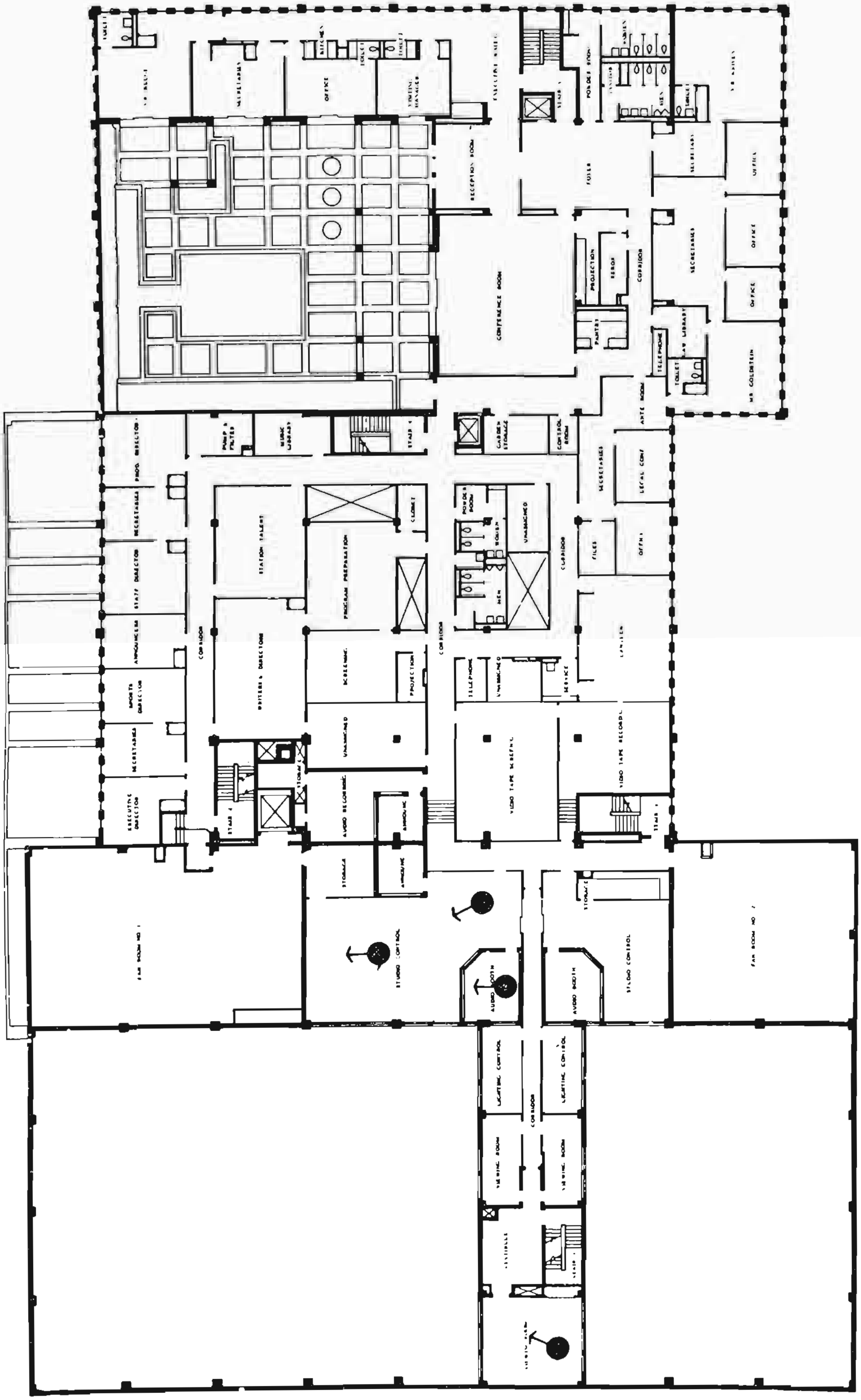

Fig. 25. Third Floor KTTV-TV.

MICROPHONES—APPLICATION AND OPERATION[6]

Things are not always what they seem. It takes a complete understanding of microphones and their operating parameters to make valid assumptions by looking at their specifications. Obviously, the real test comes when the microphone is used; however, by remembering some of the basics about microphones and their design, a more accurate guestimate can be made as to the performance of a microphone by carefully examining its performance characteristics from the data sheet.

As can be noted from Fig. 26, there are two response curves. One with the low frequency rolloff and a rather major high frequency rise in the 5 kHz area. The other curve is relatively smooth with the low end extended and the high frequency rise gone. These two response curves are from the same lavalier microphone. When used in the lavalier position the high frequency peak, because the user is off-axis, is reduced and the low frequency response of the microphone is increased because of the location of the lavalier in the chest cavity area.

The three types of microphones normally considered for professional applications are (1) condenser, (2) ribbon, and (3) dynamic. They are depicted in Fig. 27.

The normal pickup patterns for microphones are (1) omnidirectional, (2) unidirectional, and (3) bidirectional. The unidirectional or cardioid pattern has many variations such as supercardioid, hypercardioid, etc., but for discussion purposes, it is basically a microphone that picks up from the front and rejects from the rear.

An omnidirectional microphone is a favorite for general purpose use since it performs reasonably well. Without knowing the limitations of directional type microphones, the user is sometimes plagued with either handling, pop, or wind noise, and shies away from using a directional microphone even though it might provide superior performance for a particular pickup.

An omnidirectional microphone should, theoretically, pick up equally well from any direction; that is, however, not true. An omnidirectional microphone when rotated off-axis from the sound source will exhibit what is known as a shadow effect, and the high frequency response from the rear of the microphone is not as good as it is on-axis. Therefore, an omnidirectional microphone is only omnidirectional from mid and low frequencies.

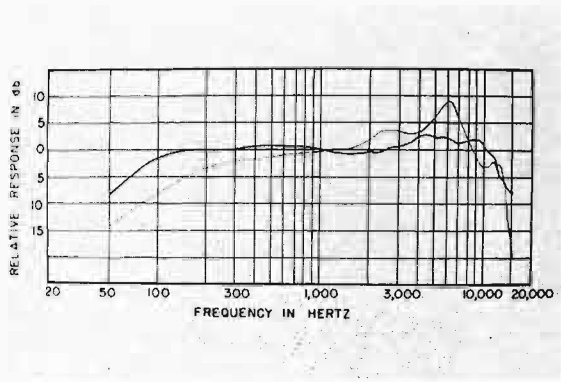

Fig. 26. Two response curves—one with low frequency rolloff and the other relatively smooth with the low end extended and the high frequency rise gone.

A bidirectional microphone, which normally is of the ribbon variety, has a pickup pattern that is sometimes referred to as the figure eight; that is, front and rear have equal pickup while the sides, top, and bottom have maximum cancellation. It was very common to see a large ribbon microphone hanging from a rope in radio studios over a desk with announcers on either side talking towards each other into the ribbon microphone. This particular arrangement, because of the cancellation at the top, bottom, and sides gave maximum rejection of the unwanted paper suffling noise on the desk below and, consequently, was an excellent choice for this type of application.

There are many sound reinforcement applications where a bidirectional microphone works extremely well, especially where ceiling loud speakers are fairly close to the microphone. The dead part of the bidirectional microphone can be pointed toward the ceiling loud speaker, and maximum rejection of the unwanted direct signal coming from the overhead system is then achieved.

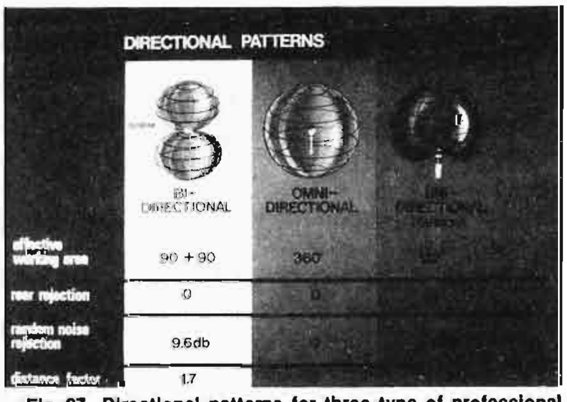

Fig. 27. Directional patterns for three type of professional microphones (1) condenser, (2) ribbon, and (3) dynamic.

[6]Written by K. K. Reichel, Shure Brothers.

'The unidirectional microphone on the other hand has maximum rejection from the rear, or slightly off-axis from the rear in the case of a supercardioid microphone, and has a front working angle of approximately 132°. This figure will vary with the type of pattern, but the data sheet for the microphone should state precisely what the front pickup angle is. This usually refers to its 3 dB downpoint, so the user can determine the proper placement of a unidirectional microphone. Note that the random noise rejection of the various microphones indicates that a bidirectional or unidirectional microphone has a 9.6 dB random noise rejection. This means that in many applications the comparison between a directional and an omnidirectional microphone, in a studio or stage environment, would indicate that the directional microphone is considerably quieter in terms of background noise than the omnidirectional microphone. When rejection of unwanted background noise is desirable, whether it be an air conditioner or audience noise, elimination of this noise is better achieved by using a directional microphone.

Not only does the directional microphone help reduce the unwanted background noise but also choosing the correct pattern, whether it be bidirectional or unidirectional, can be determined by the direction of the unwanted noise source assuming a direct radiation from the noise source. In other words, point the deadest portion of the directional microphone directly toward the noise that is in need of elimination. The distance factor relates very much to the same concept as does the random noise rejection and this simply shows that in comparison to an omnidirectional microphone, a directional microphone will allow the performer to work 1.7 times further from the microphone with the same effective background noise level in a room.

The concept of placing the unwanted signals outside the pickup pattern of a directional microphone is shown in Fig. 28. Here both guitar amplifier speakers and public address loud speakers are outside the 132° pickup angle of a directional microphone. If these loudspeakers were moved into the pickup pattern of the microphone, obviously, in the case of the sound reinforcement system, there would be a greater tendency towards acoustical feedback and in the case of the guitar amplifier, a greater amount of sound pickup by the microphone that eminated from the guitar amplifier loudspeaker. However, the performer may not be able to hear the sounds coming from the public address or guitar amplifier loudspeaker as well as he might like to; therefore, a solution is to use a stage monitor loudspeaker, which is normally placed at the foot of the performer pointing up into the deadest part of the undirectional microphone. This

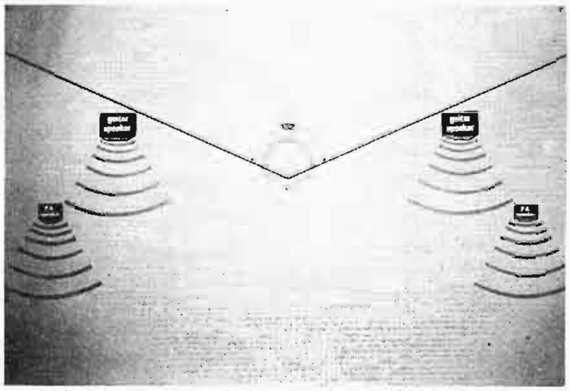

Fig. 28. The concept of placing the unwanted signals outside the pickup pattern of a directional microphone.

will then let the performer hear enough of the musical amplifier signal as well as his own voice to satisfy his needs and yet allow a good level in terms of gain before feedback and isolation of instruments from vocals.

All unidirectional microphones exhibit a phenomena called "proximity effect" which is depicted in Fig. 29. This means that as the performer gets closer to the microphone, the low frequency output of the microphone goes up faster than does the high and mid frequencies. This is neither good nor bad, but it depends on the application of the microphone as to what degree of proximity effect is desired.

Many recording studios and broadcast stations use microphones with appreciable proximity effect to increase the separation between musical instruments. As an example, in Fig. 29 the top curve (dotted line) represents the microphone when brought from 2 ft. to 6 in. If on the console the microphone is re-equalized so it has the same response at 6 in. that it had at 2 ft., the user can effectively gain the amount of isolation shown in the stripped area on the bottom of the curve in terms of added rejection from unwanted sounds from the rear of the microphone.

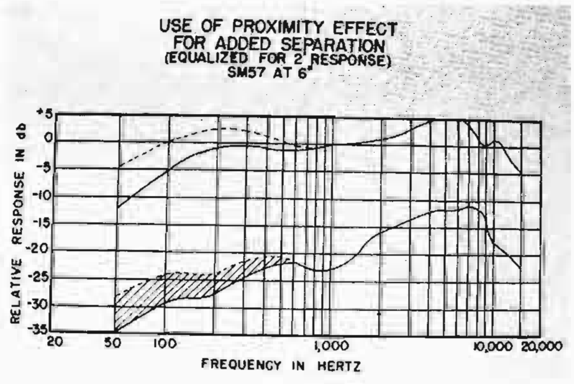

Fig. 29. Use of promimity effect for added separation.

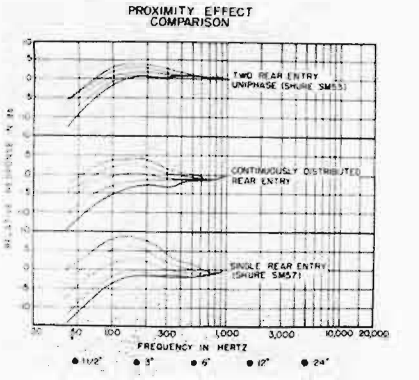

Fig. 30. Promimity effect comparison.

Take two microphones, one with more proximity effect than the other and listen only to that particular channel and compare the two microphones when set for the same level. The microphone with the higher degree of proximity effect would sound as if it had less pickup of the unwanted noise than did the microphone with less proximity effect.

Many performers use microphones with proximity effect to get an intimate warm sound. Many entertainers use this as part of their act and require the proximity effect to make their performance sound normal. Omnidirectional microphones do not exhibit proximity effect whereas bidirectional microphones typically have quite a bit of proximity effect.

Fig. 30 is a comparison of three types of unidirectional microphones and their amount of proximity effect. The curves are shown from 24 in. down to 1½ in.

Depicted on the lower curve is a single entry unidirectional microphone and the amount of proximity effect achievable. In the center curve is a continuously variable rear entry microphone and its associated proximity effect. The top curve is a two-rear entry uniphase microphone and the amount of proximity effect achievable.

In general, if a performer does not know how to use a microphone, he may be better off using a microphone with minimum proximity effect or an omnidirectional microphone which has no proximity effect. This may minimize microphone placement and the consequent result of having a differing tonal balance that is not coordinated with the performance.

There are certain single entry unidirectional microphones that have the low frequency response precontoured as shown in Fig. 31. The normal usage of the microphone, that is, close to the mouth, brings the low frequency back to nearly flat response; and when the microphone is picking up sounds at a further distance, the low frequency response is considerably rolled off thus yielding better rejection at low frequencies. This is not uncommon in hand-held unidirectional single-entry microphones.

In directional microphones, it is important that the off-axis response be the same as the on-axis response except to be lower in overall level. If this is not the case, the microphone will have a different frequency response depending on the angle the sound is coming from. This could mean that a vocalist using a directional microphone that was not linear in its off-axis response could have a band being picked up off the side or rear of the directional microphone that would sound very strange and possibly tinny. However, a microphone with uniform off-axis response would pick up the orchestra in its normal blend and simply be attenuated in overall level.

You will note from Fig. 32, that the 180° or rear response of the microphone is very similar to that of the front response and therefore would tend to sound the same on the front and rear. Only the level would be greatly attenuated.

Fig. 33 is a polar response curve of a directional microphone. Note that the polar pattern of the microphone is plotted at six different frequencies from low to high and that the microphone should have basically the same characteristics at all frequencies if it is to be considered a

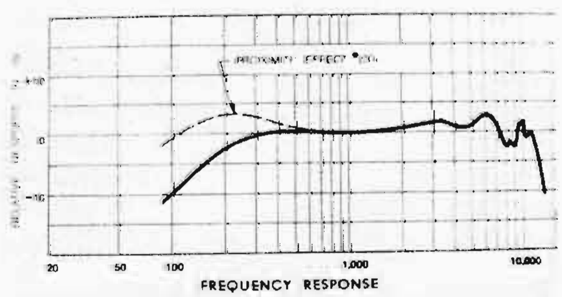

Fig. 31. Unidirectional microphones that have low frequency response precontoured.

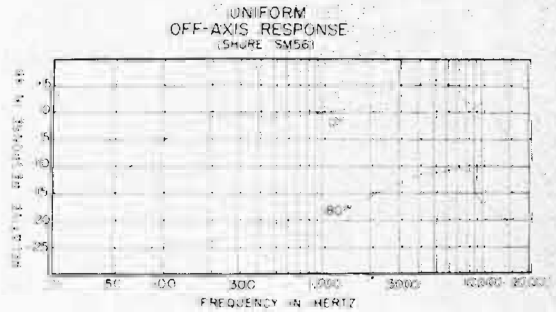

Fig. 32. Uniform off-axis response.

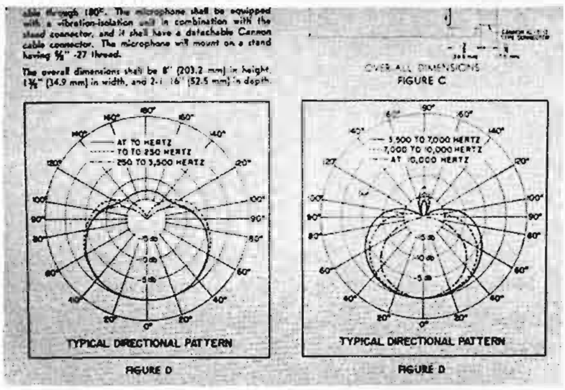

Fig. 33. A polar response curve of a directional microphone.

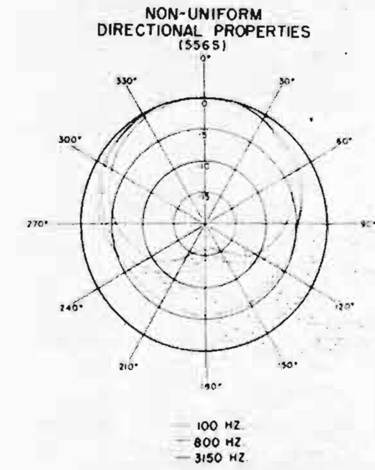

Fig. 35. Nonuniform directional properties of a Unidyne 2 microphone.

good unidirectional microphone. Remember, an omnidirectional microphone actually is not omnidirectional at high frequencies, and therefore its sound characteristic would change as one went off-axis. The low frequency and midfrequency content would be approximately the same but the sibilents or highs would be attenuated. A good unidirectional microphone should not display this characteristic and should simply attenuate the overall level of sounds reaching it from other than on-axis.

One can easily test this in several ways. In a very quite studio simply place a unidirectional microphone on a floor stand. If it should be a probe type microphone, place it parallel to the floor. Stand about 1 ft. from the microphone and talk into the front while slowly rotating the microphone in small increments, recording the output for playback later. When 90° off-axis the level should be down approximately 6 dB and as the microphone is rotated 180° the level should drop to 20−30 dB. When talking into the rear of the microphone, note that the room sound has appreciably increased. Should a great deal of low frequency content, above and beyond what was originally heard, develop it can be assumed that the rear rejection of the microphone is not good.

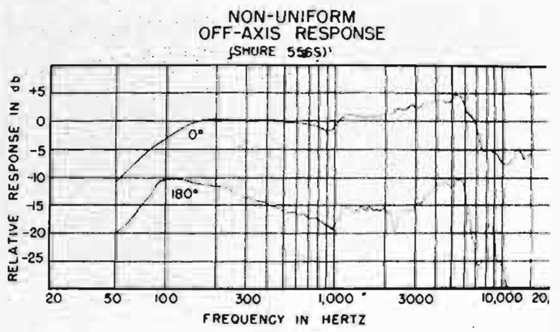

Fig. 34. Nonuniform off-axis response curve.

Another interesting test is to hold a unidirectional microphone horizontally and speak into it at its 90° axis. While speaking, rotate the microphone about its horizontal axis to see that the sound quality does not change. This test can become very enlightening on certain types of microphones.

As an example, Fig. 34 is a response curve of a Shure Unidyne 2 microphone. Note from the curve that the low frequency rejection is not as good as the midfrequency rejection and consequently when speaking into the rear of this microphone, one will note that it does not reject the low frequencies as well as it does the mid or high frequencies. This would give a problem in certain applications in terms of off-axis response.

Fig. 35 is the polar response curve of a Unidyne 2 microphone. Note the curve when plotted at three frequencies is not the same at all frequencies.

Originally in television broadcasting the microphone was seldom seen. Either booms or lavaliers were used and hidden under clothing. In dramas, microphones were hidden all over the sets to keep the viewing public from seeing a microphone. However, now the most common place to see a microphone is on the television screen and usually being hand-held by the performer. This means that microphone technology has had to change and considerations such as handling noise, pop, size and ruggedness have all become major considerations in the design of hand-held microphones.

New microphones as seen in Fig. 36 have built-in rubber isolation mounts to provide a maximum amount of mechanical isolation from the case assembly. This eliminates the banging

Fig. 36. New microphones with built-in rubber isolation mounts.

Fig. 37. New microphones showing the internal construction where a rubber isolation doughnut is used.

Fig. 38. Microphones without rubber isolation doughnuts can add this feature to mechanically isolate the microphone from the table as shown.

and thumping sounds when the microphone is hand-held.

The internal construction can be seen in Fig. 37 where a rubber isolation doughnut is used to minimize both case coupling and handling noise of a microphone.

If microphones that do not have internal or adequate shock mounting characteristics are used, rubber isolation doughnuts such as seen in Fig. 38 can be used to mechanically isolate the microphone from the stand or the table. Another method of mechanical noise entry into the microphone is through the cable itself. A small 3-ft. cloth-covered isolation cable attached to the microphone minimizes all mechanical noise transmitted up into the microphone through the cable assembly.

This same concept works very well on boom microphones as seen in Fig. 39. This is the normal rubber band type mount that is used for boom mounting.

Another alternative as shown in Fig. 40 is to use the rubber isolation doughnut and the isolation cable to give maximum mechanical isolation. This minimizes the lighting and shadowing problems in television productions.

Fig. 41 is a curve showing the effect of the rubber isolation doughnut. Curve A is the natural mechanical resonance of the microphone when excited on a shaker table. By putting the microphone in an isolation mount, the mechanical resonance is shifted down to about 10 Hz as well as lower in amplitude. By activating the high pass filter in the microphone or using an external high pass filter, the overall mechanical noise can be reduced immensely. Another problem quite common in microphone applications is reflections from hard surfaces.

In Fig. 42 one sees a performer some distances from a microphone with two sound sources reaching the microphone—the direct wave and the wave reflected from a hard surface floor. The reflected wave is delayed due to the distance

Fig. 39. Shows a boom microphone with the normal rubber band type mount.

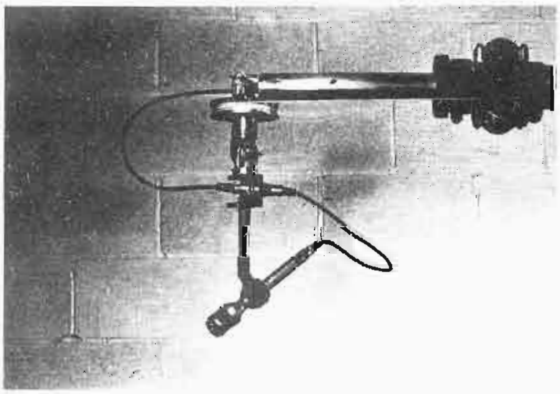

Fig. 40. Shown is a boom microphone using the rubber isolation doughnut and the isolation cable to give maximum mechanical isolation.

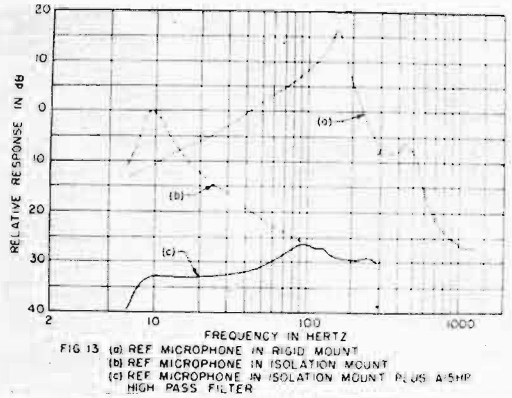

Fig. 41. Shown is a curve that demonstrates the effect of the rubber isolation doughnut.

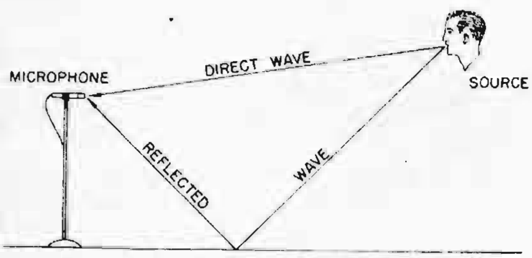

Fig. 42. A diagram showing a performer some distance from the microphone with two sound sources reaching the microphone.

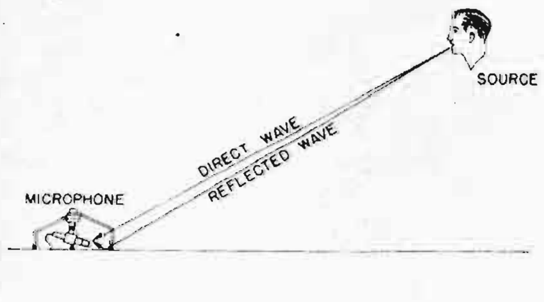

Fig. 43. A diagram of a performer with the microphone in position that the direct wave and the reflected wave reach the microphone simultaneously.

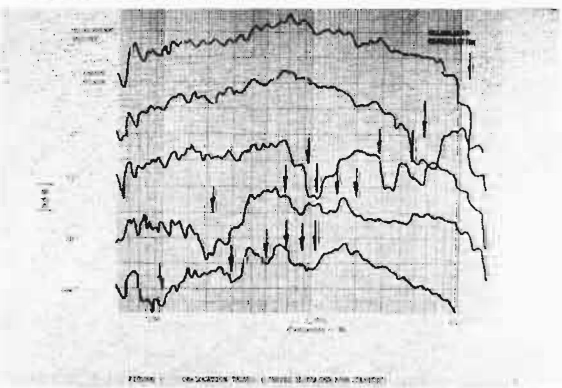

Fig. 44. Depicts the relationship between height variation when the sound source remains constant.

it travels and consequently phase cancellations will result.

To minimize this problem put the microphone in such a position that the direct wave and reflected wave reach the microphone simultaneously as suggested in Fig. 43. In this case, there is very little cancellation and the overall level and audio quality are improved.

Fig. 44 depicts what can happen to a microphone under varied conditions of height when the sound source remains constant and the microphone height is varied from 1-in. to 144-in. above the floor. As the microphone is moved up and down the reflective signal causes cancellations that vary with the height of the microphone off the floor. The same type of variation would take place if the performer moved back and forth or up and down.

This same principle applies to desk top applications as noted in Fig. 45. Here is an example of what can happen to the microphone in a desk top application due to the reflective signal, causing cancellation at certain frequencies. A good rule-of-thumb to follow is, when the distance from the performer to the microphone is greater than two times the distance of the microphone to the reflecting surface, more desirable results will be achieved by placing the microphone very close to the reflecting surface.

Fig. 46 is an isolation assembly that holds the microphone very close to the floor (reflecting surface) and uses the rubber doughnut method to provide mechanical isolation so that vibration or noises will not be transmitted into the microphone assembly.

Fig. 47 is a typical microphone placement when a podium is used, that is, one microphone on each side of the podium.

As long as only one microphone is in operation, there is no problem; however, if both are in use, the type of response curve as indicated in Fig. 48 will result as the individual moves off center of the podium. This phenomenon is another form of cancellation only this time the sound source is not reflected but directed from the speaker, and the distance between the speaker and microphone 1 and 2 are not necessarily equal. Consequently, some frequencies out-of-phase with each other cause this type of cancellation.

Fig. 49 is a polar response of this type of microphone mount shown at three different frequencies. Note that the smooth linear polar characteristics of the microphone are badly distorted.

One proposed solution is to place the microphones nose-to-nose as shown in Fig. 50.

This method indeed minimizes the frequency distortion as seen in Fig. 51 with a small loss of high frequency response.

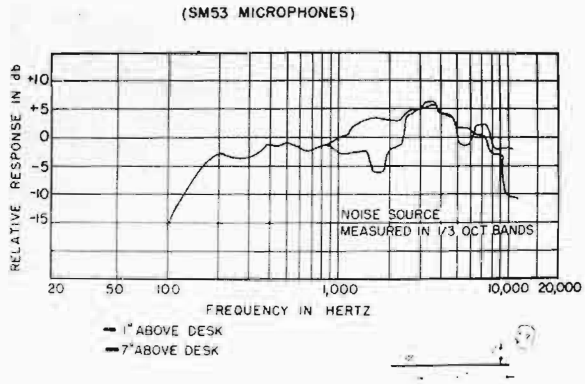

Fig. 45. Effect of microphone height on desk pickup.

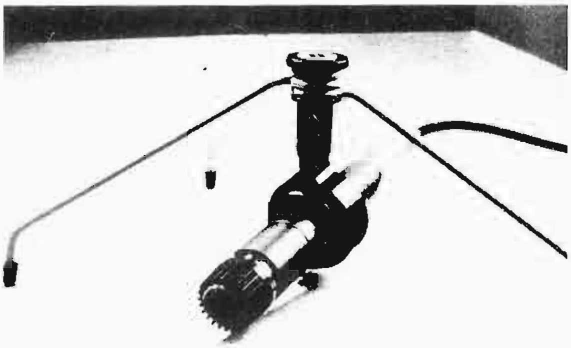

Fig. 46. An isolation assembly that holds the microphone very close to the floor, using the rubber doughnut method.

Fig. 47. Typical microphone placement when a podium is used.

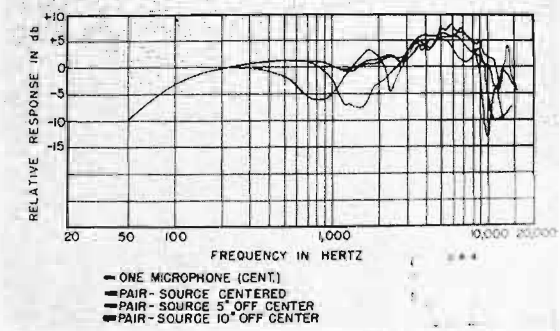

Fig. 48. Combined response of microphone pair spaced approximately 20 in. apart.

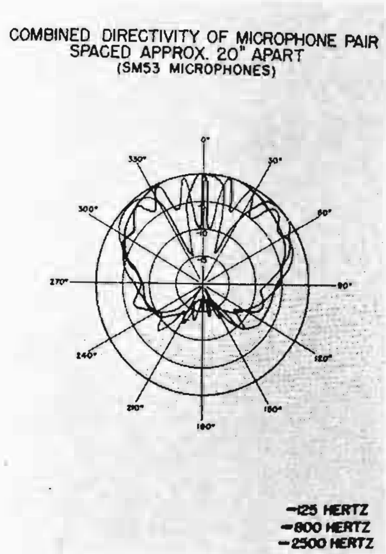

Fig. 49. Combined directivity of microphone pair spaced approximately 20 in. apart (SM53 microphones).

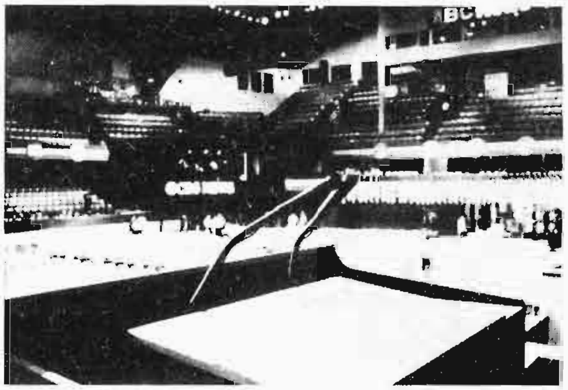

Fig. 50. Placement of microphones nose-to-nose.

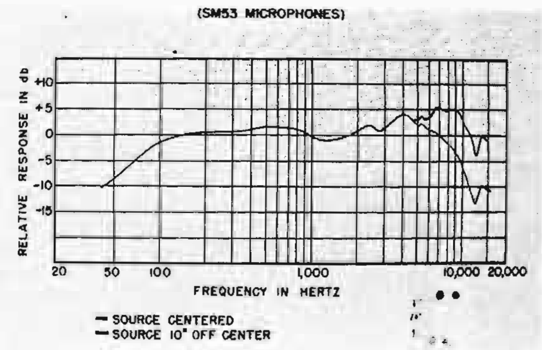

Fig. 51. Combined response of microphone pair grille spacing ½ in.-angled approximately 40 in. (SM53 microphones).

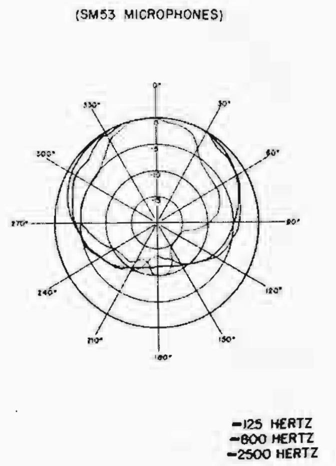

Fig. 52. Combined directivity of microphone pair grille spacing ½ in.-angled approximately 40 in. (SM53 microphones).

It can be seen in Fig. 52 that the polar response of the microphones are still not nearly as good as the microphones own polar characteristics and some rejection loss has occurred at the rear of the microphone. This leaves the possibility of either gain before feedback problems if sound reinforcement is used or not being able to minimize the unwanted sounds.

A vertical mounting of two directional microphones as suggested in Fig. 53 will minimize the bad effects of a dual microphone system and provide as wide a pickup angle as either of the other two methods mentioned before.

Many users assume that the "pop" characteristics of a microphone are always a good indicator of how well a microphone will perform in high wind applications. This is not necessarily true, and many microphones that have quite good on-axis pop rejection are quite susceptible to wind blowing into the side of the microphone. This can be easily checked by simply blowing into the side opening of a directional microphone and noting the amount of turbulence created. In the case of directional microphones with distributed or other low frequency entries in the handle, one must remember that these are just as susceptible to wind and pickup as the front of the microphone. By blowing or talkiing into the port entries of a directional microphone, the user will indeed find that it picks up sound. It is therefore necessary when using a directional microphone outside to make sure that all rear entries are completely covered by the porous foam windscreen.

Again, one advantage of single entry unidirectional microphones is that the entry is normally right around the top of the microphone, therefore, a small less obtrusive windscreen can be used to provide excellent wind and pop rejection.

Colored windscreens are now available for many microphones as shown in Fig. 54. The colored windscreens not only provide an interesting visual effect but also they are very handy in identifying hand-held microphones that are moved randomly. By color coding the mixer with little dots that match the colored windscreen, the audio operator can always tell which microphone is which without relying on colored tape wrapped around the bottom of the microphone or some other such method.

Fig. 53. Vertical mounting of two directional microphones.

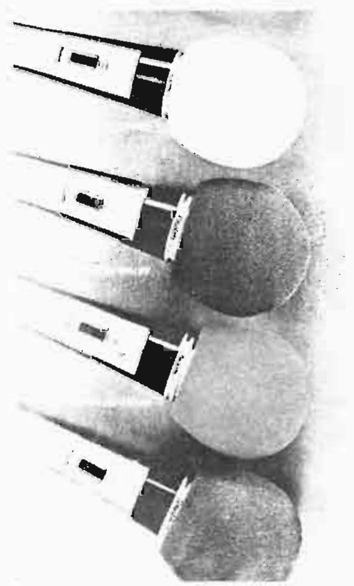

Fig. 54. Microphones with colored windscreens.

Windscreens should be checked for their acoustical properties and this again can be done in a studio by talking into the microphone while listening on a wide-range monitor loudspeaker systems and then sliding the windscreen over the microphone listening for any changes especially in the sibilence of the voice.

A final consideration is that of reflections back into directional microphones. In this case, four microphones were installed on a podium that had a light cavity. This is not an unusual type of podium but one which is in occasional use. Fig. 55 shows the response curves of the four microphones. The top curve is a single-entry unidirectional microphone. The second curve is an inexpensive omnidirectional microphone. The third curve is a distributed entry directional microphone and the bottom curve is a two rear entry uniphase system microphone. Those response curves were prepared from tests in an anechoic chamber and look very similar to those found on the data sheets for the particular microphones. However, when they are installed in a normal position in this lectern, it is interesting to note what happens to the response curve of the various microphones.

From the lower two curves in Fig. 56 it will be seen that the multiple entry directional microphones have picked up the 250 Hz resonance of the lectern light cavity. Since the rear entries are designed to be out-of-phase with the front of the microphone, the reflected signal causes a rise in the 250 Hz area which makes the microphone sound very muddy.

The omnidirectional microphone, as it picks up equally at all mid and low frequencies no matter what direction, sees the signal being reflected back from the light cavity as an out-of-phase signal with a resulting canceling effect at both the fundamental and its harmonics.

The top curve is the single entry unidirectional microphone. Since its entry is all the way towards the top of the microphone, it is least affected by the signal coming back from the lighting cavity and consequently gives the smoothest overall response in this particular application.

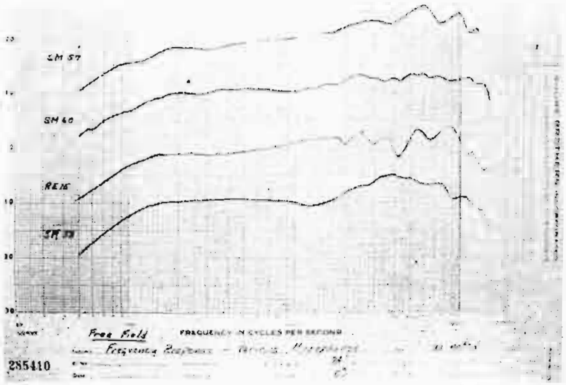

Fig. 55. Response curves of four microphones, from top to bottom: (1) a single-entry unidirectional microphone, (2) inexpensive omnidirectional microphone, (3) distributed entry directional microphone, (4) a two rear entry uniphase system microphone.

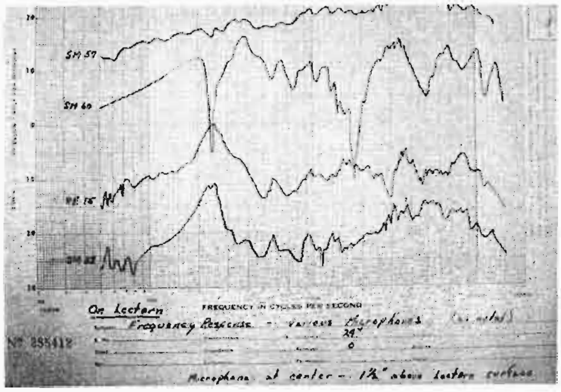

Fig. 56. Multiple entry directional microphones curves from a lectern showing a pickup of 250 Hz.

25

Planning and Design of the Studio Lighting Equipment

Larry E. Nelson
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Kliegl Bros.
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In order to do any type of television production, some sort of a facility designed for production is required. This facility is called the Television Studio.

A properly designed television studio is a necessity to do any sort of production—even very limited production. The more planning and thought that is put into the studio, the better the results. An improperly designed studio will hamper all production capability and will be very uneconomical to use. The heart of any production studio is the lighting equipment that is designed into the studio. Both the type and quantity of fixtures as well as the lighting control (dimming) system should be designed for maximum flexibility in your particular studio.

If you are building a new studio from the ground up, then you have the advantage, with proper planning, to design-in exactly what you think you will need. This is, of course, the ideal situation. However, in many circumstances, a newly constructed studio is out of the question and instead you are renovating an existing structure. Even though physical parameters are pretty much fixed by the architecture of the existing building, you still can, with proper planning, increase the flexibility of your existing facility.

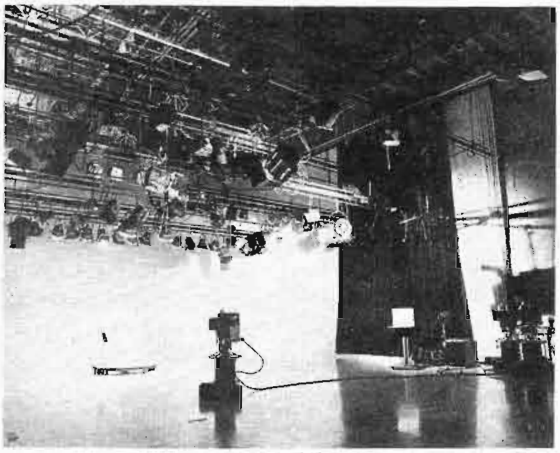

Fig. 1. Production studio-cathedral teleproduction (courtesy of Kliegl Bros).

Size

The size of the studio will determine how complex a production you can create. Generally speaking, the larger the studio, the more flexibility. However, there are practical limitations to this.

In new studio construction, one of the most popular sizes is a 50 X 70 ft. studio. This 3,500 sq. ft. area will allow the average TV station to do any type of production programming that is required. A more common size, especially among existing installations, is a 40 X 60 ft. studio. This 2,400 sq. ft. studio will normally take care of the majority of productions that are encountered in local markets.

Since most facilities have more than one studio, it should be planned that at least one studio is at least 2,400 sq. ft. with a smaller studio at least 1,200 sq. ft. A typical facility, for example, will have a production studio 40 X 60 ft. and a news studio 30 X 40 ft. In this way, there is the advantage that news and local shows can be done in the smaller studio with semi-permanent sets with the larger studio being reserved for special productions, such as commercials, etc.

Height

The height at which the lights are hung, commonly referred to as "grid" height, is also an extremely important facility parameter. A low grid height can completely destroy the flexibility of a large studio. Ideally, the grid height should be a *minimum* of 14 to 16 ft. for a studio up to 2,400 sq. ft. and 18 to 20 ft. for a larger studio. A low ceiling will not allow the lighting equipment to be effectively utilized since a low grid height will not allow for long, wide angle shots.

Electric Pause

The amount of electrical power that is required for the lighting equipment in the studio is determined by two things: the square footage of the studio and the foot candle levels required by the cameras. Using an illumination level of 250 fc, 60 watts per square foot of studio net production area is required. Net production area is defined as the usable area within the cyclorama curtains. By simple mathematics, it can be shown that 60 watts/per square foot equals approximately one 1 kw circuit per every 16 sq. ft. (1,000 watts divided by 60 watts/sq. ft. ≅ 16 sq. ft./circuit.)

The table, shown in Fig. 2, will give the approximate power service in kilowatts for various size studios and footcandle levels. These power requirements do not include the power required for the cyclorama lights. For cyclorama lighting, utilizing the new hi-efficient type of fixture, add in an additional 250 watts/linear foot of cyclorama for overhead lighting only. As an example, for a 3,500 sq. ft. studio with a net production area of approximately 3,000 sq. ft., a power level of 180 kilowatts is required. (Not including cyclorama loads.) For a 100 ft. cyclorama, add 25 kw to the 180 kw.

The most desirable ac power service for studio purposes is 3-phase, 4-wire 120/208 v ac 60 cycles. This type of power service is available in most areas and is normally the most economical power service that can be provided for the studio. Since there are three phases, each carrying equal loads, each phase is only required to carry one-third of your total connected load. In the above example, the 180 kw service required for the 50 X 70 ft. studio would be 1,500 amps total. By using a 3 phase, 4-wire power feed, each of the phases would only have to carry 500 amps. This will keep the size of feed wire down and, therefore, cost to a minimum.

Another very common power feed that is available in older facilities is single phase, 3-wire service more commonly known as 120/240. This type of service uses 3 wires each of which carry one half of the total load. In the above example, the 180 kw load will be broken down into two feeders of 750 amps each, plus 750 amps neutral.

It is most desirable to have a separate service provided for the studio lighting loads. In this way, there will be no fluctuation in your electrical equipment when the heavy loads of the lighting equipment are turned on.

It should be noted that in all cases such services as electrical power and air conditioning should be sized so as to take into account ultimate requirements. It is very costly to increase these services at a later date.

SERVICE POWER IN KILOWATTS (KW) FOR NET PRODUCTION AREA (NPA) AND REQUIRED FOOTCANDLE (fc) LEVEL

NPA (ft^2)	50 fc	100 fc	200 fc	300 fc	400 fc	500 fc
500	7	14	27	40	54	67
1000	14	27	53	80	106	134
1500	20	40	80	120	160	200
2000	27	54	107	160	213	267
2500	34	67	134	200	266	334
3000	40	80	160	240	320	400
3500	47	94	187	280	372	467
4000	54	106	213	320	426	534
4500	60	120	240	360	480	600
5000	67	134	267	400	532	667
6000	80	160	320	480	640	800
7000	94	187	374	560	745	934

Fig. 2. Power requirements for typical television studios (courtesy of Sylvania).

Air Conditioning

Since almost all of the electrical power used for lighting is converted to heat, sufficient air conditioning must be available to keep the studio within a reasonable temperature range that will not adversely affect other studio equipment or personnel. Due to the inefficiencies of lamps, either quartz, iodine or standard incandescent, all power applied must be considered as heat.

It takes approximately .14 tons of air conditioning for every 1 kw (1,000 watts) of lighting. These figures may vary from one geographical location to another, but may be used generally as a starting point. For the 50 X 70 ft. studio, previously discussed, the air conditioning for the studio lighting alone would be 30 tons. It must be noted that this figure of .14 tons per kilowatt is for the lighting fixtures only and does not take into consideration any other air conditioning requirements such as electronic video equipment, talent, or general illumination.

Now that the construction details have been discussed, let us proceed to the design of the actual production facilities. The first section of the design has been aimed at the engineering staff. The remainder of the discussion is concerned with the production staff.

SUSPENSION SYSTEMS

After the studio size has been determined and power service and air-conditioning designed for the studio, it must next be determined how to use the lighting fixtures in the studio. It is imperative that all lighting fixtures, with few exceptions, be suspended from the overhead mounting system. This gives the most flexible type of studio operation since the floor is free to be used for sets, cameras, and talent only. Only specific lighting fixtures for special effects should be floor mounted through the use of lighting stands.

The simplest type of lighting suspension system is a series of pipes that are suspended from the ceiling parallel to the short walls in the studio. These pipes, which are normally spaced 4 to 6 ft. on centers, support not only the lighting fixtures, but can also act as a mounting point for the overhead electrical power distribution equipment. This system is also the most economical since the material requirements are limited to pipe. This pipe, normally 1½ in. ID, when painted black is an ideal hanging medium for the "C" clamp equipped fixtures. These pipes can either be fixed mounted to the ceiling through the use of threaded rods, metal strap and brackets, or can be chain hung. The advantage of having the pipes chain hung is that they can be raised somewhat, if necessary, for special productions. There are inherent limitations in the fixed pipe system. In order to have total flexibility and utilize the entire studio, short pipes perpendicular to the fixed pipes can be added if the lighting fixtures are required to be used perpendicular to the pipes. These pipes can be clamped onto any pipe in the studio on a temporary basis. Fig. 3A shows a batten plugging strip with five pigtails (circuits). The pipe is mounted in the brackets below the plugging strip.

In place of the fixed pipes and the "C" clamp mounting method for fixtures, some studios have gone to a steel channel called Unistrut. Special Unistrut mounting brackets are available which will allow the fixtures to be quickly mounted on these channels.

Another very common type of suspension system is the fixed grid, where pipes are mounted from the ceiling in rows perpendicular to each other in a grid configuration. In this type of suspension system, the pipes are normally on 4 to 5 ft. centers, giving a cross hatch grid with squares approximately 16 to 25 sq. ft. Since earlier calculations call for a circuit every 16 sq. ft., it can be seen how this grid system fits nicely into the studio. This will allow maximum flexibility since the fixtures can be mounted in any direction. Again, this grid acts as a mounting device for the electrical distribution equipment.

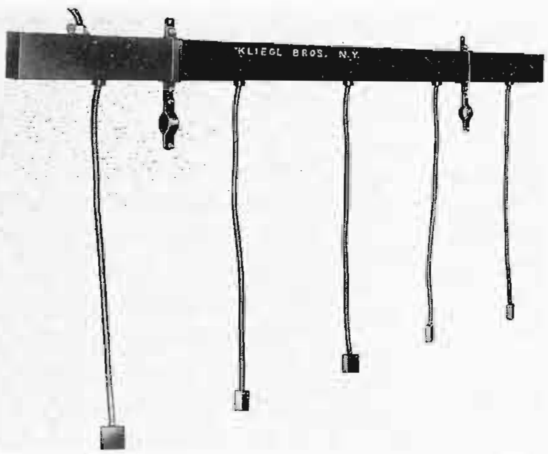

Fig. 3A. Plugging strip (bottom) and pipe mounts below strip (courtesy of Kliegl Bros.).

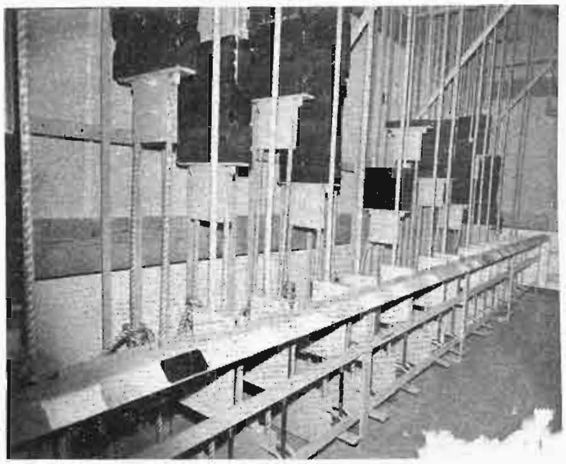

Fig. 3B. Counterweight system at the Indiana University TV studio, Bloomington, Indiana (courtesy of Tiffin Scenic Studios).

By far and away, the most flexible, and unfortunately, the most expensive type of suspension system is that utilizing movable pipes. This type of system will allow the fixtures and power distribution equipment to be lowered to just above the studio floor for service and maintenance.

There are two ways in which to make the fixture pipes and plugging strip distribution (battens) movable. The most common and inexpensive method is through the use of a counterweighted system. This type of system utilizes a block and tackle method to raise and lower battens. Fig. 3B shows a typical counterweight arrangement as installed at the Indiana University TV facility in Bloomington, Indiana. This type of system uses lead counterweights to offset the forces required to raise and lower the lighting battens. This type of system costs from $700.00 to $2,500.00 per batten. A "batten" can either be a single pipe or a set of two or more inline pipes. A typical 40 X 60 ft. studio would have at least seven such "battens" (seven pairs of pipes). The cost range will depend upon the capacity of the "system" as well as the degree of safety to be incorporated. One of the main disadvantages of a counterweight system is the amount of studio floor space required for counterweight hardware. Approximately 4 ft. along one of the longer studio walls is lost due to the required hardware. This will obviously cut down on the studio's net production area.

Another method of raising and lowering the batten is through the use of an electric winch with a grooved drum. This type of system costs from $1,500.00 to $5,000.00 per batten including limit switches. Fig. 4 shows a view of the winches in a loft just below the acoustic ceiling at the Indiana University TV facility. This system has the advantage of not taking up any floor space whatsoever since all of the operating mechanisms are mounted overhead. Fig. 5 shows

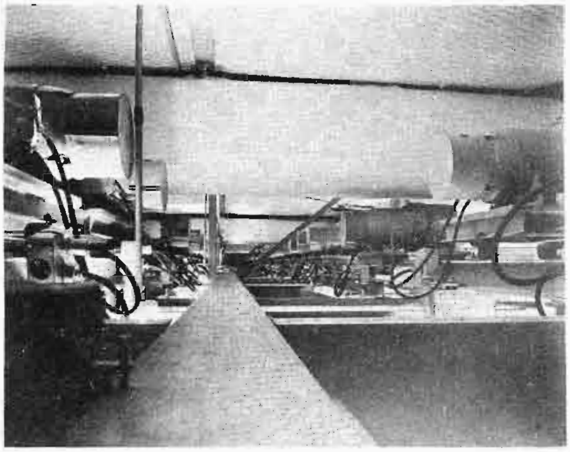

Fig. 4. Lifting motors for suspension system Indiana University Studio (courtesy of Tiffin Scenic Studios).

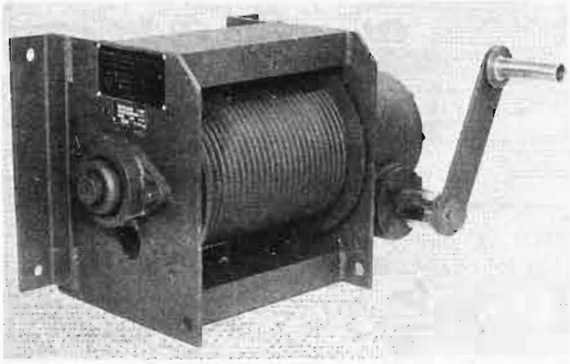

Fig. 5. Hand winch at the studio of Indiana University (courtesy of Tiffin Scenic Studios).

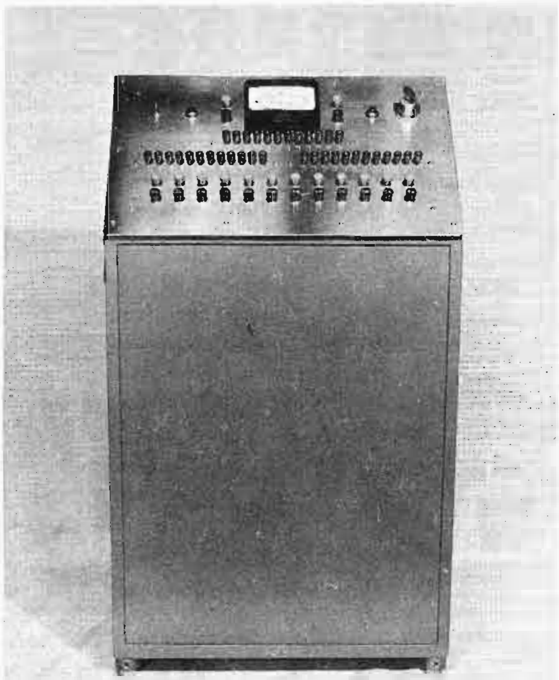

Fig. 6. Motor control to console for motorized suspension system (courtesy of Tiffin Scenic Studios).

a modified hand winch which can be used with a reversible drill motor. The motorized system and the motorized batten can be remotely operated from the control room through the use of a control panel. A typical panel is shown in Fig. 6.

Please note that before any type of suspension system is decided upon, it is imperative that the architect and building engineer be consulted as to roof loading factors for safety. It would be a very good idea at this design stage to call in a professional rigger for his advice.

Another very important part of your suspension system is the cyclorama curtain. A cyclorama curtain is a fabric that is either on a movable track or permanently put into position to act as a background. By the use of special cyclorama lights and color media the color of this curtain can be changed to provide various colored backgrounds. It is advised that the initial installation includes a single or double cyclorama rail around the entire studio perimeter. The track only costs approximately $5.00 per foot for a single rail and $10.00 per foot for a double "concentric run." For most installations, a single track is normally sufficient.

The cyclorama curtain itself is a seamless flameproof muslin, which will cost approximately $25.00 per linear horizontal foot, up to 18 ft. high. A seamless and flameproof sharkstooth faced material will run approximately $20.00 per horizontal linear foot, up to 30 ft. high. If a show type velour drapery, pleated for 75 percent fullness is desired, the approximate price per linear horizontal foot up to 18 ft. high is $40.00. It is suggested that at least half of the studio be equipped with a cyclorama curtain to start with. The velour drapes could, of course, always be added at a later date.

STUDIO LAYOUT

Once the studio size has been determined, it is necessary to properly layout the plugging strips that makes up the lighting electrical power distribution. It is important that the distribution system be layed out in such a way that power can be easily distributed to all parts of the studio. Fig. 7 shows the electrical power distribution for a typical 40 X 60 ft. studio. As can be seen, the electrical power is distributed through the use of plugging strips 16 ft. long with 11 circuits in each strip. These plugging strips, which are on 8-ft. centers with 3 ft. pigtails, will allow a fixture to be mounted in any position, on any pipe in the studio, and receive its power from the plugging strip. Between each plugging strip is a pipe for mounting additional fixtures. Since each fixture also has a 36 in. pigtail, there

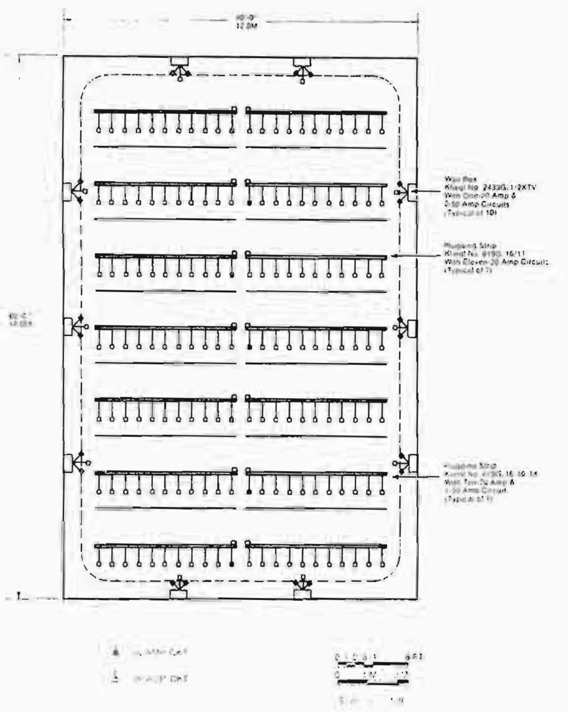

Fig. 7. Layout of a 40 X 60 ft. studio (courtesy of Kliegl Bros.).

is no trouble providing power to the fixtures mounted on these pipes.

In addition to the overhead circuits which total 154 (147 rated at 20 amp and 7 rated at 50 amp), there are 30 circuits around the perimeter of the studio that are mounted 30 in. above the floor. These circuits will allow power for the stand mounted lights and other special equipment that may be required. It is important that these circuits be provided since there are many times when floor power is required.

All of these circuits shown are wired into the dimming system which will be discussed in the next section.

A typical lighting package, consisting of fixtures, distribution equipment, and dimming equipment is shown in Fig. 8. This package of equipment provides all of the necessary hardware including cyclorama lights to do production in a 40 X 60 ft. studio. Of course, larger studios would require larger packages of equipment and smaller studios would require smaller packages of equipment. The number of fixtures and dimming system size is directly proportional to the size of the studio.

40' x 60' STUDIO PACKAGE — CATALOG #94060TV

KEY AND BACK LIGHTS

Qty.	Cat. No.	Description
10	3508TV-955G	6-3/8" 750W Quartz Fresnel
10	23508TV	8 Way Barndoor
10	13508TV	Diffuser/Gel Frame
10	EHF	750W Quartz Lamp 3200°K
30	3608TV-955G	8" 1000W Quartz Fresnel
30	23608TV	8 Way Barndoor
30	13608TV	Diffuser/Gel Frame
30	CYV	1000W Quartz Lamp, 3200°K
10	3610TV-955G	10" 2000W Quartz Fresnel
10	23610TV	8 Way Barndoor
10	13610TV	Diffuser/Gel Frame
10	CYX	2000W Quartz Lamp, 3200°K

BASE AND FILL LIGHTS

Qty.	Cat. No.	Description
40	3451TV-955G	16" Quartz Scoop
40	13451TV	Diffuser/Gel Frame
40	FHM	1000W Frosted Quartz Lamp
2	835TV	Spun Glass
20	117TV	10' Monopole Telespcopic Hanger
20	10E955GTV	10' Extension Cable

CYCLORAMA LIGHTS - 80 LINEAR FEET PLUS TWO CORNERS

Qty.	Cat. No.	Description
4	6901TV-955G	1 Light 1 Circuit Cyc Light with Color Frame
9	6902TV-955G	2 Light 2 Circuit Cyc Light with Color Frame
22	FFT	1000W 3200°K Quartz Lamp

EFFECTS LIGHTS

Qty.	Cat. No.	Description
2	1357/6WTV-955G	6" 1000W Wide Angle Klieglight with Pattern Holder and Set of Patterns
1	13571/6WTV-955G	6" 1000W Wide Angle Klieglight with Iris
3	FER	1000W Quartz Lamp, 3200°K

DISTRIBUTION EQUIPMENT

Qty.	Cat. No.	Description
7	619G/16/11TV	Plugging Strip, 16'long with 11-20 amp 39" (1M) pigtails terminating in 3 pin grounding connectors
7	619G/16/10/1XTV	Plugging Strip, 16' long with 10-20 amp and 1-50 amp 39" (1M) pigtails terminating in 3 pin grounding connectors
10	2433G/1/2XTV	Wall Box with 1-20 amp & 2-50 amp 18" pigtails terminating in 3 pin grounding connectors

CONTROL EQUIPMENT

Qty.	Cat. No.	Description
1	2911TV	Dimmer Bank containing: 12-12KW SCR Dimmers 6-7KW Non-Dims
1	2910TV	Retractable Cord "Cold Patch" Patch Panel containing: 180-20 amp load cords 30-50 amp load cords 114-20 amp cold patch jacks with circuit breakers 30-50 amp cold patch jacks with circuit breakers 1-Illumination Hood with Dimmer
1	2909TV	Two Scene, Four Sub-Scene Control Consoles containing: 24-Plug-in Rear Illuminated Controllers (2/Scene) 24-3 position Function switches (Sub A-Off-Sub B) 4-Sub Masters 1-Split Handle Cross Fader 6-Non-Dim switches 1-Non-Dim Master 1-Key switch 1-10' Control Cable with No. 2902TV recpetacle box

Fig. 8. Bill of materials for a 40 X 60 ft. studio (courtesy of Kliegl Bros.).

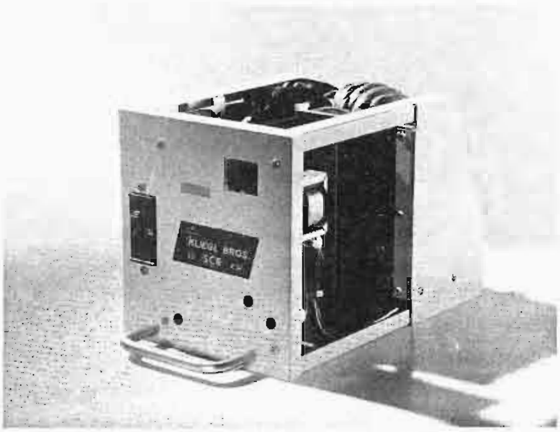

Fig. 9. A 12 kw SCR[R] Dimmer (courtesy of Kliegl Bros.).

LIGHTING CONTROL (DIMMING) EQUIPMENT

The lighting control system is the most important tool that the lighting man has to work with. The lighting control system, commonly called the Dimming System, is the nerve center of any lighting package. The control system allows the studio production lights to be varied in intensity for the various special effects that are required. It's the dimming system that allows color blending of the cyclorama curtain background. It is the dimming system that sets the mood of the production. It is the dimming system that allows complex light changes to be easily accomplished.

The dimming system consists of three major components: The dimmerbank, the patch panel, and the control console. Each of these components has a certain job to perform.

The Dimmerbank

The dimmerbank houses the dimmer modules. The heart of any dimming system is the dimmer module. The standard dimmer module utilizes silicon controlled rectifiers (SCRs). The SCRs are currently the state of the art for light and power control. These solid state devices are very efficient, rugged and extremely reliable. Dimmer modules are available with ratings from 2,400 watts to 12,000 watts. Fig. 9 shows a typical SCR 12 kw dimmer. The dimmer has a high level filter built into it to increase the sharp rising wave form created by the SCR switching. This increased rise time, due to the filter, suppresses RF interference and reduces the lamp filament sing. It is imperative that any SCR dimmer utilized in a television studio be fully filtered. The 12 kw SCR module shown in Fig. 9 is approximately 8 X 8 X 12 in. This compact size allows for a very neat and clean installation. A magnetic amplifier dimmer, predecessor of

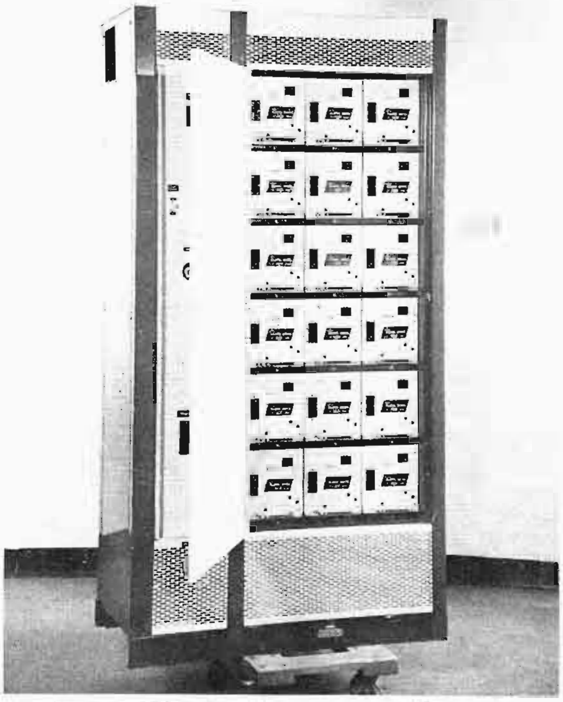

Fig. 10. SCR[R] dimmer bank (courtesy of Kliegl Bros.).

the SCR dimmer, of this capacity would be over 2 X 2 X 3 ft.! Needless to say, all manufacturers of dimming equipment are using the SCR and similar devices today. A typical dimmerbank using 18 SCR dimmers is shown in Fig. 10.

It is important to note that the dimmerbank should *not* be placed in the studio proper due to the inherent noise created by the filter of the SCR dimmers. Ideally, the dimmerbank should be placed as close to the studio as possible, such as in the prop storage or other suitable area, where moderate temperatures are prevalent.

The Control Console

The control console is the "brain" of the dimming system. The console, upon instruction from the lighting man tell the dimmers what to do and how to behave. This is accomplished by sending a low voltage, low current (nom. 24 v @ 1 ma) signal to the dimmer to control the 120 v 100 amp. dimmer.

The most common type of control console used in television today is a two-scene preset control console with two submasters per scene and cross fading. Fig. 11 shows this type of console. "Two scene preset" means that each dimmer can be set to two separate and distinct levels and recalled or put into action by actuating the proper (Scene 1 or 2) scene master. The two submasters on each scene will allow these two individual scenes to be further broken down into four more groupings giving a further degree

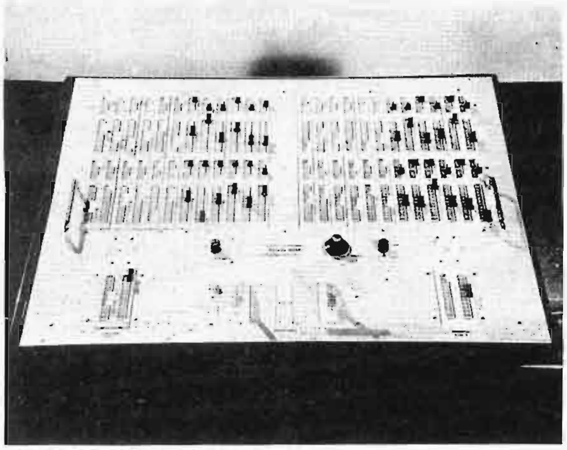

Fig. 11. Two scene preset control console (courtesy of Kliegl Bros.).

of control flexibility. For most local productions, a two-scene preset system is ideal. For more complex productions, a five-scene preset is required. This type of system will allow each dimmer to be set to five distinct levels, individually recallable for each of five sets of lighting cues.

For even more complex productions, a computerized memory system has been developed. This type of system uses an electronic memory to "memorize" your dimmer settings electronically. Fig 12 shows the Q-File system. This type of system allows a lighting man to do things that would be impossible with a conventional (manual) preset type of system. A somewhat less complex system, the Q-level, is becoming more and more popular in television. Due to the price reductions in integrated circuits and solid state devices, a memory system can be provided for less than the cost of a large manual preset system. Fig. 13 shows a Q-File console in Studio 42 at the CBC in Montreal. In either memory system, the lighting man sets his various dimmers to the desired level and merely presses a single button to completely "memorize" (record) the entire set of dimmers. By pressing another button, these settings are recalled upon demand.

Patch Panel

In order to transfer the power from the dimmerbank to the lighting fixtures in the studio, the final component of the system, the patch

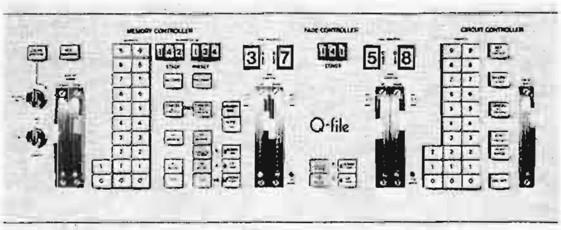

Fig. 12. Q-file memory system (courtesy of Kliegl Bros.).

Fig. 13. Q-file in Studio 42-CBC (courtesy of the Canadian Broadcasting Corp.).

panel, is required. The patch panel is a switchboard which will "patch" (assign) any light in the system to any dimmer.

Fig. 14 shows an overhead style patch panel. Each lighting circuit in the studio is represented by a load cord and plug assembly in the patch panel. When the operator plugs the desired lighting circuit into a dimmer, power to that particular lighting fixture is provided. There is normally one cord per studio lighting circuit. The patch panel is normally located in the studio.

Since the patch panel is used to assign lighting fixtures to the dimmers in the system, its operation must be fast and trouble-free. One of the biggest problems in the patch panel has been the pitting of the load plugs and the dimmer receptacles during "hot" patching. The Kliegl SafPatch system, shown in Fig. 15, completely eliminates this possible source of malfunction. As can be seen by the illustration, due to the unique design of the cord and receptacles it is physically impossible to make or break a patch "hot." This automatic "cold" patching system completely eliminates any possibility or arcing

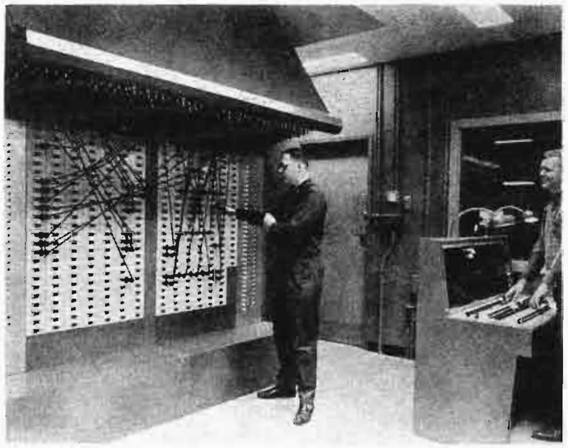

Fig. 14. Overhead batch panel (courtesy of Kliegl Bros.).

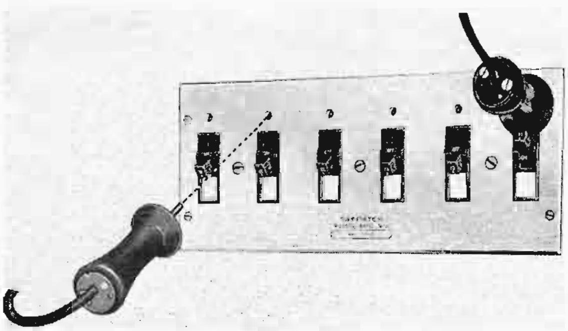

Fig. 15. Safpatch receptacle (courtesy of Kliegl Bros.).

or pitting. This fool proof system will allow even untrained personnel to operate the lighting control system without any danger of system malfunction.

Another type of control system that has been used is the dimmer per circuit system. In this system, rather than have a large number of load circuits going through a patch panel to a smaller number of dimmers, there is a dimmer provided for each lighting circuit in the studio. The thought behind this type of system is increased flexibility since each light can be individually controlled. In practice, however, this system has not proven to be feasible either practically or economically. A dimmer per circuit system will cost 2½ times as much as a conventional patch panel system. For most installations, the convention system will be by far and away the best choice.

Fig. 16 is the electrical riser diagram illustrating the inner connection wiring between the elements of the lighting system with patch panel.

The budget prices for the various elements that make up studio lighting equipment are given below. As stated earlier, the cost to equip a studio is directly proportional to its size.

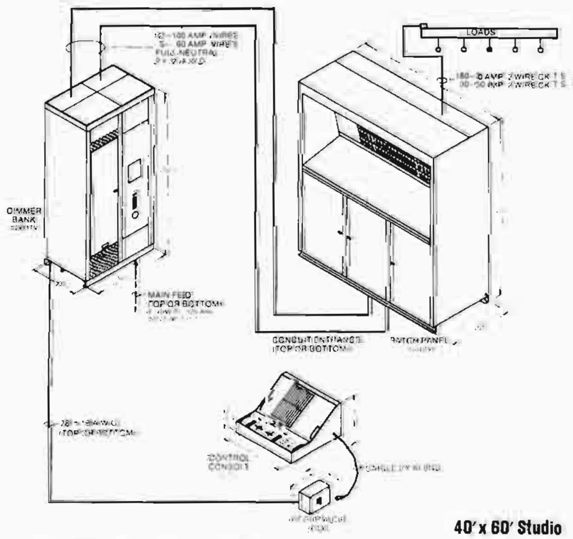

Fig. 16. An electrical riser diagram (courtesy of Kliegl Bros.).

Budget Estimates for Lighting Equipment

Studio size	30 X 40	40 X 60	50 X 70
Fixtures (inc. lamps and accessories)	$16,000	$28,000	$41,000
Electrical distribution equipment	6,000	9,000	15,000
Dimming equipment (patch panel system)	24,000	33,000	44,000
Total package	$46,000	$70,000	$100,000

LIGHTING FIXTURES

The lighting fixtures, or luminaires, are the basic tools of the lighting man. These various types of luminaires are each designed to perform specific functions. Each fixture has its own application. A misapplied fixture will cause no end of grief. The "heart" of the lighting fixture is the lamp or bulb that is used to produce the illumination.

Nowadays in television, the tungsten halogen lamp, commonly called the quartz lamp, is the only type of lamp in use. This lamp has the advantage that its initial light output when first put into service will not vary appreciably until it burns out. The more conventional incandescent lamp, conversely, will lose approximately 38 percent of its initial light by the end of its life. This output versus operating life is shown in Fig. 17.

A conventional lamp loses its light output and also its color temperature due to the blackening of the lamp envelope from the evaporating tungsten filament. The tungsten-halogen lamp has a special halogen gas added to the lamp's atmosphere to absorb this blackening, keeping the envelope clean. Due to its constant output and color temperature through its life and longer rated life, the cost per hour of operation for a tungsten halogen lamp is the same or less than that of its incandescent predecessor.

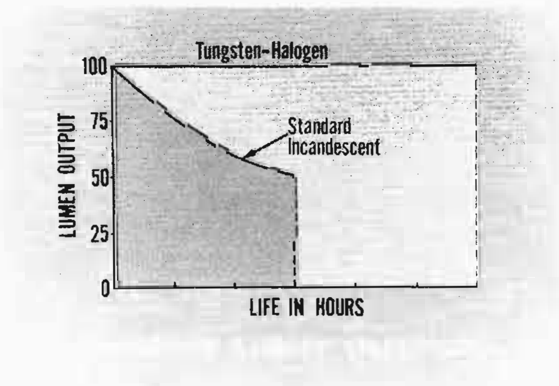

Fig. 17. Light output versus life in hours (courtesy of Sylvania Lighting Production).

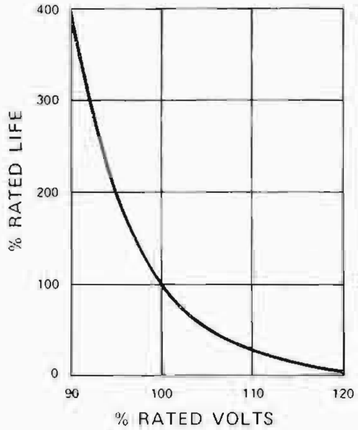

Fig. 18. Typical life variations (courtesy Sylvania Lighting Production).

It should be noted here that lamp life is a direct function of the voltage applied to the filament. If the filament voltage is higher than its rating, the lamp's life is adversely effected. If only a 5 percent overvoltage is applied, the lamp life expectancy is reduced by approximately 50 percent. Conversely, a 5 percent undervoltage will practically double lamp life. Fig. 18 illustrates lamp life versus filament voltage.

In many installations where the lamp voltage is high, complaints of short lamp life are common. The actual voltage at the fixture's socket should be measured to determine the exact voltage at the lamp before any complaints of short lamp life are sent to the lamp manufacturer.

Fresnel Spotlights

The most common type of studio fixture is the fresnel spotlight. This unit, whose output intensity can be varied by changing the relative position of the lamp to the lens, is a highly controlled directional source of light. These fixtures, when equipped with a set of barndoors, gives a smooth even soft-edged field that is easily controllable. These units, which vary in lens size from 3 to 20 in., have corresponding wattage ranges from 150 to 10,000 watts. Fig. 19 shows a 6 in. 750 w fresnel.

When the tungsten halogen lamp was first introduced, the so-called open faced or lensless fresnel was introduced. Even though this unit was more efficient than its earlier incandescent fresnel counterparts, it soon lost its favor in the studio due to lack of control.

For studio applications, 8 in. 1,000 w fresnels are commonly used as back lights with the larger 10 in. 2,000 w fresnel being used for key lights. There are, of course, applications where a larger or smaller fixture is used.

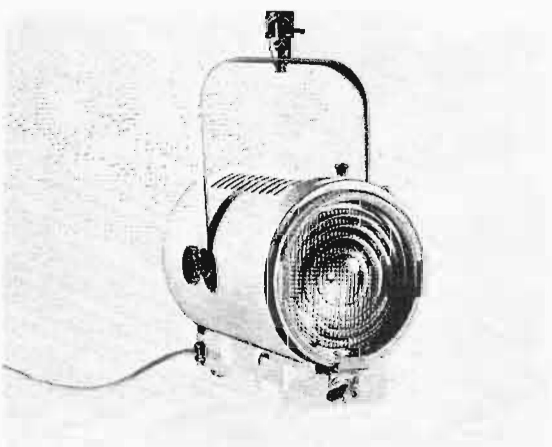

Fig. 19. A six in., 750-w Fresnel (courtesy of Kliegl Bros.).

Scoop Floodlights

The scoop floodlight is the second most commonly used fixture in the television studio. The scoop, which is common as either an 18 in. 2,000 w unit or a 1,000 w 16 in. unit, acts to provide base and fill light. A properly designed scoop produces a soft diffuse light in a wide angle configuration.

Fig. 20 shows an 18 in. 2,000 w scoop. Fig. 21 shows a 16 in. 1,000 w focusing scoop. Focusing of the scoop is sometimes a great help. For added versatility, each scoop should be purchased with a diffusion/color frame holder to allow the use of light diffusion material or color media. A scoop can be used as a cyclorama light under certain conditions. It is also very desirable to be able to lower a scoop for better lighting angles. For this, a scissor hanger or pantograph is required. A pantograph is shown in Fig. 22.

Cyclorama Lights

For background lighting of the cyclorama curtain, a special type of cyclorama light is required. These units, when equipped with a color media, will transmit colored light to the cyclo-

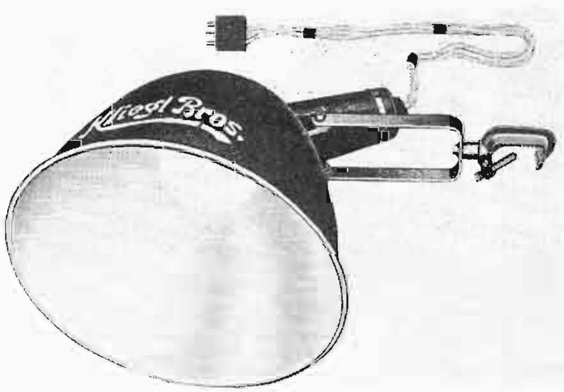

Fig. 20. An 18 in., 2000-w scoop (courtesy of Kliegl Bros.).

Fig. 21. A 16 in., 1000-w scoop (courtesy of Kliegl Bros.).

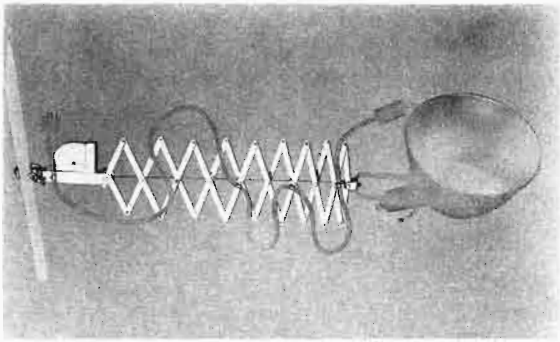

Fig. 22. A pantograph (courtesy of Kliegl Bros.).

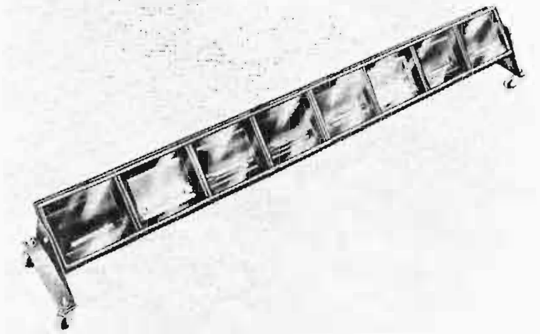

Fig. 23. An eight light strip (courtesy of Kliegl Bros.).

rama curtain. Fig. 23 shows a typical cyclorama strip light. This type of fixture is placed approximately 3 to 4 ft. from your curtain. This type of fixture, with lamps on approximately 11 in. centers, uses considerable power. A new type of cyclorama light called the "Space Cyc" has recently been designed (Fig. 24). This type of fixture does not require continuous strips of fixtures, but only one fixture spaced every 8 ft. The savings on wattage is considerable. This type of fixture will light a 20 ft. high cyclorama with fixtures overhead only on 8 ft. centers requiring only approximately 250 watts per linear foot. This is by far and away the best type cyc light available.

In most studio applications, a three-color cyclorama lighting system is desired. This will allow the cyclorama to be lighted to an infinite number of colors by blending the three primary colors. If budget is of prime concern, two color circuits can be used with a corresponding sacrifice of versatility.

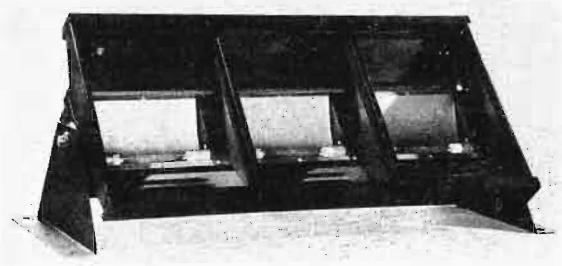

Fig. 24. Space cycle (courtesy of Kliegl Bros.).

Fig. 25. A 3½ in. Klieglight with patterns (courtesy of Kliegl Bros.).

Klieglights

A very special type of lighting fixture found in television studios is the Klieglight pattern projector. This fixture is in essence an optical projector that is used to project patterns on the background of the set area. Fig. 25 shows a 3½ in. 400 w Klieglight and an assortment of patterns. This fixture can be focused so that the pattern projected can be sharp or diffused. This type of fixture should not be used to light talent due to the characteristics of its light output. Fig. 26 shows the most popular sized fixture for studio application. This unit is a 6 in. 1,000 w wide angle unit that is ideally suited for short throws with large coverage areas. In place of the pattern feature, the units can be provided with an iris.

Follow Spots

The follow spot is a fixture that is being used less and less in television today. This is because of the person required to operate the unit. There is, however, no way to duplicate the effect of the follow spot for theatrical type productions in the studio. It is a good idea to plan to have a follow spot in the studio. Fig. 27 shows a 3,000 w dynabeam follow spot.

Fig. 26. A 6 in. wide angle Klieglight (courtesy of Kliegl Bros.).

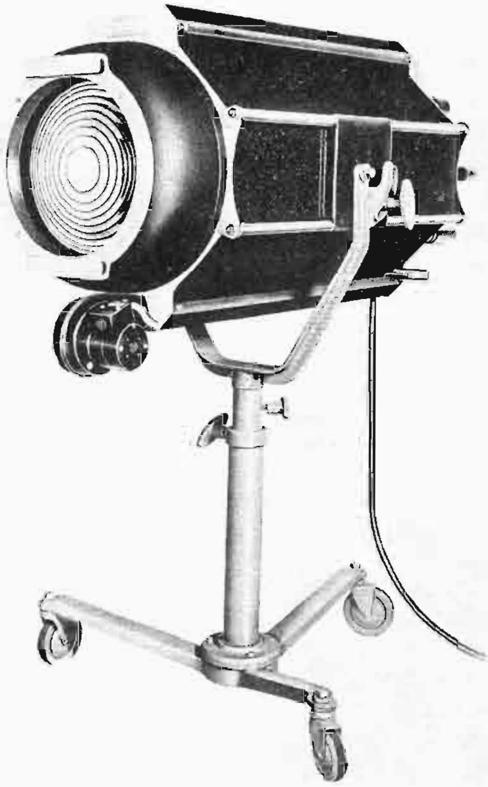

Fig. 27. A 3000-w dynabeam (courtesy of Kliegl Bros.).

FIXTURE APPLICATIONS

There are basically six special types of light that are required to light the average television set. Each one of these special lights will be discussed in detail.

Key Light

The key light or spotlight is the main apparent source of illumination on your set. It is the job of this light to make your subject or subjects stand out to the viewer. It is this light that highlights or "keys" the subject and draws attention to the subject.

A key light must have the following characteristics in order to be an effective key light:

1. *Control:* Since this is the main apparent source of illumination, output of this light must be controllable so that unwanted spill light can be avoided by the use of barn doors. The barn door is an accessory that is slipped onto the front of the spotlight that can be used to control this unwanted spill. For most television applications, a set of barn doors would have four leafs allowing the light beam to be controlled in all four directions.

2. *Soft edge:* The key light should have a soft edge. By soft edge, it is meant that the light pat-

tern of the unit does not have an abrupt cutoff but tends instead to disappear gradually around the edge of the pattern. This is important because on many sets more than one key light is used and if the units had a hard edge or a distinct cutoff, the overlap would be readily apparent.

3. *Harsh shadow:* Since it is the key light's main function to highlight the subject, the light must by definition, be a harsh light which will key and highlight certain features of the subject. Harsh shadow is a term used to describe the shadow that this light throws on the background.

4. *Focusing:* A key light must be capable of adjusting its beam from wide to narrow with a corresponding change in foot-candle level so that the exact coverage and/or intensity can be realized without the necessity of moving the fixture. The quality of the light output from the unit should not change when going from wide to narrow beam coverage. In other words, the light should still exhibit the controllable feature, soft edge feature, and harsh shadow feature no matter in what focus position the unit is used.

One of the single most important characteristics of the key light is its control. No matter how efficient a fixture may be, if the light is not completely controllable, it is almost totally useless. Take, for example, boom shadow problems. If the key light was not controllable, boom shadow could become a major problem in set lighting.

Back Light

Another very important fixture in the television studio is the back light. The back light is a fixture that is often not properly applied or overlooked completely. The main function of the back light is to separate the individual subjects from the background and give them depth and dimension. Without the use of a properly applied back light, the television picture has a very flat, dull appearance. The back light has the following characteristics:

1. *Control:* The back light must be every bit as controllable as the key light. This control is very important in keeping the back light flare out of the camera lens. The exact position of the back light and how it is used will be discussed in another section of this paper.

2. *Soft edge:* As in the key light, the back light fixture must exhibit a soft edge for the previously mentioned reasons.

3. *Harsh edge:* Again, the same note applied for shadow factor on the back light as does the key light.

4. *Focusing:* The focusing feature in many ways is more important in the back light than in the key light. This is true because of the variety of subjects that must be properly backlit. For example, a subject with dark hair must be backlit differently than a subject with light or blonde hair.

As in the case of the key light, the most universally used fixture in studios is the fresnel spotlight. As a rule, the intensity of back lighting required is half to one-third of the intensity of your key light. Therefore, the size and wattage of the back light is normally smaller than that of the key light.

Base Lighting

Base lighting is the third type of light that is required to light a television set. It is the job of the base light to establish the ambient light level that brings up the entire set area to a usable intensity for the studio cameras. The base light has the following characteristics:

1. *Noncontrollable:* Due to the fact that the base light should cover a very large area as evenly as possible, the unit should have a very large apparent source. Because of this large apparent source, the light is very uncontrollable by design. As a rule, the more uncontrollable the light, the better its quality for smoothness.

2. *Soft edge:* Since a number of base lights are normally required for set lighting, the units must exhibit a very soft edge so that these multiple lights can be easily blended.

3. *Soft shadow:* A base light must, by design and application, be a very soft source of illumination. In contrast to the key light with its harsh shadow, the base light should produce very soft shadows which do not detract from the picture and cause background shadows. The shadows cast by the base light should be undistinguishable on the background.

4. *Focusing:* The ideal base light is a unit that can have its coverage as well as intensity continuously adjustable by merely turning a small lever or crank. This allows the user maximum flexibility and ease in setting up his lighting levels.

Fill Light

A fill light is used in studio lighting to mask the "mistakes" created by the individual doing the lighting. It is the job of the fill light to cover up and fill the shadows created by the key light. In addition, the fill light can be used to improve the subject's appearance by use of soft, direct lighting. The characteristics of the fill light are identical to that of the base light and, in fact, the terms fill and base are used interchangeably. A fill light properly positioned can also serve to act as a base light and, conversely, a properly applied base light can also be used as a fill light.

Again, the most commonly used fixture for fill lighting is the scoop.

The four lights previously discused and mentioned make up the bulk of the units required to properly light a television set. As can be seen, only two basic fixtures, the fresnel spotlight and the scoop floodlight are required to light the talent on a set. In order to completely describe all of the lighting required, we must discuss set-cyclorama lighting and effect lighting.

Set Lights

Set lights are fixtures that are designed primarily to bring up the background levels to blend in with the overall set or mood. These lights are very specialized fixtures which are designed to smoothly light a wall or backdrop. Cyclorama lights, on the other hand, are lights that are designed to light a background curtain or cyc. With the use of color media, the cyclorama curtains can be "colored" through the use of these special cyclorama lights previously described. These units can be wired and controlled to produce 2, 3, or 4 individual colors on the curtain. With the use of dimmers, these colors can be blended to give any one of many possible shades and tints.

Effects Lighting

Effects lighting mainly concerns itself with shining a pattern or design on the background to add variety or interest to the picture. The light normally used for this pattern projection is a Klieglight, or ellipsoidal spotlight.

Now that the various types of studio fixtures have been discussed in detail, how are they applied?

For most basic lighting requirements, the triangular approach is used (Fig. 28). If the back light is directly behind the subject and the camera directly facing the subject, the key light is placed to one side of the subject and the base/fill light is placed an equal distance to the other side of the subject. If a line is drawn from each light toward the subject, they would intersect at the subject and form a 3-legged open triangle.

There is no steadfast rule as to which side the key light is on, that is left up to the individual doing the lighting. In some instances, the subject may be more easily lit from one side or the other.

In order to be effective, the back light should be 45°-60° above the horizon behind the subject. In this way, any unwanted shadows created by the back light will fall out of the camera area. The subject should be at least three feet from this back wall for proper separation of the light. By having the light at this high angle, direct radiation into the camera is substantially reduced.

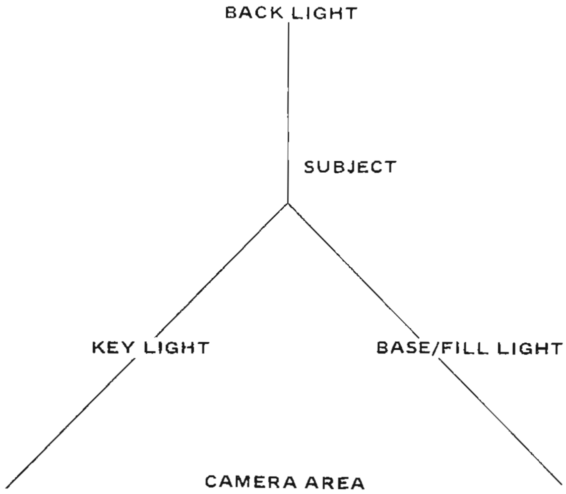

Fig. 28. A three-point light plot (courtesy of Kliegl Bros.).

The key light, on the other hand, should be 45° above the horizon. This angle was chosen for two reasons: by using 45°, the subject can look straight ahead at the camera without the direct radiation of the light into his eyes; and secondly, the light is not so high that it creates unwanted shadows under the nose and chin. The base/fill light is normally from eye level to a maximum of 30° above the horizon. This lower angle is required to ensure that the shadows created by the key light are adequately filled by this base light. In many applications, a pantograph or scissors hanger is used with the fill light so that its exact vertical height can be set upon application. Many studios use some sort of base/fill light on movable stands so that low level fill lighting can be easily accomplished.

The lighting levels that are required are set up by the particular camera that you are using. The ratio of the various lights is important to your overall picture quality. For a starting point, if your base and fill light is given a numerical value of 1, your key light could have a value anywhere from 2-3 with your back light having a value of from 1½-2. In other words, with a base light of 100 fc, the key light should be set for 300 fc and the back light for 150 fc. The exact ratio depends upon experience, subject matter, and the effects desired. It must be emphasized that these rules are only for starting purposes.

So far, the discussion has concerned the most basic type of setup which is the one camera-one subject set. As more subjects and cameras are added, so are the lighting requirements increased. Generally speaking, each subject should have his own key light and back light. In addition, there are many instances when the subject must be key lit and back lit from two separate lights because of multiple camera angles. Again, the basic triangle method of lighting can be utilized.

SUMMARY

As can be seen, the most important thing in designing and equipping a television studio is in the preplanning and forethought that goes into the facility. It is extremely important that the equipment be matched to the requirements of the studio. Misapplied equipment is more of a hindrance than inadequate equipment. A great deal of advice and information can be gathered from both lighting manufacturers and lighting consultants that are engaged in this business.

GLOSSARY OF TERMS

Absorption Filter—A filter which transmits certain wavelengths and reflects those not transmitted. The absorbed power appears as heat raising the temperature of the filter.

American National Standards Institute (ANSI)—An independent industry-wide association that establishes standards to promote consistency and interchangeability among manufacturers. This organization was formerly known as the United States of America Standards Institute (USASI or ASI), and previous to that as the American Standards Association (ASA).

ANSI—Abbreviation for the American National Standards Institute.

Arc Light—A luminaire using a carbon arc discharge as the source of illumination.

Aspect Ratio—The width of a screened image divided by its height.

Autotransformer Dimmer—A variable voltage transformer.

Backlight—Illumination of the subject from behind to produce a highlight along its pictured edge; light is from a direction substantially parallel to a vertical plane through the optical axis of the camera or viewer.

Barndoor—Shutters of flaps, usually two or four, which are attached to the front of the luminaire in order to control the shape of the light beam.

Baselight—Uniform, diffuse illumination used to establish a sufficient ambient level of light for quality type television and film pickups at desired lens aperture.

Batten—Horizontal pipe on which luminaires or scenery can be hung.

Beam Angle—Those points of the candlepower curve where the candlepower is 50 percent of maximum candlepower define the beam of the luminaire. The included angle is defined as the beam angle. Fifty percent of maximum candlepower is the criterion used for theatrical and photographic lighting equipment; the definition varies in other applications such as floodlighting.

Beam Lumens—The amount of light (lumens) within the beam angle of a luminaire.

Blackout Switch—A master on/off switch used for controlling the overall production lighting for either stages or studios.

Brightness—See Luminance.

Broad—A wide angle floodlight.

Candela—Unit of intensity.

Candlepower—A term that is sometimes used in place of "intensity."

Chaser Lights—A linear string of lamps wired in several circuits; equally spaced lamps (generally 4 or 5 apart) are connected to the same circuit; as the circuits are sequentially energized, spots of light sppear to be chasing along the string.

Chroma—In television, a measure of color intensity; saturation.

Chroma Key—A television special effect which electronically uses a monochromatic color background to key the insertion of another background picture. Deep ultramarine blue commonly is used for the background when the foreground involves people. This process is analogous to the traveling-matte systems used in motion picture photography.

Chromaticity—The hue and saturation aspects of colored light considered together; it is independent of the brightness aspect.

Color—An encompassing term referring to the characteristics of light other than spatial and temporal inhomogeneities; principally the aspect of the hue, saturation, and brightness. Object color involves the capacity of a surface to modify the color of light.

Color Frame—A metal frame used to support color media at the front of a luminaire.

Color Media—Any colored transparent material that can be placed in front of an instrument to color the light. These are often referred to as "gels" (for gelatin); cut glass and other plastic materials are also used.

Color Temperature—The temperature of a blackbody that generates light with the closest *visual* color match to the source being specified.

Console—See Lighting Control Console.

Contrast Range—The ratio of the highest luminance divided by the lowest luminance in a scene.

Cross Connect System—A connecting system which permits studio outlets to be temporarily connected to various dimmer and non-dim circuit outputs. Also see Patch Panel and Selector Switch System.

Cross Light—Equal illumination in front of the subject from two directions at substantially equal and opposite angles with the optical axis of the camera and a horizontal plane.

Cyclorama—A vertical surface which is used to form the background for a theatrical type setting. Although it can be fabricated of a solid material, which is referred to as a "hard cyc," usually it is made of heavy cloth which is drawn taut in both the horizontal and vertical planes in order to achieve a smooth, flat surface.

Cyclorama Strip Lights (also *Cyc Strip*)—A strip light mounted horizontally at the top or bottom of a cyclorama to light it in a smooth or uniform manner.

Dichroic Filter—A filter which transmits certain wavelengths and reflects those not transmitted; the absorption is small.

Diffuse—A reflecting or transmitting media for which the reflected/transmitted light is distributed uniformly in all directions. When used in reference to light, it indicates a soft light.

Dimmer—A device used for controlling the amount of light radiated from a luminaire. Common types are: resistance, autotransformer, magnetic amplifier, silicon controlled rectifier or semiconductor, thryratron, and iris type dimmers.

Dimmer Curve—The performance characteristics of a dimmer indicated in terms of the light output of a lamp controlled by the dimmer versus the arbitrary linear scale of zero to ten associated with the dimmer control.

Dimmer Room—A room or space where remotely controlled dimmers are housed.

Edge Effect—An increased emphasis of outlines common to the image-orthicon.

Effects Machine—A scenic projector, often involving multiple slides and/or motion.

Efficacy (also *Luminous Efficacy*)—The effectiveness of a light source in converting electric power (watts) to luminous flux (lumens) expressed in lumens per watt (LPW). In the past, this concept was called luminous efficiency. Also see Lumens per Watt.

Efficiency—The ratio of a specifically designated output flux (lumens) to the flux (lumens) generated by the lamps in a luminaire; e.g., beam efficiency, field efficiency, luminaire efficiency, etc. Various utilization efficiencies involve the ratio of flux delivered to a specific location divided by the total flux generated by the lamps used.

Ellipsoidal Spotlight—A luminaire embodying a lamp, a reflector, a framing device, and a single or compound lens system, together with provisions for accommodating a pattern hold and patterns.

Eye-Light—Illumination to produce a specular reflection from the eyes (and teeth) without adding a significant increase of light on the subject.

Fader—A term sometimes applied to master dimmers controlling many dimming circuits.

Field Angle—Those points of the candlepower curve where the candlepower is 10 percent of the maximum candlepower define the field of the luminaire. The included angle is defined as the field angle.

Fill Light—Supplementary illumination to reduce shadow or contrast range.

Fixture—A name applied to luminaires.

Floodlight—A luminaire consisting of only a lamp and reflector with fixed spacing; generally, the reflector has a diffused finish and is often physically large in size.

Flux—A measure of the amount of light. The unit is the lumen.

Fly—To lift scenery or equipment above the stage floor (and usually out of view) by means of lines from the gridiron.

f-Number (also *f-Stop*)—A measure of the light-transmitting ability of a camera or projection lens; also referred to as lens speed or lens aperture. As the numerical value increases, less light is transmitted by the lens.

Focal Length—Distance between a particular point of a lens or reflector and the focal point. For simple lenses in lighting instruments, it is usually adequate to measure this distance from the center of the lens.

Focal Point—The small region where a lens or reflector concentrates all light rays received from a distinct source of light.

Focus—In addition to its optical meanings, focus is used as a verb to indicate the aiming and adjusting of a luminaire.

Follow Spot—A high power, narrow beam spotlight suited for long throws (typically 100 to 300 ft.), generally with iris, shutters, color boom, and other controls. It is designed for hand operation to follow the movement of performers.

Footcandle—A unit of illumination. $1\ \text{fc} = 1\ \text{lm/ft}^2$.

Footlambert—A unit of luminance. A *diffuse* surface emitting one lumen per square foot has a luminance of one fL.

Fresnel Lens—A lens that acts similarly to a plano-convex lens but is thinner and lighter due to steps on the convex side. Often the flat side has a rough surface to smooth light beams by slightly diffusing the light.

Fresnel Spotlight (also *Fresnel*)—A luminaire embodying a lamp and a Fresnel lens, with or without a reflector, which has a soft beam edge. The field and beam angles can be varied by changing the spacing between the lamp and lens.

Front Lighting—Lighting from the general direction of the viewer.

Frost—One of a series of color media that is translucent but colorless, used to diffuse light.

Funnel (also *High Hat, Snoot, Top Hat*)—Metal tubes of various sizes that can be mounted on the front of spotlights to control stray light.

On certain instruments a funnel can be used to reduce beam size.

Gel—See Color Media.

Hard Light—A light that produces hard or sharply defined shadows.

High-Key Lighting—A type of lighting which, applied to a scene, is intended to produce a picture having gradations falling primarily between gray and white; dark grays and black are present but in very limited areas.

Illumination—General—synonym of lighting. Specific—the amount of light (flux) per unit area incident of a surface. The unit is either the footcandle or the lumen per square foot.

Intensity—A measure of the "strength" of a light source in a particular direction. Intensity is independent of the distance from the source. The unit is the candela. Also see Candlepower.

Inverse Square Law—An equation relating the intensity of the source to the illumination it produces at a given distance.

Iris (also *Iris Diaphragm*)—An arrangement of thin plates that form an opaque area with a circular opening in the center. The size of the circular opening is adjustable. As an example of its application, an iris diaphragm commonly is used in follow spots to vary the size of the beam.

Kelvin—A temperature scale where each degree is the same size as a degree centigrade but has its zero at -273°; i.e. -273°C = 0°K, 0°C = 273°K, 100°C = 373°K, etc. This is the unit of temperature used to designate the color temperature of a light source.

Key Light—The principal source of light which establishes the character of the actor together with the atmosphere and mood of the scene.

Lens Spotlight—A luminaire embodying a lamp and a simple lens (plano-convex or biconvex), with or without a reflector, which has variable field and beam angles obtained by changing the spacing between the lamp and the lens.

Light Center Length (LCL)—The distance between the center of an incandescent lamp filament and an arbitrary, but standard point of the lamp base.

Lighting Batten—A pipe and wireway assembly suspended by wire cables with pigtails or receptacles which serves both to physically support the luminaires and to provide electrical power.

Lighting Control Console—The assembly, usually a desk-type of housing, used to contain the controls required for adjusting the production lighting, such as dimmer, nondim, and other control functions.

Lighting Grid—A fixed structure of either aluminum or steel members, such as pipe, which is located above the studio floor for the purpose of supporting luminaires and to support the electrical outlets required.

Low Key Lighting—A type of lighting which, applied to a scene, is intended to produce a picture having graduations from middle gray to black with comparatively limited areas of light grays and white.

Lumen—A unit of (light) flux.

Lumen per Square Foot—A unit of illumination. 1 lm/ft^2 = 1 fc.

Lumens per Watt (LPW)—The number of lumens produced by a light source for each watt of electrical power supplied to the light source. E.G., if a 1,000 watt lamp produces 20,000 lumens, then $\frac{20{,}000}{1{,}000} = 20$ lumen/watt. Also see Efficacy.

Luminaire—A complete lighting unit consisting of a lamp or lamps together with the parts designated to distribute the light, to position and protect the lamps, and to connect the lamps to the power supply.

Luminance—A measure of the light (flux) per unit area leaving a surface in a particular direction. The unit is the flootlambert. This quantity was formerly known as "brightness."

Luminous—An adjective to indicate the production of light, e.g., "luminous source" to distinguish from electrical sources, etc. It is sometimes used before "intensity" or "flux."

Lux—The unit of illumination used predominately in Europe; equal to one lumen per square meter. Ten lux is approximately equal to one footcandle.

Maximum overall Length (MOL)—The maximum dimension of a lamp from base to base for double ended lamps or base to extreme point of bulb for single ended lamps.

Memory System—An automatic device using controls such as punched cards or magnetic tape to control successive settings of dimmers or cross connect systems.

Nondim Circuit—A circuit supplying electrical power to a luminaire by means of a switch or a relay in order to permit an on-off function rather than a dimming function.

Nonlens Spotlight—A luminaire embodying only a lamp and a reflector which has variable field and beam angles obtained by changing the spacing between the lamp and the reflector. (Not for studio use.)

Pantograph—A hanger-type assembly having a scissor-type mechanical action which permits variable height adjustment and which is counterbalanced with tension springs and friction devices.

Par Light—A spotlight-like luminaire using a PAR lamp. The beam characteristics depend upon the PAR lamp used.

Patch Panel—A cross connect system using a plug and jack assembly.

Plugging Box—A portable box with one electrical feed and outlets for two or more branch circuits; often contains branch fuses.

Preset Control—The control, usually a potentiometer located on the lighting control console, used to program or preset the output of a dimmer, and in turn, the light output of the luminaire connected to the dimmer.

Remote Controlled Dimmer—A dimmer which requires an electrical circuit or circuits as part or all of the transmission system between the central lever and the dimmer unit.

Scene Master—A device for controlling a group of dimmers which are assigned to a specific set or scene.

Scoop—A deep floodlight with a diffuse, generally elliptical contoured reflector; the field angle commonly is less than 100°.

SCR—Abbreviation for Silicon Controlled Rectifier; a solid state semi-conductor device operating as a high-speed switch and is the basis for most modern dimmers. (Kliegl copyright)

Set Light—Separate illumination of background or set other than that provided for principal subjects or areas.

Soft Light—A well-diffused light source which produces soft or poorly defined shadows when an object is placed in between the luminaire and the light background.

Specular—Description of a mirror-like surface. When used to describe a light, it implies a hard light.

Spill Light—Stray light outside of the main beam of a luminaire; light that is misplaced or undesired within a scene.

Striplight—A luminaire with a number of lamps arranged in a line. Often each lamp is in an individual compartment. There may be a reflector behind the lamp and/or a color media in front of the lamp. Striplights are normally wired in three or four circuits.

Throw—To direct the light of an instrument in a particular direction. Also the effective distance between a luminaire and the area being lighted.

Underwriter's Laboratories (UL)—An independent testing laboratory that will test equipment to see if it meets certain safety standards when properly used.

Unit—A name applied to theatrical type luminaires, basically jargon for lighting unit.

Worklights—A general lighting system permanently installed in the studio or stage production area, which provides sufficient illumination for moving scenery and general work when the production lighting system is not in use.

Bibliography Lighting

1949

S. McCandless, *A Method of Lighting the Stage.* Theatre Arts Books.

1953

W. Boast, *Illumination Engineering,* McGraw-Hill.

1954

J. Rubin and L. Watson, Theatrical Lighting Practice, Theatre Arts Books.

1960

Rollo Gillespie Williams, *Evaluation and Control of Brightness Levels for Television Studio Lighting,* July, 470-474.

Walter A. Levy, *New Technology in Lighting Control Equipment,* April, 253-255.

1961

Frederick P. Bentham, *Design of Lighting Control Consoles Used in British Television Studios,* October, 814-821.

Jean De Backer, *A Storage Memorized Light-Control System,* November, 906-909.

1962

F. Alton Everest, *The Efficient Use of Light in Macrocinematography,* September, 664-667.

S. C. Peek, *Quartz Iodine Lamps and Reflectors for Set Lighting,* September, 667-669.

K. R. Ackerman, *Studio Lighting in the BBC Television Centre,* London: Equipments and Techniques, April, 266-268.

1963

None.

1964

L. E. Barbrow, *International Lighting Vocabulary,* April, 331-332.

Don V. Kloepfel, *Xenon Projection Lamps: A Resume,* June, 479-480.

1965

Maxwell A.Kerr, *High-Intensity Lighting (HIL) for Photography of Launch Operations,* NASA Projecto Apollo, February, 73-79.

Harold P. Field, *Spot Photometers in Exposure Control,* July, 592-593.

A. T. Puder and D. Mortenson, *Xenon Illuminator Systems for 35mm and 70mm Projection,* July, 594-597.

1966

Harold Plumadore, *Use of the Blown Arc Lamp in 35mm and 70mm Projection,* January, 32-33.

Albert Spitzak, *Film Scan System Using a Semiconductor Light Source and Light Detector,* February, 103-105.

J. Karl Justin, *Lecture Hall and Learning Space Design,* March, 183-190.

Francis D. Harrington, *Summaries of Papers on Several Light Sources and a Framing Drum Spectrograph,* April, 355-357.

George Gill and Charles F. Sorenson, *Making Available Light Available,* March, 310-312.

Robert E. Levin and Arnold E. Westlund, *Design Parameters for the Use of Quartz-Iodine Lamps,* June, 589-593.

1967

David J. Degenkolb and Jack P. Hall, *Dichroic Safelight,* January, 15-17.

Frederick T. Sharp, *Myth and Reality of Lighting for Surgical Photography,* November, 1094-1095.

R. de B. McCullough, et al. *Lighting and Layout for Small TV Studios,* The Strand Electric and Engineering Co., Ltd., London.

E. A. R. Herren, *New Developments in Stages and Equipment at Major Studios in Great Britain,* September, 877-883.

M. A. Hankins, *History of Motion-Picture Set Lighting Equipment,* July, 671-674.

Donald V. Kloepfel, *The Characteristics and Compatibility of Projection Light Sources,* March, 182-184.

Leo Levi, *On Contrast in Rear-Projection Screens,* December, 1193-1195.

C. N. Clark and T. F. Neubecker, *Evolution in Tungsten Lamps for Television and Film Lighting,* April, 347-360.

1968

Armand Roux and Jean Vivié, *A New Additive Light Source with Color Control for Motion-Picture Printers,* August, 806-808.

G. M. Berggren and R. W. Townsend, *High-Efficiency Projection for a 35mm Curved Screen Theater,* July, 721-722.

Robert E. Levin, *Luminance—A Tutorial Paper,* October, 1005-1011.

R. E. Levin and T. M. Lemons, *Television and Film Applications of Tungsten-Halogen Lamps,* February, 124-128.

T. M. Lemons and R. F. Levin, *Tungsten-Halogen Replacement Lamps for Standard Incandescent Types,* November, 1194-1198.

J. S. Chandler and J. J. De Palma, *High-Brightness Projection Screens with Ambient Light Rejection,* October, 1012-1024.

C. G. Clarke, *Professional Cinematography,* American Society of Cinematographers.

I. A. Kugler, *Xenon Lamps in Film and Television,* June, 693-701.

Herbert Tummel, *An Historical Survey of the Development of Xenon Light for Projection Purposes,* June, 630-632.

1969

R. E. Putman, J. F. Wiggin, C. N. Clark, and H. G. Williams, *Discharge Lamps and Color Television,* September, 700-706. (See Errata and Addendum, October, 888.)

T. M. Lemons and R. E. Levin, *Performance Ratings of Incandescent Lamps,* December, 1064-1069.

Pierre Mertz, *Current Approved Terms Dealing With Light and Vision,* February, 97.

Arthur I. Bodkins and William B. Elmer, *Television Studio Laminaires with Selective Reflectors,* February, 86-88.

Harold Plumadore, *An Advanced-Design 6-kw Xenon Projection Lamp,* March, 157-159.

1970

Robert S. Freeman and Russell J. Ayling, *Xenon Arc Searchlight Illumination of the Apollo 8 Launch Area,* April, 313-316.

Ralph L. Baker, *The Electroluminescent Panel as a Binary Light Source,* July, 600-603.

Chan Street, *A Three-Element Projector Condensing System,* February, 85-87.

Larry A. Nelson, *An Engineering Approach to Studio Lighting,* NAB.

1971

Thomas Earle-Knight, *The Design and Operation of Remotely Controlled Luminaires for Television and Film Studios,* April, 265-269.

Larry E. Nelson, *Design of Local Origination Studio,* NAB.

1972

Adrian B. Ettlinger and Salvatore Bonsignor, *A CBS Computerized Lighting Control System,* April, 277-281.

H. S. Strauss, W. E. Thouret, J. Leyden, H. Kee, and T. W. Hunt, *New Xenon Compact-Arc Projection Lamps for Horizontal Operation,* January, 33-38.

Illuminating Engineering Society, *IES Lighting Handbook* (5th Edition).

1973

S. Henderson and A. Mursden, *Lamps and Lighting,* Crane, Russuk, & Co.

Yorick G. Hurd, *Measured and Observed Discepancies of Screen Luminances,* February, 87-91.

1974

Albert Kaufman and Dietrich Sauter, *Problems of Lighting in Color Television Outdoor Broadcasts,* January, 20-26.

Uwe-Jens Amlong, Jurgen Heller, Lutz Grambow, and Hans-Raimar Pohlenz, *Light for Color Television with a System of Metal Halide Lamps,* January, 26-30. (A Translation)

William E. Glenn and Salvatore J. Bonsignore, *A New Method for Cyclorama Lighting,* September, 722-724.

Werner Block, Michael J. McGovern, and Thomas M. Lemons, *A New Daylight Source,* September 725-728.

Robert E. Levine (editor), *Sylvania Lighting Handbook* (5th Edition), no date.

26

Audio Recording on Magnetic Tape

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The material presented in this chapter was gathered from the many available sources for a general guide to the installation, maintenance, and operating engineer. It is intended for use as a supplement to the instruction manuals for specific tape machines in the station and to explain some of the basic principles.

MAGNETIC TAPE

Audio magnetic recording tape consists of a backing or base material, typically polyester ("Mylar") or acetate, and finely divided magnetic particles suspended in a strong binder (oxide coating) that is deposited on the plastic backing. Tapes used in NAB Cartridges have an additional dry lubricant deposited on the plastic backing opposite to the oxide coating side, generally in a dot pattern. This lubricant permits the tape to slide on the adjacent layer, on through to the center of the tape pack, and out past the heads again in a continuous loop.

Some audio tapes have a highly polished oxide coating side and even some open reel (nonlubricated) types have an etched or rough coated base side that may cause confusion as to which side to put in contact with the tape head. If such tape is used intermixed with tape having a dull oxide coating surface and polished base side, a positive identification of the oxide coating side of both types is desired.

Audio tapes of interest in ¼ in. to 2 in. widths are "½ Mil" to "1½ Mil" thick as commonly referenced. Actually, these dimensions are for the backing or base film thickness. Total thickness includes one or more coatings:

Nonlubricated Tape

Thickness in mils (0.001 in.)	Scotch #111	1 Mil	½ Mil
Backing (base)	1.42	0.92	0.50
Oxide coating	0.44	0.40	0.40
Total	1.86	1.32	0.90
Static tensile, lbs/¼/in.			
Yield strength	5.0	4.0	3.0
Breaking strength	6.5	6.0	5.3

Lubricated Tape

Thickness in mils	1 Mil	1 Mil	¾ Mil	¾ Mil
Backing (base)	0.92	0.92	0.75	0.75
Oxide coating	0.37	0.27	0.38	0.38
Backing lubricant	0.11	0.11	0.10	0.04
Total	1.40	1.30	1.23	1.17
Static tensile, lbs/¼/ in.				
Yield strength	4.0	4.0	3.1	3.9
Breaking strength	6.0	6.0	4.9	5.9

Scotch #111 is listed because many other tapes are referenced to it, especially the peak bias reference. It is acetate base, while all of the others listed are polyester. The ½ mil example has a tensilized polyester base, which gives it proportionally more strength per unit thickness of the base.

Oxide coating thickness has some effect on peak bias requirements, even more on the maximum undistorted output level. The intrinsic magnetic properties have much more effect on the peak bias requirements, but are difficult to interpret as to the amount of peak bias change since no single parameter is the controlling factor. If it is desired to keep the peak bias requirements within a narrow range to prevent the necessity of changing machine bias adjustment for consistently optimum results, tape of the same type and manufacture or a closely matched alternate is all that should be used. Manufacturers typically have their own peak bias reference, which is not easily matched to another manufacturer's reference, so tests should be conducted to assure an acceptable match.

There are many factors to consider in selecting the tape desired for general use in your plant, in addition to cost and playing time per reel size. High output, low noise, low print through, output uniformity, and the way they interrelate should be weighed against overall requirements for your operation. A tape applications engineer for one of the tape manufacturers can be of great assistance in the selection process.

If the selected tape has appreciably different characteristics than tape currently used, intermixing them for recording can present a problem. Consider dedicating separate machines for recording the two types of tape in order to optimize the bias current for each type. The method of adjusting bias may be covered for tapes having medium biasing requirements only. If the frequency response of one of the tape types rises or falls more than the machine specification in the instruction manual, refer to the section on optimum biasing later in this chapter. After a period of time most of the older tape will be phased out of the rerecording process and a single bias setting can be used for all recordings.

With the bias properly adjusted, a new tape under consideration should be checked for headroom, or the level differential between the NAB Standard Reference Level and the 3 percent 3rd harmonic distortion point at 400 Hz. If only total harmonic distortion can be measured with test equipment available, this will give a sufficiently close approximation. Professional tape recorders should have no more than 2 percent total harmonic distortion in the record/play process with good tape having medium bias requirements at a level a few dB above normal, where the tape and machine noise level is more than 46 dB down. If the machine will not reach the 2 percent distortion point, check the bias waveform distortion, flutter, etc., to find and correct the cause.

After finding a distortion reading of 2 percent or less, increase the input level to the recording amplifier at 400 Hz until the distortion reads 3 percent THD and note the output level of the playback amplifier. This level should be approximately 8 dB above the normal operating level of the machine, which should be set to agree with the level derived from an NAB Test Tape Standard Reference Level, or some traceable standard, if interchangeability with most prerecorded tapes is desired.

If the new tape under consideration does not have the 8-dB minimum headroom, it should not be adopted unless some special parameter is desired such as extended play that will justify a nonstandard operating level or insufficient headroom. Many other factors should be considered in selecting a new tape (Spratt, 1964) in addition to those covered. The surface characteristics of each side, the degree of stiffness, tape width tolerance, and erasing requirements are among them.

The magnetic material is typically in the form of long needle-shaped particles (Lowman, 1972), some of them are bound to project from the surface of the tape. Quite naturally, this would cause unwanted head wear. Several methods of reducing this form of surface roughness are employed; one of the better is rolling the particles back into the heat softened binder with a highly polished roller surface. The quality of the surface is important to prevent excessive shedding of the oxide and binder, which rapidly builds up on the tape machine heads, pinch roller, etc., which it contacts. Also, a smooth surface permits a more intimate contact between the tape and the head to prevent additional high frequency losses.

MAGNETIC RECORDING THEORY

All sound recording processes are essentially techniques for the storage of information where acoustic signals are transformed into some form of permanent or semipermanent record (Spratt, 1964) from which they can subsequently be converted back into sound. In magnetic recording, the sound information is stored in the form of elemental permanent magnets corresponding in length and strength to the signals to be recorded; these permanent magnets being formed in a continuous strip of some suitable magnetic material.

During the recording process, the magnetic medium is moved through the magnetic field of the gap in the recording head and the resulting flux pattern on the tape is a function of instantaneous magnitude of the recording signal at the moment the tape leaves the head gap. Ignoring the various losses in the heads, etc., which are fairly small in the 200 Hz to 2 kHz region on professional audio tape recorders, flux density on the tape is directly proportional to the recording current.

The heads normally take the form of rings of low coercivity, high permeability laminations split at one point at least with a narrow airgap and wound with one or more coils of fine wire. The length of the airgap ranges from 0.020 to 0.003 in. for an erase head (Spratt, 1964), to 0.0001 in. for a reproducing head. In its travel past these heads, the tape always moves perpendicularly to the line of the airgap. Currents corresponding to the recorded signal are fed into the coil(s) of the recording head and as a result, a flux, also varying in accordance with the recording signals, is produced in the magnetic circuit of this head. The greater part of this flux passes straight across the airgap, but a small portion appears as fringing or leakage flux in front of and behind the airgap. As the tape coating passes across the face of the head, that portion of it in the immediate vicinity of the airgap is magnetized by the magnetic field there. Since the magnetic particles in the coating are of high coercivity, some of this magnetization is retained after the tape has left the gap as the actual recorded signal.

ERASURE

One of the several advantages of magnetic recording lies in the ability to erase the signals which have been previously recorded on the magnetic tape, making it ready to accept a new set of recorded signals. Although permanent magnet erasure is used in a few specialized applications such as delay cartridges, the spacing of the several sections for minimum acceptable operation is very critical.

Bulk erasure gives the most complete erasure of any method employed to date, and will reduce the residual noise level of an audio tape of medium characteristics to approximately 1 dB above that of virgin tape, when carefully done. The bulk eraser must have sufficient power to completely saturate the tape, then the flux field must be slowly reduced on the tape to gradually reduce the remanent flux to zero. The field of the bulk eraser may be reduced by pulling the tape out of it, or by gradually reducing the current to it. The power to the bulk eraser must be a sine wave of relatively low distortion, such as most commercial utilities provide. Any asymmetry of the positive versus the negative waveform will leave a higher residual noise on the tape.

Where only one of two or more tracks on a tape, or a segment rather than the entire reel of tape is to be erased, bulk erasure is impractical. To accomplish demagnetization of just part of a tape, an erasing head with the proper track configuration is required. Of course, a full track head may be used to erase the entire tape instead of a bulk eraser. The erase head is usually similar in general construction and appearance to the recording head. The basic difference lies in the length of the gap (Haynes, 1957). In order to produce a diffuse field, the erase gap length may be as much as 200 times as long as in the associated reproducing head, or approximately 0.020 in. long.

If a normal erase head is employed, it is more than likely that the first erasure will be found imperfect and that a second run past the erase head is found necessary to achieve anything approaching virgin tape conditions (Spratt, 1964). This is due to the fact that the "erased" tape, when leaving the head and still subjected to the diminishing erase field, is likely to be affected by the recorded field not yet erased from the tape on the other side of the head, so that the original recording is recorded, but at a very much lower level, on the tape. Hence the need for a second run past the erase head, which will almost certainly prove effective. This rerecording effect is less likely to occur when the erase head gap is made large, i.e., 0.20 in. in length, so as to give a correspondingly wide spread of the erase field.

Like the bulk eraser, the erase head must have sufficient power to completely saturate the tape, then the field is slowly reduced by tape moving away from the erase head gap. The feed to the erase head must also be a sine wave of relatively low distortion without even-order harmonics of any significance that would cause asymmetry of the positive versus the negative waveform and a higher than necessary residual noise on the tape.

High Frequency Bias

If recording is attempted without bias, operation would have to be confined to the immediate neighborhood of the origin of the B-H curve; otherwise, the amount of distortion would prove intolerable (Spratt, 1964). This restriction on the maximum operating level inevitably results in poor signal-to-noise ratio. The oldest method of obtaining a linear recording with magnetic media is through the use of a permanent, or dc bias, added to the signal (Stewart, 1958). If the medium is first completely demagnetized, the transfer characteristic can be arranged to operate on a comparatively linear portion of the B-H curve of that medium by adding a dc component to the signal. However, only a portion of one-half of the B-H curve is used, with a resultant low signal output.

This was greatly improved upon by the introduction of hf bias, which increased sensitivity as well as maximum undistorted output level, while absence of a dc component in the magnetizing force assures a low noise level. Bias frequencies of five to ten times the highest signal frequency are preferred. This is usually called supersonic bias and is in the 75 kHz to 150 kHz range. The bias current through the recording head coil is always many times as great as that of the signal being recorded. Using the correct value of bias current is very important, for this affects the frequency response, distortion and signal-to-noise characteristics of the recording.

A bias value that is too low for the type of tape being recorded results in a "boost" in high frequency response, high distortion, and a poor signal-to-noise ratio. A value that is too high will cause a loss of high frequency response, due to partial erasure as the signal leaves the recording head airgap. It would be expected that there exists some value or range of values of hf bias current to optimize performance in sensitivity, maximum distortionless output level, frequency response, or all of them (Spratt, 1964). This value could be set to the prescribed point on a meter of the tape machine. This is largely the case but optimum conditions are somewhat different for each parameter and one should not be favored at the expense of the others.

A better method of bias adjustment is to select a tape that has average characteristics for the type used. Reduce the bias current well below the normal level, then slowly increase it for a peak in the 400 Hz output level at full operating level. Note the current or the position of the control. Increase the bias further, closely watching for a rather sharp decrease in output level which is characteristic with some types of tape (Spratt, 1964). A further increase in bias with this type of tape should soon cause the output level to rise again to a gentle peak. An optimum setting for the bias will be for about 1 dB of output level reduction caused by a further increase in bias current. Other types of tape will rise smoothly to a gentle peak without any intermediate dip, and can also be set for optimum bias by further increasing it for a 1 dB reduction in output level beyond the peak.

Frequencies above 400 Hz should then be checked to see that none fall outside the frequency response limits. Some machines have auxiliary peaking controls or suggested changes of fixed component values to make small adjustments in frequency response. If they cannot be used to correct the response, the bias current should be dropped slightly to raise the high frequency levels, or raised to lower the high frequency levels even more. If the results are far from the specified limits in the instruction manual, check for defective components in the equalization circuits or signal path, replace them, and repeat the bias adjusting procedure.

The bias adjustment should not be set on the steep slope of the bias current versus output level curve since small changes in tape characteristics, even those found on the same reel, will cause considerable variation in frequency response, output level and distortion. The only penalty of slight overbiasing, assuming the frequency response is acceptable, is a small reduction in headroom at the shorter wavelengths.

MAGNETIC REPRODUCTION

During the reproducing or playback process, the recorded tape is moved past the airgap of the reproducing head, which may be similar to or even the same head used for recording. The movement of the tape and the magnetic flux patterns it contains induces a voltage in the winding(s) of the reproducing head, which is proportional to the amplitude of the recorded signal and to the frequency of the recorded signal (Stewart, 1958). As the frequency increases, the output signal increases at a rate of 6 dB/octave, assuming the recorded signal is constant in amplitude. Doubling the reproduced frequency by doubling the tape speed will produce the same 6 dB/octave increase in output as doubling the recorded frequency, again assuming the recorded signal is constant in amplitude and that the head losses, etc., are negligible over the frequency range under consideration. When the tape is stopped and there is no relative movement between it and the reproducing head, the flux is fixed in value in the airgap and no signal is generated in the coil.

High Frequency Response

The length of the airgap and the relative tape speed across the airgap are key factors in the high frequency limit of the reproducing process. With typical airgap lengths of 0.0001 in. to 0.0002 in. that are difficult to measure within 10 percent accuracy, an additional hardening of the head surfaces near the gap, due to the final lapping and polishing, reduces the permeability of the iron in that critical area. This, along with other factors (Spratt, 1964), led to the accepted practice of referring to the physical airgap length, i.e., the dimensional length specified in the design and the effective airgap length, estimated from the first head-induced null frequency. This null is caused by cancellation of the flux in the airgap when the signal wavelength is comparable to the length of the airgap. This effective airgap length is nearly always at least 15 percent larger than the physical gap length.

During the recording process, the tape coating assumes a permanent state of magnetization at the instant it leaves the recording head airgap, so the gap length or dimension across the gap is relatively uncritical. It must be large enough to permit the magnetic flux to fringe or leak far enough away from the gap to provide deep penetration into the oxide coating or the magnetic tape (Lowman, 1972). On the other hand, the gap must be small enough so that sharp changes or gradients of the flux may be generated. Thus, the recording head airgap length is a compromise between a large gap, for strong recorded signals, and a narrow one, for definition of small increments of change. A typical recording gap length is 500 μ in.

However, in reproducing, the magnetic flux emanating from the moving tape must induce a voltage differential across the reproducing head coil if the current is to flow in that coil, which is proportional to the sum of the positive and negative flux patterns in the gap at any given instant. When the wavelength of the recorded frequency is equal to the effective airgap length, the sum of the positive and negative flux patterns in the gap at that instant is zero, as is the voltage induced in the head coil. Except for those using very low tape speeds, i.e. below 3.75 ips, the typical 100 μ in. airgap used in the reproduce heads of professional tape machines places the frequency subject to gap cancellation well above the highest signal frequency of interest.

The resonant frequency of the reproducing head inductance and the actual or distributed capacitance of the head and associated circuit should also be well above the highest signal frequency of interest. The head and circuit capacitance, especially in the head cables, must be kept to a minimum because reducing the inductance to raise the resonant frequency reduces the head output over the entire passband, and will particularly diminish low frequency signals.

Low Frequency Response

As previously stated with some qualification, flux density in the tape coating is directly proportional to the recording current. Below approximately 2 kHz on a typical reproduce head at a tape speed of 7.5 ips, there is a 6 dB/octave loss for the longer wavelengths. Consequently, the recorded lower frequencies in the neighborhood of 50 Hz will be approximately 24 dB below the 1,000 Hz level (Haynes, 1957). During playback, therefore, a considerable amount of postequalization is required to attain a nearly flat overall response. The unusual amount of low frequency "boost" required will result in raising all low frequency noise and hum components as well. This procedure usually results in an overall marked reduction in dynamic range.

The long wavelength signals cannot be correspondingly increased in recorded level to compensate for the 6 dB/octave loss in playback because of tape overload and saturation with higher levels. The NAB reproducing characteristic and associated compensating recording requirements have been optimized for tape overload versus other parameters of interest with tapes of medium characteristics. It is essentially the only equalization standard used for professional audio tapes in the US.

The lowest frequency which can be reproduced in any tape system is determined by the signal-to-noise ratio which can be tolerated. As noted, the voltage developed across the coil(s) of the reproducing head decreases with frequency until a level is reached which is insufficiently above the noise threshold of the system and, therefore, considered unusable. The maximum effective bandwidth of most audio tape recorders/reproducers is around nine octaves, i.e., 30 Hz to 15,360 Hz.

Print-through

If a tape is recorded and stored for a period of time, there is a phenomenon occasionally encountered called print-through. It occurs because a strongly magnetized tape section is wound next to a low level or unmagnetized portion, and the strong fields transfer the signal to the adjacent layer. Since the transfer is through the polyester or acetate base, the effect is quite small, but often objectionable. This is not a linear effect, it becomes more serious as the recording level increases and will decrease about 2 dB for a 1 dB decrease in recording level.

The effect increases with time of storage, higher temperatures and exposure to stray magnetic fields. Most of the effect is in the mid-frequency range, where the ear is most sensitive, with high and low-frequency print-through virtually unnoticeable. The use of thinner base tapes will slightly increase the effect.

If a tape is to be stored for some time, the following precautions will help in eliminating print-through: Program peaks should be held to a level not exceeding 0 VU on the recording meter. The storage temperature should be kept below 75° F, and the reel should be stored in a steel can to protect against stray magnetic fields. To protect valuable recordings, it would be well to use a special tape rated for up to 8 dB lower print-through effect than general purpose types. Occasional playing or rewinding of the tape will redistribute the signals on adjacent layers, thereby reducing the effect. Most machines wind the tape more tightly when rewinding than when playing. Therefore, it is best to store tapes "tails out," or before rewinding to take advantage of the slightly increased spacing between adjacent layers.

TAPE HEAD

The individual tape recorder/reproducer is designed for a set of tape heads of certain characteristics, and the user should not attempt to replace them with heads of other characteristics. The physical configuration, mounting style, track configuration, and head contour as well as the

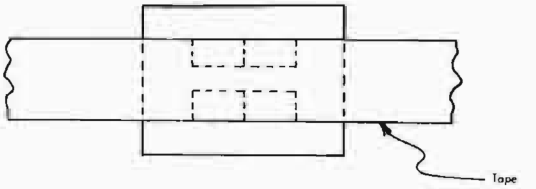

Fig. 1. Correct height adjustment (front view). (Originally published in the September 1974 *Broadcast Engineering Magazine.*)

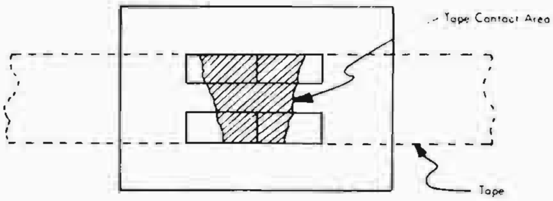

Fig. 3. Keystone Wear pattern (front view). (Originally published in the September 1974 *Broadcast Engineering Magazine.*)

electrical characteristics must be matched in replacement heads. More popular types are available from several manufacturers and may be selected from cross-reference charts or by matching the important parameters.

Correct height adjustment of the tape to the heads, or in most tape machines the heads to the tape path, is important for single track heads as well as multitrack heads. Maladjustment of a single track head to tape height adjustment will reduce the amount of signal output from the tape and may cause uneven wear of both tape and head. Proper alignment is even more important on multitrack heads to maintain maximum guard-band width between tracks for minimum crosstalk.

All of the line drawings which follow utilize a 2-track stereo head for illustration (Zeman, 1974). Fig. 1 shows the correct height adjustment for a head of this type. The head should be adjusted so the top edge of the stack in Channel 1, and the bottom edge of the stack in Channel 2 are even with the edges of the tape. On reel-to-reel machines this is usually accomplished by two small Allen head set screws which are located on the center line of the head mounting plate, but are sometimes placed to one side of this plate. If these screws are on one side, the opposite side has wells containing two compression springs to supply the pivot action necessary to azimuth the head gap. Regardless of where these two set scews are located, they serve a dual function, adjusting for zenith or tilt as well as height. Cartridge machines may use regular machine screws instead of Allen head screws, but they serve the same purpose. In addition, there is typically a locking screw in the center of the head adjustment screws that is used to hold the head mounting very securely after it is adjusted. This is desirable because the heads on a cartridge machine may be struck with the cartridge when it is inserted for play.

Head Alignment

Fig. 2 is an exaggerated view of a head incorrectly aligned for zenith. The head face should be at a 90° angle to the transport base plate or deck. Any appreciable deviation from this angle will result in marginal tape contact which will become much more noticeable as head wear progresses.

Fig. 3 shows the result of incorrect zenith alignment. In this case, the head was tilted downward toward the transport base plate at the time it was installed. The keystone wear pattern indicates excessive tape contact at the top of the head and insufficient contact at the bottom. Had this head been tilted away from the base plate, the keystone effect would have been reversed.

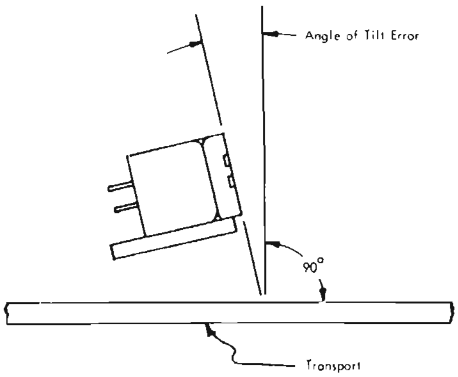

Fig. 2. Misaligned zenith adjustment (inside view). (Originally published in the September 1974 *Broadcast Engineering Magazine.*)

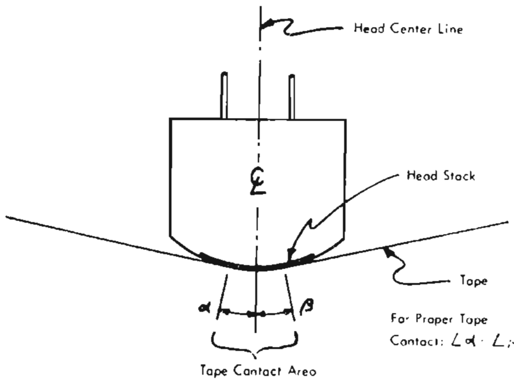

Fig. 4. Proper tape contact adjustment (top view). (Originally published in the September 1974 *Broadcast Engineering Magazine.*)

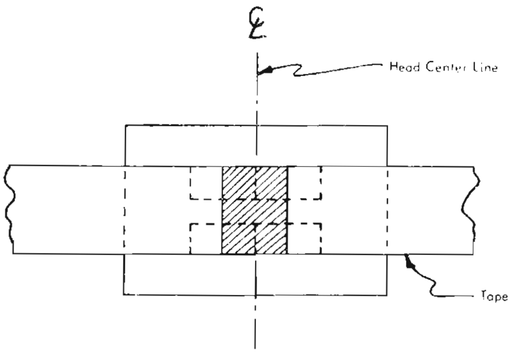

Fig. 5. Proper tape contact area (front view). (Originally published in the September 1974 *Broadcast Engineering Magazine*.)

Any adjustment made on the head height is likely to also change the zenith, and vice-versa. When either is adjusted, the other should be checked and, if necessary, readjusted and then cross-checked until both are correct.

Fig. 4 is a top view of the adjustment for head to tape contact. As indicated, using the centerline of the head as a reference, the contact is correct when angle alpha = angle beta, or when the tape contacts the head an equal amount on either side of the airgap as shown in Fig. 5. This is a front view of the proper head to tape adjustment. Contact alignment is accomplished by rotating the head cup or assembly mounting block until the head face is positioned properly.

In factory installation and replacement, tape heads are typically adjusted with gauges and fixtures which are seldom available in the field. A good field method of checking for correct adjustment of the parameters covered so far is to use a black marking pen with a soft felt tip to coat the head face from top to bottom and about ¼ in. on either side of the gap. Run some tape through the machine in the play mode; five or six ft.

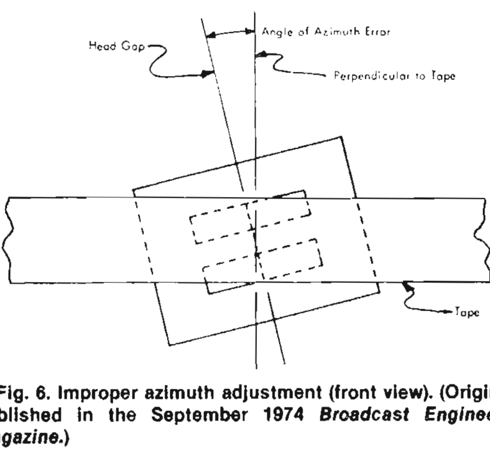

Fig. 6. Improper azimuth adjustment (front view). (Originally published in the September 1974 *Broadcast Engineering Magazine*.)

should suffice. Stop the machine and check the head. The tape will have removed the ink from the head face and this clear area will show area of contact. If it shows the least amount of keystone effect, recheck the zenith. The clear area on the head should look like the shaded area in Fig. 5. When it does, the machine may be considered acceptably adjusted for height, zenith, and contact.

The ink can be removed with a damp (not wet) cotton-tipped applicator. Most head cleaners will dissolve the ink. If the one used will not, use lighter fluid. Be sure to clean the head between each adjustment and position check. Do not coat the face too heavily with the ink. The tape used for making the adjustments should not be a valuable recording, but it must be in good condition and from a reel that runs true. The marking pen should be new and the felt tip not contaminated with foreign particles that could scratch the head face.

Fig. 6 shows the final mechanical adjustment required by a new head - azimuth. The reproduce head gap must be perpendicular to the tape so that all tape equipment in the station conforms to a standard setting to permit interchangeability of tapes between all machines in use.

A preliminary visual alignment of all head airgaps at a 90° angle to the plane of the tape travel, which is almost always parallel to the deck or base plate, is very helpful. A 90° gauge block, small toolmaker's square, or any small plastic lettering guide, etc., with a 90° angle between two adjacent sides may be used. The accuracy of the angle may be confirmed by comparison with the inside angle of a good combination square. With the edge of the gauge-block firmly against the deck or base plate and the adjacent vertical edge just in front of the head airgap(s), adjust the azimuth to align the gaps in parallel with this vertical edge. Use a magnifier (Fidelipac Division of Telepro Industries, Inc.). Careful alignment can result in a surprisingly good preliminary azimuth setting. Also, there are several small optical devices available on the market for a quick mechanical check of the azimuth on cartridge machines.

Although azimuth is adjusted mechanically, it must be done while playing a standard alignment tape. At a speed of 7.5 ips, a frequency of at least 12 kHz should be used, with 15 kHz preferred.

As the head is slowly rocked from side to side, the head output will increase and will reach its maximum level when the head gap is directly lined up with the recorded high frequency on the azimuth alignment tape. When the head is perpendicular to the tape path, the upper and lower airgap edges will experience the same phase and there will be no azimuth error. If the gap is tilted in respect to the tape path, however, the upper and lower gap edges see a phase difference. This will result in magnetic flux lines flowing between the upper edge and the center line, and the lower edge and the center line of the gap (Lowman, 1972). These flux patterns will be slightly out of phase and, therefore, will produce an output voltage that will be lower than from a head with no azimuth error. With further tilt so that the upper edge of the gap is crossing the south pole while the lower edge is simultaneously crossing the north pole of the adjacent half wave of the recorded signal, and vice-versa, the total resultant flux is zero. The output voltage from the head will also be zero.

Tilting the gap even further will give an increased output at high signal frequencies, such as used for azimuth adjustment, and will peak when the upper edge of the gap and lower edge of the gap span 1½ wavelengths of the recorded signal. This will give a false indication of correct azimuth alignment, although the peaks on either side will be lower in amplitude than the center peak of true azimuth. Thus, it is important to tilt the head gap back and forth sufficiently to find the true Azimuth peak and adjust it for maximum output level. This establishes the reproduce head as a standard for setting azimuth on the recording head, which is done by removing the alignment tape, threading a blank tape on the machine and recording a 15 kHz signal on it while monitoring it with the reproduce head. Rock the record head slowly from side to side through its arc while recording the signal on the tape until maximum output is obtained from the reproduce head monitoring the recording. Note that the same 1½ wavelength azimuth error may be obtained with the record head as on the reproducing head and true azimuth should be found in the same manner. There will be a slight delay between recording and reproducing the 15 kHz alignment signal because of the tape travel time between the two heads, so a slight pause between adjustments of the record head will be helpful.

Useful Head Life

Electrically, as wear progresses on a reproduce head, the inductance of the head drops and the high frequency response begins to fall off (Zeman, 1974). This can generally be compensated for by readjustment of the high frequency equalization up to a certain point, where the 4 to 6 kHz area rises above machine frequency response specifications, then the head must be replaced to restore the desired response.

As the wear progresses in the record head, the inductance also drops and the head requires less and less bias current for optimum frequency response. This in turn affects the signal current required and also requires readjustment of the recording equalization. If the head is not replaced, the wear/readjustment cycle repeats with increasing frequency until finally the airgap abruptly opens and satisfactory performance is impossible.

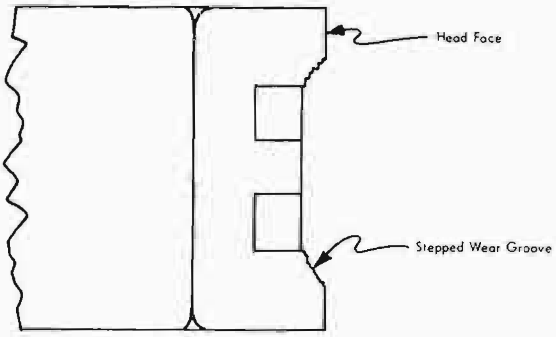

Fig. 7. Wear groove (side view). (Originally published in the September 1974 *Broadcast Engineering Magazine*.)

In addition to this, there are performance difficulties encountered that are not electrical in nature but show up as electrical malfunctions in the form of dropouts, erratic output (starting first at the high frequency end and working down the audio range as the condition worsens), warbling, and a wide assortment of weird sounds caused by variations in tape contact, and wandering of tape due to wear grooves in the heads.

Fig. 7 shows an exaggerated view of the step effect in a deep wear groove. Originally, the groove was fairly straight, but as wear progressed, the edges of the tape (which are not as rigid as the center portion) tend to cup and become rippled. At the point where the edge curls, and firm contact begins, another groove is started. Tape of varying widths, with different width tolerances or even within the typical ±0.002 in. tolerance range, can also cause this condition.

Fig. 8 shows the flat that is developed in a head face as wear progresses. This flat exists regardless of whether a wear groove is present or not, and spreads the tape contact area over an

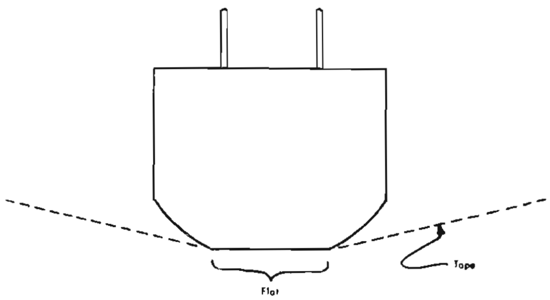

Fig. 8. Wear flat (top view). (Originally published in the September 1974 *Broadcast Engineering Magazine*.)

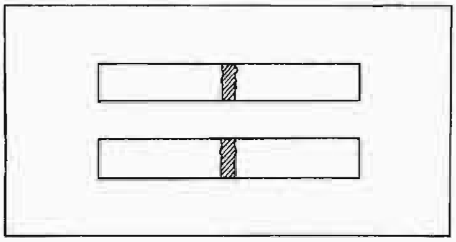

Fig. 9. Open head gap (front view). (Originally published in the September 1974 *Broadcast Engineering Magazine.*)

increasingly wider space, tending to create poor contact at the airgap. Of course, this is where the critical action of the head takes place, so the problem should be corrected before operation is degraded significantly. Once a keystone wear pattern is observed, as shown in Fig. 3, the zenith should not be readjusted on that head, as erratic contact and output will result. If this wear pattern is not excessive on a professional head, it can be relapped and polished by manufacturers specializing in this service, then reinstalled and the zenith error corrected.

Fig. 9 is an illustration of a head with a completely open airgap. Such a head is fit only for the trash can. It may be difficult to believe that anyone could or would use a head until such a condition occurs, but they are not uncommon in stations with a casual inspection/maintenance program. The head face is particularly vulnerable to scratches, nicks, or gouges which can really degrade performance, because good magnetic performance requires annealed metal of high permeability that is physically soft. Before installing any tape head, it is suggested that the head face be covered with a strip of heavy, adhesive-backed plastic tape to protect it during installation. Once installed, the tape should be removed and the head face cleaned prior to making any adjustments.

Cleaning Tape Heads

Isopropyl alcohol is one of the most widely used cleaners for tape heads because of its universal availability. It may also be used for cleaning the pinch roller, which is not true of some commercial head cleaners. Ethyl (grain) and methyl (wood) alcohol serve as well in their almost pure forms, when available. Carbon tetrachloride was once used and is recommended by older reference books, but has been long banned for general purpose cleaning because of its hazard to health.

The record, reproduce, and erase heads are the most critical elements of a tape machine and should be kept immaculately clean. They should be cleaned at regular intervals, not as a maintenance procedure but as an important part of the operating practice. Some suggest daily cleaning, which if properly done will result in consistently superior results. Some clean heads hourly, which indicates an abnormal problem, such as the use of tapes with a poor binder or very poor surface characteristic. This may also be caused by some element in the tape path that is scraping the oxide and binder from the tape, or perhaps the lubricant from tapes used in cartridges. The cause should be determined and corrected if tape heads require hourly cleaning.

Cartridge tape machines typically need cleaning much more often than reel-to-reel machines because of the lubricated backing and the sliding of the tape layers on each other in the cartridge. Yet, some stations have found that "dry" cleaning the heads permits much longer intervals between required cleanings than those using a generous amount of alcohol or commercial head cleaner. With new machines or new heads, more frequent cleaning is required for approximately the first two months, perhaps every other day. At six months and after, the heads are polished sufficiently that a weekly cleaning is reported to be adequate. The heads are simply cleaned with a dry cotton swab or soft cloth. The normal residue does not adhere tightly to the head surfaces and seldom requires any solvent to remove it. An alternate method reported is to use alcohol very sparingly on a swab, followed immediately with a dry swab to remove the cleaner and residue, and then a second dry swab to polish the head surface and remove any traces of cleaner/residue film. This last step is considered very important.

Regardless of the cleaning solvent and method used, it is good practice to avoid putting large numbers of cartridges or open reels with new magnetic tape into a system in a short period of time. This sudden influx of new tape will drastically increase the amount of residue deposited on the head, etc., with most tapes, and pose an excessive cleaning requirement. It is much better to plan a long term or continuous phasing in of a few new tapes at a time for replacement and expansion of the tape library.

TYPICAL MAGNETIC RECORDER/REPRODUCERS

The NAB cartridge machine is used in greater quantities in more US stations than any other type of audio tape machine. Some stations use cartridges for practically every segment of programming broadcasted, while others use them primarily for commercial messages, station IDs and other short nonmusic applications. The cartridge machines are available in several forms

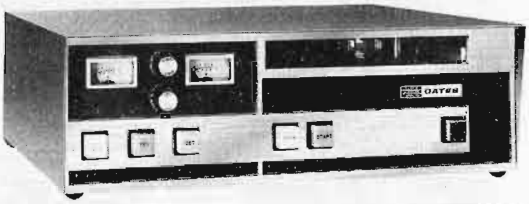

Fig. 10. Single deck record/produce cartridge machine (courtesy of Harris Corporation, Broadcast Equipment Division).

from single deck to multiple deck and magazine units.

Single deck units are available in reproduce only or combination record/reproduce equipments, such as shown in Fig. 10. This unit will accept NAB size A cartridges with up to 10.5 min., size B with up to 16 min., and size C with up to 31 min. of tape @ 7.5 ips. Others will accept only sizes A and B, while some will accept just the A size cartridge. Nearly all can be mounted in standard equipment racks, some being small enough to mount two or three across a standard panel width. Also, most of them can be enclosed in a desk top housing for operator convenience. Mono units use a separate program and cue track, with the program track at the top of the tape. Stereo units with three track heads use the top track for left signal, center track for right signal, and the bottom track for cue signals. Standardization of parameters important in cartridge interchangeability is outlined in the *NAB Standard on Cartridge Tape Recording and Reproducing,* printed in another section of this handbook. Most manufacturers follow this NAB Standard in the design and production of their machines.

Fig. 11 shows a pair of 3-deck cartridge machines that will accept NAB size A and B cartridges in a 19 in. rack housing. Each unit has a common direct drive motor with a long shaft that all three cartridges engage. Except for cleaning of the heads, motor capstan, pinch

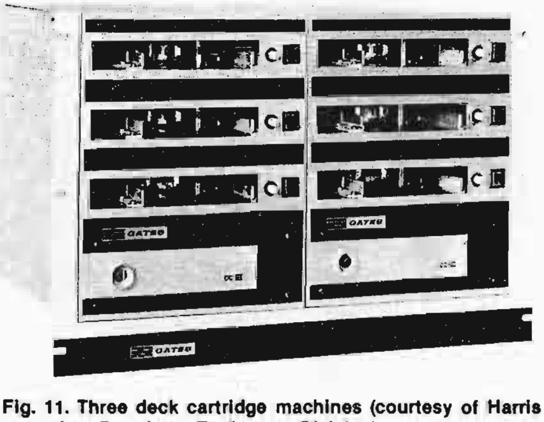

Fig. 11. Three deck cartridge machines (courtesy of Harris Corporation, Broadcast Equipment Division).

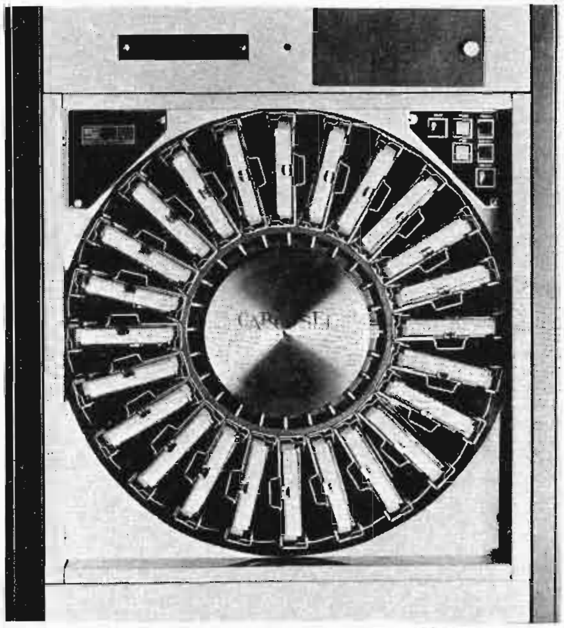

Fig. 12. Single deck/rotary magazine cartridge machine (courtesy of Sono-Mag Corporation).

roller, etc., the top and center decks are removed for adjustment and maintenance. A hinged front panel, quick disconnect deck fasteners and connectors facilitate the maintenance operation.

The multiple cartridge machine shown in Fig. 12 contains up to 24 NAB size A cartridges in a magazine which rotates to align the selected cartridge with the surface of the single playing deck, located at the 3 o'clock position. The cartridge is pulled back into the deck position, played, and returned to the "tray out" magazine position in a typical sequence. The rotation of the drum magazine is relatively slow, taking several seconds even for bidirectional models, making more than one cartridge reproducer necessary if back-to-back operation is desired.

The multiple cartridge machine illustrated in Fig. 13 contains up to 12 NAB size A cartridges in a vertical stack and up to four stacks to an assembly for a total of 48 cartridges. This unit also mounts in a 19 in. rack cabinet. Each stack has a common motor with a long shaft that all 12 cartridges engage. Its principal advantage over the machines as shown in Figs. 12 and 14 is that it provides random instant access to any of the cartridges for back-to-back playing in any sequence. This may be offset by a somewhat more complex loading operation.

The multiple cartridge machine shown in Fig. 14 has a deck behind each stack of 16 cartridges which may be raised or lowered to align with the selected cartridge magazine slot. Up to three of these modules may be fitted into an assembly that mounts in a 19 in. rack cabinet. While it

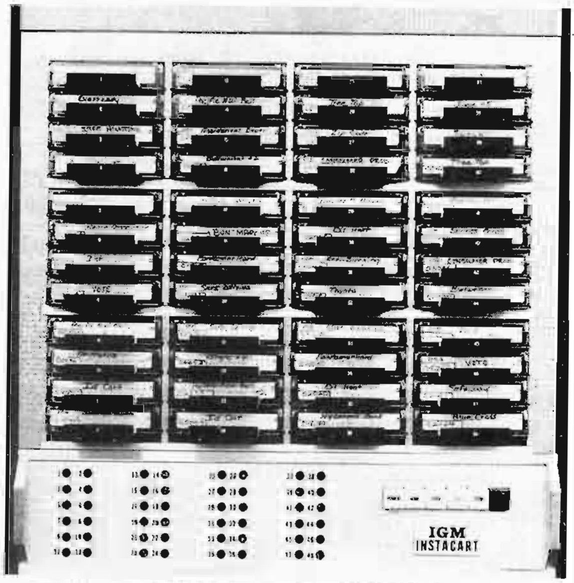

Fig. 13. Forty-eight deck cartridge machine (courtesy of Northwestern Technology, Inc.).

does not give full random instant access, this machine can play a cartridge from a module back-to-back with a cartridge from another module. With some care in loading, the unit shown can play up to three cartridges in a continuous sequence, or even more if the playing time of intermediate selections is sufficient for cueing out and reloading in modules used early in the sequence.

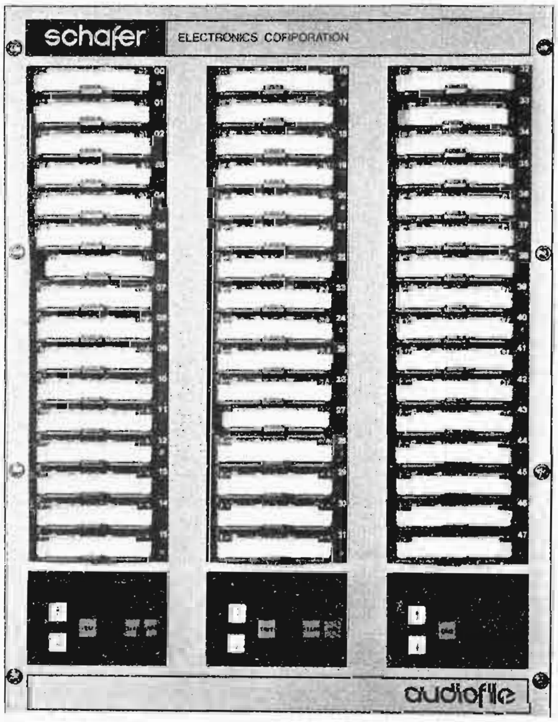

Fig. 14. Three Deck/Fixed Magazine Cartridge Machine (courtesy of Schafer Electronics Corporation).

Fig. 15. Reel-to-reel tape recorder/reproducer (courtesy of International Tapetronics Corporation).

Reel-to-reel machines come in many sizes and are typically used with the larger 7, 10½ or 14 in. reels now that tape cartridges are predominantly used for short segments of programming. Switching logic, motion sensing, dynamic braking and automatic tape lifters are some of the newer features that practically eliminate mishandling of the tape on the machine. Almost all professional reel-to-reel machines use individual motors for the supply and take-up reels, plus a third motor to control the record/reproduce speed. For a fast starting time and almost immediate stability, the capstan motor runs continuously and the solenoid actuated pinch roller moves the tape against the capstan as the brakes are released on the reels.

For the fast-forward and rewind functions, the pinch roller and reel brakes are disengaged, allowing the tape speed to be controlled by the reel torque motors. Power can be varied between the two motors, by either a rheostat or switched resistors. The tape moves in the direction and at the rate of speed determined by the relative power division.

Another form of the reel-to-reel machine, the Philips Cassette machine, is used in news gathering and other portable applications requiring somewhat reduced quality. Comparison of the specifications in the NAB Standard on the Audio Cassette Recording and Reproducing with those for the reel-to-reel or cartridge Standards indi-

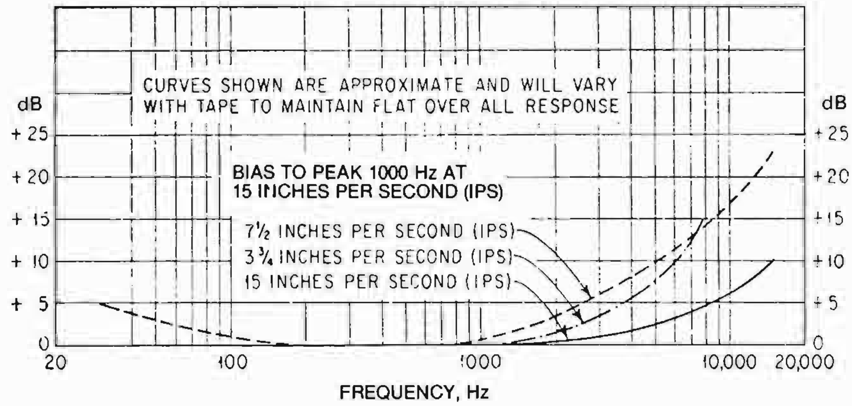

Fig. 16. Standard recording curves (courtesy of Ampex Corporation).

cates the difference in quality in several parameters.

MAINTENANCE

Maintenance instructions in the individual equipment Instruction Manual should be followed on all items covered, unless lengthy experience has proven a variation in some areas will give superior results. For items not covered, the following should be of assistance.

Amplifiers

The recording amplifier is used to raise the output of a microphone to the level necessary to drive the recording head. Since the head airgap length, tape to head velocity, and many other factors determine the frequency response, noise and distortion of the recording/reproducing process, it is advisable to include as much pre-emphasis as possible in the recording amplifier.

The standard recording curves shown in Fig. 16 were derived from the tape distortion characteristics. The tape, when recorded with these curves, will have approximately the same distortion at all frequencies in the audio signal bandpass.

The reproduce or playback amplifier raises the signal generated in the reproduce head to a level suitable for feeding the control console, or next element in the system. This amplifier contains a de-emphasis circuit to adjust for a flat overall response.

Fig. 17 shows standard playback curves, initially derived from the nonlinearities of the record-reproduce process, including the characteristic 6 dB/octave rise in the playback process (until head losses overcome it at the high frequency end). The playback curves are now standardized to provide essentially a flat response from a NAB Frequency Response Test Tape, and the recording amplifier adjusted in the individual equipment for a flat overall response within specified tolerances. The playback amplifier must have an input circuit with exceptionally low inherent noise level. Distortion of any significance is seldom generated within the playback amplifier unless it contains some defective components.

In testing a playback amplifier, it is advisable to adjust the input level to obtain a constant

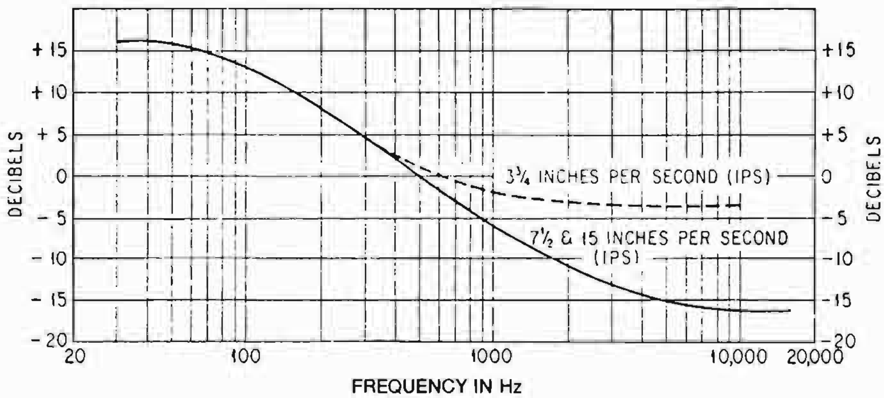

Fig. 17. Standard playback curves (courtesy of Ampex Corporation).

output level for all frequencies. This will prevent overloading the amplifier, which will never occur except on the test bench with a constant input level.

Contour Effect and Fringing

When the length of contact between the tape and the reproduce head pole faces is long with respect to the signal wavelengths, contour effect is insignificant. As long as this is true, the magnetic flux generated in the pole faces by the wavelengths will generally cancel, with no important effect on the flux from pole to pole through the coil (Stewart, 1958). However, as the wavelengths grow longer, the whole head structure, or some part of it in combination with various leakage paths such as through the shield or around the coil to the rear part of the core, may act as a poorly defined gap. Thus, at low frequencies with long wavelengths, a response like that shown in Fig. 18 may be obtained.

This contour effect is especially prevalent in cartridge machines with the narrow heads required to fit within the cartridge windows, and a major peak may be observed in the 120-130 Hz area, with the effect diminishing to insignificance in three to four ripples. Correction is a function of head design primarily, where the contour effects can be reduced by an asymmetrical arrangement so proportioned that the effect of one pole counterbalances the effect of the other.

Fringing is another low frequency effect that occurs when a reproduce head contacts a tape recorded with a track that is wider than the head track. It is generally encountered with multitrack heads on a full-track test tape, and can cause up to 5 dB increase in the extreme

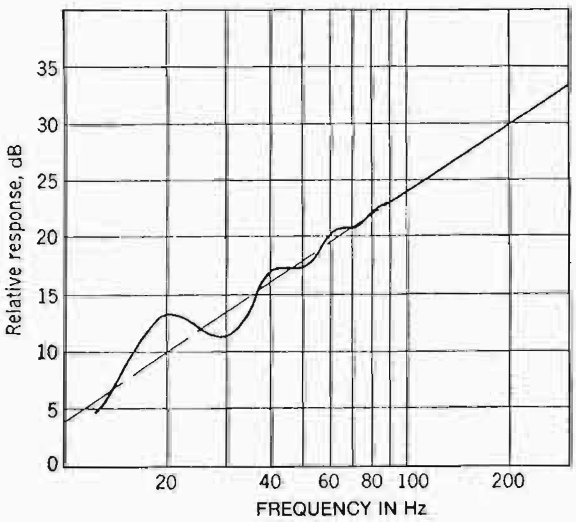

Fig. 18. Contour effects on reproducing-head response.

low frequency signals. If this effect is anticipated and accounted for in the measurements, a full-track test tape is very useful for machines with different track configurations.

Mechanical

All tape recorder/reproducers have precision components that require periodic maintenance and adjustment. Brake tension adjustment should be checked with the methods and equipment prescribed in the instruction manual to maintain optimum performance. No attempt should be made to improve or change the basic design of a tape machine without consulting the manufacturer. Typically the warranty is voided with unauthorized modification, in addition to possible degradation of performance.

Lubrication. If available, the instruction manual on the individual tape machine must be followed for lubrication instructions. If not, older machines typically require lubrication of the capstan drive motor and capstan idler shaft bearings (if indirect drive) about every 3 months or after 1,000 hours of operation with a few drops of SAE 20 oil of good quality. Some reel motors have oil holes and should be lightly oiled after about the same period. If the pinch roller bearings is lubricated, it should be done very sparingly, with any excess carefully removed by blotting with an absorbent cloth or paper and the entire surface subsequently cleaned with alcohol on a soft lint-free cloth.

Cleaning. See the paragraph under Cleaning Tape Heads. The capstan, pinch roller, tape guides, and other elements in the tape path should be cleaned often, sometimes daily with heavy use. Isopropyl, ethyl or methyl alcohol only should be used on the pinch roller, and is generally preferred for the other items. Use a soft cloth or cotton swabs that are lint and contaminant-free, and be sure all surfaces are completely dry before coming in contact with the tape again. It is best to wipe away the residual film with a clean dry cloth or swab after the cleaning operation.

Demagnetize all Heads. All heads should be demagnetized before playing test tapes or other valuable reference recordings, and after every maintenance operation involving the heads. Older machines need head demagnetization at least once a month because of accumulated switching transients and surges due to removal of tubes, etc. Current machines have essentially eliminated demagnetization requirements except when the heads or other items in the tape path are brought in contact with gauges or tools that can be magnetized. Head demagnetizers or hand held bulk erasers should be used on the heads and other tape path elements, being very careful to avoid scratching any of the surfaces. Slowly withdraw the demagnetizer from the items after completely saturating them with the magnetic flux, much in the same manner as used for erasing the tape.

Take-up and Holdback Tensions. These should be checked with a small scale while the machine is running in the normal play mode. NAB hub size reels should produce 6 to 8 oz. tension; the smaller size should produce 3 to 4 oz.

Brake Tensions. These are adjusted with no power applied to the machine, with the scale pulling a string wrapped around the reel hub in the direction of forward tape travel. The tension should be from 12 to 16 oz. In the opposite direction, it should be from 6 to 9 oz.

Capstan Idler (pinch roller) Pressure. The pressure of this idler on the capstan shaft should be sufficient to cause positive drive to the tape, but not so great as to cause the motor to slow down. Ideally, the shaft holding the pinch roller should be parallel to the capstan (assuming the contact surface and bearing surface of the pinch roller are parallel) in the operating position to prevent skewing the tape. This may require several pounds of pressure and may be measured as the point of disengagement between the pinch roller surface and capstan surface when the pinch roller shaft is pulled away with a scale.

Playback Level Adjust. The gain control in the playback channel should be adjusted to give the output level specified by the manufacturer when playing the Standard Reference Level on an NAB Test Tape or equivalent. Depending on the output capability of the playback amplifier and amount of noise reduction versus gain reduction with the amplifier gain control, variations from the specified output level may be acceptable for special applications. However, the amplifier must be capable of at least 10 dB higher output level than the output level read on a standard VU meter for signal peak headroom.

Erase Current. See paragraph under Magnetic Recording Theory.

Bias Current. See paragraph under Magnetic Recording Theory.

Signal-to-Noise Measurements. Terminate the amplifier output in its rated load impedance and connect a high-impedance noise meter across it. Using the Standard Reference Level from the test tape as a reference, measure the noise below this reference level with the tape stopped. This should read well below the noise specified for the machine playing tape with no signal. Replace the test tape with a virgin or well-erased tape and record a section with bias only (no signal), and read the noise from the playback channel with a low-pass filter to remove the bias frequency. A 0.02 MFD capacitor may be placed across the input terminals of the noise meter instead of a low-pass filter. With a simultaneous record/playback machine, adjust the bias balance control for lowest noise (generally a popping or crackling noise). Use the prerecorded tape with bias only for checking playback-only machine noise.

Azimuth Alignment. See the paragraph under Tape Heads.

Playback Response. Terminate the output of the playback amplifier and play the frequency response portion of the test tape. Connect the input terminals of the noise meter to the amplifier output to read the reduced signal level from this portion of the test tape, typically 10 to 20 dB below the Standard Reference Level. Adjust the playback amplifier equalizer(s) for the optimum frequency response specified in the instruction manual. If difficulty is encountered, inspect the heads for defects described in the paragraph under Tape Head.

Record Response. After adjusting the playback response, use a new or erased tape to record test signals from an audio generator over the frequency range of interest. Record the level 10 to 20 dB below Standard Reference Level to prevent any possibility of overloading the tape. With a constant input level to the recording amplifier, adjust the recording equalization to obtain a flat response within rated tolerance from the playback amplifier. If difficulty is encountered, read previous paragraphs to find similar symptoms and the probable causes.

Tension Scales. These are difficult to find in the ranges required for measuring tape machine tensions. They can be purchased from John Chatillon & Sons, 83-30 Kew Gardens Road, Kew Gardens, N.Y. 11415. The following scales are recommended for reel-to-reel machines: LP8 (0-8 oz), LP36 (0-36 oz) and LP72 (0-72 oz).

Care of Test Tapes. Tape intended for repeated use in checking machines must be properly cared for if its full usefulness is to be maintained (Morrison, 1967). Physical deformation of the tape can be a serious problem. Edge damage can be prevented by winding the tape smoothly under moderate tension and evenly spaced between the reel flanges. The tape pack should not be wound in contact with one reel flange, as this will result in irreparable edge damage if it is stored in this condition for long periods of time.

Tapes should not be stored in fields from motors or permanent magnets; i.e., a tape stored in a cabinet next to a loudspeaker or microphone may be affected. Heads and tape guides should be demagnetized before using the test tape. When a reproducer test tape is used for continuous check-out purposes, age and wear as described above often become the primary sources of inaccuracy.

REFERENCES

Fidelipac Division of Telepro Industries, Inc.: "Aligning Your Cartridge System."

Haynes, N. M.: *Elements of Magnetic Tape Recording,* Prentice-Hall, Englewood Cliffs, N.J., 1957.

Lowman, C. E.: *Magnetic Recording,* McGraw-Hill, New York, 1972.

Morrison, R. K.: "Reproducer Test Tapes: Evolution and Manufacture," *Journal of the Audio Engineering Society* (April), 1967.

Spratt, H. G. M.: *Magnetic Tape Recording* (2nd ed.), Nostrand, Princeton, N.J., 1964.

Stewart, W. E.: *Magnetic Recording Techniques,* McGraw-Hill, New York, 1958.

Zeman, F.: *Magnetic Tape Head Maintenance Considerations,* Broadcast Engineering (September), 1974.

27

Video Magnetic Recording

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In the early fifties, there was great interest by the television industry in developing magnetic recording devices for television images. By the mid-fifties, several major breakthroughs had been made in the magnetic recording industry that culminated in the display of a quadruplex video tape recorder at the 1956 National Association of Television and Radio Broadcasters Convention. This new device substantially changed the operational aspects of television broadcasting.

The new High Band FM Signal System, pressing the technology even further into its present-day status, has allowed for multiple generations of color television recording to a point where television program syndication and sophisticated teleproduction techniques on video tape have become a reality.

Other developments contributing to the improvement of magnetic video recording have been the *dropout compensation*, minimizing picture defects or short interruptions as a result of small imperfections of the video tape material, *velocity error compensation*, eliminating color hue shift band and *autochroma*, automatic chrominance level control, adding further refinement to the quadruplex recording system.

Further contributions in the development and improvement of video heads and video tape manufacturing have been accomplished. The Society of Motion Picture and Television Engineers has developed standards and recommended practices providing for interchangeability among machines which have been accepted by manufacturers of broadcast television recorders.

Specific devices are used throughout the following text in order to aid in the discussion of various aspects of video tape recording. It should be recognized that the proper names used in the text for devices or functions may be called by other proper names when associated with similar devices of other manufacturers.

Quadruplex Video Tape Recorder

The Ampex VR-2000 as shown in Fig. 1 will be used as an example to describe a current magnetic video tape recorder.

Tape Transport

The dual-speed tape transport closely resembles similar mechanisms found in high quality audio recorders, in that the tape is pulled from the supply reel and across the erase, record, and playback heads by a rotating capstan, and then re-wound by a motor-driven takeup reel as shown in Fig. 2. However, video recording requires precise control of tape positioning and of head drum phase that transcend the requirements imposed on an audio tape transport in many ways. The primary nominal linear video tape transportation speed is 15 ips, the secondary 7.5 ips.

Fig. 1. VR-2000 recorder/reproducer.

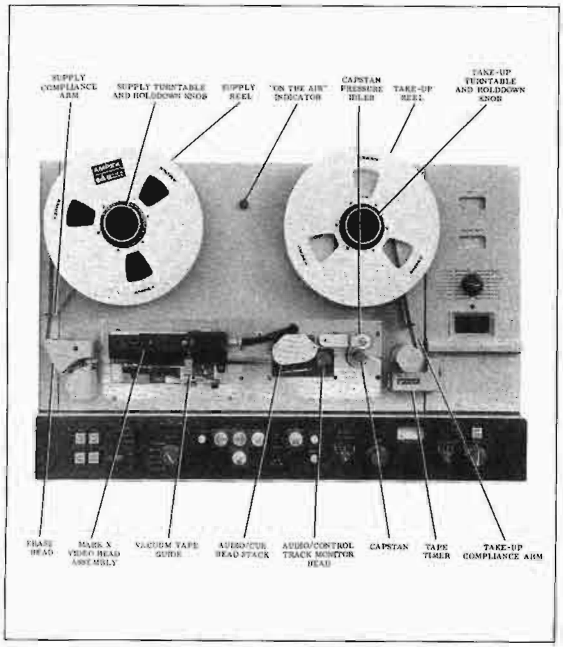

Fig. 2. Overall view of tape transport system.

The tape passes the left tape tension arm, two idlers on the erase head assembly, the full-width erase head, the rotary video head drum and associated vacuum block tape guide, the control track record/reproduce head, and the audio and cue erase record/reproduce heads before passing the capstan and its associated pressure idler. It then passes the tape timer and the right tape tension arm before it is wound onto the takeup reel.

Tape motion in the record and reproduce processes is controlled solely by the capstan, which pulls the tape from the supply reel (on the left), through the tape path and drives the tape toward the takeup reel on the right. Each reel hub is mounted on a torque motor. The supply torque motor opposes the motion imparted to the tape by the capstan, thus providing hold-back tension. The takeup motor supplies just sufficient torque to take up the tape as it is supplied by the capstan. In fast-forward or fast-rewind modes, the capstan idler is removed, the torque of the appropriate turntable motor is reduced allowing the tape to be pulled from that turntable by the greater torque of the other turntable motor.

Servo Control System

The following paragraphs describe the interrelationship between tape position and head drum phase as established during the recording mode, and how it is re-established during the playing mode, as well as the actions of the head drum servo and their relationship to the video signal.

During the recording mode, the video head drum motor rotates at 240 Hz rate (14,400 rpm). At this time the drum tachometer generates a square wave signal whose instantaneous phase and frequency is identical with the instantaneous phase and frequency of head drum rotation. This sine wave signal is recorded longitudinally along the control track at the lower edge of the tape. The rotational rate of the capstan motor is determined by the drive frequency, ¼ that of the drum motor, a 60-Hz rate.

During the playing mode, the video head drum again rotates at the 240-Hz rate and the drum tachometer generates a square wave signal indicative of the instantaneous head drum phase and frequency. The latter signal is phase-compared with the 240-Hz reproduced control track; the resulting error signal is used to establish and maintain the exact relationship between the head drum phase position and the longitudinal position of the tape that existed during recording. Table 1 shows the relationship of recorder system factors depending on the television standard applied.

The head drum servo employs a phase and a velocity servo loop. The phase servo loop locks the head drum synchronous motor to either the video signal being recorded, the station reference sync, or the power line, depending on the mode of operation. The velocity servo loop suppresses the tendency of the synchronous motor to hunt.

During recording, the head drum motor may be locked to the video signal, to the power line frequency, or to an external sync source, e.g., a sync generator; during the playing mode, it may be locked to an external sync source or to the

TABLE 1

The Relationship of Recorder System Factors Depending on the Television Standard Applied

Factor	Television Standard		
	525/30	625/25	405/25
Power line frequency	60 cps	50 cps	50 cps
Frames per second	30	25	25
Vertical rate (fields/sec)	60	50	50
Horizontal rate	15,750 pps	15,625 pps	10,125 pps
Capstan motor power frequency	60 cps	62.5 cps	62.5 cps
Drum motor power frequency	240 cps	250 cps	250 cps
Drum motor revolutions per minute (i.e., the "drum rate")	14,400	15,000	15,000
Nominal tape speed	15 ips	15.625 ips	15.625 ips

power line frequency. In the recording mode, the equipment is normally locked to the video signal; in the playing mode, it may be locked to the power line frequency, or to station reference sync.

For the corrections, the phase servo loop uses the error signal resulting from phase comparison of the drum tachometer signal with the power line frequency or with vertical sync, depending upon whether the operating mode is in record or play. If the phase of the incoming video signal suddenly shifts, which could occur during signal discontinuity or when the program source is switched, the phase comparator generates an error voltage which acts to gradually shift the frequency generated by the voltage-controlled drum oscillator until the drum phase matches the phase of the incoming sync.

The velocity servo loop employs the drum tachometer signal as a trigger for a low Q ringing circuit which is resonant at the drum frequency. The trigger and the output of the ringing circuit are phase compared to detect any changes of the drum tachometer signal frequency caused by drum motor hunting. The resulting error signal is used to control a phasing circuit that shifts the phase of the voltage applied to the drum motor in a direction that opposes the velocity error, thereby reducing or cancelling out the hunting excursions.

The original video tape recorder was designed as a delay device and did not provide synchronous integration with studio operations. The limitation when switching to and from the recorder produced vertical image disturbances and video signal discontinuities at the studio output.

There are two levels to this problem. The first level could be described as frame locking, where the recorder is made sufficiently synchronous so that vertical transfer switching will produce no visible jump in the image. This can be accomplished by drum servo lock, which should not exceed approximately half line accuracy, i.e., ±30 microseconds. The most complex problem is to achieve full line-lock, wherein the signals recorded on tape are within one-tenth microsecond accuracy of the studio reference signals. This was accomplished by the use of phase modulation of the drum motor, allowing its instantaneous position to be corrected on a line-by-line basis, as shown in Fig. 3.

An early technique used multiphase sine wave signals to drive the capstan and drum motors. There were some inherent defects in the use of this approach. The phase splitting accomplished through Scott-wound transformers did not always produce precise 120° displacement of the three phases needed for the drum motor. Individual amplitudes of these three phases were difficult to maintain in perfect balance and the instantaneous phase correcting circuitry was somewhat limited by the low pass filtering action of the power

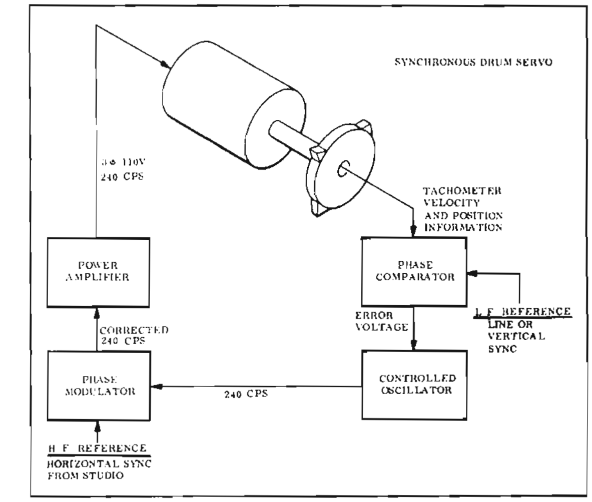

Fig. 3. Block diagram of synchronous servo system.

transformers that acted as the final drive element for the motor windings.

The modern approach to this problem is the use of transistor power switching circuits which gate on a common power supply at the designated times so that phase-to-phase amplitude balance is near perfect. The 120° phase displacement is accurately maintained by logic circuitry and binary count downs. Holding response to phase modulation is virtually instantaneous (Fig. 4).

Phase shifts can be accomplished by altering the switching time of the binaries. The drum motor windings are driven by square waves which add algebraically between any two terminals and result in a staircase waveform with almost complete attenuation of the odd harmonics. This is a particularly desirable condition since the smoothness of angular velocity is dependent upon precise equality of the angularity of pulses applied to the rotor on whose shaft the video head drum is mounted.

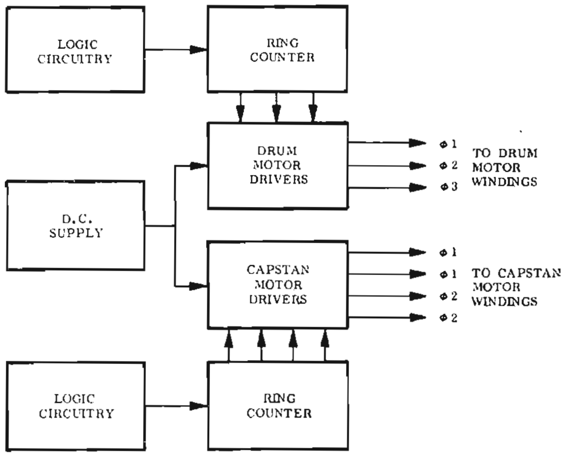

Fig. 4. Block diagram of 2 and 3 phase power switching circuits.

The use of these methods in driving the rotary head assembly has resulted in a long time-base stability in the order of 200 nanoseconds or better when the signals from video tape playbacks are referenced to a stable studio source.

Intersync Servo Control System

The magnetic tape recording and reproduction of television signals involve the scanning of a moving tape by four video heads that are mounted in precise quadrature on the periphery of a rapidly rotating head drum. The longitudinal movement of the tape is synchronized with the rotation of the head drum by the action of two mutually synchronized electronic servos. In the basic system, tape speed is controlled by the action of the capstan servo system; head drum rotation is governed by the head drum servo. By precisely controlling both servos, the Intersync servo system provides improved stability of the reproduced video signal.

A better understanding of the Intersync servo functions and circuitry will be gained by a brief review of the television industry standards and how they relate to problems accompanying the achievement of a high degree of servo synchronization and timing stability.

Elements of the Television Signal

To produce a complete frame of a television picture, the raster is completely scanned twice by the electron beam in the camera and in the picture tube. Each scan starts at the top of the picture and ends at the bottom, resulting in a series of closely spaced horizontal lines of which the horizontal paths traced by the electron beam on the second scan are interlaced midway between those horizontal lines traced on the first scan.

The USA television standard (525 lines 30 frame per second, 60 fields) requires 60 scans per second. When each scan is completed, the scanning beam is blanked out and returned to the top of the raster by a vertical synchronizing pulse occurring at the vertical rate, 60 times per second. The vertical synchronizing pulses are recorded midway across the area occupied by the video information, and recur on every sixteenth path of video information recorded across the width of the tape. The vertical pulses that initiate the first scan of a frame coincide in time with a 30 pps frame pulse that is recorded simultaneously on the longitudinal control track at the lower edge of the tape. The frame pulse recorded on the control track will always appear on the tape in the same relative position with respect to the corresponding vertical sync information which is recorded as a part of the composite video signal.

The 525 line/30 frame television standard uses 525 horizontal traverses of the raster by the electron beam for each complete frame. There are, therefore, 15,750 such traverses per second, requiring 15,750 horizontal pulses per second. This is well known as the horizontal rate or 1H. When video information is present during the recording, the space following each horizontal pulse, with one exception, contains a full horizontal line of video information.

The particular vertical synchronizing information that initiates a new frame is always preceded by a half-line of video information; the similar information that appears on the sixteenth path following completes the frame and is always preceded by a full-line of video information. Thus, complete frames are presented 30 times per second. Fig. 5 shows vertical synchronizing information which appears at the middle of every sixteenth transverse path, and may be seen to include (in sequence) six equalizing pulses, six vertical sync pulses, and six equalizing pulses. The recorded 240 Hz control track signal and the superimposed 30 pps control track frame pulses appear at the bottom edge of the tape. Fig. 5 also shows that the stationary control track record/reproduce head is located approximately ¾-in. "downstream" from the plane of the video heads, and is mounted on the video head assembly. It records and reproduces the 30 pps frame pulses in addition to the 240 Hz control track signal. Because of its "downstream" location, the vertical sync information associated with each frame pulse is 45 video tracks "upstream" from it. SMPTE Recommended Practice, RP-16, "Specifications of Tracking Control Record for 2-in. Video Magnetic Recordings," is shown in Fig. 6.

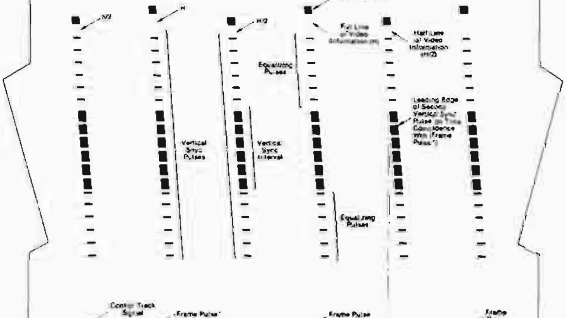

Fig. 5. Positional relationship of video and synchronizing information on the oxide-coated surface of the tape.

APPENDIX

(This Appendix is not a part of SMPTE Recommended Practice RP 16-1964, Specifications of Tracking Control Record for 2-In. Video Magnetic Tape Recordings, but is included to facilitate its use.)

1. The transfer characteristic of magnetic tape is nonlinear. The B_r, I_r curve of the tape as recorded has a shape indicated in Fig. 2a. When a sinusoidal record current (Fig. 2c) is applied to the record head, the resulting recorded flux density is as shown in Fig. 2b. The playback voltage waveform (Fig. 2d) is the first derivative of the recorded flux. Thus, the zero axis crossing region of the playback signal corresponds to the maximum recorded flux region. The verge of saturation is considered to be the condition where the recorded flux waveform is just noticeably flattened on its peaks. This flattening of the flux peaks results in an inflection in the playback signal waveform in the zero axis crossing region. The verge of saturation can thus be determined by increasing the record current until a just perceptible inflection occurs in the zero axis crossing region of the playback signal.
2. Areas to which a compass is attracted (see Section 5.4) do not coincide with point of maximum record current. The compass will be attracted to two areas (X, as shown in Fig. 2) adjacent to the point where the record current crosses the zero axis. The two areas will appear as bars when the track is developed with carbonyl iron or an equivalent material.
3. The location of vertical sync and the frame pulse, as specified herein, will apply only if the recorder video head and capstan servos are referenced to the incoming video signal or its sync generator.

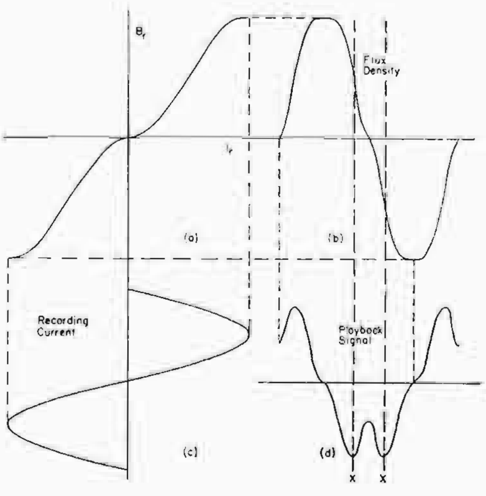

Fig. 6. SMPTE recommended practice RP 16-1964, specifications of tracking control record for 2-in. video magnetic recordings.

Limitation of Timing Errors

There is a minimum degree of inherent timing error in the record/reproduce process. Because of this, any recording will contain a normal amount of timing errors to which the playback process will add more. Timing errors originate from a variety of causes, of which the following are the more frequently encountered:

1. Momentary changes of head drum velocity caused by variations of head drum loading.
2. Momentary phase transients in either the reference signal or the video signal.
3. Momentary loss or degradation of horizontal or vertical sync.
4. Instability of the reference signal caused by a malfunction of the plant sync generator system.

The principal function of the Intersync servo system is the maintenance of synchronization between the reproduced video signal and other video sources to a degree permitting program switching between these sources without interruption of picture continuity. The Intersync servo unit accomplishes this by locking the reproduced signal to the plant sync reference to which the other video signals are locked and by holding the timing errors in the reproduced signal within very narrow limits. Fig. 7 shows the Intersync servo system in a simplified block diagram form.

Servo Record Mode Functions

During the record mode, the Intersync servo unit provides two closed servo loops that control head drum rotation and maintain maximum timing stability of the recorded signal.

The "positional" loop, shown in Fig. 8, determines the average rotational rate of the head drum and the instantaneous angular position (or phase) of the video heads with respect to the reference signal. Its gain and bandwidth are designed to provide a "soft" servo control that resists the reaction of the head drum to high rate-of-change disturbances that may appear in the video or the reference signal. Control is maintained by the phase (i.e., time) comparison of the tachometer signal (representative of head drum phase), with the sync components of the incoming video signal. The resulting measure of timing error is represented by a proportional voltage that controls the frequency of the drum oscillator output. This action places video head number 4 in position to record the vertical sync information at the precise center of the tape width

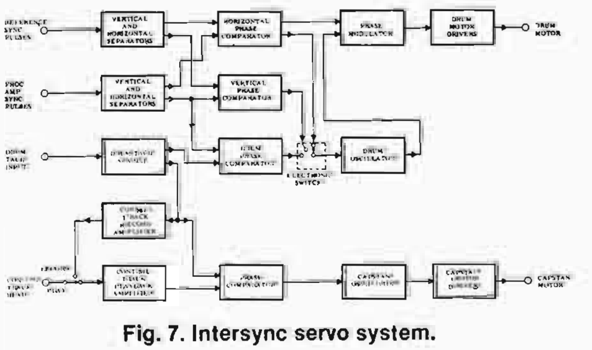

Fig. 7. Intersync servo system.

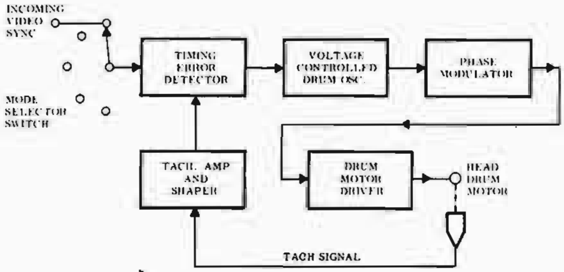

Fig. 8. Block diagram of positional loop.

and in accordance with SMPTE Recommended Practice, RP-16-1964.

If a program transition to a nonsynchronous video signal source is required during the making of a recording, the "positional" servo must correct the angular position of the head drum at a controlled rate, in order to minimize a corresponding instability that will occur during the subsequent reproduction. In the event of severe interruptions of the video sync component, the Intersync servo unit may be switched to the POWER LINE or external as a reference.

The second loop, shown in Fig. 9, provides damping and is used during all modes of operation. Its damping action minimizes high rate-of-change disturbances that affect the instantaneous frequency of head drum rotation, including those resulting from the natural tendency of the drum motor to "hunt" at a 7 to 10 Hz rate, or momentary changes of head-to-tape pressure (drum loading) caused by the passing of a tape splice. The minimizing of these disturbances establishes a flat frequency characteristic within the bandpass of the servo system.

In the damping loop, the tachometer signal is routed to a frequency sensitive detector which derives a signal voltage that is proportional to any instantaneous changes of the tachometer signal frequency. This signal voltage is applied to a phase modulator which also receives the drum oscillator signal. The latter is modulated in terms of corresponding momentary phase shifts to counteract the disturbance and then routed to the drum motor driver.

During the record mode, the capstan servo system maintains constant velocity of the tape in its movement past the rotating video head drum. The frequency of the capstan drive signal is 60 Hz

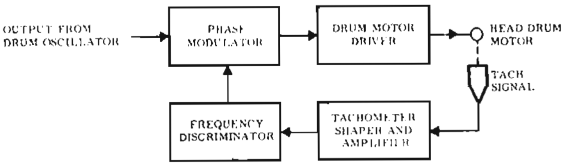

Fig. 9. Block diagram of damping loop.

derived from an oscillator and locked to the drum tachometer signal. The capstan synchronous motor is thus caused to drive the tape at the primary nominal linear rate of 15 ips, but is electronically locked to the rotation of the video head drum.

Using this method to develop the capstan drive signal causes any change in head drum speed to bring about a proportional change in capstan speed. As long as the head drum speed and capstan speed maintain correct relationship, the proper interval between the recorded transverse tracks across the tape is maintained.

Servo Play Mode Functions

At the time of the recording, the tape moves longitudinally at the nominal rate of 15 ips, while the video heads rotate at the rate of 14,400 rpm. The carefully controlled positional relationship between vertical sync information and the 30 pps frame pulse is established at this time, during which the tachometer scans the rotation of the video head drum and generates one complete cycle of a square wave during each revolution. Because the drum turns at 240 rps, the square wave produced by the tachometer has a frequency of 240 Hz and is in exact phase with the drum position.

The tachometer signal is recorded on the control track at normal level together with the 30 pps frame pulse which is recorded at the level of tape saturation. The considerable difference between the record level of the frame pulse compared with that of the control track permits positive identification of both reproduced signals.

Reproduction of the recorded composite video signal requires accurate servo controls that will position the tape longitudinally and phase the video heads transversely to re-establish the positional relationship existing during the recording process.

The tape is positioned longitudinally by the capstan which is controlled by comparison of the reproduced control track signal with a reference signal. Simultaneously the phase of the video head drum is precisely indicated by the phase of the tachometer signal which is compared with that of the reference signal. An error in the longitudinal position of the tape, or in the phase of the head drum results in an error correcting voltage that acts on the respective servo system to cancel the error.

Intersync Servo Control Modes

The Intersync servo unit allows manual selection of five operating modes, providing great flexibility in every operational situation both color and monochrome. The modes are as follows:

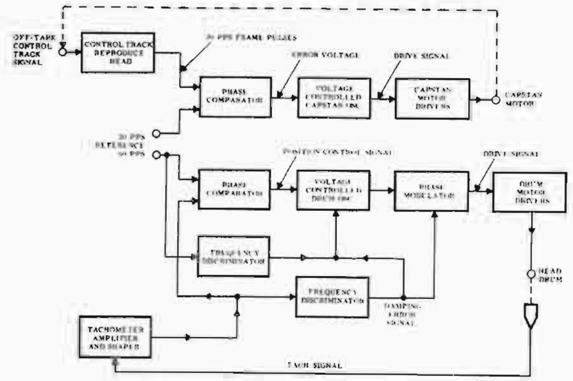

Fig. 10. Automatic mode—initial condition.

Automatic mode. This mode locks the recorder to the incoming video vertical sync signals in record and permits full Intersync operation which tightly locks the recorder to reference horizontal and vertical sync in playback mode.

Intersync servo unit performs its major function during the recovery of signal information from a tape recording. To do this, in the automatic mode it provides servo controls that identify the particular transverse tracks in which a frame begins, positions the tape to cause the video heads to scan the exact center of each transverse track, and phases the head drum rotation to cause one particular video head No. 4 to scan the identified track when switched to Track 1. Other heads may be selected to scan the identified track. Fig. 10 shows a block diagram of the Automatic Mode, Initial Condition and Fig. 11 shows a block diagram of the Automatic Mode, Final Condition.

Track identification is derived from the 30 pps frame pulse recorded on the control track, which controls capstan rotation to position the tape longitudinally. During this period, head drum rotation is locked to a reference signal (e.g., station reference sync), but the video heads are not yet in contact with the tape. Thus the longitudinal positioning of the tape is accomplished by relatively large changes of tape speed during a period when recorded vertical and horizontal sync information is not being reproduced. Because the control track record/reproduce head is in contact with the tape at all times, frame pulses are reproduced as soon as tape movement begins. It should be recalled that each frame pulse coincides, in time, with the vertical sync information that initiates a new frame, and that the frame pulse is recorded on the control track, while the vertical sync information is recorded on a transverse video track. See Fig. 12.

After 1 or 3.8 sec., depending on the type of start up used (head override on) and after capstan rotation has stabilized or nearly stabilized the longitudinal position of the tape, the vacuum tape guide brings the tape into contact with the video heads which then begin reproduction of the recorded video information. If for any reason the control track frame pulses are not present and framing is not accomplished as described previously, duplicate framing information is derived from the reproduce video tracks and used to control the capstan in the same manner as the control track frame pulses. When framing is completed and video is being satisfactorily reproduced, the capstan servo and head drum servo switch to the same condition as the horizontal mode final condition.

Horizontal Mode

This mode locks the recorder to the incoming video vertical sync signal in record and tightly locks to external reference horizontal sync in playback. Use of the horizontal mode minimizes effects from signal discontinuity and permits improved quality when playing back physically spliced color and monochrome tapes. The reproduced video will not necessarily be vertically framed with respect to reference sync.

In this mode, capstan rotation is controlled by phase comparison of the reproduced control track signal with the tachometer signal. There is no other correction of the longitudinal position of the tape. Fig. 13 shows the horizontal mode in the

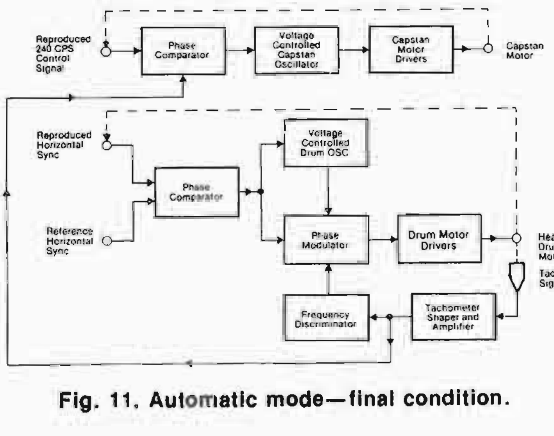

Fig. 11. Automatic mode—final condition.

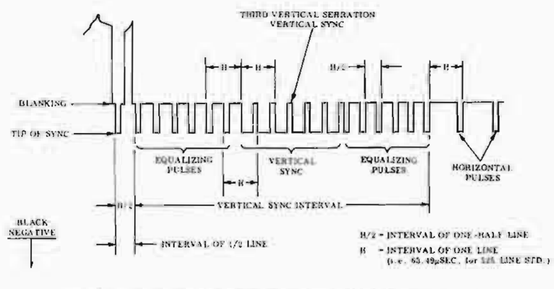

Fig. 12. Elements of the television waveform including the vertical sync interval associated with the generation of a frame pulse (525/30 television standard).

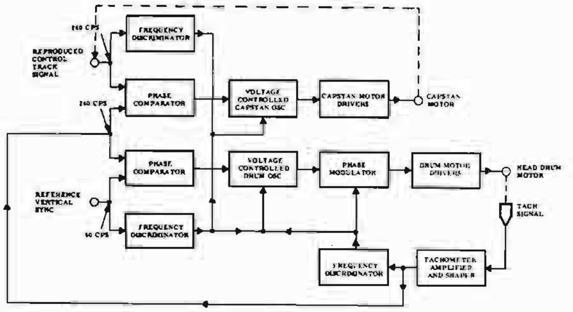

Fig. 13. Horizontal mode, initial condition.

initial condition and Fig. 14 shows the horizontal mode in the final condition.

During the few seconds following the appearance of the reproduced control track signal and before the vacuum guide engages the tape with the video heads, head drum rotation is stabilized by phase comparison of the tachometer signal with reference vertical sync. At the conclusion of this interval, if reproduced video sync pulses are being received, the control of head drum phase is transferred to the output of the horizontal comparator. It remains under this control unless the tachometer phase comparison shows a slipping condition of the tachometer phase with respect to reference vertical sync or the reproduced video sync completely disappears.

Whenever resynchronization is required by the appearance of momentary phase transients, or by the momentary loss of reproduced horizontal sync, it is accomplished by again locking the reproduced horizontal sync to the nearest reference horizontal sync pulse.

The horizontal mode is particularly designed for use with Colortec which is the direct color process. Because this mode provides rapid recovery of lock-in, the interval during which timing errors in the reproduced signal exceed the Colortec correction range is minimized. However, horizontal mode does not provide frame or field synchronization either initially or in the restoration of lock-in following momentary loss of sync. Consequently program switching between reproduced video and other video sources will produce brief disturbances in the picture presentation.

Vertical Mode

This mode locks the recorder to the incoming video vertical sync signal in record and to vertical reference sync in playback and maintains accurate frame lock when no-roll switching is desired.

Frame synchronism within ± 10 microseconds of the reference is achieved rapidly in two sequential operations. Initially, the capstan positions the tape to place the beginning of a frame, in the recorded signal, in line with the head drum coincidentally with the beginning of a frame of information in the reference signal. This is accomplished by phase comparison of a reproduced frame pulse with a reference frame pulse and is normally completed within 3 to 4 sec. following the appearance of the reproduced control track information. During this period head drum phase is corrected to place Video Head 4 at the center of the tape width coincidentally with the occurrence of reference vertical sync. This is accomplished by phase comparison at the tachometer signal. Fig. 15 shows the vertical mode in the initial condition.

At the conclusion of this period, capstan control is transferred to a control voltage derived by phase comparison of the reproduced control track signal with the tachometer signal. Tape movement is then locked to head drum rotation. Control of head drum rotation is transferred to a control voltage derived by phase comparison of the reproduced vertical sync with reference vertical sync. The occurrence of a phase transient or an imperfect tape splice may cause loss of lock. If this occurs, the capstan will accomplish reframing. Fig. 16 shows the vertical mode in the final condition.

Normal Mode

For monochrome use, this mode locks the recorder to the incoming video signal vertical sync in record and to the power line in playback.

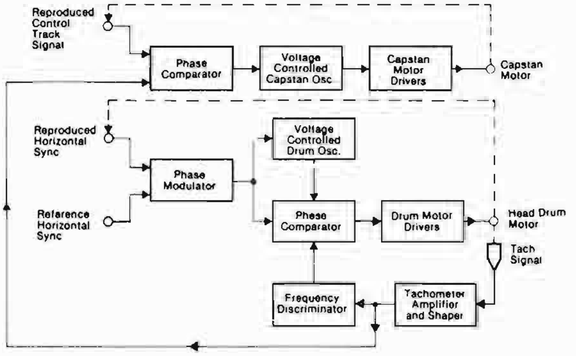

Fig. 14. Horizontal mode, final condition.

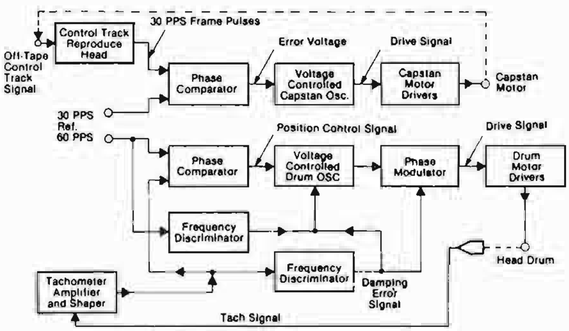

Fig. 15. Vertical mode, initial condition.

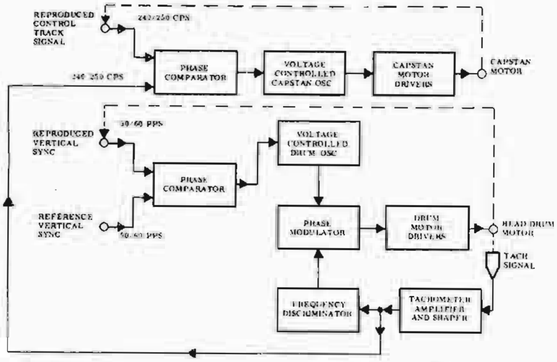

Fig. 16. Vertical mode, final condition.

The normal mode is recommended for monochrome reproduction when the recording is known to contain sync timing discontinuities such as when a tape is improperly spliced. Reproduced video is "soft-locked" to the power line frequency. However, reproduced sync timing is totally ambiguous with the station sync generator reference. Tape reproduction results without regard to framing and is based on phase comparison of the 240 Hz control track signal with the drum tachometer signal, which in turn is phase-locked to the power line. Fig. 17 shows the Intersync servo when operated in normal mode.

Preset Mode

In the preset mode the controls of the Intersync servo unit may be set to any desired record and/or reproduce reference. This mode is used mainly for checking various areas of the circuitry and to meet unusual requirements of the user. Preset mode is similar to normal mode except that its timing reference source is chosen by means of two selector switches.

The Video Head Assembly

The Video Head Assembly includes four video heads that are mounted 90° apart on the periphery of the video head drum. The drum is approximately 2-in. (50.8 mm) in diameter, and rotates during record, play, or ready modes at 14,400 rpm (240 rps).

At the rotational rate of 240 rps, and with tape movement at 15 ips, the actual head-to-tape velocity is approximately 1,500 in./sec., caused by the fact that each video head traverses the (2-in.) width of the tape once during each revolution of the video head drum.

The width of the recorded video track across the tape is that of the video head tips of the video head assembly. At 15 ips tape speed, while using the 10-mil assembly, the guard band separation between recorded tracks is 5.6 mils; while using the 5-mil assembly, the guard band becomes 10.6 mils. In either case the center-to-center track spacing is 15.6 mils. At 7½ ips (using the 5-mil video head assembly) the center-to-center track spacing is 7.8 mils, and the guard band between tracks is 2.8 mils. The 5 mil assembly is required for 7½ ips operation; it may as well be used to reproduce 15 ips recordings to reproduce recordings made with a 10 mil assembly. Generally, the 5 mil assembly is not used when recording at 15 ips.

Under the 525/30 TV standard as each head sweeps across the tape, 16 to 17 horizontal lines of picture information are recorded. The 525 lines that constitute one frame are contained in 32 successive parallel tracks that occupy ½-in. (12.7 mm) of tape length when the tape speed is 15 ips.

Over the past ten years there have been major design refinements in precision-rotating video recording heads. New approaches in construction of unitized transducers as well as new innovations in head drum design have eliminated to a great extent time-consuming and complicated mechanical quadrature maintenance adjustments. The need for electronic quadrature delay lines previously required to compensate for electronic quadrature adjustment and positioning of transducer on the head drum have as well been eliminated.

Improved head tip materials have provided high efficiency performance and markedly im-

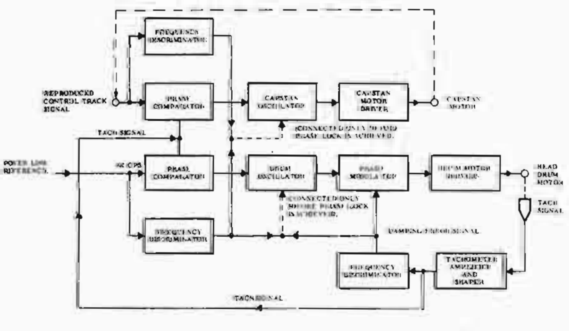

Fig. 17. Block diagram of normal mode.

Fig. 18. Mark video ten head.

proved signal-to-noise ratio, and improved appreciably head tip life.

Air Bearings

The air-bearing system for rotary heads was developed mainly for color television signal recording. Air bearings provide for much improved rotational stability with a reduction of mechanical friction, and as a result at the outset the time base stability is superior requiring a lesser degree of electrical correction as well as minimizing the accumulative effect of time base error, particularly in multiple generation recordings. Geometric distortion (water fall), (jitter), inherent in the early ball bearing counterpart head assemblies has been for all practical purposes eliminated with air-bearing improvements. Again, video head assembly reliability in broadcasting has been substantially improved, and there is no lubrication concern, or mechanical ball bearing wear-out while in service providing the supply of clean, dry, oil-free air is maintained at the proper pressure level.

Rotary Transformers

Modern rotary transformer development provide for low-noise coupling of the video head tip transducer to the preamplifier input, and at the same time increase signal-to-noise ratio as well as minimize crosstalk from channel-to-channel of the RF signal.

In addition there has been a substantial reduction in operational maintenance with the elimination of slip rings or mechanical commutation, relieving considerable difficulty. This rotary transformer has proven and enhanced the reliability of "on-air" performance as well as simplified operations and head assembly maintenance. Generally, manufacturing tolerances have been tightened in the construction and refurbishing programs of video head assemblies—yielding to improved quality, matching of electrical characteristics, and overall improved performance from assembly to assembly.

Preamplification

New developments in nuvistor and transistor preamplification electronics provide the first stage of a cascade low-noise circuit. The preamplifiers are designed and located in close proximity to the video head rotary transformer further improving signal-to-noise ratio as well as individual piston capacitors for accurate matching of electrical characteristics to further equalize performance in each head channel system. New head assemblies provide a nonambiguous tachometer disc for more precise timing control of head drum velocity.

Video Head Testing

New head alignment systems have been developed to perform accurate checkout of video head assemblies with nuvistor preamplifiers prior to operational recording. Sweep test modules are designed to plug in line standard module sockets when alignment is performed. The sweep modules generate a saw tooth test signal that modulates the recorder's built-in modulator. A head test loop assembly provides an RF coupling device that is mounted on the vacuum guide of the video head assembly. This induces a sweep test signal through the individual head tips under test while the head drum motor is off and the drum is stationary, allowing separate head checkout. In operation, the RF coupling device is connected to a detector and the output is presented to an oscilloscope for adjustment of the recorder's "Q compensation and frequency compensation" controls. This system allows for accurate compensation of video head resonance.

Another new system developed to reduce video head optimization time has proved most satisfactory and efficient in setting the video record drive levels of the video tape recorder.

The tape transportation speed is reduced 75 percent, i.e., at 15 ips operation the tape speed is reduced to 3.75 ips.[1] The first head is allowed to go into the record mode while the other three heads reproduce. The following head immediately plays back approximately 66 percent of the first head's recorded track. There is sufficient playback to allow for immediate determination of head drive optimization, or the point where the record drive excitation voltage or current to the transducer is selected to an optimum, at the verge of saturation producing the greatest RF output with minimum background noise in the channel. The same procedure is repeated by the "A" track selector switch for heads two, three, and four. This procedure is convenient to implement and requires only a few seconds from what was a 5-to 15-minute task and a most important one in maintaining high-quality video recording, particularly color.

Video Head Tips

With development of high-band color video recording considerable additional engineering has been required to provide for more efficient video head transducers and at the same time achieve a higher frequency record capability. In order to provide higher output level and to improve signal-to-noise ratio, new transducer designs have been developed. The length of the video tip gap has been reduced from roughly 100 microinches

[1]At 7.5 ips operation, the tape transported at 1.78 ips.

SMPTE Recommended Practice RP 11

This Recommended Practice originated in the Video Tape Recording Committee. The proposal, approved by the initiating committee and the Standards Committee, was published for trial and comment in the October 1961 Journal. The recommendation received final approval by the Society's Board of Governors on February 16, 1962.

Tape Vacuum Guide Radius and Position for Recording Standard Video Records on 2-in. Magnetic Tape

1. *Scope*

This recommended practice specifies the tape vacuum guide radius and position for recording standard video records on 2-in. magnetic tape.

2. *Mechanical Dimensions*

2.1 The radius of the tape vacuum guide shall be 1.0334, +0.0000, −0.0005 in. (26.248, +0.000, −0.013mm).

2.2 The position of the vacuum guide shall be set so that the eccentricity of its center of curvature with respect to the axis of rotation of the video heads is as indicated in the table. The eccentricity shall be such that the extension of a line joining the center of curvature of the vacuum guide and the axis of rotation of the heads intersects the tape at the midpoint of its width. The center of curvature of the vacuum guide shall lie between the axis of rotation of the heads and the vacuum guide.

Vacuum Guide Radius		Eccentricity	
Inches	Millimeters	Inches	Millimeters
1.0334	26.248	0.0000	0.000
1.0333	26.246	0.0001	0.003
1.0332	26.243	0.0002	0.005
1.0331	26.241	0.0003	0.008
1.0330	26.238	0.0004	0.010
1.0329	26.236	0.0005	0.013

Note: These dimensions are based on a nominal tape thickness of 0.0014 inch (0.0356mm) and a radius of rotation of the magnetic head pole tips of 1.0329 inch min. to 1.0356 inch max.

APPENDIX

The achievement of tape playback interchangeability requires, among other things, that means be provided to accommodate variations of (a) the radius of rotation of the magnetic head pole tips, (b) the radius of the vacuum guide and (c) tape thickness. These effects are compensated by the stretching of the tape into a slot cavity in the vacuum guide by virtue of the radius of rotation of the magnetic head pole tips projecting beyond the unstretched oxide surface of the tape as held in the vacuum guide. Over the limits normally encountered, the stretching provides automatic compensation if the vacuum guide is positioned to give the minimum geometric distortion in the reproduced picture.

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Fig. 19. SMPTE RP-11, Tape vacuum guide radius and position for recording standard video records on 2-in. magnetic tape.

to a nominal 50 microinches, in order to accommodate the higher frequency associated with high-band recording.

The engineering improvements in signal-to-noise ratio and increasing frequency response of the transducer tip have been major achievements, not to mention that at the same time there has been an improvement in head tip life. These three advances in video recording are in part the reasons for today's state of the art, the ability to make several multiple generation recordings, half speed, 7.5 ips operation, and maintain high-quality broadcast pictures.

The Society of Motion Pictures and Television Engineers has provided a recommended practice, RP-11 "Tape Vacuum Guide Radius and Position for Recording Standard Video Records on 2 in. Magnetic Tape." All video tapes should be recorded to a standard *Tip Engagement* as specified in SMPTE RP-11, see Fig. 19.

This, from a practical point of view, can be done through the use of a standard alignment tape supplied by the equipment manufacturer. In the case of Ampex, their alignment tape is designated as 50262-07 and RCA as MI-41699-A. Both tapes conform to this standard. The key to keeping the total required adjustment range of the tape vacuum guide block as small as possible lies in the regular use in the field of these alignment tapes, enabling operators to regularly position the vacuum guide with respect to the video tips and maintain it. The actual adjustment

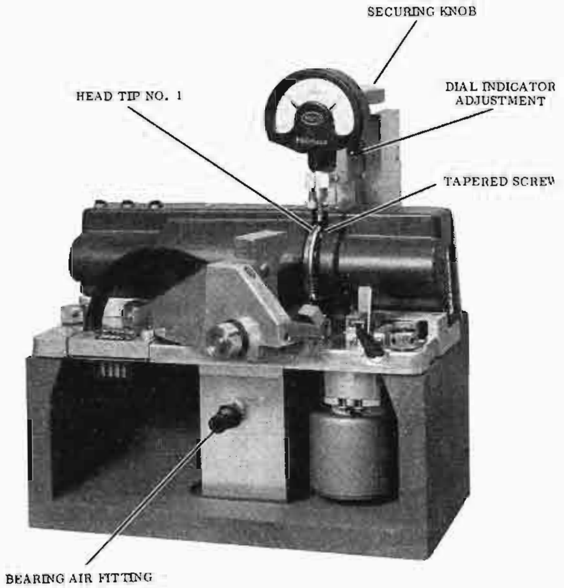


Fig. 20. Video head tip measurement setup.

range needed for the guide is quite small, under normal studio variation of temperature and humidity. The adjustment to compensate for head tip wear is negligible since there is a *self-compensating* change in the amount of tape stretching. Proper alignment of vertical positioning of the *guide height* can as well be made by use of the alignment tape. It is important to head life and picture quality to maintain proper tip engagement. With excessive tip engagement into the tape, it can be expected to have a serious reduction of head tip life, not to mention excessive wear and damage to the video tape. On the other hand, insufficient tip engagement will bring about a degradation in the television playback signal particularly excessive signal drop-out activity, recorded in drop-out activity, and reduction of signal-to-noise ratio. Aside from the extreme of poor head tip life to the other extreme of poor quality picture, it is of paramount importance to maintain interchangeability of video tape recording from one machine to another and one organization to another. Regularly align the vacuum guide block with a standard alignment tape to achieve best possible head tip life consistent with best picture quality and to maintain standardization for interchangeability and interspliceability.

Drum Diameter

In the design of the Ampex television recorder the video head drum is based upon a nominal diameter of 2.06405 in. *All measurements are referenced to this diameter.* Because of machining tolerances, individual drums may differ slightly from the reference diameter.

Tip Projection

The tips of the four video heads on each drum assembly extend out from the drum a maximum of 3.3 mils (.0033 in.) past the reference diameter. This yields a maximum tip-to-tip diameter of 2.06405 in. + .0066 in. or 2.07065 in. The common method of using a dial indicator to measure projection of the tips is valid as a standard measurement under two conditions only:

1. If the diameter of the drum is exactly equal to the reference diameter, or
2. If the dial indicator reading is corrected by the amount the drum is above or below the reference diameter.

As an example, a drum is measured and found to have a diameter 0.2 mil under the reference diameter. Suppose further that the measured tip projections with an indicator are tabulated as follows:

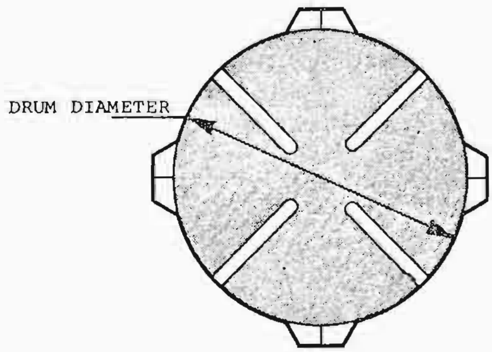


Fig. 21. Head drum diameter.

HEAD	MEASURED PROJECTION	CORRECTED PROJECTION
#1	3.2 mils	3.1 mils
#2	3.3 mils	3.2 mils
#3	3.1 mils	3.0 mils
#4	3.1 mils	3.0 mils

Fig. 22. Measured and corrected tip projection.

To find the corrected or actual projection, half the excess diameter or .1 mil must be subtracted from the measured projection.

Tip Engagement

To assure tight contact between the video heads and the tape, there is negative clearance between the head tips and the tape in the guide. The tape guide is relieved in line with the tips so the tape may stretch as the tip travels across it. *The negative clearance is the tip engagement.*

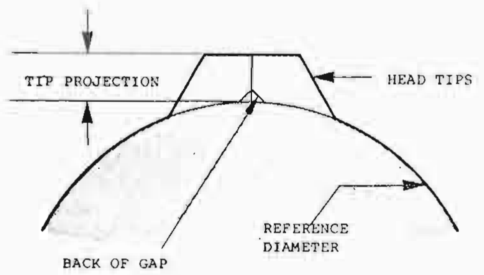


Fig. 23. Tip projection.

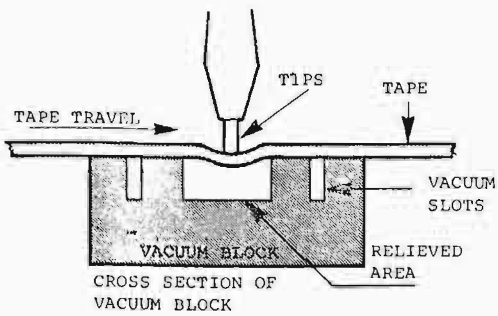


Fig. 24. Head tip engagement.

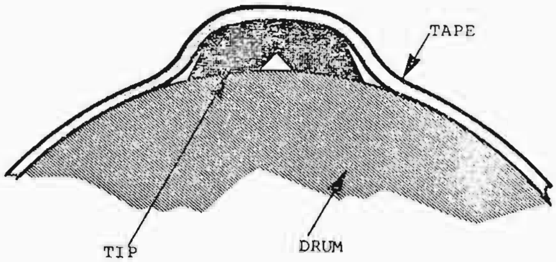


Fig. 25. Head-to-tape contact.

Departure Point

As negative clearance is decreased by moving the guide away from the head drum, signal output will remain relatively unchanged until only a small amount of negative clearance (engagement) is left and intimate contact between head and tape starts to be lost. At this point output will start to fall and finally reach zero. Because horizontal movement of the guide away from the drum destroys concentricity between the two, intimate contact will be lost first at the mid-point of the head's travel across the tape, and a dip will be introduced at the center of the RF envelope of the head's output, as viewed on an oscilloscope, see Fig. 26.

Complete loss of contact between tape and tip is indicated when the envelope dips to zero, see Fig. 27. This point in the guide's movement is called the "Departure Point." To adjust *approximately* for a desired tip engagement, it is only necessary to locate the "departure point" and move the guide towards the drum the distance equal to the desired engagement, the corrected tip projection valve.

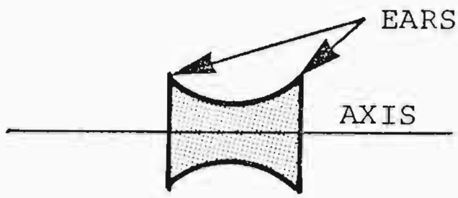


Fig. 26. RF-envelope—partial disengagement.

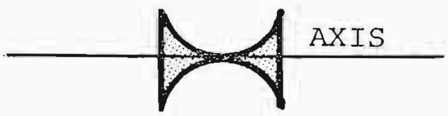


Fig. 27. RF envelope—departure point.

Self-Compensation

At first glance it would seem that a tape recorded with a given tip engagement must always be played back using the same tip engagement. *This is not true.* To understand why, examine what will happen when a tape recorded with a head having 3 mils tip projection is reproduced using a head which has only 2 mils tip projection. When the tape is played back by the 2 mils head, it is found that the tip engagement (when the guide is adjusted to remove skewing) is now only 2 mils. The explanation is this: since the *angular* velocity (video drum rpm) is held the same during record and reproduce, it follows that the tip velocity (ips) must have been greater during the record process due to the longer tip radius. If correct timing is to be maintained, the length of tape traversed by the shorter reproduce tip radius must be less or, in other words, *less tape stretch* has occurred. The reduction in tape stretch due to decreased tip pentration is complementary to the reduced velocity due to decreased tip radius.

The significance of this self-compensation principle can be appreciated by understanding the following experiment. Record a tape with the four heads which has a tip projection of 3.0 mils all

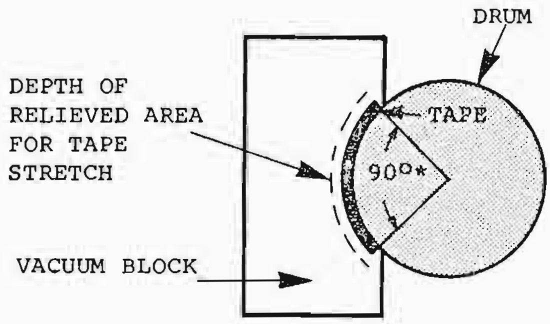


Fig. 28. Video head drum and guide block.

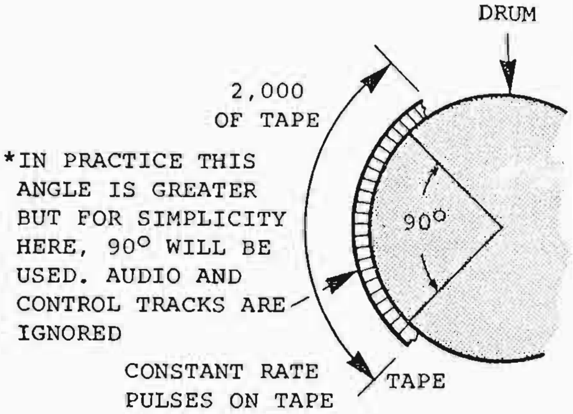


Fig. 29. Video head drum.

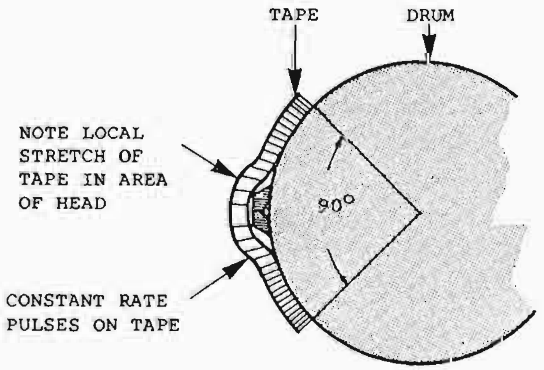


Fig. 30. Tape stretch.

equal, and use 3 mils of tip engagement. Now simply grind one of the four head tips down to 1 mil tip projection prior to reproduce. If you now reproduce the tape which was recorded when all the tips were equal, *you will see no visible defect in the picture:* The reduced velocity of the short tip has been compensated by the reduction in stretch due to reduced tip penetration.

One important idea to be kept in mind is that the stretching will be a localized affair. The effect of stretching is shown in the exaggerated figures that follow. The position of equally spaced recorded pulses on the tape is indicated by black bars on the cross section of the tape.

Facts to Note:

1. The head will sweep the same angle in the same time regardless of amount of tip projection.
2. The peripheral speed of the tip is greater with more projection, but the local stretch of the tape balances out the increased speed by increasing the separation of the pulses on tape.
3. The horizontal position of the guide relative to the chrome surface of the drum remains constant throughout the life of a head and tip engagement decreases as the tips wear down.

Guide Radius and Position

The vacuum guide radius of curvature is specified in SMPTE RP-11 as ranging from 1.0329 to 1.0334 in.

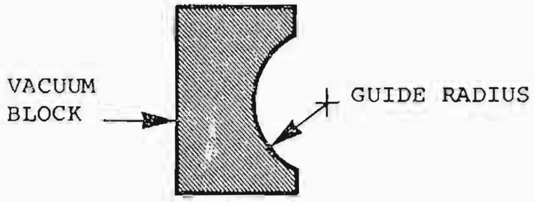


Fig. 31. Guide block radius.

To a first approximation, the variations in guide radius can be accommodated by varying guide position slightly so that the same length of track is always recorded or reproduced regardless of guide radius. Only when the guide radius is 1.0334 are the center of curvature of the guide and the axis of rotation of the drum coincident; for all other values a slight eccentricity exists.

Because guide radius is controlled by the manufacturer, the only variable under the control of the recorder operator is the guide position which determines eccentricity. In practice there are two ways for an operator to set up the proper eccentricity. The most accurate method is to play back a standard tape designed for the purpose and adjust guide position both horizontally and vertically for minimum geometric errors in the reproduced picture. A less accurate method which can be used if a standard tape is not available is the one described previously in the subsection entitled "Departure Point."

Guide Height

SMPTE RP-11 states that the eccentricity shall be such that the extension of a line joining the center of curvature of the vacuum guide and the axis of rotation of the heads intersects the tape at the midpoint of its width. This statement defines what most of us know as guide height, and this positioning of the guide is also under the control of the operator.

The best way for the operator to set guide height is to use the same standard tape used for setting eccentricity, and as in the former case, guide height should be adjusted for minimum geometric distortions in the reproduced test pattern.

When the vacuum guide block is properly adjusted, with reference to a standard tape, various guide engagement errors can be quickly seen and evaluated in the picture monitor. Examples of error configuration displacements are shown in Figs. 32 through 37.

If a standard tape is not available, there are two other less accurate ways available for setting guide height which can be used in an emergency. The simplest way is to make a short recording and then observe the RF output of the switcher during playback while moving the guide away from the head. The RF pattern from the heads will dip as in Fig. 26, and if the guide height is correct, the

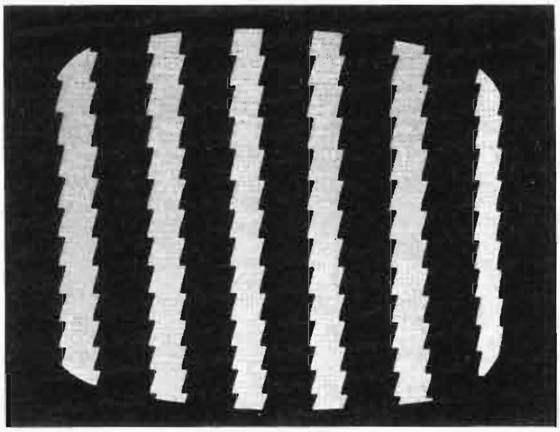


Fig. 32. Guide block too far back tip engagement shallow.

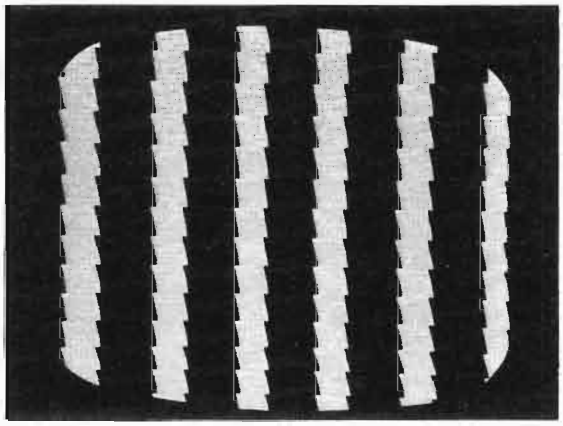


Fig. 33. Guide block too far in tip engagement deep.

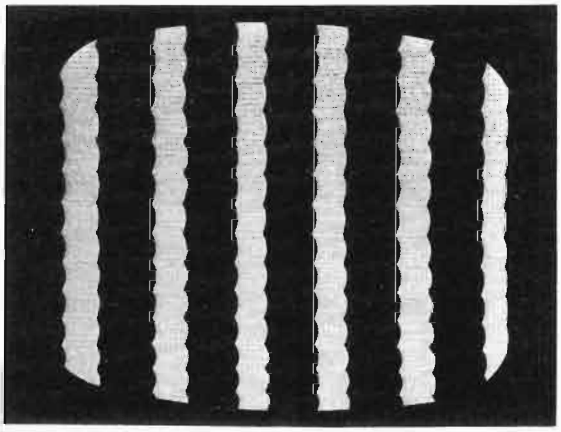


Fig. 34. Guide block too low.

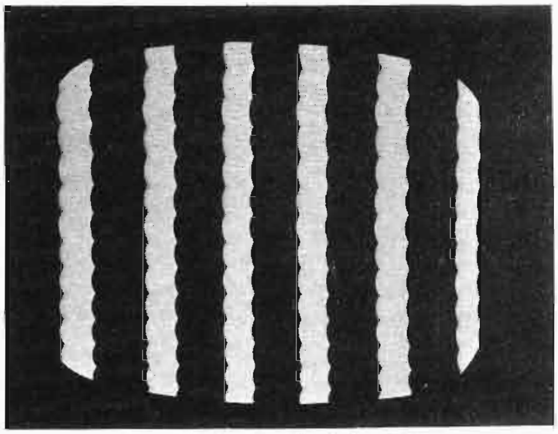


Fig. 35. Guide block too high.

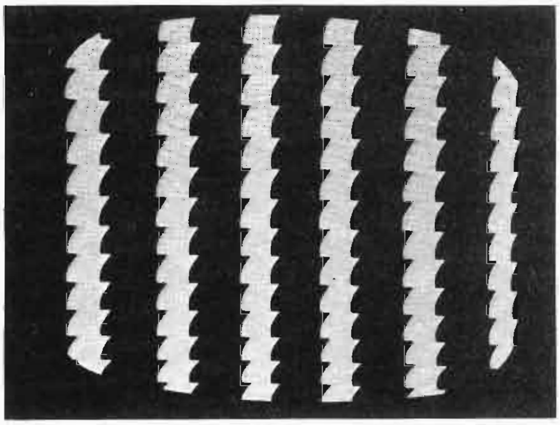


Fig. 36. Guide block too high tip engagement shallow.

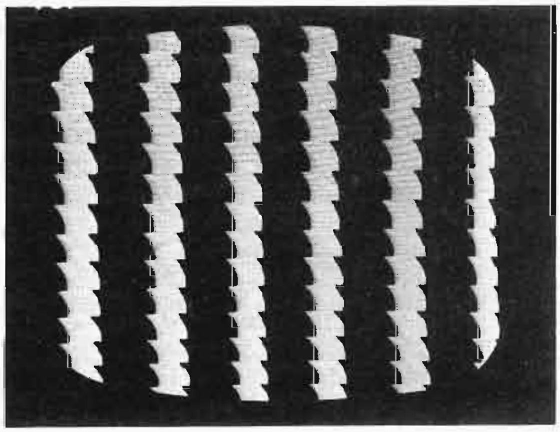


Fig. 37. Guide block too low tip engagement deep.

ears at both ends of the RF burst will remain equal in height as the guide is backed away. The process of recording and playing back must be repeated several times to zero-in the correct setting. In addition, it must be determined that the transport, panel and tape combination is not producing an RF tilt.

A second method is to make a recording with the control track signal also recorded on the Audio I track and then play the tape back upside down. The guide height should be adjusted to remove half of the geometric error observed. The record-playback process should be repeated several times to zero-in the correct guide setting. A certain amount of experimentation with control track level will be necessary to obtain proper playback levels.

Video Head Life

The wear rate of new heads with tips at or near maximum will be relatively high, but will decrease exponentially as the head tip wears down; the head wear rate simply decreases as the tip projection declines. General video tape operating experience has shown that the head wear *rate* during the first 50 operating hours, when a new head is initially installed, may decrease as much as twice during the second 50 operating hours under normal conditions. In the third increment of 50 hours use (up to approximately 150 hours) an additional 25 percent reduction in head wear rate may be expected and finally a point is reached where a minimum descending value of tip wear continues until the final normal failure of a head tip occurs. This point is near or when the "back-of-gap" is reached. The point is clearly seen when finally there is no signal output from a given head tip or when noise banding, chroma level flutter, or difficulty in optimizing the drive to a head tip occurs. Another point is as well-considered failure when the signal drop-out activity rises rapidly around 1 mil of tip engagement. An idealized head wear characteristic curve is shown in Fig. 38.

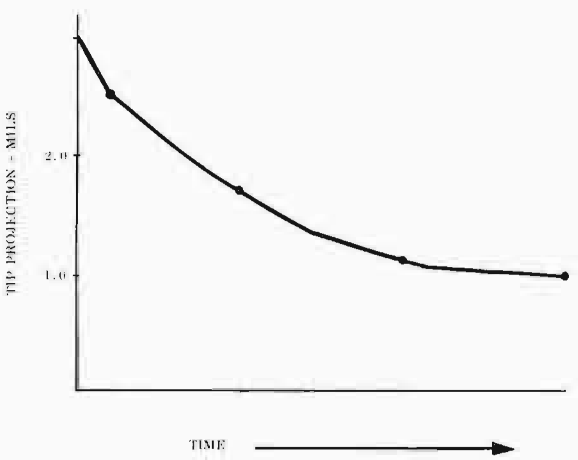


Fig. 38. Idealized head wear curve.

Measurement of Wear Rates

The wear rate per hour equals the difference between the initial tip projection and the remaining tip projection divided by the operating time in hours. If .000050 in. is worn from each tip over an operating time of two hours and 30 minutes, the wear rate is 20 microinches per hour. This can be simply done as follows:

VTR Elapsed Time Indicator Readings:

Time VTR Head Removed _______
minus Time VTR Head Installed _______
= VTR Head Hours Used _______

and finally

Head Wear Rate:

Total Head Tip Wear _______
÷ ———————————
VTR Head Hours Used _______

= _______ Average wear rate microinches/hour.

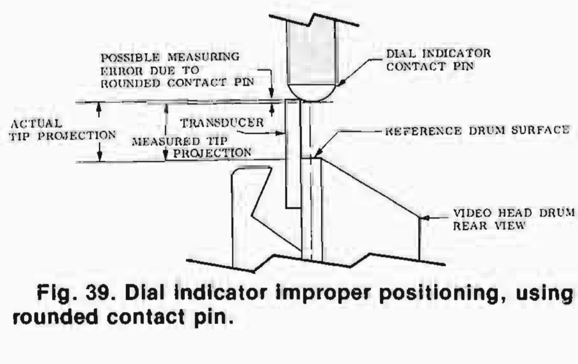


Fig. 39. Dial indicator improper positioning, using rounded contact pin.

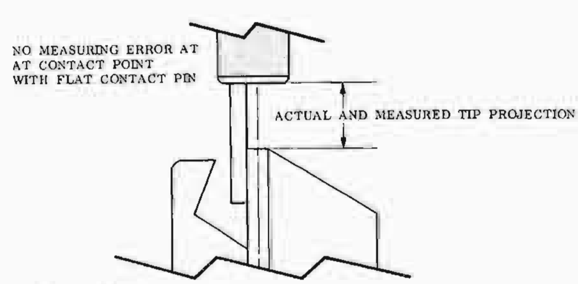


Fig. 40. Dial indicator properly positioned, using flat contact pin.

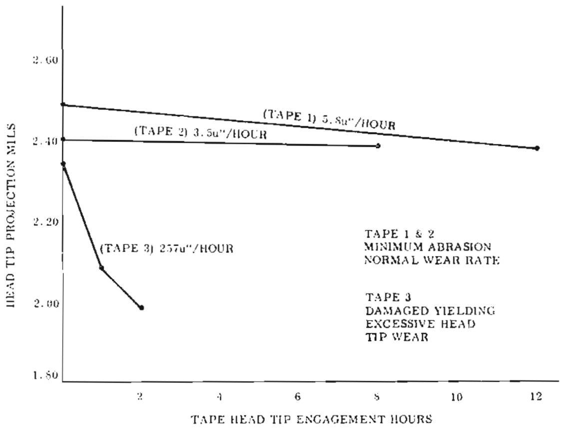


Fig. 41. Comparison head tip wear rate using damaged tape.

It is important to maintain accurate records on the time VTR heads are in actual use, particularly if the heads are moved from machine to machine. Dial indicator readings as well should be made with extreme care to provide accurate drum reference and tip projection readings, as shown in Figs. 39 and 40. Further, special care should be taken so as not to damage or abuse the head tip during the time dial indicator readings are being taken.

Factors Affecting Video Head and Tape Life

Video recorder head life and video tape life are directly related. Video head tip wear is affected by the condition of the tape in use, cleanliness of the tape, the abrasive characteristics of the tape, cleanliness of equipment, environment of the VTR operational area, adherence to recording standards, adjustment of the VTR tape transportation system, and the general operational handling procedures of the VTR and video tape. Likewise, the video tape material life is affected by the condition of the video head tip, the tape path surfaces of the video recorder, and many of the factors just mentioned relating to video head life—in addition, the condition of reels, reel hubs, circumstances of packaging, shipping, and storage, and mainly the video tape handling procedures, as well as the tender loving care given by the video tape operator.

Factors Affecting Video Head Tip Life

Video recorder head tip wear is of great concern in relation to the cost of operation as well as providing high quality performance of the video tape recordings and the proper handling of video tape materials. Factors concerning video head life as well affect the "on-air" picture quality and wear of video tape stocks in use.

Factors concerning video head tip life are directly related with that of the video tape material utilized, their care, and the handling procedures used in general operations. The overall "on-the-air" quality, cost of operation, and care of video tape and heads are vital.

All magnetic recording tapes present an abrasive (oxide-coated) surface to the video head tips in the recorder reproducing equipment. Thus, head wear begins the moment the first tape is recorded or reproduced. The rate of wear produced by undamaged tape of good quality is relatively low, but it has a finite value. Tape that has been mechanically damaged in a way that distorts its oxide-coated surface is quite another matter. Head wear is directly related to moisture content in the tape binder system. The higher the moisture content, the higher the head material wear rate. The moisture content level is related to relative humidity that the tape is either stored or run in the recorder system. The ideal RH % to store or operate for maximum head life is 30 to 40% RH.

In the case of video head tips which traverse the tape at high writing speeds (e.g., 1,500 in./sec.), undamaged tape allows a useful head life in excess of 100 hours. On the other hand, damaged tape may cause rates of wear ranging up to 400 microinches per hour, thereby reducing useful head life to only a few hours. Fig. 41 compares head tip wear rate using damaged video tape.

Damaged Tape

Tape that has been physically damaged by creasing, crumpling, or scratching is the prime cause of the high wear rates approaching 400 microinches per hour mentioned earlier. Any sharp deformation or scratching of the oxide coating interrupts its continuity and uniformity, resulting in a cutting action somewhat akin to that of a file. It also loosens individual particles of oxide, which may be picked up and retained by the head tips or the head drum. When physically damaged tape passes the head tips, the tips are scratched by this cutting action as shown in Fig. 42. Then, as more tape passes the scratched tips, it is damaged in turn by the milling action of the tips. For this reason, severely scratched head tips must be polished before further use.

Fig. 43 illustrates typical damage to tape caused by creasing or folding. When creased sections of tape pass the head tips, the rate of wear increases drastically, and loosened particles of oxide are picked up and retained by the head tips and the drum.

Fig. 44 shows the random redeposit of oxide particles near the edge of the tape. The appearance of these streaks reveal the end of useful tape

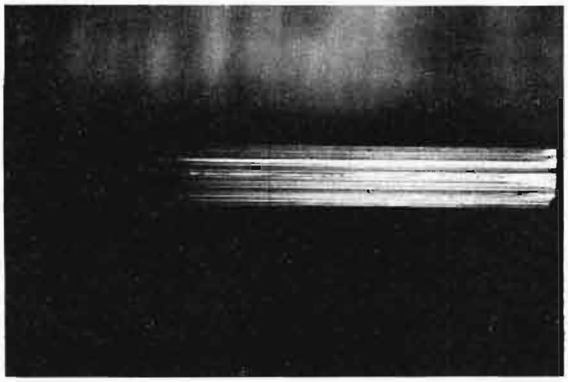


Fig. 42. Damaged video head tip.

Fig. 43. Creases cause oxide buildup, high tip-wear rates.

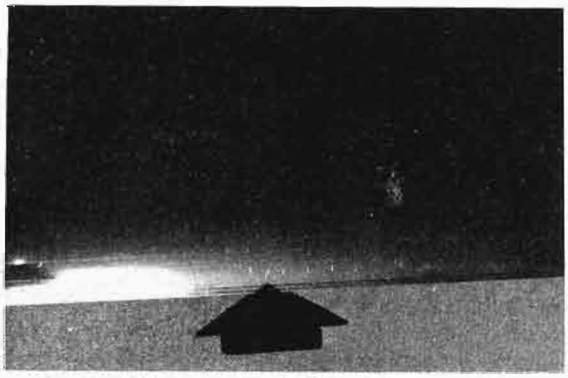


Fig. 44. Oxide redeposits signal end of useful tape life.

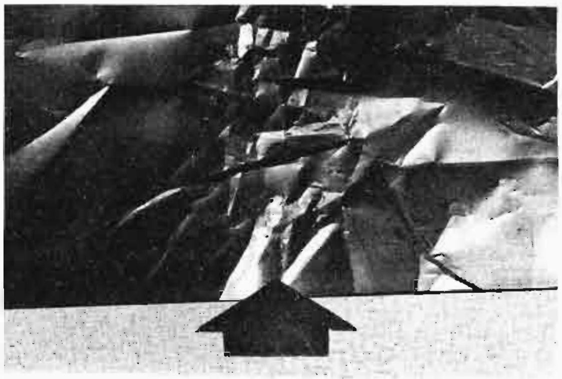


Fig. 45. Crumpled tape scratches tips, causes oxide buildup and rapid wear.

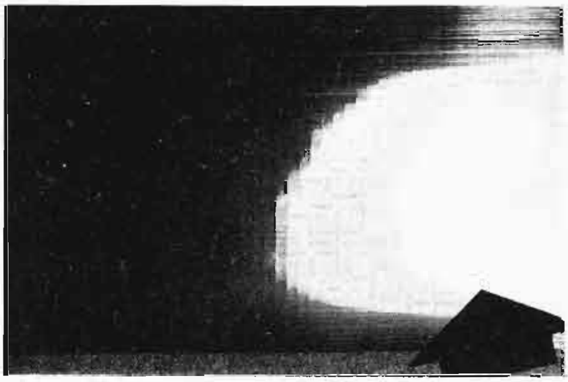


Fig. 46. Transverse burns from passing over a damaged tape cause wear.

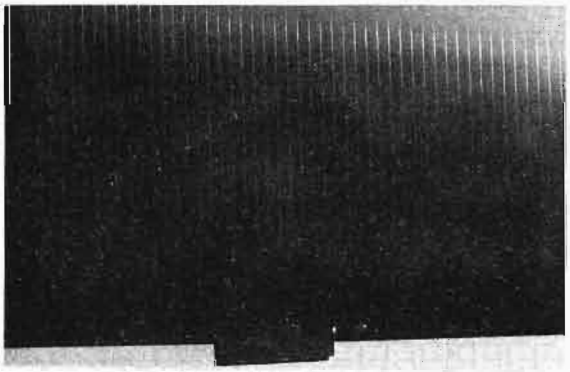


Fig. 47. Opposite side of tape; backing permanently deformed.

life, because it indicates a general breakdown of the oxide binder.

Fig. 45 illustrates a typical random crumpling of the tape from edge to edge. Crumpled tape represents the greatest danger that the head tips may encounter. There is a virtual certainty of tip damage in the form of long, deep scratches, and the subsequent damage of good tape by the damaged tips. Also, a rapid buildup of loose oxide may accumulate on the drum surfaces to aid in the destruction of the tape.

Fig. 46 shows the repeated transverse burns or scratches across the width of the tape caused by damaged head tips or by an oxide-loaded head drum. The deformation of the backing over the same tape section is illustrated in Fig. 47.

Before each day of use, closely inspect all metal surfaces (including tape guides, idlers, compliance arms, head tips, and drum) that touch the oxide-coated surface of the tape for an accumulation of oxide. If any is present, remove it immediately, using a cotton-tipped swab moistened with head cleaner. Be alert for sections of tape that are crumpled, creased, or scratched. These sections appear most often near the beginning of the tape. But wherever they appear, they must be removed before the tape is used to avoid needless head-tip damage.

Examine the head tips regularly by means of a tool-post-mounted microscope equipped with a diffused light source, as shown in Fig. 48. The condition of the tapes being used may be determined by the appearance of the head tips. If severe scratches are detected, polish the tips by running the head for a short period with tape that produces a polished condition. If any head tips are found to be broken, do not use the video- head assembly until it has been repaired or exchanged.

While tape is being manipulated by hand, use care to avoid situations that may lead to creasing or crumpling. In order to avoid severe dropout on tape, gloves should be worn when handling tape. The preferred type are rubber gloves, although cotton gloves do offer some protection from getting the skin oil on the oxide of the tape.

Remember that degradation of the reproduced picture, caused by a buildup of oxide on the head tips, is usually accompanied by a buildup of oxide on the drum surfaces as well. Make it a practice to clean the head tips and the head drum as soon as possible after such degradation first appears.

Environment of Videotape Operational Areas

The environment in which the location of the tape is actually used should approach, as closely as is realistically and practicably, a "clean-room." By definition, then, this area is characterized by the absence of normally expected airborne dust and lint. Various air-conditioning filtration systems are available to accomplish this cleaning.

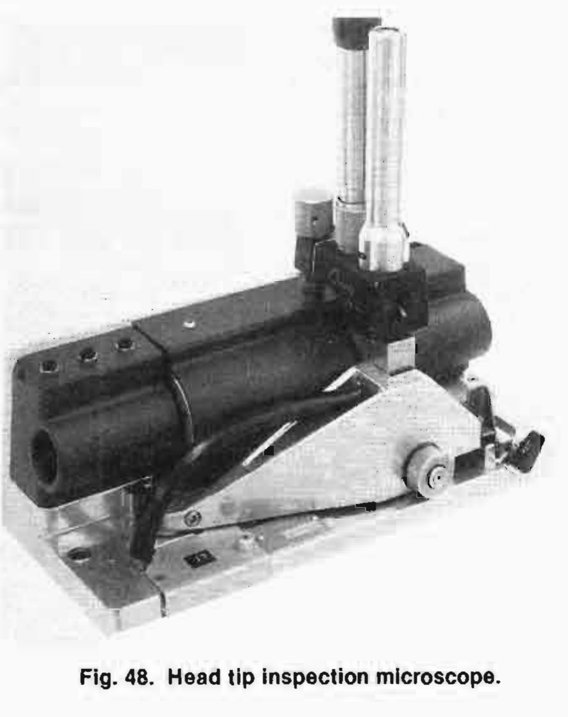


Fig. 48. Head tip inspection microscope.

Whenever possible, the air pressure in the room should be maintained so as to be somewhat higher than the surrounding area. This positive internal pressure will prevent the infiltration of dust through doors and windows that are not absolutely airtight and, of course, is most important in preventing dust from entering when a door is opened.

The surrounding walls and ceilings should be painted. *Air intakes should be well filtered to eliminate outside dust and dirt from entering, even to the point of electrostatic air cleansing when possible.* Carpets or rugs should not be used, but a hard surface such as vinyl, properly waxed, proves best for keeping clean floors. Daily accumulation of dust can easily and frequently be sponge mopped. Video tape recording equipment, racks, shelfs, and video tape reels must be kept clean. The practice of bringing video tape boxes and packaging materials into operation areas is considered to be a source of contamination. A room adjacent to video tape operations, but isolated, is a good place to leave empty boxes for storage, handling, and packaging.

The design of the equipment area should be such that reasonable control of temperature and relative humidity can be exercised. Variations of temperature should be held to within $\pm$ 5° F., of a preselected value and the relative humidity should be kept constant to within $\pm$10 percent. The general recommendation would be an environment that is comfortable for the operating personnel, as this is also ideal for the tape. In broad terms, this would be a temperature in the 70's and a relative humity of about 35 percent. It is doubtful if smoke will contaminate the tape, but ashes can; therefore, great care should be taken when smoking. Food and drink should also be restricted. Minute food particles can easily be transmitted to the video tape and recorders from the operator's hands, resulting in unnecessary collection of debris and ultimately excessive dropout activity as shown in Fig. 49.

Aside from the direct benefits gained from a well-maintained, clean, temperature and humidity controlled environment, the psychological effect upon the employees is of great importance. It is found that operators exercise more care and are more concerned with *quality* when working in an environment such as just described. Cleanliness in video tape operational areas is *absolutely essential* to the long-term life of video tape material stocks and subsequently as well to video head tip life.

Proper Machine Transport Adjustment and Inspection

Supply and take-up holdback torque brake tension adjustments are most important and

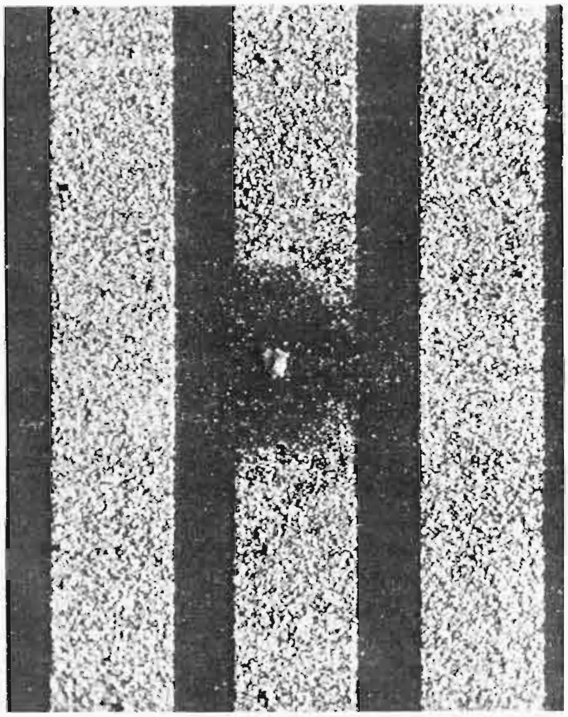


Fig. 49. Dropout.

should be maintained at regular intervals, particularly for the supply reel to minimize geometric imperfections or time base errors, both during record and playback operations. The take-up reel is isolated by the capstan and pinch roller; however, the proper pressure is important at this point to minimize tape slippage and provide stable tape transportation. Bent reel flanges, eccentric reel hubs, and defective supply and take-up motor bearings can be a cause of severe instability problems.

Excessive or nonuniform guide block vacuum levels can further add to geometric distortions and degrade picture stability. Both torque and guide block vacuum fluctuation appear as variable tip engagement errors. Motor tension adjustment and the degree of vacuum in the guide block can contribute to excessive video head tip wear if they are not properly adjusted or are in difficulty.

Regular inspection of tape transport tape path should be accomplished to determine that all surfaces coming into contact with the tape are clean and/or there are no mechanical surface irregularities damaging tape. The vacuum guide, erase head, audio head, tape path guides, and tension arms should be cleaned at regular intervals with a cleaning solvent such as Freon TF[2] and a soft applicator.

Extra care should be given in cleaning the rubber capstan pinch roller, particularly when using solvents. Alcohol has been found best and the pinch roller should be cleaned regularly as well so that the rubber surface does not take on a shine.

Video Tape Operational Handling

The hub is the strongest and most stable part of the reel. This fact is the reason why operators should always handle the reel by the hub and not the flanges. If this single fact is recognized, operators will not squeeze the reel flanges together or apart when picking up a roll of tape and, at the outset, minimize flange damage and subsequently tape damage.

When handling tapes, operators should use utmost caution to insure that the tape does not become contaminated by fingerprints. Simply stated, fingerprints are nothing more than deposits of body oils and salts. These oils will not attack the oxide-binder system, but will form excellent "holding-areas" for dust and lint. The same condition will exist if the tape is contaminated by marking with soft grease or wax pencils.

Fingerprints or grease pencil marks on the backing are just as serious as on the coating because dirt deposits will transfer from the backing of one wrap to the coating of the next wrap on the reel. When a reel that has been contaminated in this manner is put into use, the video recorder itself can be affected and will spread this contamination to other clean reels of tape that are used after the dirty reel.

This is one of the reasons why the stress of importance in visually inspecting the recording equipment after each roll of tape is run to determine where cleaning is necessary. If the recorder becomes contaminated with dust, complete contamination of an entire roll of tape can easily be the result. Debris can collect on heads and guides and be dumped along the backing or coating surface of the tape. This debris will then be wound into the reel under pressure causing it to adhere firmly to the surface. These deposits could appear as a dropout or group of dropouts the next time the tape is used.

Tape contamination caused by fingerprints can be reduced by remembering not to touch the tape unnecessarily. Frequent cleaning of the recorder will reduce the chance of spreading contamination from one reel of tape to others in a library. A cotton swab or lint-free pad moistened with Genesolve-D (an Allied Chemical Trademark), or Freon TF, or similar cleaner is recommended for cleaning all elements of the tape path on the recorder. If other types of cleaning agents are used, they should be given time to thoroughly dry before loading the tape. This will prevent damage to the tape should the cleaner have any tendency to attack the coating of the magnetic tape.

[2]TM, E.I. du Pont de Nemours & Co., Inc.

Empty reels should be thoroughly inspected and cleaned before winding tape on them for storage. Reels with hub damage, or with dirt on the hub winding surface can cause tape distortion. The effect of hub nonuniformity is evidenced by a "spoked" appearance of the tape layers wound upon the hub. This is caused by the pressure of the discontinuity being reflected up through each tape wrap. Maintaining reel integrity cannot be overemphasized as recorded information can be lost not because of tape failure, but because the tape was distorted by a damaged or dirty hub.

One of the most serious and more common forms of tape failure is generally categorized as edge damage. Damaged edges can be caused by the reel, the recorder, or the operator. A damaged or bent reel flange can quickly mutilate the edge of the tape.

Since the tape will probably be damaged with each revolution of the reel, the result of this series of damaged edges will often appear as a bump on the otherwise smooth surface of the wound tape. A similar situation could result if the reel were not mounted evenly. If the reel pedestal height is improper, a guide is misaligned, or the audio "stack" is excessively worn, the resulting edge damage may appear as a "lip" on one side of the tape around the entire reel circumference.

Any of these faults can result in serious damage to a roll of tape. The debris generated from edge damage could be redeposited back onto the surface of the tape across the entire width. An examination of the edges of a tape that has been damaged in this manner probably would disclose an accumulation of loose polyester fibers and loose oxide, as well as damaging to the video head tips.

While this type of damage is serious, it is sometimes difficult to ascertain its cause or even to notice the effect until the damage is severe. Operators should acquire the habit of physically inspecting the recorder in the area of the guides and head for an excessive build-up of oxide, or backing debris. This is generally the first clue that something is wrong.

It is also good practice to continually observe the physical condition of the tape. A sure sign of developing edge damage would be the lip or distortion that was mentioned earlier. When wound on the reel, the effect of this lip will be cumulative and can stretch the backing. The stretched backing will be rippled and will not conform to the heads the next time the reel is used.

Operating personnel should use care in handling the reels of tape. It is important that the reel be picked up in a manner that will not cause the flanges to be squeezed together, or pulled apart. If the flanges are forced against the tape, this could result in edge damage. This is particularly true if the roll has a scattered wind, as the exposed edges of the misaligned strands can be folded over and creased. It is strongly recommended that operators be constantly on the alert for signs of potential trouble. This can best be accomplished by understanding what to look for, and by making continuing inspections of both tape and the recorder tape path. *Know your recorder.*

Video Tape Shipping

Since the widespread use of recorded video tape material requires that the tape be sent from one station to another, certain precautions that apply to the shipment of magnetic tapes should be followed to insure safety in transit.

Logically, the first consideration would be the physical protection of the tape while being transported. The shipping container into which the tape is placed must afford the necessary strength and rigidity to protect the roll from damage caused by dropping or crushing. The ideal container should have provisions within the case to allow a rotational movement of the tape reel. This reel movement minimizes the possibility of tape cinching due to sudden torque created if the case is dropped or roughly handled. The case should also provide protection for the reel flanges.

While a container that is 100 percent watertight may not be necessary, it must, nevertheless, provide a reasonable degree of water resistance. It should, for example, be capable of protecting the contents from being damaged, if, during shipping, it is left on a loading dock in the rain. While it is good practice to always secure the free end of a reel of tape, it is particularly important when preparing reels for shipping. This tabbing-down can be easily accomplished by securing the end to the next wrap on the reel with pressure sensitive tape. The tape chosen should be one that has an adhesive that will leave no residue when removed. Even though the purely physical shipping precautions are not unique to magnetic tape, but are considered good practice in preparing any item of value for transport, there is another consideration that is of prime importance. Since the tape is a carrier of magnetic information, measures must be taken to protect the reels from accidental erasure.

Tests conducted at 3M Laboratories to determine what would constitute adequate protection from stray magnetic fields of a magnitude that might possibly be encountered in transit, found that field strengths within the tape of 50 oersteds or less caused no discernible erasure.

The typical bulk degausser, purposely designed to produce a maximum external field that is used to erase tape while still on the reel, produces a field of about 1,500 oersteds. Sources of magnetic energy to which tape being shipped might be subjected would be motors, generators, transformers, etc. These devices are designed to contain their magnetic fields to accomplish some type of work. It is felt safe to assume that field strengths of more than 1,500 oersteds would not be encountered in ordinary shipping situations. Because field intensity decreases rapidly with distance from the source, the 50-oersteds point (mentioned earlier as not affecting the tape) is reached at a distance of 2.7 in. from a 1,500-oersted source. From this it can be seen that the easiest and least costly method of obtaining erasure protection is by insuring a degree of physical spacing from the magnetic source.

The shipping experience data of NET-National Educational Television over the past ten years representing well over one million individual shipments proved the losses of program to be only three or four video tape reels through possible accidental erasure from stray magnetic fields during shipments. Most accidental erasure comes from poor VTR maintenance practices, where the tape transport or head tips become magnetized. These components should be degaussed on a regular basis. A shipping container such as the "Scotch" Brand Shock-shield plastic case gives adequate protection and minimizes the potential for accidental erasure. This highly protective container can provide excellent protection against physical damage to the contents, as well.

Tape in transit may be subjected to temperature extremes. Temperatures as low as -40° F might be encountered on a loading dock in the far north or in jet flight. A temperature of 120°F could easily be encountered in a motor vehicle in the summer sun. If a reel of tape that has been subjected to extremely low temperature is put into use before it is given the time to return to normal environmental conditions, it may become physically distorted when used. When the roll is subjected to the start-stop action in use, the individual tape layers can shift due to momentum and result in severe "cinching." This can also happen if a very cold tape is dropped or handled roughly. It is recommended that incoming tape be allowed to stabilize in the operating environment for 24 hours before being put into use. Artificial means to hasten this stabilization period is not suggested.

Video Tape Storage

The temperature and humidity of the storage area should approach, as closely as possible, that of the work area. The smaller the environmental change experienced by the tape, the better will be its operation and reliability. As a general rule, the temperature should be maintained between 60° and 80°F., and relative humidity between 30 percent and 50 percent.

Protection from accidental erasure while in the storage area is easily accomplished and is, ironically, of little concern. There are two reasons why this is true. First of all, fields strong enough to cause erasure are not usually or normally found in an office storage atmosphere. Secondly, if the tape is kept as little as 3 in. away from even a strong magnetic source, this spacing should be sufficient to offer adequate protection.

The hub is the strongest and most stable part of the reel. Not only should the reels always be handled by the hub, but, in storage, they should be supported by their hubs. This is one of the two basic reasons why the reel should be returned to its container (a cardboard box, or plastic shipping case) before being placed into storage. Most storage containers are designed so that the reel actually hangs by the hub with little or no weight on the flanges. The other reason for using the storage container is obviously protection of the reel from dust and dirt.

The closed containers should be placed into storage on edge, so that the reel is in an upright position. During storage, additional protection from dust and moisture can be gained by enclosing the tape in a plastic bag. It is generally considered good practice to clean the container before bringing it out of storage so dust that has accumulated during storage will not contaminate the tape as it is being removed.

Of primary importance is the way the tape is wound on the reel, as poor winding can result in distortion of the tape's backing. It is recommended that a wind tension of four to five ounces per ½ in. of tape width as sufficient to render a firm, stable wind. This tension, while great enough, does not result in high pressures within the roll that could permanently distort the polyester backing. Backing distortion, caused by extreme pressures within the tape pack, may result if a roll of tape wound too tightly was subjected to an increase in temperature while in storage.

Just as there is the possibility of problems if the tape tension is too great, too low a wind tension can cause difficulty as well. If the wind is too loose, slippage can occur between the tape layers on the reel. This "cinching" as it is called can permanently damage the tape by causing a series of transverse creases or folds in the area that has slipped. When the roll is unwound, the surface will be wrinkled. When an attempt is made to use the tape again, the wrinkles and creases will disrupt the necessary intimate contact between the tape and the head, resulting in a series of dropouts. If, immediately after an occurrence of cinching, the tape is properly rewound, there is a possibility that the recording may be saved.

Fig. 50. Video tape "cinching."

Along with proper tension, another important consideration is wind "quality." The successive layers of tape should be placed on the reel so that they form a smooth wind with no individual tape strands exposed. A smooth wind offers the advantage of built-in edge protection. A scattered wind will allow individual tape edges to protrude above the others. Since there is no support for these exposed strands, they are vulnerable to damage.

Again, if recommendations as to the storage environment and the actual preparation for storage are followed, no serious problems should be encountered even in long term storage.

Winding and storing magnetic tape properly will lessen the possibility of damage in the event of fire as tape is a poor conductor of heat. It is sometimes possible to recover information from a tape receiving slight fire damage by carefully rewinding it at minimum tension. The information it contains should be transferred immediately to another reel of undamaged tape.

It is recommended that CO_2-type fire extinguisher for combating burning magnetic tape be used. CO_2 is clean and this type of extinguisher contains no chemicals that could harm the tape. If water reaches the tape, it will probably not cause complete failure but there may be some evidence of "cupping" or transverse curvature. The amount of "cupping" would depend on the quality of the wind and the length of time the roll was exposed. If the wind is loose or uneven, the water can more easily reach the oxide surface and the cupping would be more pronounced. The tape, of course, should be removed from the water as soon as possible.

After removal, the rolls should be allowed to dry on the outside at normal room temperature and then slowly rewound most carefully, as well provisions taken to protect the recorder equipment. This will aid the drying and will also help the rolls to return to equilibrium faster.

If a temperature increase is also incurred while the tape is water soaked, steam or at least high humidity will be present. This is likely to cause more damage than water alone. A temperature in excess of 130° F with a relative humidity above 85 percent may cause layer-to-layer adhesion as well as some physical distortion.

Plastic containers and inner plastic bags will provide better protection from water and moisture than will a cardboard box. They are more effective in keeping the water spray from a sprinkler system from reaching the tape. These containers also will offer the tape more protection from the radiant heat of a nearby fire.

To prevent fire involving magnetic tape, store tape in a noncombustible area and make sure that no combustible materials are stored in the vicinity. For maximum fire security, store magnetic tape in a fireproof vault that is capable of maintaining a desirable internal temperature and relative humidity for a reasonable length of time. Under proper storage conditions, magnetic tape has the ability to retain intelligence for an indefinite period of time. Of greatest importance is the physical perservation of the medium so that adequate head to tape contact can be maintained when the tape is again put into use, as well as the

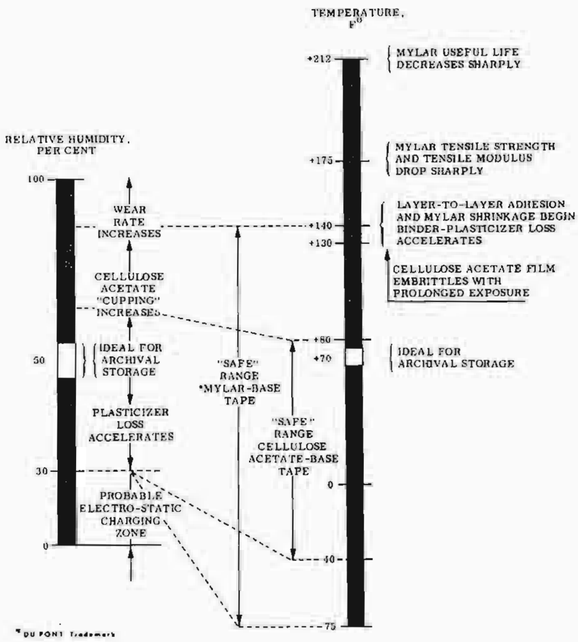


Fig. 51. The effect of environment on magnetic recording tape.

protection to the recording/reproducing equipment and video head tip life.

Signal System

All video recorders use essentially the same type of signal system since the function is identical, i.e., the varying amplitude video signal is converted into a constant-amplitude frequency-modulated signal for impression on the recording medium.

Each recording channel output is coupled by a rotary transformer to its associated video head in the video head assembly. The relative signal level applied to each video head may be selected for measurement by the RECORD CURRENT meter. Each video head thus receives the RF signal continuously from its associated record amplifier, and records that signal during the time it is moving across the tape.

Because the heads are positioned 90° apart on the head drum, and the tape is curved (by the vacuum tape guide) to contact 120° of the drum periphery, there is an interval when one head makes contact with the top edge of the tape before the preceding head loses contact with the bottom edge. During this overlap interval, identical information is recorded simultaneously by both heads. Some of this redundant information is removed in subsequent erasing and recording operations. The remainder provides an overlap period that includes approximately 2 lines of video information. This redundant information is eliminated by the switcher during subsequent reproduction. Thus, either 16 or 17 horizontal television lines of video information are reproduced from each tranverse track.

Since longitudinal tape transportation is at a velocity of 15 ips, head rotational rate is 14,400 rpm, or 240 rps, and since four tracks are traced transverse to the direction of longitudinal tape motion during each revolution of the head drum, 960 tracks are laid down at 90°33 min. during each second of recording or reproduction along 15 in. of tape. The tracks are 10 mils (0.010 in.) in width, with a center-to-center spacing of 15.6 mils. Each frame occupies ½ in. of tape; one field occupies ¼ in.

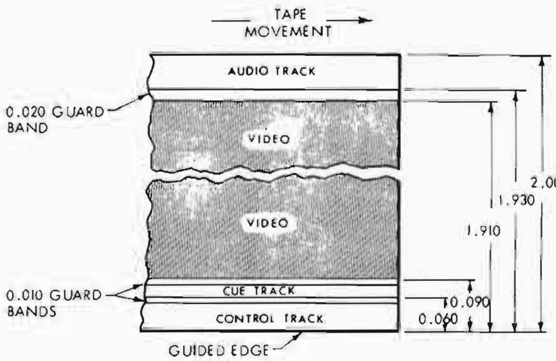


Fig. 52. Recorded track positions and widths in inches. (Width dimensions shown are maximum and tolerance of 5-Mils; guard band dimensions are fixed.)

The recorded track position and dimension are shown in Fig. 52; further reference should be made to the USA Standard published by the United States of America Standards Institute, Standard Number C-98.6.

Coincident with the beginning of each new frame of the recorded video signal, a frame pulse is recorded on the control track, and this is superimposed on the recorded control track signal. During subsequent playback, the servo system uses the reproduced frame pulses for fast framing the picture as the initial step of locking onto the tape recorded signal.

The signal system in the record mode consists of a modulator, record driver, and record amplifier, all of which serve to shape the input video signal into its final form for magnetic impression on the tape.

The frequency modulated signal is amplified by the record driver and fed simultaneously to four identical 75 ohms impedance output paths through separate coaxial cables to individual video record amplifiers in the head channel assembly. Each of these recording channels includes a pad level control.

During playback, the RF signal is recovered, and is passed through a playback network having a straight-line slope characteristic. The region of interest in the sidebands extends from the carrier frequency minus the highest modulation frequency, to the carrier frequency plus the highest

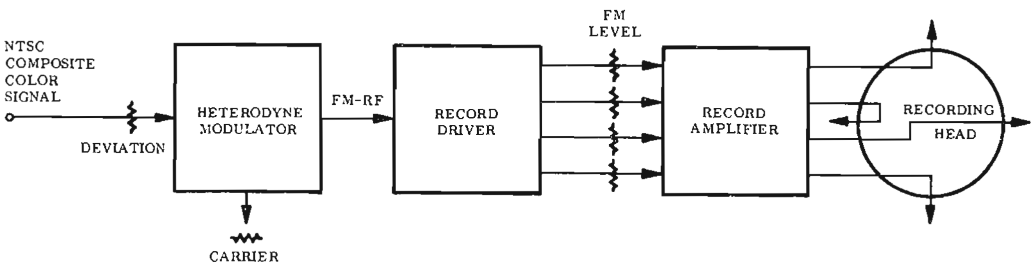


Fig. 53. Block diagram of VTR record mode.

modulation frequency. More specifically, the region of interest when operating under a high-band recording, extends from approximately 2 MHz through 15 MHz.

Modulation

There are basically three types of modulators that are presently in use, each of which has specific advantages and the selection of which is dependent upon the end use involved. All modulators have certain common features. The video input signal is usually limited by a low pass filter, so that frequencies above those that normally are encountered in that particular television standard are adequately attenuated so they do not affect the modulator. The filtered signal is then clamped to eliminate any unwanted distortion (hum, tilt, etc.).

To allow for ease in adjustment of the video recorder to exact frequencies, peak white calibration pulses are also obtained from reference crystals. The crystal output at the designated "white" frequency for the recommended practice in use is applied to the demodulator and deviation may then be adjusted in the modulator so that the calibration pulse and peak white of the picture are equal.

The improvement in video head design has made it possible to elevate the carrier frequencies at which the FM system operates. The new head assemblies permit the maximum carrier deviation frequency to extend to over 10 MHz, refer to Figs. 54, 55A, and 55B. The specific frequencies of the recommended practice have been very carefully selected to minimize interference from the harmonics of the carrier frequencies and give optimum overall signal-to-noise ratio.

Operation at high band frequencies (HB) provide greatly improved specifications of performance. Further, a better appreciation has been obtained from the theoretical considerations of the FM system employed that allow selection of

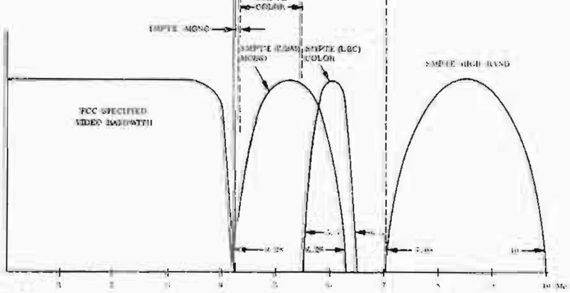


Fig. 54. High band frequency spectrum 525 line.

operating parameters in which the results can better be predicted in advance and which will permit the attaining of a high level of performance in new equipment design.

The three reference carrier frequencies utilized in video tape recording FM systems are generally known as low band monochrome (LBM), low band color (LBC), and high band (HB), the latter, the most recent, provides a single system suitable for monochrome or NTSC color signal recording. The Society of Motion Picture and Television Engineers Recommended Practice RP-6 specifies the reference frequencies of the carrier deviation and the de-emphasis characteristic, as shown in Figs. 55A and 55B.

The Modulator

There are three major categories of modulators, which operate to varying levels of proficiency. The simplest modulator consists of a multivibrator (Fig. 56) whose rest frequency is set to blanking level with deviation frequencies extending from sync tip to peak white. Present day multivibrators using transistors with very rapid switching times and carefully designed for symmetrical cancellation of video feed-through and unwanted harmonics are able to provide accurate long-time operation with very little frequency drift. The advantage of the multivibrator modulator lies in its inherent simplicity. It has few controls and requires very little adjustment. The heterodyne modulator (Fig. 57) uses a fixed oscillator, which is beat against a reactance controlling oscillator whose frequency is determined by the amplitude of the video signal. This circuit may have certain inherent advantages over the multivibrator, since the frequencies of operation are many times that of the actual carrier and deviation desired and filters may be used to eliminate unwanted spurious signals.

The most advanced modulator utilizes the dual-heterodyne principle (Fig. 58) in which two oscillators are driven in opposite directions by the video signal applied to them. The dual-heterodyne modulator takes advantage of the fact that the unwanted signals are 180° out of phase at the mixer and cancel each other out, leaving only the desired component to be amplified and applied to the tape. The mixing circuit is designed so as to obtain extreme linearity of response and very little amplitude modulation of the FM envelope.

Most modulators also have input filters to eliminate spurious signal components that lie above their acceptable frequency spectrum and pre-emphasis filters to properly shape the response characteristics. The output of the modulator is amplified and divided into four adjustable channels to permit head record current optimization. The final amplifier, which provides the

SMPTE RECOMMENDED PRACTICE — RP 6–1967

Reference Carrier Frequencies and De-Emphasis Characteristics for 2-In. Quadruplex Video Magnetic Tape Recording

Introduction

In quadruplex television magnetic recording systems, the level of the reproduced signal is controlled by three factors, viz., (a) adjustment of the playback video amplifier gain setting, (b) the reference frequencies to which the video signal deviates the carrier (at frequencies not affected by pre-emphasis), and (c) the combination of the video pre-emphasis used in recording and the video de-emphasis used in reproduction. In order to achieve uniformity in playback, it is essential that video tape recordings be made in accordance with the practices defined herein. It is also essential that all signals contained in a composite recording made by electronic editing or physical splicing of the recorded tape be recorded in accordance with the same one of the practices defined herein.

1. *Scope*

1.1 This recommended practice specifies the reference frequencies to which the carrier is deviated and the associated video de-emphasis, for each of the recommended modulation practices used in 2-in. quadruplex video magnetic tape recording of U.S. standard color and monochrome television signals. (The video pre-emphasis to be used in recording is specified indirectly by requiring a flat input-to-output video response along with a specified de-emphasis in reproduction.)

2. *Practice HB*

2.1 This practice is suitable for color and monochrome signals.

2.2 Recorded carrier frequencies:

(a)	Reference white level	10.0 ± 0.05 MHz
(b)	Blanking level	7.9 ± 0.05 MHz
(c)	Sync tip level	7.06 ± 0.05 MHz

2.3 The general de-emphasis characteristic is defined in Section 5 below.

2.3.1 Values:

(a) T = 0.600 microsecond
(b) X = 1.5

3. *Practice LBM*

3.1 This practice is suitable only for monochrome signals.

3.2 Recorded carrier frequencies:

(a)	Reference white level	6.8 ± 0.05 MHz
(b)	Blanking level	5.0 ± 0.05 MHz
(c)	Sync tip level	4.28 ± 0.05 MHz

3.3 The general de-emphasis characteristic is defined in Section 5 below.

3.3.1 Values:

(a) T = 0.132 microsecond
(b) X = 4.0

4. *Practice LBC*

4.1 This practice is used for color signals.

4.2 Recorded carrier frequencies:

(a)	Reference white level	6.5 ± 0.05 MHz
(b)	Blanking level	5.79 ± 0.05 MHz
(c)	Sync tip level	5.5 ± 0.05 MHz

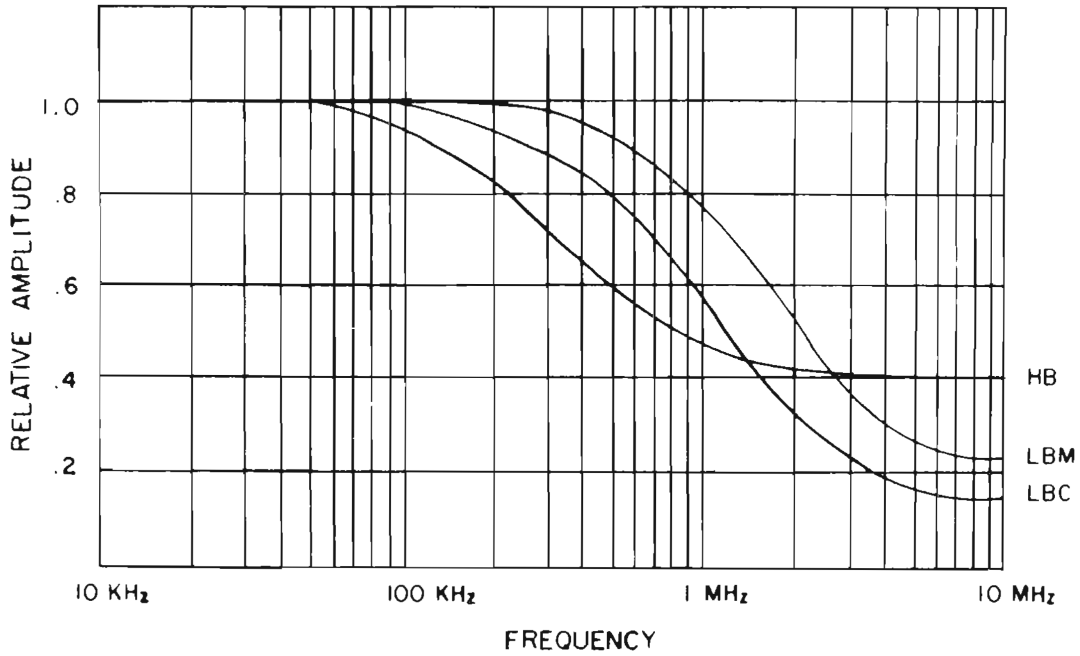
4.3 The general de-emphasis characteristic is defined in Section 5 below.

4.3.1 Values:

(a) T = 0.240 microsecond
(b) X = 6.56

Revision of RP 6–1960
Approved March 1967

Fig. 55A. SMPTE Recommended Practice RP 6-1967, Reference carrier frequencies and de-emphasis characteristics for 2-in. quadruplex video magnetic tape recording.



Graph A. Video De-emphasis Curves.

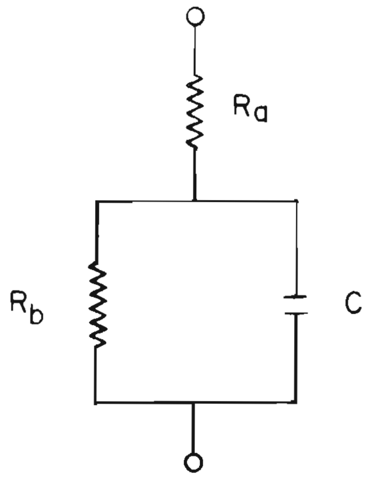
5. *De-emphasis Characteristic*

5.1 The video de-emphasis characteristic curves are described in Graph A.

5.2 The video de-emphasis curves are defined as the normalized impedance of the following two-terminal network:

$R_b = XR_a$
$T = R_bC$

where T is time constant, R is resistance in ohms, and C the capacitance in microfarads.



5.3 The de-emphasis characteristic is introduced following the demodulator in the signal playback circuitry. (To obtain a flat input-to-output video response over the passband of interest, a complementary video pre-emphasis characteristic is introduced ahead of the frequency modulator stage during recording.)

Appendix

(This Appendix is not a part of SMPTE Recommended Practice RP 6-1967, Reference Carrier Frequencies and De-Emphasis Characteristics for 2-In. Quadruplex Video Magnetic Tape Recording, but is included to facilitate its use.)

This recommended practice assumes that all pre-emphasis and de-emphasis is placed in the video portion of the signal path and that the response of the RF portion of the signal path is flat over the passband of interest. Ideally, the magnitude of the remanent flux on a recorded tape should be independent of frequency over the passband of interest, but since there is no practical way of measuring it, the most practical approach is to ensure that record current in the video heads is independent of frequency over the passband of interest.

Fig. 55B. SMPTE Recommended Practice RP-6 1967, Reference carrier frequencies and de-emphasis characteristics for 2-in. quadruplex video magnetic tape recording.

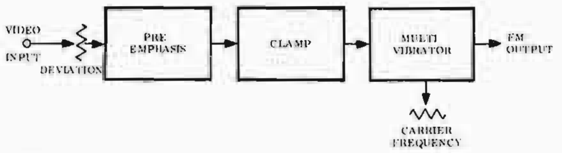


Fig. 56. Block diagram of multivibrator modulator.

current pulses to the head transducer, is also designed to give a flat current versus frequency result so that no distortion of the signal occurs as it is transferred to the tape. Any nonlinearity in this process produces unwanted modulation which is difficult to eliminate in the playback process.

Common to all modulators is the requirement that carrier frequencies remain stable so that the recovered blanking level will be of the

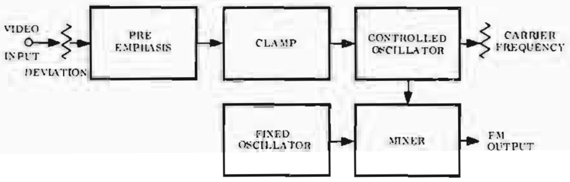
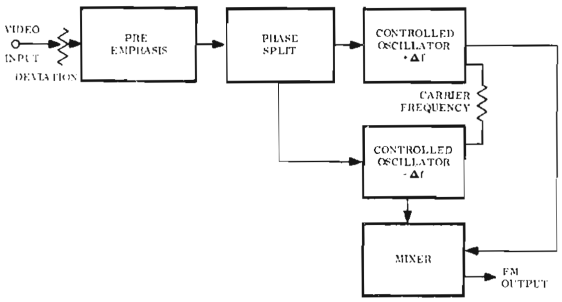


Fig. 57. Block diagram of heterodyne modulator.

same frequency on any recorded video tape. Special circuitry is usually included in the modulator, which uses a crystal reference as a source of AFC control. Blanking level frequency is compared with the crystal source and any error signal derived serves to keep the modulator at the correct frequency.

Carrier and deviation frequencies are recommended by the SMPTE VTR standards committees and when adhered to produce fully interchangeable tapes with regard to reference carrier frequencies.



Fib. 58. Blcok diagram of dual heterodyne modulator.

In determining recommended recording practices for professional broadcast usage, there are three basic considerations that must be kept in mind:

1. The recommended practice should result in as high as possible an order of performance with equipment that can be built today.
2. Its theoretical limitations should be such that future improvements in equipment and in the tape medium itself may be taken advantage of.
3. It must be capable of being accurately specified, allowing good interchangeability between tapes made on differing designs of recorders.

There are two areas to be decided in the determination of a new recommended practice: the choice of the type of pre-emphasis to be used, and the selection of carrier frequencies and deviation.

Choice of Pre-emphasis Method

It is customary in video tape recording practice to apply some degree of pre-emphasis to the signal before it is recorded on tape, followed by a like amount of de-emphasis during playback, in order to improve the signal/noise ratio of the playback signal. The process is comparable to that employed in FM sound broadcasting, in which higher modulation frequencies, containing a small portion of the total signal energy but a large portion of the total bandwidth, produce a greater amount of deviation of the carrier than that produced by low frequencies. Similarly, in video tape recording, high video frequencies, which in a monochrome picture contain only a small portion of the total signal energy, are recorded with a greater deviation than they would have had in the non-pre-emphasized case.

An obvious problem occurs with a color television signal, in that a large amount of signal energy is concentrated at the frequency of the color subcarrier which is located fairly high in the video band. The maximum level of the subcarrier determines the limit of pre-emphasis that can be employed with a color signal.

As is well known, the sensitivity of the human eye to noise in a television picture varies as a function of frequency, being in general more sensitive at low video frequencies than at high. It is important that a pre-emphasis scheme give as much improvement in signal/noise as possible at frequencies that have both a high visibility factor and are present in substantial amount in the output of a video tape recorder. Because of the triangulation effect of FM, very low video noise frequencies are not encountered and the region centered broadly around 1 MHz is the area where signal/noise improvement is most needed.

Types of Pre-emphasis

Two basic schemes of pre- and de-emphasis have been used. Video pre-emphasis in which a boost of high frequencies is applied to the video signal before modulation, and a complementary reduction of highs is applied after demodulation, while RF current (or flux) in the recording head is kept constant as a function of frequency, has been the type in most common use.

An alternate system, called RF pre-emphasis, in which the video signal before the modulator and after demodulation is unaltered but the recording head current is increased for sideband frequencies away from the carrier region, has also been used. In this method, an equalizing network in the RF playback signal path is used to reduce gain at the sideband frequencies which have been pre-emphasized. Both single-sided (in which sidebands on one side of the carrier region are boosted) and symmetrical (both sides boosted relative to the carrier) types have been proposed.

The result of boosting the amplitude of certain sidebands relative to the carrier is to increase the amount of phase deviation of the crossovers of magnetic information for modulation frequencies represented by these sidebands. A similar result would have been achieved by increasing the deviation for these frequencies directly in the modulator's output. In either case, the result is to increase the modulation index of the tape crossovers.

The information on the tape is no longer the same for the two methods when the carrier moves about, as occurs from the lower frequency portion of the video signal. With video pre-emphasis, the increase of modulation index for high video frequencies is independent of the position of the carrier. With RF pre-emphasis, the amount of increase depends on the carrier's position relative to the boost network and upon the slope of the network.

A brief comparison of the two methods follows with an eye towards determining which method would be most suitable in a newly recommended practice for the recording of both color and monochrome signals at a high level of performance. The assumption is made that the VTR to be used already has excellent performance characteristics in all respects except that of signal/noise ratio, and employs "straight-line" playback equalization.

Overall Noise Performance

The maximum amount of deviation of tape crossovers at high video frequencies is determined by the unavoidable spurious outputs, or moire, that will be produced by the color subcarrier on highly saturated colors. This in turn is determined by the spurious output "shelf" that has been selected, as will be explained later.

Certain monochrome test signals, such as the "multiburst" signal, produce similar amounts of spurious output to that produced by color signals, and are subject to the same limitation. The principal source of this spurious output from tape is in lower sidebands of the third harmonic of the carrier, which is generated by the tape's limiting action.

Therefore, the limits of the amount of pre-emphasis for any given modulation frequency, and consequently the signal/noise improvement at that frequency become the same for both video and RF pre-emphasis. For differences in signal/noise performance between the two, we must look at the way the amounts of pre- and de-emphasis vary with modulation frequency and with picture brightness level.

Noise versus Frequency

It is essential that RF pre-emphasis network does not significantly alter the record current characteristic in the carrier deviation region. It should boost sideband frequencies as near to the deviation region as possible, in order to achieve noise reduction for the more visible frequencies. This requires a sharp step in the network response, which is difficult to design and even more difficult to match in the playback path. In practice, not much improvement can be made in the critical 1 MHz region by this method.

There is little difficulty in designing video pre-emphasis networks to boost the region of 1 MHz and above, but limitations of another sort are encountered here. If the boost occurs at too low a frequency, the spikes and overshoots on transitions in the video signal applied to the modulator, which are a normal result of video pre-emphasis, will become relatively wide and will result in considerable carrier energy lying outside the normal deviation range. In addition, head switching transients and tape dropouts will develop long "tails" from the de-emphasis network. It has been found in practice that a time constant of 0-6 μsec in the network is a reasonable compromise. In a network in which an 8 dB boost is applied to the highest frequencies, this time constant gives a 6.7 dB boost at 1 MHz.

Noise versus Brightness Level

Practical networks for RF pre-emphasis methods result in a considerable variation in signal/noise ratio with picture brightness level, some 8 dB being reported in one case. The networks were chosen in this case so that the greatest improvement in signal/noise occurred at a grey level. It being argued that the eye's sensitivity is greatest at this level and with worsening results at white and black. It should be noted that the sync pulse and burst regions, which are used for control of timebase-correcting devices, do not get the most favorable signal/noise ratio.

Video pre-emphasis, when applied to a properly equalized VTR, particularly when using straight-line equalization, results in a nearly flat curve of noise versus brightness. Variations are typically under 1 dB.

Frequency and Transient Response

When the carrier is perfectly centered on a symmetrical RF pre-emphasis network, the boost of each sideband of a pair is equal, and we could expect the phase response to be symmetrical as well. Under these conditions a limiting action applied to the signal (as in the tape) will not alter the relative amplitude or phase of the sidebands and an exactly complementary network will return the signal to its original condition without distortion. When the carrier is located at some other position, however, the sidebands will be altered by limiting and the complementary network cannot return the signal to its original state. This effect causes a variation to occur in frequency and transient response as a function of brightness level. RF de-emphasis networks have usually been chosen on an empirical best-overall-result basis to minimize this effect.

As the effects of video pre-emphasis are not a function of carrier frequency, the networks employed here may be made exactly complementary to each other. It is a requirement that the modulator and demodulator be able to handle the increased deviation without incurring nonlinearities, in order for frequency and transient response to be unaffected.

Differential Gain and Differential Phase

Varying frequency and phase response with brightness level will show up as differential gain and differential phase when color signals are used. For the same reason as discussed above, good results with these parameters are more easily achieved with video pre-emphasis.

Moire in E-E Condition

RF pre-emphasis clearly has the advantage here because of the lower amount of deviation present in the modulator at the color subcarrier frequency.

Moire Off-Tape

As explained earlier, the modulation index of tape crossovers at the subcarrier frequency is the same for both systems. Spurious components caused by the tape's limiting action will, at least to a first approximation, be the same as well. There is some evidence that limiting an RF pre-emphasized signal will produce a greater increase of third and higher order sidebands than limiting a wave employing an equal amount of video pre-emphasis. If a frequency "shelf" is selected which permits these sidebands to be the major source of spurious interference, then lower moire off-tape should result from video pre-emphasis. Calculations indicate that for a modulation index of 0.2 and with 10 dB of pre-emphasis, third order sidebands are approximately 29 dB below the first order ones in the case of RF pre-emphasis, and 36 dB in the case of video pre-emphasis. In the same example, second order sidebands are treated nearly equally at a level of -16 dB relative to the first. Older recording systems, in which moire is caused by folded second order sidebands, would therefore be affected equally by either method.

Problems of Equipment Design

Because of the wider deviation of high frequencies with video pre-emphasis that must be handled by the modulator and demodulator, the achievement of adequate linearity in these units is more difficult. On the other hand, the design of the networks required in RF pre-emphasis is quite a problem, especially that of the de-emphasis network when attempting to minimize response variations with carrier position.

The exact specification of pre-emphasis is simpler with the video method because the networks involved are generally simple resistor-capacitor combinations which can be accurately described.

Considering all of the above comparisons between the two methods, it is apparent that the video pre-emphasis technique allows the highest performance level to be achieved and can be more accurately specified. The greater linearity requirements in modulator-demodulator design, it is felt, are well within the range of achievement with present-day techniques.

Choice of Carrier Frequencies and Deviation

There are a number of conflicting and interlocking requirements that are considered when choosing frequency and deviation parameters for color video tape recording, necessitating the making of many compromises. In order to sort the various considerations, the procedure for arriving at a set of frequencies is presented as a series of steps. It is to be expected that after going through the procedure, it will be necessary to return to some early steps and make trades of one parameter for another, to achieve a well-balanced recommended practice. The procedure is based on the use of video pre-emphasis.

1. *Determine the bandwidth required.* This is based on the requirements of the particular television standard being accommodated.

2. *Locate the null frequency for this bandwidth.* The overall video bandwidth of the system is determined by the output low-pass filter following the demodulator. Its rejection characteristics, beginning at the first null, are employed to eliminate spurious signals.

Consideration should be given here to the use of both complex and somewhat simpler filters. In a typical Bode-type design having four critical frequencies in the pass-band, the ratio of flat response: 3 dB down; first null frequencies is 1.0 : 1.875 : 1.375. This seems a reasonable minimum complexity of filter to require for a broadcast recorder. A filter with a somewhat more complex design, of course, may achieve a wider flat response with the same null frequency. An example of this is the filter employed in the Ampex VR-2000 recorder, in which the ratio of those frequencies is approximately 1.0 : 1.10 : 1.25.

3. *Select the "shelf" of operation.* It was seen that the higher order sidebands produced by heavy deviation at a single high modulating frequency (the color subcarrier frequency in our case) can produce spurious signals in the output, depending on the carrier frequency used. These spurious outputs arise from: (a) "negative" or folded frequencies due to the spacing between the sideband and the carrier being greater than the carrier's frequency and (b) lower sidebands (of the same order) of the carriers' third harmonic, resulting from limiting (as in the tape) at the carrier frequency, followed by filtering. Both sources produce the same spurious frequency and respond to moving the carrier in the same way.

When the carrier frequency is increased, the reduction of spurious outputs does not occur smoothly, but rather in discrete steps. This happens when an interfering sideband, producing a video output that increases in frequency at twice the rate that the carrier is moved upwards, moves into the rejection band of the low-pass filter. After this happens, the next higher order sideband will be the controlling factor, and since this sideband has a lower amplitude, the spurious output will be less. The "shelf" in the spurious output curve thus formed is not level since the output from a sideband is a function of its distance from the carrier. The lowest spurious level on a given shelf occurs when the rejected sideband has just passed into the rejection area.

Since the selection of a shelf determines which order of sideband will produce interference, it therefore determines the amount of deviation that will produce a given level of interference, and this deviation in turn controls the signal/noise ratio. While higher order shelves allow greater amounts of deviation, they also require higher operating frequencies. One must weigh, therefore, the effect of the generally lower efficiency of the head-to-tape process at shorter wavelengths, with resulting lower playback signal levels, against the signal/noise improvement of increased deviation.

Recording recommended practices for 525 line color recording in the past have used a second order shelf, that is, second order sidebands produce interference. To avoid impossibly large amounts of spurious moire in the picture, the amount of deviation had to be kept low, at a cost in signal/noise ratio.

Ability to operate at higher frequencies has led to the "high band" recommended practices, which are intended for both color and monochrome operation at improved levels of performance. The 625 line version employs a third-order shelf, and the 525 line "high band" standard, due to the narrower bandwidth and lower subcarrier frequency of 525 line signals, is able to use a fourth-order shelf.

4. *Determine the lowest carrier frequency permissible for this shelf.* This is calculated using the filter null frequency and the rejected subcarrier sideband. The lowest-swinging carrier frequency that can contain superimposed color information is placed at this frequency. For standard white-upwards deviation polarity, the blanking level of the signal, where the color synchronizing burst is located, is placed here.

5. *Calculate the high frequency (subcarrier) deviation which will produce the specified level of interference.* Several approaches to this calculation are possible. A conservative method is to add the contribution of the folded sideband of the carrier to the contribution of the (same order) lower sideband of the third harmonic, assuming limiting to a square wave and subsequent filtering out of the third harmonic itself. This represents a "worst case" simulation of the recording process.

6. *Decide on the amount of low frequency deviation.* If the deviation of the lower frequency (unpre-emphasized) portion of the signal is too large, differential gain and differential phase effects, particularly in playback, will be difficult to minimize. Too small a deviation will result in excessive sensitivity to tape dropouts and switching transients and in poor low frequency signal/noise ratio. A compromise is definitely required here. Experience has shown that a ratio of about 8 dB between high and low frequency deviation is practical. This results in low frequency deviation from blanking to white of the order of 1½ to 2 MHz in high-band practice.

7. *Select the pre-emphasis time constant.* With the ratio between deviation at low frequencies and

at the subcarrier frequency previously determined, the time constant of the video pre-emphasis network will determine the slope of the curve. A short time constant produces a sloping curve throughout the video band and minimizes the "tails" on transients. A larger time constant gives a curve that climbs quickly at relatively low and mid-frequencies and levels out at high. It will give a better weighted signal/noise ratio due to lower playback gain in the more visible frequencies. Recent choices have tended in this direction. As mentioned earlier, a time constant of 0.6 μsec has been found to be feasible.

The Playback System

The magnetic flux recorded on the tape induces a voltage in each video head as it traverses the tape during PLAY mode. This output of each head is coupled through a rotary transformer and preamplifier to its associated playback amplifier, which also provides equalization of the signal response.

Following additional amplification, the individual channels are sequentially gated by a switcher to re-form a continuous FM signal. Switching from the output of one head to that of its successor is performed during the blanking interval. In modern equipment this switching is performed on the front porch of horizontal blanking, and is triggered by a front porch switching pulse derived within the switcher. The re-formed FM signal from the output of the switcher is de-emphasized, limited in the demodulator to remove unwanted amplitude modulation, and demodulated to the form of the original composite video signal by the demodulator.

Demodulators

The most common method of demodulating utilizes the pulse count principle. There are several approaches to providing constant width pulses. Two commonly used methods are with delay lines or the use of a one shot multivibrator, to convert the FM modulated signal into its video component. The reflection of the delay line, or precisely calibrated length, provides a round-trip period for the incoming pulses, generating fixed width pulses whose repetition rate carries the wanted video intelligence. The one-shot multivibrator system varies only in that a trigger for the multivibrator is used to generate the fixed width pulse. In the case of the delay line, pulses are rectified and applied to an integrating filter. In both cases the filter attenuates the carrier and multiple carrier components and yields the video signal ready for processing. Limiters are necessary to accommodate variations in signal amplitude from the video head (Fig. 59).

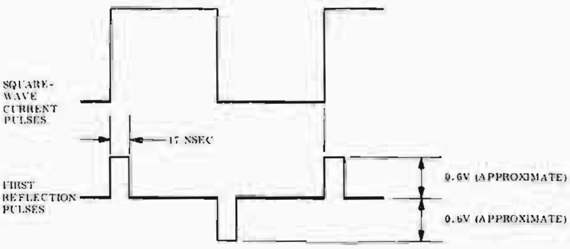


Fig. 59. Waveform of delay line constant with pulse generation.

Time Element Compensation (Amtec)

The Time Element Compensation provides for line-by-line compensation of timing errors in the composite video signal by sampling the timing accuracy of the signal once each 4 times 63.5 μsec, relative to a stable time reference. In normal operation, an internal AFC controlled oscillator is used as the reference signal. When the intersync servo system is in use, external station sync is applied. The instantaneous time difference between the sampled and reference signals is converted to a proportional voltage which in turn controls the delay time of a voltage controlled delay line in the video signal path (Fig. 60). The unit is normally inserted between the demodulator output and the processing amplifier input of the video tape recorder. The line-by-line time element compensation eliminates picture geometric distortion problems, such as skewing, scalloping, quadrature, single band essing and waterfall effects, as well as extends the tolerance from effects at physical splice points with different tapes from different sources that have minor guide block alignment differences. Time Element Compensation was not intended to eliminate the need of vacuum guide block alignment and careful attention should always be given to assure that proper guide block alignment is accomplished at the outset of all video tape recordings. The uncorrected composite video signal is shown

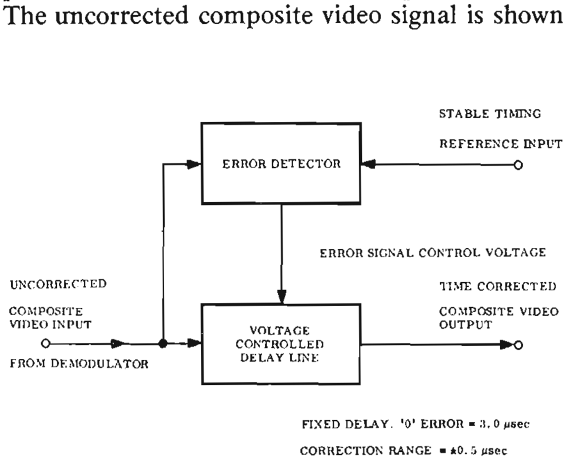


Fig. 60. Block diagram of geometric time base corrector.

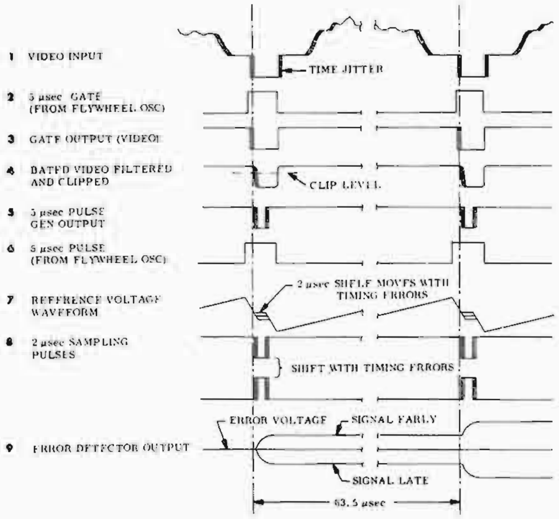


Fig. 61. Amtec waveform timing diagram.

in Fig. 61, the waveform timing diagram. The noncorrected composite video signal from the demodulator passes through a voltage controlled delay line. The noncorrected incoming sync information is routed to the error detector (Waveform 5) where it is time compared with a stable timing reference signal (Waveform 7).

The error detector produces a bias voltage that is approximately proportional to the fourth power of the timing difference between the compared signals (Waveform 9). This bias voltage becomes a control voltage that is applied to the voltage controlled delay line, causing the latter to insert a varying delay affecting the lines of video information and partially correcting the horizontal sync pulses. The inserted delay is the precise opposite of the original timing error in the reproduced signal and thus causes error cancellation. The time corrected composite video signal is then delivered to the processor.

Fig. 62 shows the functional diagram. The error detector is primarily concerned with the time (or leading) edge of the horizontal sync pulses contained in the incoming composite video signal. For this reason the horizontal sync pulses are clamped to a reference voltage and routed to a 5 μsec gate (Waveform 2) while enroute to the error detector. The gate allows approximately the last 0.75 μsec at the front porch and approximately 4.25 μsec of the sync pulse to pass (Waveform 3) to the 2 μsec pulse generator.

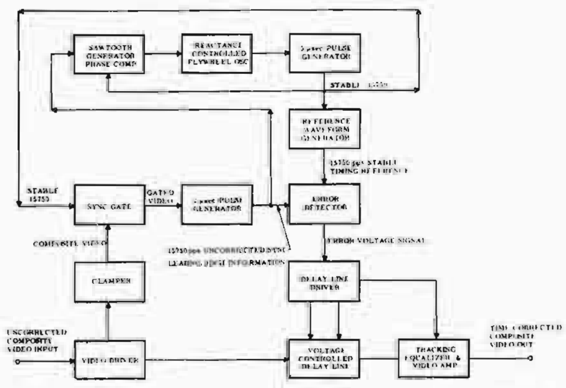


Fig. 62. Time element compensator functional block diagram.

The pulse generator produces a rectangular pulse of 2 μsec duration (Waveform 5). It is formed by the leading edge of the sync pulse and the output is therefore timed by sync. This is the signal that the error detector time compares with a stable timing reference for the derivation of the error (or bias) voltage.

The error voltage is developed during the interval of each pulse, at the horizontal rate, and is the bias that is ultimately applied to the voltage controlled delay line. During the interval between sampling pulses, the bias voltage is held constant by the charge on a capacitor. In this way the line of picture information following each sync pulse is held at the corrected time until the next sampling pulse occurs (Waveform 9). No additional sampling or correction takes place during the visible portion of the picture.

During the "picture straightening" mode the error signal contains only the ac, or high rate-of-change timing error information. The dc or low rate-of-change components are not required for the correction of picture geometry.

As previously stated, the timing coincidence gate and relay driver receive the noncorrected incoming horizontal sync information from the sampler/driver. It also receives the *long-term average* of the rate of incoming horizontal sync from the 5 μsec pulse generator. When the two signals are in coincidence, the timing coincidence gate and relay driver energize the relay. Under this condition the connected circuit time constant will be the one selected by the manual switch position, and the correction rate will be either "normal" or "fast." The timing coincidence gate also recognizes the condition of noncoincidence of the two signals by causing the relay driver output to fall to the minimum, deenergizing the relay. This causes the insertion of the "very fast" time constant correction rate in the circuit, and disables the gate.

The 5 μsec time averaged pulse (Waveform 2) is routed through a switch to the reference waveform generator whose action was described above. The shaped sawtooth (Waveform 7) is routed to the error detector, where it is phase compared with the 2 μsec noncorrected sync pulse sample (Waveform 8). It is here that the primary error signal is derived, that ultimately biases the voltage controlled delay line (Waveform 9).

The output from the error detector is routed to the control voltage amplifier (Board 5) which provides push-pull outputs. This output is applied to the control voltage driver on Board 4. The signal is then routed to a voltage controlled delay line. The delay line is controlled by the error bias from the error detector which is amplified by the control voltage amplifier and control voltage driver. This output from the control voltage driver is applied to silicon junction capacitors that serve as the delay control elements. The total delay is 3 μsec, variable through a range of approximately ±20 percent.

The driver amplifier causes the error bias to vary approximately as the fourth power at the output voltage from the error detector. At the output from the driver amplifier, the error bias is converted to a control voltage whose amplitude overcomes the nonlinear characteristic of the voltage controlled delay line, and whose polarity precisely coincides with that of the error detector output.

The video bandpass characteristics of the voltage controlled delay line vary with changes in delay and must be compensated. The tracking equalizer provides the required compensation. Its balanced input is connected to the push-pull bias voltage output from the control voltage driver, and its single-ended input is received from the output of the voltage controlled delay line.

The tracking equalizer exhibits variable response characteristics that are the mirror image of those exhibited by the delay line, and thus cause the overall bandpass of AMTEC to be flat to 6.0 MHz/sec throughout its range. This signal passes through the video output stage to the phase comparator from which it is routed to the processor in the videotape television recorder system.

During the Inter-sync mode, the pulse advancer produces a 5 μsec pulse that is derived from the leading edge of reference sync, but is advanced in time, by the same interval, that tape read-out is advanced by the action of Inter-sync. This pulse is applied to the reference waveform generator, and replaces the *long-term average* sync pulse that is used during the picture straightening mode. Under either mode the gate driver (and the gate) continue under the control at the 5 μsec long-term average at the rate of incoming horizontal sync. The output of the reference waveform generator is used to correct the sync timing errors contained in the incoming video signal, but corrects them to coincide with the external reference instead of the long-term average of incoming horizontal sync.

The reproduced picture elements must remain stable with respect to the corresponding picture elements of another video signal during the "Inter-sync" mode. Under these conditions, the reproduced signal is time compared with an external timing reference instead of with an average of the horizontal sync contained in the uncorrected composite video. The external timing reference is normally the local station sync generator.

Overall System Description

Fig. 63 shows the System Block Diagram. The incoming noncorrected composite video signal from the demodulator is routed to the video amplifier, which adjusts the signal level and impedance to the requirements of the voltage controlled delay line.

The signal is also routed by two converging paths through a clamped video stage to the sync gate. By the way of the first path, the signal passes through a video amplifier to the clamped stage. By the second path horizontal sync is stripped from the composite video signal and passed to the clamp pulse generator which produces push-pull clamp pulses that are applied to the clamped stage.

The 5 μsec pulse generator (horizontal rate) controls the action of the sync gate, which allows a 5 μsec sample of the noncorrected sync pulse, and its timing edge, to pass through the low-pass filter and a clipper stage en route to the 2 μsec pulse generator whose output is formed by the sample.

The 2 μsec (non-time corrected) pulse is routed to one input of the error detector and to the reference waveform generator. The latter generates a stable sawtooth waveform at the average horizontal rate, and adds the voltage received in the 2 μsec pulse to form a 2 μsec step on the slope (Waveform 7). Because the peak-to-peak descending slope time is 5 μsec, the 2 μsec step appears at a higher voltage level when the pulse is early, than when it is late.

The noncorrected 2 μsec pulse is also routed to the sampler/driver. The latter provides two out-

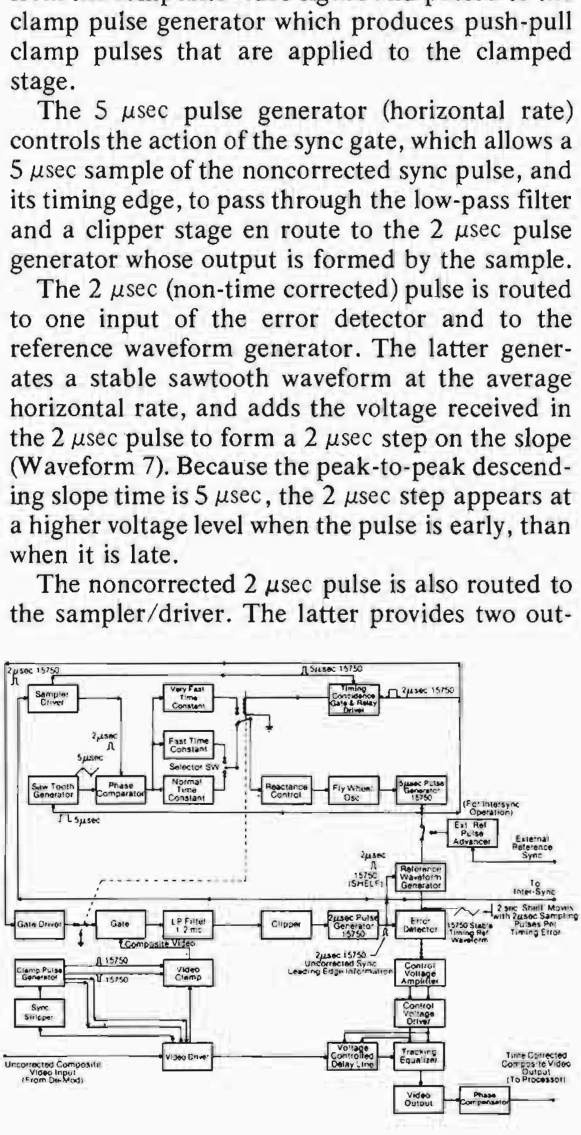


Fig. 63. Amtec system block diagram.

puts, one of which is routed to the timing coincidence gate and relay driver, the other to the phase comparator. The latter also receives a 5 μsec sawtooth waveform from the sawtooth generator which is triggered by the signal from the 5 μsec pulse generator. This signal is the long-term average of the rate of incoming horizontal sync, and is established in the reactance-controlled flywheel oscillator loop. The resulting phase comparator output voltage is routed to the inputs of 3 selectable time constant circuits, that are graded "normal," "fast," and "very fast." Manual switch selection offers the choice between "normal," and "fast;" supplementary relay switch selection adds the choice of "very fast" to the particular time constant selected by the manual switch position. One of the time constants is always in the circuit, and modifies the comparator output to the reactance control circuit of the flywheel oscillator.

The filtering action of the time constant circuits eliminates high rate-of-change components in the reactance control voltage, which causes the oscillator to remain locked in frequency and phase to the long-term average of the incoming horizontal sync rate. Because the output of the 5 μsec pulse generator is formed from the output of the flywheel oscillator, the pulse is timed at the long-term average rate.

Direct Color Recovery Process

The chrominance portion of the NTSC color television signal is modulated on a 3.579545 MHz subcarrier that has a frequency tolerance of ±10 Hz, a maximum rate-of-change of 0.1 Hz, and a phase tolerance of ±10 electrical degrees.

Analysis of these factors, together with the standard (nominal) relative head-to-tape velocity of 1,500 ips used in the television recorder/reproducer, will show that during reproduction the equivalent instantaneous position of the video heads relative to the tape must be maintained within ±11.7 microinches of their equivalent instantaneous positions during the making of the recording.

The first step toward this precision of head phase control is taken by Inter-sync which can achieve an accuracy of ±150 microinches. The second step is taken by Amtec, which can achieve an equivalent accuracy of ±75 microinches. The direct color process reduces the residual error to an equivalent time error of 0.005 μsec (5.0 nanoseconds) or less.

The recovery of color signals from magnetic tape began with typical timing errors of 10 μsec, and an equivalent head position error of 0.015 in. The reproduced chrominance signal required separate processing to stabilize the subcarrier.

While domestic color receivers could reproduce color pictures from the signal, certain of the principal properties of NTSC color were lost. For example, there was no frame interlace of luminance with chrominance components, and instead of the use of a band sharing principle, it was necessary to assign the lower part of the band to luminance, and the upper to chrominance information.

Colortec takes over in the reduction of head-to-tape timing errors where the successive processes of Intersync and Amtec terminate. While the circuit of Colortec bears some resemblance to that of Amtec, there are important and significant differences.

Colortec uses an electronically controlled variable delay line, as does Amtec, but its control signal is the result of phase comparison of the reproduced 3.58 MHz color burst with the 3.58 MHz reference subcarrier. The video input signal is received from the Amtec output which may typically contain residual timing errors of 0.05 μsec referred to the subcarrier. This is equivalent to a head position error of approximately 75 microinches.

Occasional reference to the accompanying block diagrams, Figs. 65, 66, and 67 will be an aid to clarification of the discussion of the Colortec Direct Color Process that follows.

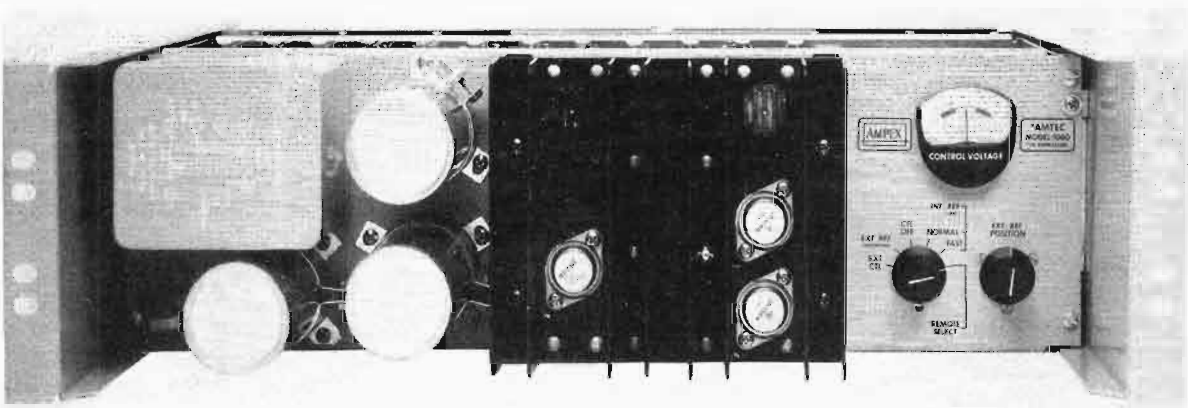


Fig. 64. Amtec time element compensator.

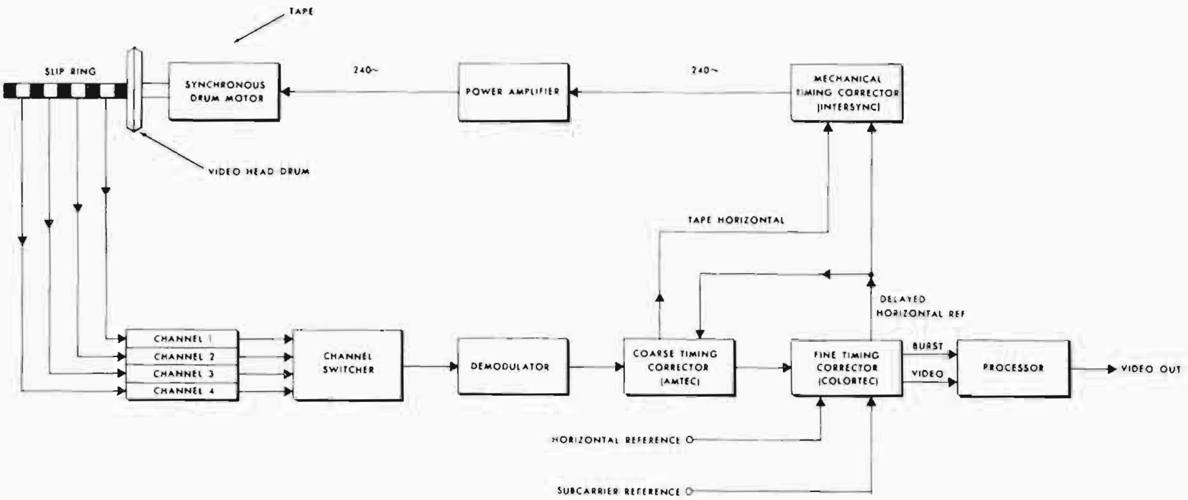


Fig. 65. Simplified reproduce mode.

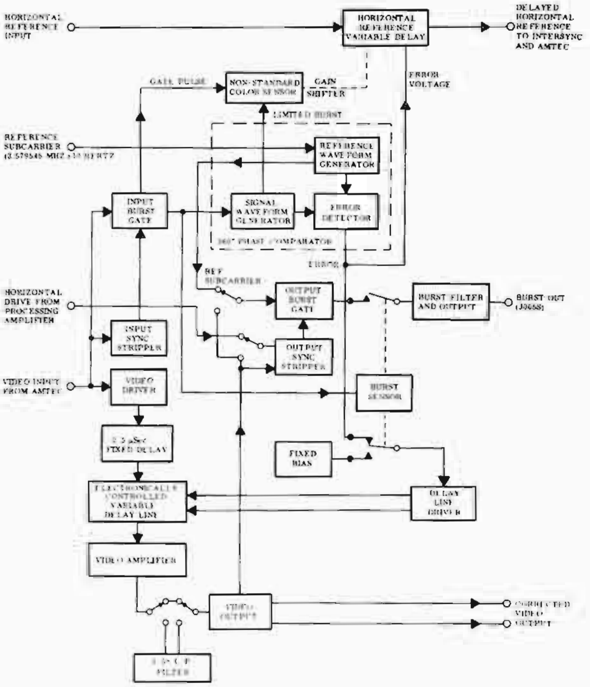


Fig. 66. Colortec simplified block diagram.

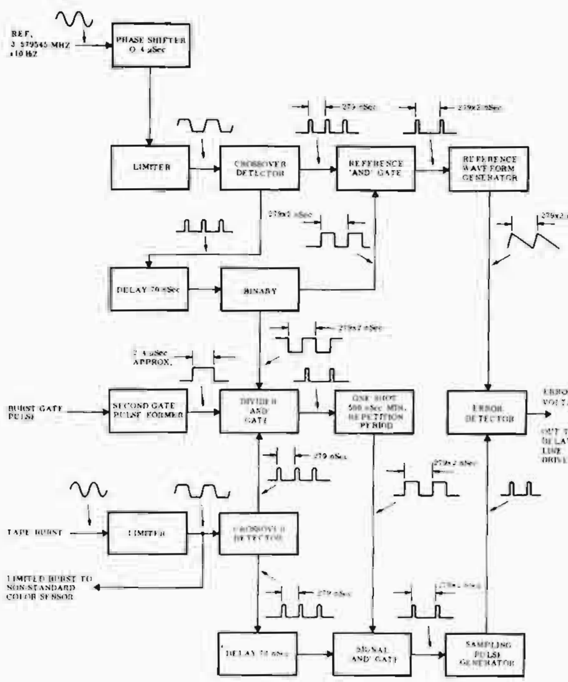


Fig. 67. 360° phase comparator.

Horizontal sync is stripped from the reproduced composite video color signal, and its trailing edge used as the timing reference for the operation of the burst gate. The burst gating pulse begins 0.5 μsec following the trailing edge of sync and has a duration of 2.4 μsec. Thus, the burst gate allows only the burst portion of the blanking interval to pass through to the signal waveform generator. The latter produces pulses from the negative-going crossovers of reproduced burst. The repetition rate of the pulses from the output of the signal waveform generator is one-half the burst frequency. These pulses are applied to one input of the error detector.

The 3.579545 MHz ($\pm$10 Hz) reference subcarrier signal is applied to the reference waveform generator, which produces a linear sawtooth waveform that is in-phase with the reference, but whose repetition rate is one-half of its frequency. This sawtooth is applied to the second input of the error detector.

The pulses received from the signal waveform generator sample the slope of the sawtooth signal received from the reference waveform generator, thus deriving an error voltage whose amplitude is proportional to the phase difference of the compared signals.

This phase comparison is repeated during each burst period; the successive error voltages thus derived are maintained until the next burst interval occurs. The error signal output therefore has continuity, but is corrected during each successive burst interval.

The error detector functions as a 360° comparator, referring to Fig. 68. This unusual attribute is made possible by causing the reference sawtooth waveform to occur at one-half the subcarrier rate, which in turn permits the occurrence of two crossover pulses during one reference waveform period. Binary logic insures that the selected sampling pulses are within the limits of the reference sawtooth slope.

By virtue of this sampling range, the comparator action permits stabilization of chrominance in the reproduced color signal despite the presence of system mechanical timing errors that exceed the correction range of Amtec. Thus, the corrected video signal that appears at the output of Colortec is held in phase with the reference, and home receiver will not lose color lock during the passage of a tape splice, vertical roll, or a large timing error, such as those that might be present in a non-standard color signal.

Following push-pull amplification by the delay line driver, the error output signals are applied to the + and − inputs of the electronically controlled variable delay line.

The video input signal, from Amtec, is also applied to the video driver which in turn drives the 2.4 μsec fixed delay line. This fixed delay permits reproduced burst to be phase-corrected by the control voltage that is derived from its phase comparison with the reference. The output of the fixed delay line is applied to the remaining input of the electronically controlled variable delay line, where the final time correction required by the direct color process is made.

Following amplification by the video amplifier, the time-corrected video signal is normally routed directly to the Colortec output stage. However, a 3.58 MHz low pass filter may be inserted by means of a switch if a nonstandard color signal departs beyond the corrective capability of the system. This filter removes all color subcarrier components from the color signal.

Because the processing amplifier removes burst from the back porch of sync, it is necessary to reinsert burst in its composite video output. Colortec provides for this by stripping burst from its corrected video output by means of a process that is identical with that applied initially to incoming video. This recovered burst is filtered to remove some of the unwanted noise, and remains fully representative of the original recorded burst in terms of amplitude and phase. It is this reconstituted burst that is routed to the processing amplifier.

If preferred, Colortec also offers the alternative of inserting totally new burst that is derived from the reference subcarrier. This new burst will contain less residual noise, and have a more symmetrical form but may not be truly representative of the original tape signal-to-burst relationship.

The incoming horizontal reference signal is applied to one input of the horizontal reference variable delay; the control voltage applied to the other input is the previously mentioned error signal derived by the error detector which controls the delay of the output sync. Delayed horizontal reference sync is routed to and used to govern the Intersync and Amtec units in the television recorder system.

Delayed horizontal reference sync makes it possible to operate the electronically controlled variable delay line near the middle of its range. The delayed sync, delays the timing of the video signal received to Colortec, and tends to maintain midrange operation regardless of the phase relationship of subcarrier-to-sync.

The scanning frequency of the NTSC color signal is 2/455 of the burst frequency. The record/reproduce systems that preceded NTSC color could not preserve this relationship, which resulted in timing difference between reproduced burst and reproduced sync amounting to as much as ±20μsec.

In order to reproduce such nonstandard color signals, the horizontal reference timing of Colortec is switched to another mode wherein feedback gain is increased, the normal reference horizontal delay is changed from 2.5 μsec to 30 μsec, and the higher frequency components of the timing error are allowed to modify the reference timing. These modifications of playback mode permit the successful reproduction of second generation nonstandard color recordings that meet the rate-of-change of sync specified by the FCC for monochrome signals.

In the automatic modes Colortec senses the type of video signal that is present, i.e., whether it is monochrome, standard NTSC color, or nonstandard color.

When a monochrome signal is present, a fixed voltage is applied to the electronically controlled variable signal delay line, and Colortec then functions as a unity gain amplifier.

The incoming 3.579545 MHz (±10 Hz) subcarrier is routed through a variable phase shifter, a limiter, and to a crossover detector. The latter passes only the negative-going axis crossovers of the subcarrier, resulting in a train of pulses whose leading edges are spaced at 279 nanosecond intervals.

The crossover detector output is routed by two paths. By one path it is applied to an input of the reference AND gate; by the other it is routed

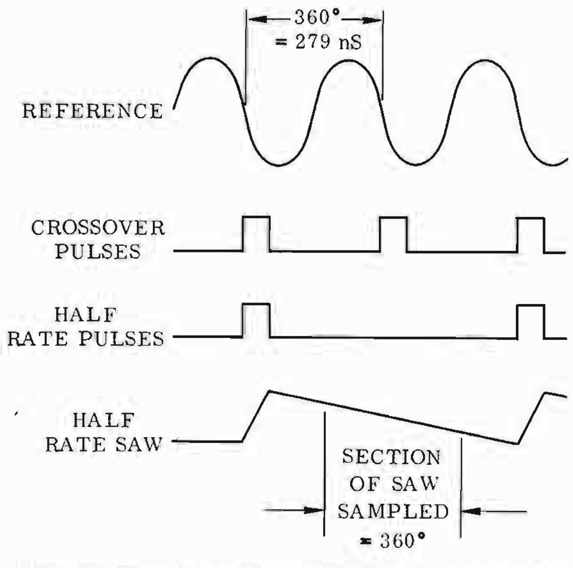


Fig. 68. Waveform diagram half-rate 360° comparator.

through a 70 nanosecond delay and then to a binary frequency divider.

The binary output is a symmetrical square wave whose repetition rate is one-half that of the subcarrier. Thus its leading edges are separated in time by 558 nanoseconds (279 nanoseconds x 2). This output is applied to the other input of the reference AND gate, and to the divider AND gate. The reference AND gate opens only when there is coincidence of the gating pulses from the crossover detector with the square wave from the binary. Its output is thus a series of pulses whose leading edges are separated in time by 558 nanoseconds, and whose widths are those of the gating pulses from the crossover detector.

The reference AND gate output pulses are applied to the reference waveform generator, which forms them into a linear sawtooth waveform whose wavelength is 558 nanoseconds. This sawtooth is applied to one input of the error detector.

Burst gated from the tape video signal is filtered, limited, and applied to a second crossover detector. The output of the latter is a series of pulses whose leading edges are separated in time by 279 nanoseconds. These pulses are routed through a 70 nanoseconds delay to the signal AND gate.

The crossover detector output is also routed to the divider AND gate. The divider AND gate requires the coincidence of three signals to open. The third signal is the burst gate pulse which is shaped to a pulse of 2.4 μsec duration by the second gate pulse former.

The output of the divider AND gate is a series of pulses whose leading edges are separated 558 nanoseconds in time, and which continue to occur for a 2.4 μsec period. These pulses trigger a 500 nanoseconds (minimum repetition period) one-shot multivibrator whose output is a series of 200 nanoseconds, pulses whose leading edges occur 558 nanoseconds apart.

Automatic Chroma Control

Automatic chroma provides for automatic playback equalization, functions more rapidly and accurately than can be performed manually, and eliminates the need for constant operator attention during playback.

Color saturation errors can occur in several forms: there are fixed saturation errors, differential gain, and nonuniformity of chroma level within a head band during playback due to variation in head-to-tape contact pressure.

The autochroma functions by measuring the amplitude of the color burst from a given head channel, and electronically adjusting the playback equalization of that channel to provide compensation. This is accomplished simultaneously and continuously over all four channels, controlling the response to provide a constant burst level in the signal output and ultimately therefore a constant chroma level. Additional manual adjustment is provided to compensate for cases where the ratio of burst to picture chroma was recorded incorrectly.

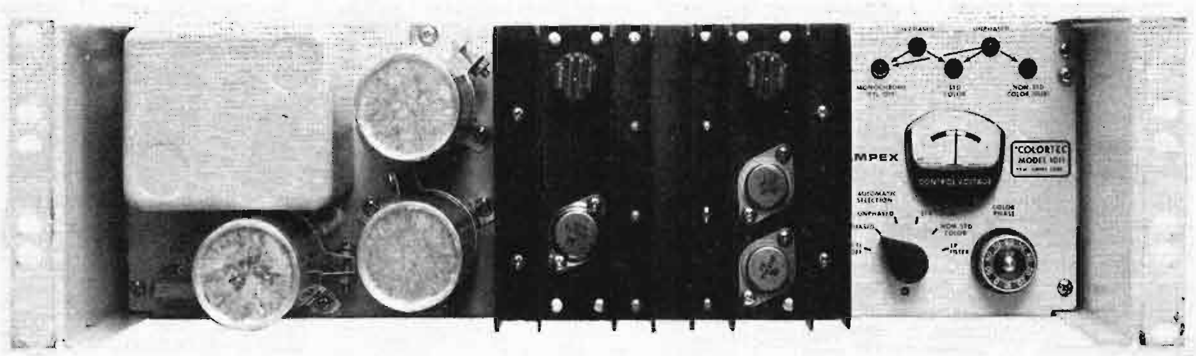


Fig. 69. Colortec.

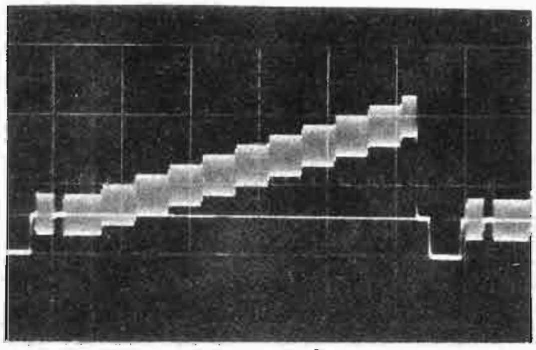


Fig. 70A. Differential gain test signal.

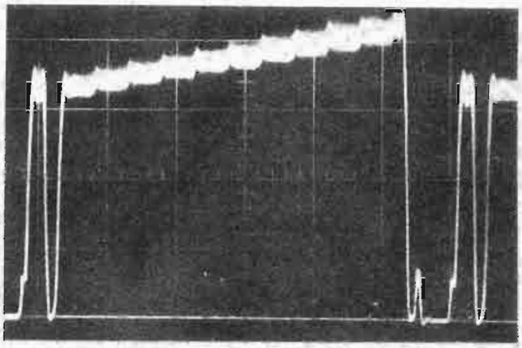


Fig. 71A. Off-tape, differential gain present.

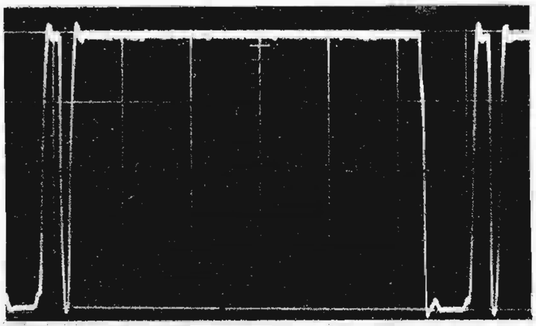


Fig. 70B. Detected subcarrier of test signal.

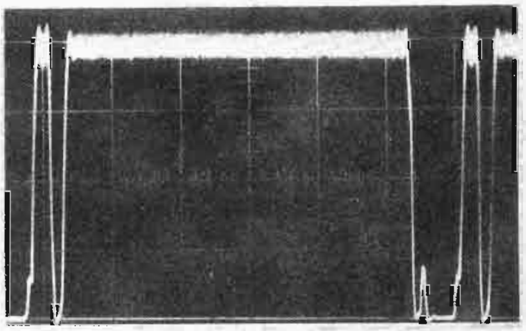


Fig. 71B. Off-tape, correctly adjusted.

Differential gain, or the dependency of chroma gain upon luminance level, could be caused by deficiencies in the modulator, demodulator, and various amplifiers in the video signal path. Fortunately, improvements in design with transistor circuitry have largely eliminated this problem. A far more important cause of differential gain is in the incorrect equalization of playback response. There are usually several combinations of settings of the various playback equalizing adjustment that will result in an apparently correct chroma level, but not all of these combinations will give a constant chroma gain throughout the brightness range. It is important that the adjustment settings providing the lowest differential gain be obtained.

The simplest and most accurate way to determine these settings involves the recording of a standard stairstep-plus-subcarrier test signal such as is shown in Figs. 70A and 70B. Deviation is adjusted so that the steps without subcarrier cover the full range of blanking to white. The subcarrier level is then made to be approximately equal to the standard burst level. On playback, the signal is fed first to a low pass filter to remove all but subcarrier components, followed by a detector, where the output is observed on an oscilloscope synchronized at horizontal rate.

The playback equalizers are adjusted for a flat waveform whose height is equal to that produced by the signal before recording, as in Fig. 71A and 71B. If differences between head channels are seen, the head resonance compensating controls may be adjusted slightly to trim out the differences. It should be kept in mind that the adjustments described are primarily to deal with effects in the playback machine itself. Any properly optimized recording should produce identical results, and therefore it is not required to repeat this test more frequently than on a routine maintenance basis, preferably when heads are optimized and resonance compensation is checked.

Automatic Velocity Compensation

The velocity compensator, in conjunction with the Colortec and Amtec, compensates for minor variances in head-to-tape velocity during playback of tapes and enhances to a large degree interchangeability by eliminating color hue shift banding effects. The automatic velocity compensator's function is to make corrections in the output signal of the VTR playback which corrects for the effects of minor difference of vertical guide block alignment, small differences in radius of the guide, differences in the contour of the guide as a result of accumulation of oxide particles, and to some degree in the amount of guide vacuum. Velocity error is a result of differences between the relative head-to-tape velocity during record

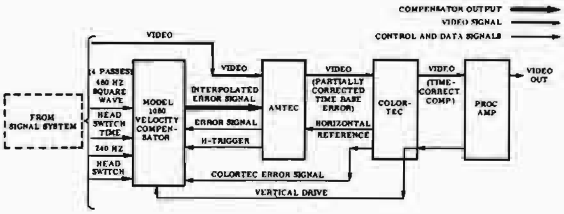


Fig. 72. Overall system functional block diagram.

and that during playback. Excessive velocity error results in a noticeable shift of hue progressing from left to right in the picture. The overall system functional diagram is shown in Fig. 72.

The compensation process adds a corrective velocity-error component to the Amtec waveform. However, the video signal is not affected since it does not pass through the compensator.

One complete rotation of the head drum covers 64 horizontal video lines, with each of the four heads covering 16 lines during its excursion across the tape. The velocity compensator is based on the assumption that the velocity error in each line is generally repetitive during successive head rotations.

The Amtec and Colortec accessories supply the compensator with time-base error indications (as voltage levels) for each line of video. The compensator algebraically adds these error indications, then stores each sum in a specific memory capacitor as a voltage level.

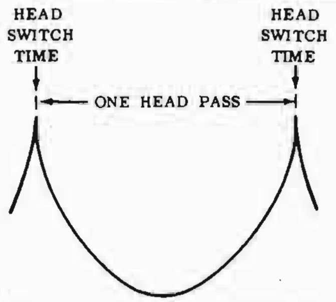
Capacitor loading proceeds repetitively for 500 μsec, building up in each capacitor a voltage level analogous to the time-base error changes occurring throughout write time. For readout, the stored voltage levels are sequentially timed into a temporary storage capacitor, which then drives a ramp generator. The generator provides a ramp proportionate to the voltage level previously stored in the capacitors.

The proportionate ramp is added to the Amtec error signal and returned to the Amtec delay line, which then provides a corrected velocity error signal to the Colortec accessory. The final Colortec output is then a time-corrected, composite video signal which is applied to the processing amplifier.

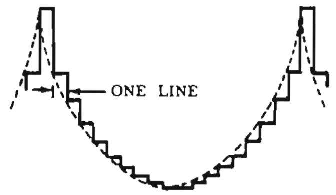
Because the proportionate ramp must begin as the Amtec starts to process a line of video, a horizontal (h) trigger signal is brought into the velocity compensator. Eight other signals are also supplied to the velocity compensator from external sources. The processing amplifier supplies one, a vertical signal which is extended and then used to inhibit the write function of the compensator during the vertical interval.

The seven other signals are parts of the head decoder timing: a 480 hertz square wave from the signal system and four 240 pulse-per-second signals from the signal system (tach, tach +90°, inverted tach, and inverted tach +90°). The signal system also provides head-switching time and head-switching information for the line-decoding function of the velocity compensator.

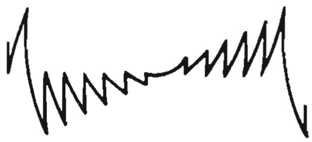
Fig. 73 shows a representation of the actual time-base error caused by guide-height misadjustment (Detail A) during one head pass, the line-by-line correction waveform of the Amtec and Colortec (Detail B), and algebraic resultant of these waveforms (Detail C). Ideally, these signals should cancel; however, since the Amtec and Colortec correct on a line-by-line basis, and not continuously, an error component is still left. This residual error component is velocity error.



Detail A. Actual Time-base Error Waveform (Error caused by misadjustment of vaccum guide height)

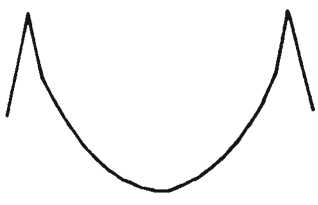


Detail B. Combined Amtec and Colortec Error Waveforms showing line-by-line correction



Detail C. Velocity error component remaining (A - B)

Detail D. Simulated velocity error signal generated by velocity compensator



Detail E. Output of velocity compensator (D + B)

Fig. 73. Derivation of Amtec delay line driving signal.

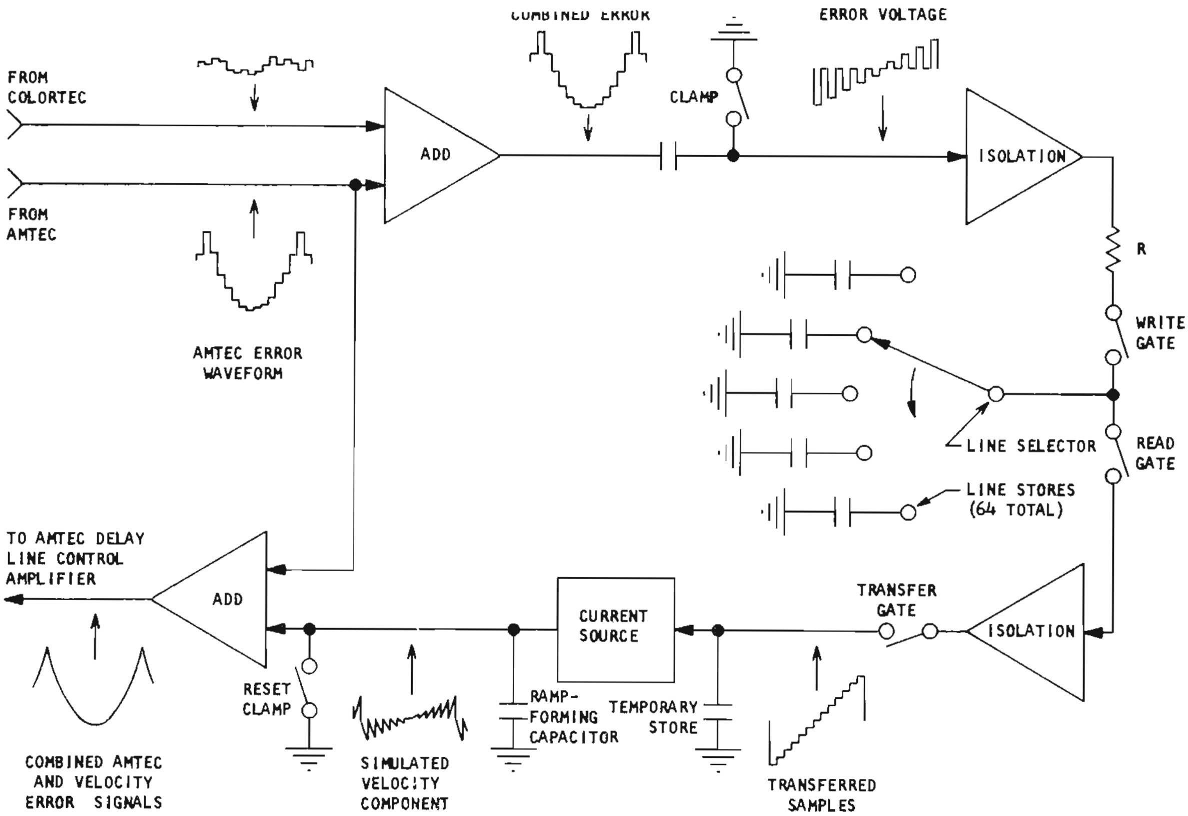


Fig. 74. Basic block diagram—velocity compensator.

The velocity compensator generates a simulated velocity error waveform (Detail D), and adds it to the actual Amtec error waveform. When algebraically added, these signals result in an error signal which very closely approximates the actual error waveform (Detail E). This signal is used to drive the delay lines in the Amtec accessory, and allows the Amtec to pass on a video signal virtually free of geometric and velocity errors. The basic block diagram of the velocity compensator is shown in Fig. 74.

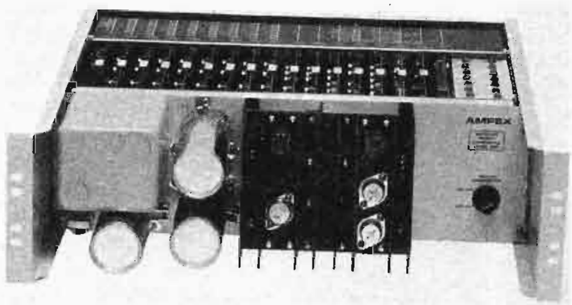


Fig. 75. Automatic velocity compensator.

Video Processing Amplifier

The processing amplifier provides for seven operating controls as shown in Fig. 76.

The primary purpose of the processing amplifier is that of providing a noise-free composite video output signal that is suitable for broadcast purposes. This purpose is accomplished by two principal groups of functions. The first group includes those common to the requirements of monochrome or color operation; the second group includes those specifically required for color operation.

In the first group, the processing amplifier clips noise and switching transients from incoming sync, reshapes the pulse form, and recombines it with video and blanking to produce a composite video signal of broadcast quality. If noise content is excessive or pulse width is incorrect, the operator has the option of replacing incoming horizontal sync with new sync generated within the unit.

The processing amplifier derives and provides switching pulses which cause video head switch-

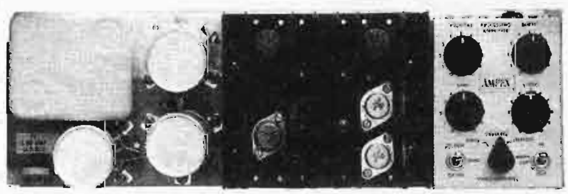


Fig. 76. Processing amplifier.

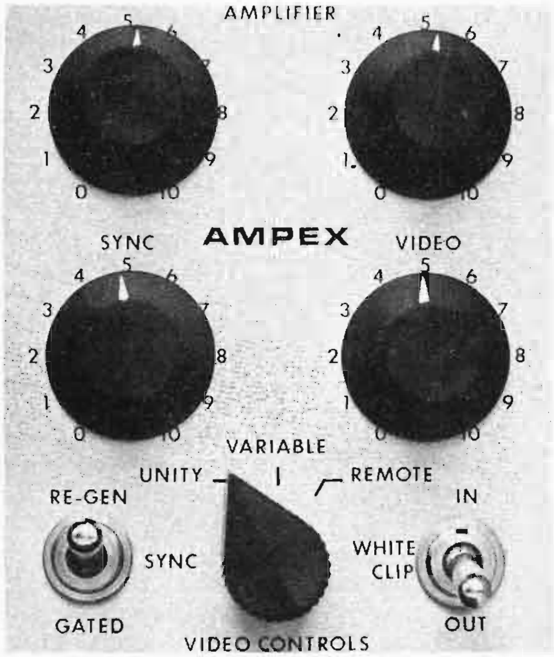


Fig. 77. Processing amplifier control panel.

ing to take place on the front porch of sync, thus avoiding any ambiguity in the timing edge of horizontal sync.

During monochrome operation the processing amplifier limits noise to a fixed level in the video portion of the signal by preventing negative noise peaks from extending below the blanking level. During color operation the signal is similarly processed, but the 3.58 MHz burst frequency, on the back porch of sync, is allowed to pass without change.

The processing amplifier eliminates all noise that occurs during the vertical and horizontal blanking intervals.

The video, blanking, and sync levels controlled by the processing amplifier are adjustable at the unit, or from a remote location.

In the second group, for color operation, the processing amplifier places color burst on the back porch of sync. In the Colortec-equipped system, the operator has the choice of retaining the original burst, or of replacing it with new burst derived from the 3.58 MHz reference, and provisions are made for a vertical drive signal required to operate the burst gate in the Colortec unit.

SIGNAL DROPOUT COMPENSATION[3]

Physical Nature of Dropouts

The discussion of full-color substitution starts properly with an analysis of what a dropout actually is. When a particle in the videotape coating interferes with head-to-tape contact, or a void exists in the oxide due to a scratch, a reduction in the recorded or reproduced signal can be caused. As a result, the normally constant FM signal used for video recording becomes amplitude modulated to a degree which depends on the signal loss produced by the particle or scratch. When this degree of amplitude modulation cannot be accommodated by the playback limiter circuits of a recorder, a momentary streak appears in the reproduced picture.

Most dropouts caused by scratches result from handling at the user level and produce diagonally organized groups on the television screen. Multiple-generation tape copies contain defects originated in previous recordings and thus multiply the incidence of visible dropouts.

High-band recording, by its very nature, increases the incidence of dropouts over that for low-band operation. Over half of the recorded energy is in the first 1/10 wavelength of penetration into the recording medium. Since the wavelength is shorter in high-band recording, the energy is closer to the surface of the tape and therefore the recording is more susceptible to the surface contamination effects which produce dropout.

Dropout streaks in a reproduced picture may be either light or dark, or any color, depending on the exact transient nature of the video signal as well as other instantaneous machine factors. Furthermore, should defects occur during the period of video clamping or color burst, polarity of the resulting effect becomes unpredictable.

In general, dropouts are most annoying when they appear as bright streaks on a predominantly dark or low-key background. It should be kept in mind that more defects may be apparent to the viewer's eye as picture composition varies, even

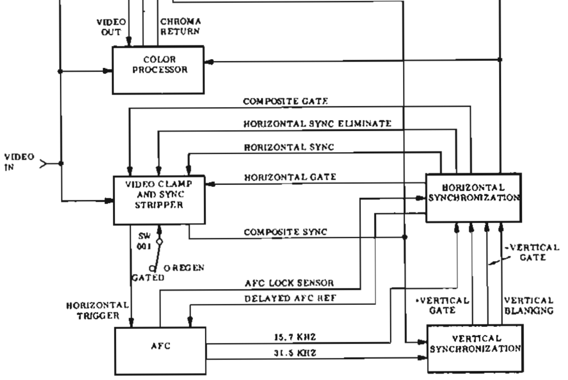


Fig. 78. Processing amplifier, simplified block diagram.

[3]The following material is from "Dropout Compensation for High-Band Color" by Fred J. Hodge, Video Projects Manager, Mincom Div., 3M Co., Camarillo; in Broadcast Engineering Feb. 1968.

though tape quality and machine constants remain unchanged.

Electrical Nature of Dropouts

A signal dropout in a video recording system consists of an abrupt negative amplitude-modulated notch in the carrier. The effectiveness of limiter circuitry in the demodulator can have marked effects on how clearly this AM component is reproduced through the FM system.

An examination of the playback carrier prior to its introduction into the limiter stages discloses that, with most samples of tape, the signal contains an entire family of dropouts of different amplitudes and durations. The change in amplitude of the carrier during these momentary events may range from a reduction of only a few percentage to a complete failure. A majority of these dropouts are never seen, as their effects are absorbed by the action of the limiters in the demodulator.

Head wear or circuit changes can cause partial loss of total limiting gain. If this occurs, an increasing number of the carrier depressions reach the discriminator and become visible on the television screen. Furthermore, improper transient response in the RF amplifying system can exaggerate the durations and amplitudes of the carrier dropouts, making their effects more pronounced.

Excessive noise also can reduce dropout immunity, since the carrier cannot be recovered by the limiter when momentarily reduced to a value less than the noise level.

Use of Redundant Signal

The principle of redundancy was applied to a standard video recorder system to compensate for the visual effects of signal dropouts. In this system, an artificial and essentially redundant signal was obtained through a delay line of requisite signal characteristics and a time delay corresponding to one television line (approximately 63.5 μsec). This selection was based on the following factors:

1. The inherently high redundancy existing between signal profiles in most time-adjacent line periods (two successive lines as displayed on a kinescope screen) comprising a television signal.
2. General inability to detect minor geometric distortions of pictorial detail which exist for short time durations.
3. The increasing availability of economically feasible delay devices of requisite bandwidths and duration.

Ideally, the one-line delay system for compensator use should retard the television signal 63.5 μsec (63.55 μsec for color) and display a conventional video frequency response and rise time. A full-bandwidth system was developed and evaluated, but until the new generation of high-band color video tape recorders became popular, a 63.5 μsec delay line with a frequency response of 500 kHz was used to store the highly redundant components of the video and sync signals.

Full-Color Compensation

To obtain accurate color replacement information, it is necessary to overcome three basic problems: (1) time-base stability of 4° phase, or about three nanoseconds; (2) differential phase and gain of 3° and 3%; and (3) allowance must be made for dot interlace of the 3.58 MHz chroma subcarrier information.

There are several ways to produce delayed substitution material for dropout compensation, and a number of circuit variations have been tested. All involve detection of the signal defect in the radio-frequency portion of a magnetic video recorder; they differ as to the location in the playback circuit where information is stored and re-inserted, and as to the sequence and duration of these insertion periods.

FM Compensation

One possible method employs an FM dropout compensator in which detection and substitution are accomplished in the RF signal portion of the reproduce electronics. In such a system, the FM signal is delayed and used directly for substitution. This is the simplest method for wideband monochrome information since the FM carrier can be transmitted directly through a high-frequency glass or quartz ultransonic delay line. However, FM substitution in the RF signal produces the same sort of discontinuity as an FM head-switch transient at the beginning and end of the dropout pulse, due to the introduction of a considerable phase discontinuity. This method cannot properly compensate the first and last portion of the dropout.

Video Compensation'

In a second basic system, the principal delay and switching operations are accomplished in the video-signal portion of the recorder/playback system, after demodulation of the RF carrier. This usually is called a video-substitution compensator. It has the advantage that the inherent delay of the filter and demodulator can be used to insure that the dropout substitution starts before the actual disturbance. Video switching can also be done with no transients, and the fill-in match in luminance and chrominance can be made nearly perfect.

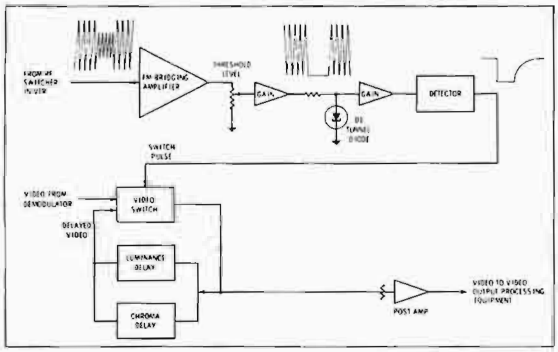


Fig. 79. Dropout compensator routes luminance, chrominance through separate delay lines, also uses demodulator delay.

Color Video Compensator Design

A block diagram of a complete compensator is shown in Fig. 79. The detector actually is a double-acting device. First, a constant-current source applies the RF signal to the level-detector stage, tunnel diode D1. The RF drive causes D1 to change state on the peaks of the RF pulses, resulting in a square wave. The threshold-level control adjusts the gain of the amplifier stages to determine the lowest RF level which will cause D1 to fire. The square wave from the dropout detector is used to reset repeatedly a ramp generator. If the generator is not reset (as is the case if loss of RF interrupts the square wave output from D1), the ramp continues to rise and eventually triggers the dropout pulse generator. This double process correlates the depth and duration of the RF amplitude disturbance for faster and more accurate dropout detection.

The delay caused by the ramp generator is just long enough to permit the activation of dropout substitution before the beginning of the dropout, which occurs in the video at a time delayed from the FM by the demodulator and filter in the recorder.

A detector timing adjustment controls the time lapse between loss of RF and dropout pulse generation. This adjustment is set to delay triggering just long enough so that the detector

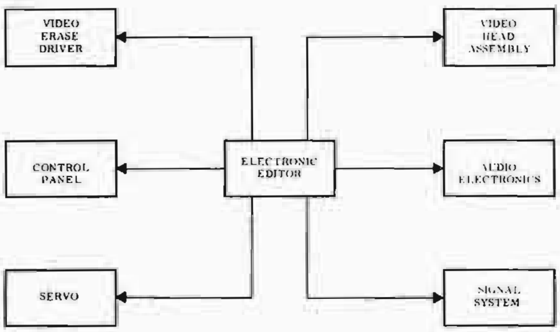


Fig. 80. Recorder system block diagram.

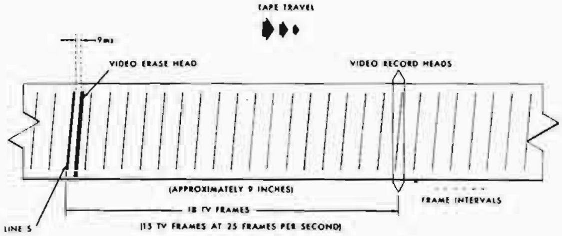


Fig. 81. Head separation measurement.

ignores spikes in the RF caused by such defects as noise and pre-emphasis in the video-recorder system for black-to-white transition.

The pulse circuitry extends the dropout signal for a short duration in case any limiter disturbance follows the dropout interval. The negative-going dropout pulse is routed to the video switch. The video switch is placed in the output of the recorder demodulator after filtering but before any sync separation or signal division. If this cannot be done, separate dropout protection must be devised for tape signal paths not routed through the switch.

The heart of the storage system is a pair of special glass memories. One of the two glass memories is designed to handle the 3.58 MHz chrominance information directly. It provides necessary response plus freedom from spurious reflections over the chroma bandwidth of 2 MHz to 4.2 MHz, as required for NTSC color. The other memory delays the luminance information at a carrier frequency of 10 MHz.

Adequate sync and blanking response to preserve timing relationships is the criterion for the luminance-channel response. Above 2.5 MHz, all energy must be removed from the luminance signal processed by the color channel. Otherwise, edge interference between the phase-corrected color and the luminance is apparent in the delay material.

The chroma signals (2.3 to 4.2 MHz) can be delayed directly. The total delay time for the chroma signal is trimmed by a variable delay line. Incorrect total delay time of the chroma signal shows as a change in the hue of the fill-in material. The chroma signal, inverted 180° in phase, is added to the delayed luminance signal

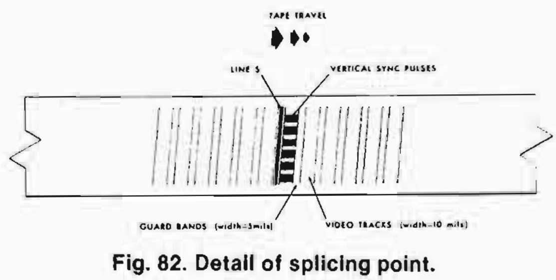


Fig. 82. Detail of splicing point.

and applied to the delayed-video input of the video switch.

System Performance

A properly designed and operated dropout compensator detects and compensates not only the gross dropouts producing the high-contrast flashes, but also the dropouts of lesser amplitude that appear in high-saturation color signals due to changes in recorder equalization. The speed of switching action is such that the switching transients are past the response limits of standard television systems. These factors, together with the relatively wide-bandwidth luminance and full-bandwidth color fill-in material, produce a system that makes it virtually impossible to see compensated dropouts on a random basis. In addition, full compensation during the sync interval eliminates time-correction errors and servo instability caused by dropouts. When such compensation is achieved, useful tape life is extended and program quality is improved.

Electronic Video Tape Editing

The electronic editor provides a sure and convenient method of editing television tape recordings without physically cutting the tape. The editor makes it possible to start and stop the recording system at any time for costume or scenery changes, insertion of commercials or new scenes, correction of production errors, or assembly of a single tape from many separate segments. The extreme difficulty of maintaining frame sync and control track signal continuity required something more than the operator's greatest skill and care together with the most ingenious splicing equipment available. This problem is eliminated by the electronic editor which permits the editing of tape with complete continuity of signals and without physically cutting and splicing. Original tape segments are not disturbed in any way during the electronic splicing process and may be reused many times. The entire splicing procedure is accomplished with the tape in motion at normal speed.

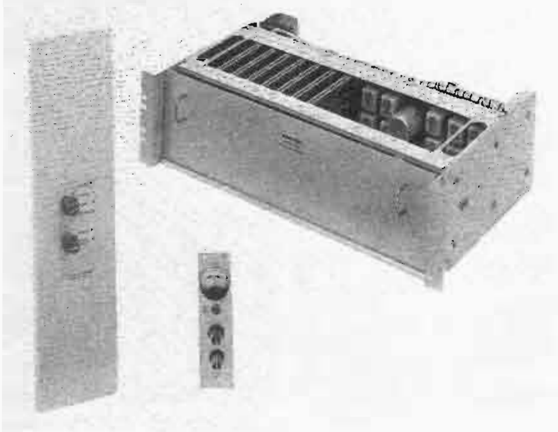


Fig. 83. Electronic editor.

The electronic editor accomplishes this by modifying and controlling signals from the various systems and subsystems of the recorder (see Fig. 80). It eliminates disturbances that arise from the cut and splice process, and, by controlling the Intersync servos, maintains the correct phase relationship between the master tape signals and the incoming new video signal. The finished splice appears the same as a change in picture content caused by camera switching.

In addition, the editor automatically makes allowance for the distance between the planes of the erase head gap and video heads by precisely synchronizing the application of erase current and video record signals. This permits the first new frame of an insertion to follow its immediate predecessor on the tape and maintains the complete continuity of video, blanking, and synchronizing signals.

The distance between the erase head gap and the video heads may be considered equivalent to time. The time value of this distance is that interval required for the tape to travel from the erase head to the video heads at the primary nominal rate of 15 ips tape speed (the tape space occupied by approximately 18 television frames). Fig. 81 illustrates the physical relationship between the erase head and the video heads. The line "S" marks the point on the tape where the insert splice will be made and where the erasure must start.

The electronic editor establishes the position of line "S" by means of a gating circuit that is triggered by the first frame pulse that follows the initiation of a random cue signal for the insertion. Line "S" is within the guard band immediately following the recorded video track that includes the vertical synchronizing pulses (Fig. 82). Since there are two groups of vertical sync pulses per frame, it follows that the correct group must be chosen to precede erasure turn-on. This is established by a framing pulse from the control track.

The electronic editor control panel (Fig. 83) has two controls that provide the operator with a choice of any four operating combinations. The selector on the right is a four-position switch from which normal, insert, assemble, or remote modes may be chosen. In Normal the editor is removed from the recorder system. With the selector set at Insert, the editor is programmed for an insert recording. When the selector is at Assemble, the editor is programmed for an assembly of prerecorded material. With the selector set at REMOTE, the editor modes may be selected by a remotely mounted editor control panel. The selector on the left is a two-position switch which provides a choice between audio-video and video. With the selector at audio-video, both audio and video are recorded. When the selector is at video, only video is recorded.

During either operating mode, the time-controlled sequential switching of erase current and video signal is initiated by pressing the Record pushbutton, producing the ingoing electronic splice. When an insertion is made, it must be terminated at a particular time, which requires a second, or outgoing splice, initiated by pressing the Stop pushbutton. The electronic editor switches off the incoming video information and the erase current on an automatically controlled time schedule that is the opposite of the ingoing splice time schedule. Both splices are timed and controlled by the editor electronics and the editor accessory panel, as shown in Fig. 83.

Editing—Time Element Control (EDITEC)

The Editec system (Time Element Control) allows for programming of the electronic editor in a wide variety of television production situations, editing, tape positioning, and provides for timing facilities by providing automatic control in editing and related studio equipment. Programs may be assembled, on a scene-by-scene basis, into a first generation master edited tape. The scenes may be recorded in any order that is convenient to the scheduling of personnel, artists, or equipment. The beginning and end of each scene can be precisely located by Editec to a one-frame accuracy, and each scene may be lengthened or shortened as required, by one or more frames. The effect of any particular splice may be previewed on the monitor before the splice is made. A scene may be inserted into an existing tape for correction or other reasons. The beginning and end of the new scenes may be precisely located, adjusted and previewed on a one-frame accuracy basis. Where performer, lighting, camera, or technical and production errors occur in a scene being inserted into a video tape, the action may be repeated as often as required and re-inserted into the video tape. The Editec control allows new scenes to be spliced in at exactly the same frame on every "take." Audio splicing as well is accomplished in time synchronism with the video splicing. The frame-by-frame accuracy allows for precision splicing of prerecorded music on the audio track with respect to video splices made to the rhythm of music.

Time base errors at splices are automatically reduced to less than a microsecond providing "jitterless splicing" or "picture whips" in the finished program. Edit points may be accurately spaced and as close together as desired relieving restriction on the frequency in the number of edits and at intervals of one frame and up. This provides for animation and allows the video recorder to automatically record any preselected number of frames onto the end of a previous recording. Edit points may be adjusted forward and backwards as required, down to one frame increments. The Editec Program Unit is shown in Fig. 84.

Video tape life is extended by means of a nonscratch erase head mechanism and special control of the tape vacuum guide, allowing rehearsal of edit points several times without damage to the master video tape. The erase head mechanism is shown in Fig. 87.

The primary function of Editec is to provide control signals that start and stop the electronic editor at the precise time a new scene is to begin and end on the program master tape. These control signals are derived from cue tones that are recorded on the cue track of the program tape. The cue tones used differ only in their frequency. One of them serves as the remote cue signal which controls remote equipment, e.g., a second television recorder; the other is the edit cue signal which controls the editing operation.

The Editec operator prepares the program master tape in advance of actual shooting, by marking an edit cue at the beginning of each successive scene as timed by the script, or a separate scene timing schedule. In some cases, this is accomplished by simultaneously recording a continuous control track signal for the full dura-

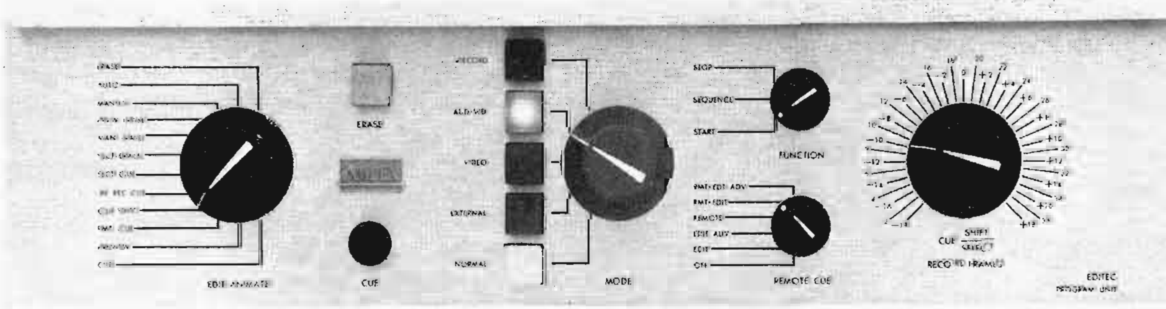


Fig. 84. Editec program unit.

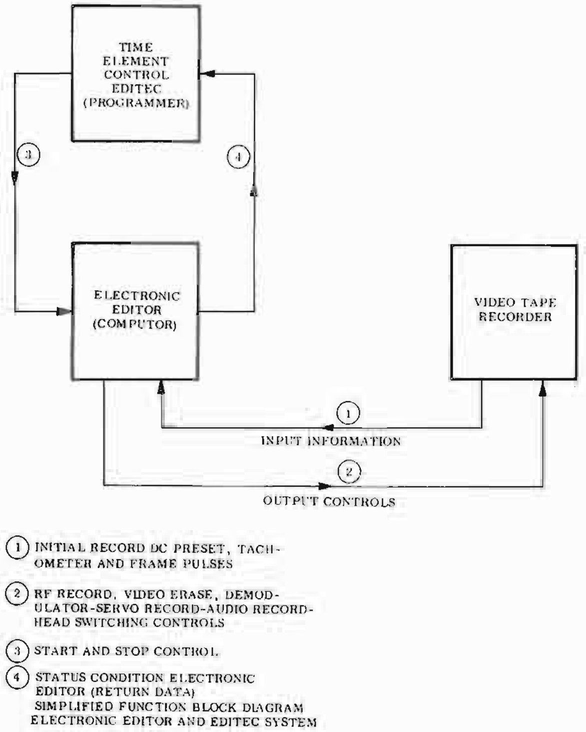


Fig. 85. Functional electronic editing system.

tion of the projected program. If external equipment is to be turned on at a desired time, the operator records a remote cue for each such occasion.

All functional elements of the basis electronic editing system are shown in Fig. 85. The connections through the demodulator relay and the record driver gates are made through electromechanical relays in the basic system. The basic system includes the electronic editor, the erase switch, the RF switch, and Intersync.

The Inter-Sync controls rotation of the recorder head drum to synchronize recording and playback with external reference signals. During play operation of the recorder, with Intersync set for automatic mode, reproduced vertical and horizontal sync are compared with reference vertical and horizontal sync signals. A position error output proportional to the phase error between these signals is generated. The position error output is applied to the head drum drive system, causing the head drum to rotate faster or slower to reduce the phase error, synchronizing the signals. When the recorder is switched to record operation, the reproduced signals are, of course, not available for synchronization. Instead, the tachometer sync signal produced by the rotary head assembly is compared with reference vertical

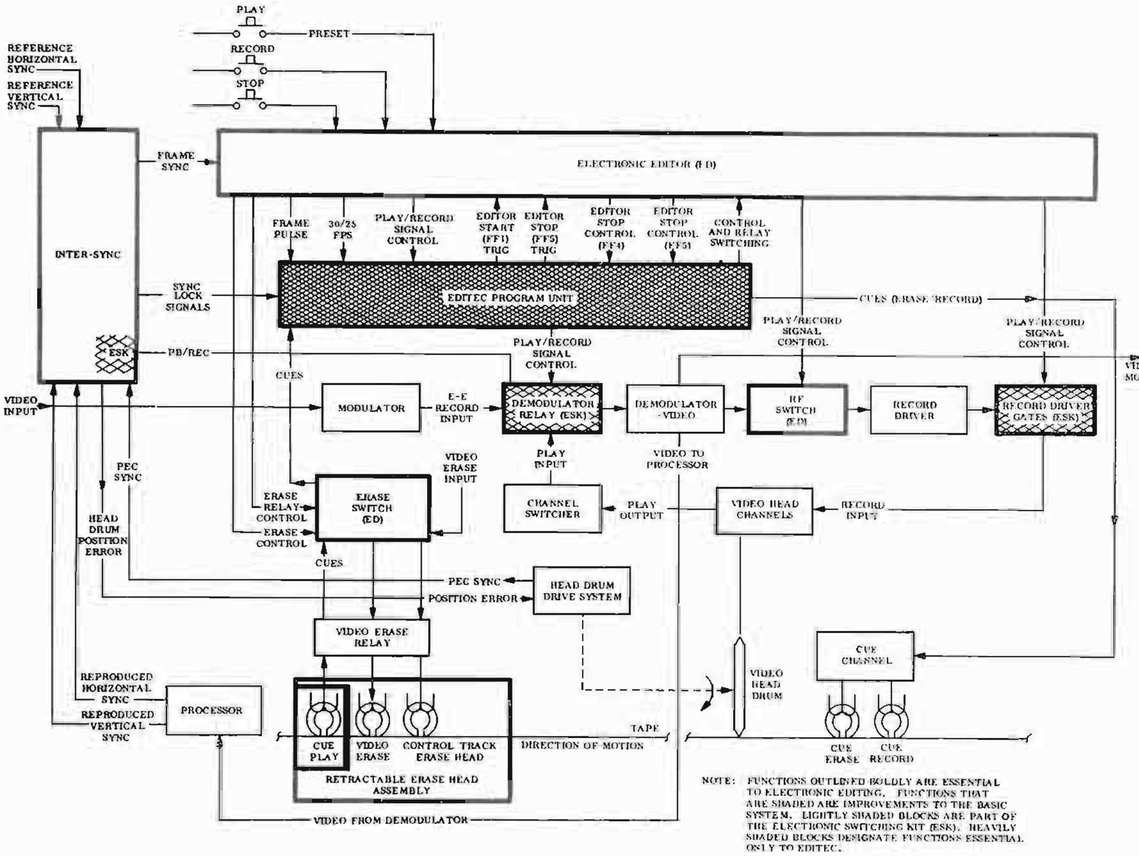


Fig. 86. Editec—controlled editing system, simplified diagram.

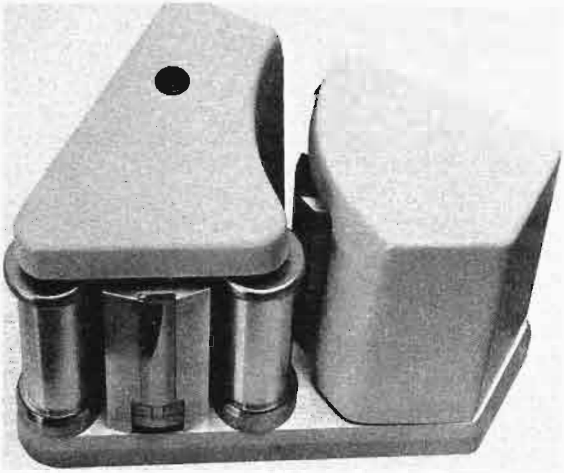


Fig. 87. Back of tape erase head showing cue playback head mechanism.

sync. The position error output produced by Intersync in this mode is used to place recorded vertical sync information at the precise center of the video tape.

The electronic editor times the making of an electronic splice so that there is no blank tape and no overlapping of recordings. This is accomplished in assemble or insert mode. During normal mode, all recorder functions operate normally, bypassing the control afforded by the electronic editor. The editor makes an electronic splice as follows:

1. The recorder is first started in play mode, which presets the timing and logic circuits of the editor. During this mode, the signals being played from tape are taken from the video heads on the head drum, preamplified in the video head channels, combined in the channel switcher, connected to the demodulator, demodulated, and displayed on the external monitor.

2. At the desired point, the splice is initiated by depressing the record pushbutton. This allows the video erase, RF record, Inter-Sync, and audio erase to be programmed by the electronic editor logic. In addition, a pulse is generated which initiates the editor programming cycle. Inter-Sync places vertical sync in the center of the tape and the play/record relay connects the outputs of the record driver to the video heads on the head drum.

3. After a brief settling period that allows the first transverse track of the next frame to move into position for erasure, the editor turns-on the erase switch. If insert mode is being used, erase energy is not switched to the control track erase head by the video erase relay. In assemble mode, the control track is erased.

4. Coincidentally with the start of erasure, the editor starts counting frame pulses received from Intersync. At the count of 18 frames, the editor turns on the RF switch, audio record, and the Intersync is switched to the record mode. This connects the new video information to the record drivers coincidentally with video head scanning of the first transverse track that was erased 18 frames earlier and also switches the modulator E-E output to the demodulator, causing the record input to be displayed on the monitor. Because Intersync position error signals keep recorded frame sync centered on the tape, the first and subsequent vertical (frame) sync pulses are lined up with the sync pulses on the previous section of the recording.

5. Recording is terminated by depressing the stop pushbutton. At the correct instant, when a complete frame has been erased, the editor turns off the erase switch, stopping erasure of the video track. At the count of 18 frames, the editor turns off the RF switch, stopping the recording of new video information on the tape. The editor turns off audio erase and record signals. Two seconds later the recorder has stopped completely.

Electronic switching of Intersync from play to record concurrently with the start of the electronic "splice" improves continuity of recorded sync. When Intersync is kept operating in automatic mode until the precise instant of the "splice," the higher sample rate of this mode reduces drift from synchronism with the reference signals almost to the vanishing point. As a result, the maximum discontinuity between the sync of the last frame preceding the "splice" and the first frame of the "spliced-in" recording is 0.2 μsec.

Editec System Functions

Cue recording and playback is the key to the functioning of the Editec system. Edit cues recorded on the audio 2 track of the tape are used to represent splices. Once recorded, edit cues have a fixed physical relationship to the splices they represent. From the reference thus established, the responses to the cues or the cues themselves can be shifted in a controlled manner, frame-by-frame, to improve placement of the splice. The reproduced edit cues are used to trigger recorder switchover from play to record or vice versa.

There are two types of cues, edit and remote. The edit cues are bursts of 4 kHz audio signal; the remote cues are bursts of 1 kHz audio signal. Both are recorded on the same track. The remote cues are also used for programming but, unlike the edit cues, they trigger the turn-on of external equipment.

When the mode switch on the Editec program unit is set at any position but normal, turning Editec on, a relay makes circuit changes in the cue channel. This relay disconnects some normal control functions and causes the cue record/play head to operate only as a record head. Each cue, whether edit or remote, is recorded individually by actuating the cue button on the program unit front panel.

Cues are thus recorded on the tape by a head that is about 18 frames "downstream" from the video heads on the head drum. The cue play head used by the Editec system is mounted on the retractable erase head assembly. This head is about 23 frames "upstream" from the video heads. Thus, when Editec is on, cues are recorded at their usual position on the tape but are reproduced 41 frames earlier. This is necessary in order that the reproduced cue signal may precede the arrival of the splice point on the tape at the plane of the video heads. It also allows the 3/5 second lead time that is required for the electronic editor to turn-on and make the "splice" at the splice point. In addition, this lead of reproduced cues with respect to recorded cues permits shifting the time position at which a reproduced cue will act, on a calibrated basis. As shown in Fig. 88, there is actually more than a second of tape movement time at 15 ips between the positions of the cue playback head and the cue record head, 41 frames at 30 fps. Cue recordings and cue responses are timed by Editec logic in response to frame pulses that are received from Inter-Sync via the electronic editor.

Editec starts the editing process by applying a start trigger to the electronic editor in response to a reproduced edit cue. After a brief, timed delay, the editor turns-on video erase energy through the agency of the erase switch and starts counting frame pulses toward the scheduled turn-on of video record energy. At the count of 18, the editor triggers record-on output voltages from Editec to the demodulator relay. The demodulator relay switches from play to record, disconnecting the playback signal from the monitor and connecting the incoming record signal to the monitor. These same control voltages are routed through the demodulator delay to Inter-Sync, which they also switch from play to record operation. At the same time, other control voltages from the electronic editor switch the RF switch and the record driver gates to record operation. All of these editor-controlled operations act to connect record energy to the video heads on the head drum.

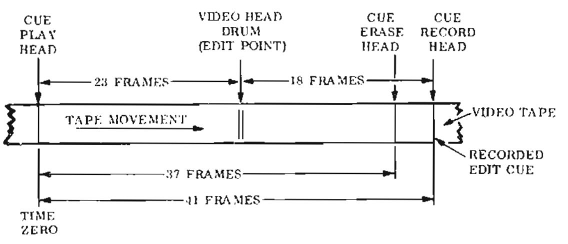


Fig. 88. Physical relationship of cue record, reproduce, erase and the video heads.

The electronic editor continues erasing and recording the video tracks on the tape until it receives a stop trigger from Editec. After a brief, timed delay, the editor turns-off erase energy and starts counting frames to the scheduled turn-off of record energy. At the count of 19, the editor turns off video record energy and switches the demodulator relay from record to play operation via Editec. This stops recording and switches the playback signal to the monitor. Intersync is also switched back to play mode.

Control of Recording and Rehearsal

To permit rehearsal of a program tape without actually recording it, overriding control of recording is given to the operator. When the mode switch on the program unit control panel is set at Record in auto or manual mode, or when the Record button on the recorder is actuated after the recorder has started in play mode, the record relay in the system control unit is energized. Splices are then recorded in response to reproduced edit cues.

Although final signal switchover from play to record is accomplished electronically when a splice is made, the record relay retains a power switching function that gives it control over whether the tape is actually erased and recorded to make a splice. The result is a rehearsal for any pass of the tape during which the record relay is not energized. During a rehearsal, the monitor is switched between the play and record inputs in response to edit cues. Except that splices are not actually made, the system operates exactly as it would if splices were being made.

Editec exchanges several other control functions with the electronic editor and with the control circuits of the recorder. One of these is the play bus which is received from the recorder circuits. Others are the rewind and stop functions, commanded from Editec during the programming of various phases of recorder operation. The details of these control functions are described later in this section. When Editec and the electronic editor are set for normal operation, control of the recorder reverts entirely to its normal control circuits.

Editec Operating Modes

The Editec has 11 basic modes of operation which are divided into two main categories, the cue record modes and the cue response modes.

There are three cue record modes used exclusively for recording edit or remote cues.

1. *Preview mode.* The purposes provided by the preview mode are varied. In some applications, such as the replacement of a commercial, it is usual to retain the display of the tape playback in

order to establish the precise placement of the edit cues that mark its beginning and its end. Under other circumstances, preview mode permits marking the exact point at which a recorded scene is to be terminated and followed by a new scene supplied by the camera. The edit cue recorded to mark the end of the recorded scene causes the picture monitor to be switched synchronously to the new scene from the camera, thus presenting a preview of the transition to the new scene. Such a preview may show that the cue should be placed earlier or later to locate the transition correctly. The judgment concerning the necessary shift of the cue position can be noted for use at the time the new scene is recorded.

2. *Remote cue mode.* Essentially the remote cue mode is the edit cue recording function of the preview mode, except that the function translator applies a 1 kHz control signal to a cue burst oscillator. The only function accomplished in the remote cue mode is the recording of remote cues on the cue track (audio 2 track) of the tape.

3. *Preview and erase mode.* This mode is the same as the preview mode, but with the added feature that all previously recorded remote and edit cues are erased before new edit cues are recorded.

There are eight cue response modes in which Editec responds to cue information recorded on the tape.

4. *Cue mode.* In the cue mode new edit cues may be recorded as described in the Preview Mode, but without previewing. In addition, previously recorded edit and remote cues are reproduced and used to initiate various control functions internal and external to the Editec system. All of the cues recorded on the cue track (audio track 2) of the tape are reproduced by the cue playback head on the erase head assembly as shown in Figs. 86 and 87. The output from the cue playback head is amplified by a preamplifier and the output of the preamplifier is applied simultaneously to the inputs of a 1 kHz and 4 kHz bandpass filter. Each of these filters reject all frequencies that are not within its passband. Thus, the output of the 4 kHz filter includes only reproduced 4 kHz edit cue signal bursts and the output of the 1 kHz filter includes only reproduced 1 kHz remote cue signal bursts.

Rejection of noise on the edit cue signal line is accomplished in cue mode and in all other modes by two methods. The first is filtering, which also separates the remote and edit cues. The second is integration, which rejects noise pulses of brief duration that may happen to pass the 4 kHz filter. The filtered reproduced signals are applied to individual r-c time constants that establish a specific runup time for the edit cue signal to reach the amplitude that is required to trigger the cue pulse generator, which is a Schmitt trigger. Thus, the triggering signal must be of the correct frequency to pass through the 4 kHz filter and must have a specific minimum duration in order to reach the level required to trigger the cue pulse generator. This prevents triggering of the cue pulse generator and subsequent Editec logic circuits by random noise.

5. *Cue shift mode.* The cue shift mode is used when the time location on the tape of a recorded edit cue is not to be disturbed but its action is to take place earlier or later. Reproduced edit cues follow the previously described cue mode path through the preamplifier, 4 kHz filter and logic circuitry. Because the time at which the reproduced edit cue takes effect is to be other than its recorded time position, the logic circuitry is linked to a matrix gate by which its action is determined by the setting of the front panel record frame selector. This switch may be set at any number of frames from minus 18 to plus 18 with respect to the exact recorded edit cue.

When the record frames selector is set at zero (mid-range), the matrix gate produces an output at the count of 19. This is the same count that is programmed into the programmed gate, as in the cue mode just described, and thus at this setting both gates produce an output simultaneously, resulting in no cue shift.

If the Record Frames selector is set at some minus number of frames, the matrix gate will produce an output at an earlier time than the programmed gate.

For example, if the selector is set at -3, the matrix gate will produce an output at the count of 16 (19-3) frame pulses (or 15 frames). If the setting is +4, the matrix gate will produce an output at the count of 23 (19 + 4) frame pulses (or 22 frames). From this point on, cue shift mode essentially parallels the processes of the cue mode.

6. *Rerecord cue mode.* Rerecord cue mode parallels cue shift mode in shifting the time at which a recorded edit cue will act. However, in rerecord cue position of the Edit-Animate selector, the cue originally recorded is erased and rerecorded at a new time position on the tape. As in cue shift mode, the cue to be given special treatment is selected by actuating the cue button just before that cue reaches the cue reproduce head.

Recording the original cue at a new position eliminates the necessity of keeping a cue sheet that shows the position of each edit cue. Since cues are rerecorded where they will act, there is no need to keep a record of cue shifts for one or more of the cues.

Extension of cue shift range by rerecording of cues can be used to extend the range of the cue shift dial, permitting the movement of a given cue any distance on the tape. For example, if cue placement is in error by 24 frames, the cue can be shifted only 18 frames using cue shift mode. In rerecord cue mode, the cue can be shifted 18 frames with one pass of the tape and another six frames with another pass of the tape.

The use of frame cutting (flash cuts or quick cuts) technique requires the recording of an edit cue to mark the beginning of a tape segment on which are to be recorded flash cuts or quick cuts. Then, with the record frames selector set at the positive number of frames to be recorded of each cut in rerecord cue mode, a new edit cue marking the start of the cut to follow is laid down as each cut is made. Successive flash cuts may have any frame duration from 1 to 18 frames. All may have the same duration, or may be at differing rates to accelerate or retard the appearance of transitions. In essence, this process is similar to animation with cue shift, which is an invaluable facility at times. When animation is required, however, it is preferable to use the manual or auto position of the Edit-Animate selector to avoid excessive wear of tape and heads.

7. *Select cue mode.* Select cue mode is used to select a particular edit cue from a closely spaced series of edit cues, to initiate an editing operation. The logic circuitry initially counts the reproduced edit cues until the selected cue is reproduced. The Editec operation then reverts to that of *cue mode* previously described.

8. *Select and erase mode.* Select and erase mode permits the selection of any one of a closely spaced series of edit cues for erasure. For example, it is desired to erase the sixth edit cue in a series of 12, the record frame selector is set at 6.

9. *Manual erase mode.* The manual erase mode permits the manual selection of an edit cue for erasure. Just before reproduction of the edit cue that is to be erased, the cue button is depressed and held down. When the cue talley flashes, the cue button is immediately released to avoid erasure of desired cues.

10. *Animate mode.* The Edit-Animate selector provides the choice of manual and auto animate. The manual animate mode requires restarting the system manually for each new take of an animation sequence; the automatic animate mode provides an automatic start for successive takes. In automatic mode, successive takes are separated by an interval of 15 to 20 seconds. The configuration of successive takes is illustrated in Fig. 89.

When Editec is to be operated in manual or automatic animate mode, an initial edit cue is recorded to mark the starting point of the animation. When this cue is reproduced it places in operation an electronic mechanism that senses the first "missing" cue. When the initial edit cue is reproduced the mechanism is alerted to find a second edit cue 1 frame later, see Fig. 89. When the second cue turns out to be missing, Take 1 is

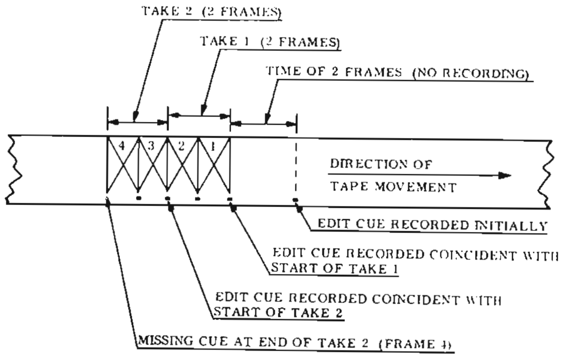


Fig. 89. Animation production in 2-frame takes (record frames selector set at 2).

initiated and an edit cue is recorded coincidentally with the start of Frame 1 and each frame that follows in Take 1. At the completion of each take, the machine recycles the tape to the starting point and stops.

The duration of each take is controlled on a calibrated basis by the setting of the record frames selector. Duration may be extended to any greater duration by holding down the record button on the program unit.

If the record frames selector is set for 2-frame takes (on its outer scale), takes and cues will be arranged on tape as shown in Fig. 89. At the completion of Take 1 (2 frames), the recorded edit cues on the tape include the initial cue and the cues that mark the beginning of Frames 1 and 2 only. There is no recorded cue that marks the end of Frame 2, which is also the beginning of Frame 3. At the completion of Take 2, there are additional recorded cues that mark the beginning of Frames 3 and 4, but as shown in Fig. 89, there is no cue marking the end of Frame 4 (and start of Frame 5). This is the "missing" cue.

11. *Animate erase mode.* Animate erase mode provides a means for precisely controlled erasure of unwanted frames at the end of an animation sequence.

The beginning of each frame in an animation is marked by a recorded cue. To achieve erasure of animation frames, it is necessary only to erase the cues that accompany them and to enter either animate mode with no record input applied. In animate erase mode, the erasure of cues that accompany undesired frames is accomplished by counting "backward" from the first "missing" cue. Erasure of cues is terminated by actuating the recorder stop button.

As in the animate mode, the indexing logic is the key to the detection of the first missing cue. It is the same in animate erase mode. When the first missing cue is detected, its location on the tape is momentarily opposite the cue playback head. As indicated in Fig. 87, the first missing cue point will be opposite the cue erase head 37 frames later.

Since the time interval between the cue playback and erase heads is known in terms of frames, it is only necessary to count back from this interval the number of frames it is desired to erase.

The timing of cue erasure in animate erase mode is derived automatically from the setting of the record frames selector. The record frames selector is set at the number of frames that are to be erased, which can be any number up to 37. The difference between the number of frames that are to be erased and the number of frames that are between the cue play and erase heads is derived automatically. A number of frames greater than 37 can be erased by repeating the animate erase procedure.

At this point, only edit cues are erased. The video frames are erased and replaced during animate mode retakes that will start with the new "first missing cue."

In the overall system the location of major equipment components described previously is shown in Fig. 90.

Fig. 91. Overall view RA-4000.

Random Access Programmer

The Random Access Programmer provides for the first time precise synchronized operation of two or more video tape recorders. The programmer allows operation to the extent of automatic search and tape cueing down to an accuracy of 1/30th of a second when running from high speed tape winding modes of the video recorders to frame-by-frame running synchronization at normal playing and record rates. This, combined with the recorder Intersync servo system, provides exact signal synchronization allowing editing capability similar to that of film double system frame-by-frame or A/B roll mixing and program editing. Electronic splices may be made precisely and by predetermining selected points, for rerecording into a master edited video tape program. A separate audio recorder may as well be controlled by the Random Access Programmer providing that provisions for transport control, capstan servo, a spare audio track and channel, and the necessary electronics and interface are provided.

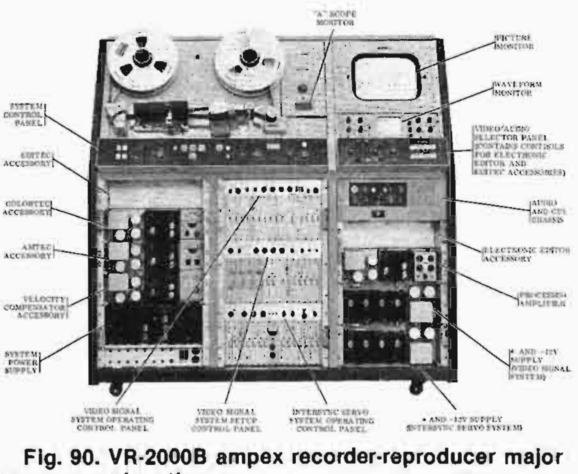


Fig. 90. VR-2000B ampex recorder-reproducer major component location.

Five control modes are provided for editing, program switching and general random access programming of video tape recorders.

Mode One. The most complex of the system provides full synchronization of two or more video tape recorders and is the primary operating mode utilized in editing.

Mode Two. Allows for "A" roll and "B" roll mixing of signals from two video recorders in synchronism to a third video recorder providing a composite program re-recorded inter master.

Mode Three. Operates one video recorder in the assemblage of scenes or sequences from a studio or single camera and other video sources. The recorder cues to a point 10 sec prior to the time set into the memory register providing precise commencement of the record function and at the exact frame time.

Mode Four. Operates one video recorder primarily for random access in playback. Scenes or short segments may be quickly located, precisely timed, cued up and integrated into live studio operation or switched directly on air from the recorder by external command.

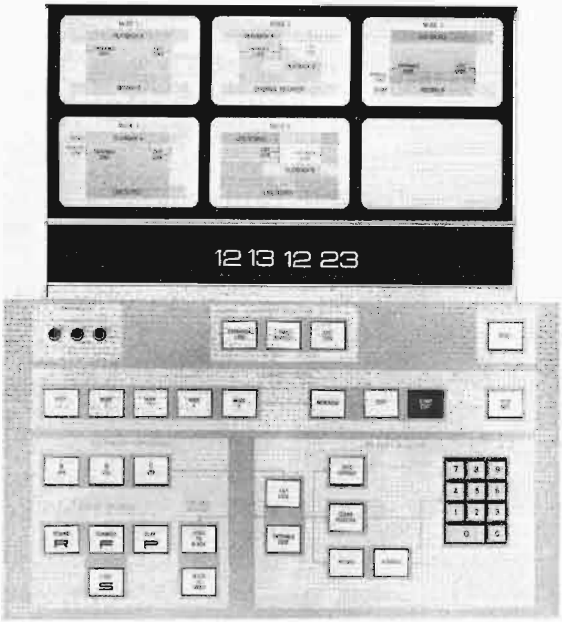


Fig. 92. Modes one to five and control panel.

Mode Five. Is primarily a variation of Mode Two, where the capability of "A"/"B" roll mixing is accomplished. However, the difference is that the "A" roll is a video signal source lacking time code data. In this case, the time code generator is providing timing data to accomplish an automatic pre-roll into full synchronization of the "B" video tape recorder, along with the foreign video signal source. This provides a composite synchronized output signal to a third recorder or directly to the air.

As with film, the accurately spaced sprocket holes provide a convenient mechanical method for exact metering of film footage, in conjunction with film edge number printing systems for identification of each picture frame. In the case of magnetic video recording, this method has been developed to identify each and every television frame on the video tape.

This system provides for the recording of a precise magnetic address code on the cue track (audio track two) in the form of a digital signal. In that the television signal scanning frequencies are closely controlled by the station synchronizing generator, it is convenient to express the address in terms of *hours, minutes, seconds,* and frame number (0 through 29). Addressing each and every frame allows a degree of redundancy that provides for greater noise immunity and as we reach the higher sample rate (one per frame), promotes faster search and synchronization. The digital code is known as Manchester Bi-Phase-Level and is useful over a wide range of tape transportation speeds from approximately 4 ips to 300 ips allowing readability in either direction of tape motion, rewind, fast forward, and at nominal linear running rates of the recorder.

A time code generator produces the necessary digital time code to be applied to the cue track (audio track two). The time code recording may operationally be recorded either from the "time of day" clock time or "elapsed time" (television time controlled from the station synchronizing generator), from the beginning zero time on each subject video recording or rerecording session. The time code may be recorded simultaneously with the video and audio program and on a start and stop basis, and or may be post recorded should this time prove convenient in the assemblage of program material for editing.

The code frame format is made up of a thirteen-bit synchronizing section together with a 65-bit addressable group. The synchronizing section performs three basic functions: a burst of uninterrupted clock transitions to enable the decoder to lock to the bit clock, a repetitive pattern to enable an address synchronizing pulse to be derived, and tape transportation direction to be defined by examination of the direction of a predetermined transition. The addressable group is divided into blocks of five, with the fourth data bit repeated to form the fifth bit. This reduces the effective data bits to four per block (or fifty-two in all). This insertion of two adjacent identical bits in each block of five addressable bits preserves the unique feature of the synchronizing section in its capability of defining address sync and tape direction. One-half of the available data bits per frame are used to form the consecutive time code, while the other half is available for identifying data that can be maintained over successive edits and generations.

When the code is recorded on the cue track, the video tape can be automatically searched for a required frame address. The desired video tape address is retrieved by placing the exact time and frame into the memory register from the keyboard

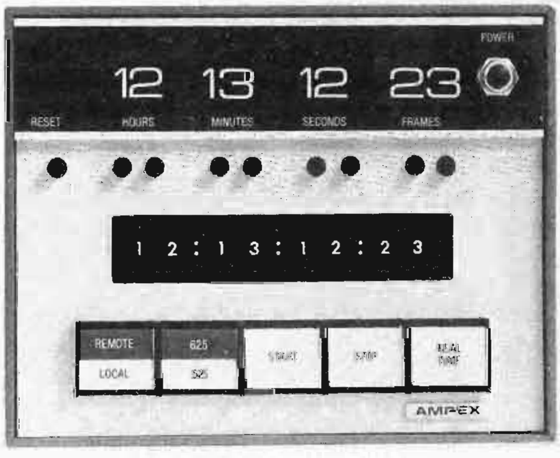


Fig. 93. Time code generator.

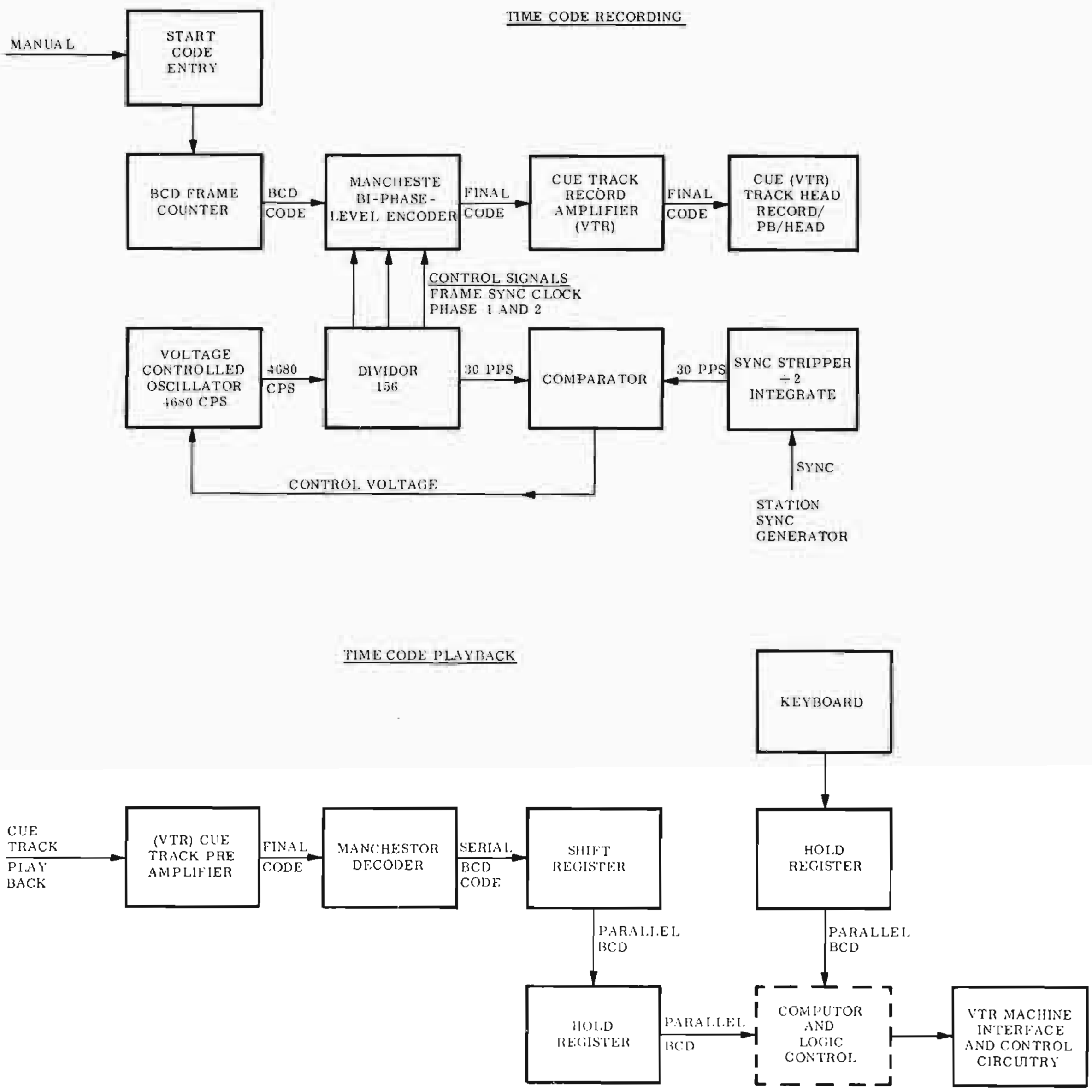


Fig. 94. Time code recording and playback functional block diagram.

control. When the recorder is activated the comparison of the code address on the tape is made with the desired code time held in the memory register. The random access programmer will continuously search by electronically subtracting the two address and, from the difference, the direction of search is determined as well as the search speed (fast forward or rewind) is regulated. As the difference decreases, the rate of search decreases until the video tape recorder transport brings the tape smoothly into position at the required address picture frame. Fig. 94 shows a simplified record and playback functional diagram of the Random Access Programmer Code System.

Magnetic Disc Video Recorder

The Ampex HS-100 Slow Motion Magnetic Disc Video Recorder and Reproducer is a fully transportable, instant replay television recorder/reproducer manufactured for use in studio, mobile vans, or indoor remote broadcast sites. It is capable of recording standard NTSC color or monochrome video signals and then immediately replaying the recorded material, either forward or in reverse, at normal speed, twice normal speed, one-half normal speed, one-fifth normal speed, or in manually controlled, continuously variable speeds ranging from stop-action, freeze, to normal. The disc recorder as well permits opera-

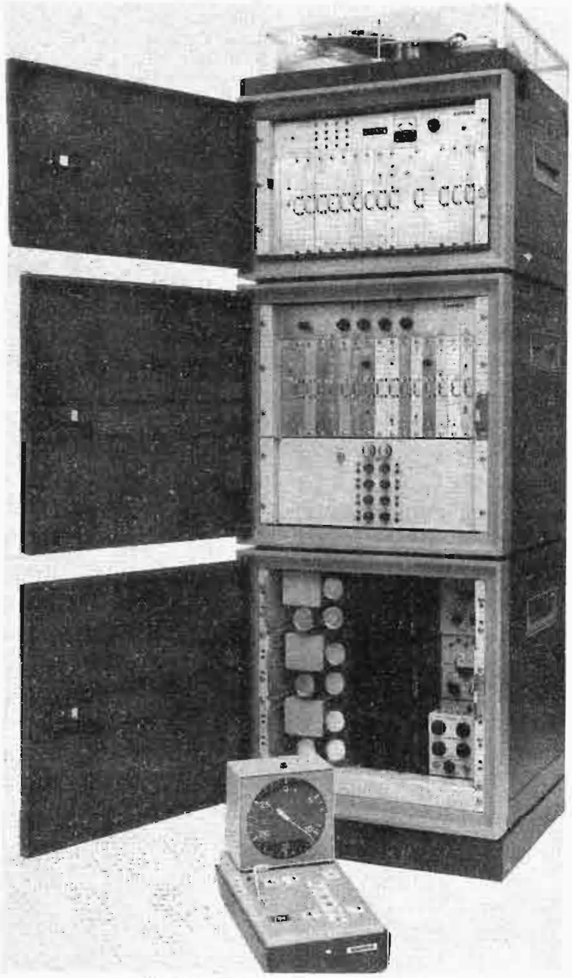


Fig. 95. HS-100 video disc recorder.

tor-controlled, single-frame video advance, either forward or in reverse, whenever playback is in the freeze mode. The video output of the disc recorder fully complies with NTSC and FCC standards regardless of speed or direction changes. Storage capacity of the recorder is 1800 television fields, corresponding to 30 seconds of video material in the normal record mode, or 60 seconds of material in the alternate field record mode, i.e., recording only every other television field.

The disc recorder is packaged in four units: the disc servo unit, the electronics signal unit, the output processing unit, and the control unit. Each unit is enclosed in a weather-resistant metal cabinet.

Disc Servo Unit

The disc servo unit, Fig. 95, contains the electromechanical components of the disc recorder and their associated electronics. Electromechanical components include a disc drive assembly with its associated circuitry and four stepper assem-

Fig. 96. Video disc recorder control unit.

blies. The disc drive assembly controls the rotation of two magnetic recording discs, each of which provides two recording surfaces, i.e., top and bottom side of each disc. Each of the four stepper assemblies controls the movement of one carriage assembly, with its record/reproduce head, across one of the four disc surfaces. The disc drive assembly and the four stepper assemblies are mounted on a machined aluminum top plate which is in turn shock mounted.

The electronic signal unit, Fig. 96, contains most of the signal system electronics, the control logic, and the major parts of the power supply system. The output processing unit, Fig. 96, contains a standard Amtec, Colortec, and a Processing Amplifier. The control unit, Fig. 96, contains all the primary controls used to operate the disc recorder. Mounted above the control panel is an illuminated clock type dial, calibrated from 0 to 30. A white pointer on this dial indicates the head location relative to the 30 seconds storage capacitor of the system. A red pointer tracks with the white pointer. This pointer can be stopped and then reset to its tracking position at the option of the operator to provide a cue marking.

Video recording in the magnetic disc recorder is accomplished by using high band (HB) systems to provide highest picture quality. The video system has two modulation systems, FM for recording and playback, and AM for the half-line delay function. The frequencies of the FM modulator are: 7.06 MHz tip of sync, 7.90 MHz for

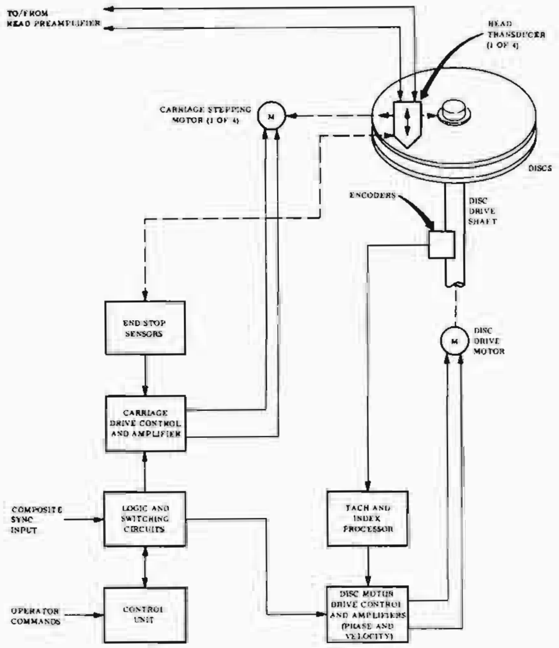


Fig. 97. Disc drive and carriage stepping motors control circuits simplified block diagram.

blanking and 10 MHz for peak white, the same as HB in SMPTE RP-6. The video system consists of four head preamplifier assemblies, each located on a carriage drive assembly, an RF switching logic module and record amplifier module and eight signal processing modules.

The modulated video signals are recorded on the four surfaces of two metal discs rotating about a common vertical shaft. Recording is continuous until the operator overrides the record mode by selecting a reproduce or fast search mode. As long as recording continues, the latest 30 seconds, 60 seconds for alternate field recording, of recorded video is maintained in storage, ready for instant playback. Material recorded prior to the 30-second storage limit is progressively erased to permit recording of new material.

Rotation speed of the two recording discs is 60 revolutions per second (3600 rpm). This speed is precisely controlled by a disc drive servo system which instantly detects and corrects disc drive motor speed variations as shown in Fig. 97. The primary purpose of the disc drive servo is to lock the rotation of the discs in phase with the external reference vertical sync. This phase lock ensures that each complete revolution of the discs corresponds exactly to one television field, beginning and ending during the vertical blanking period. The disc drive servo comprises an optical tachometer, driven by encoders on the disc drive shaft; the electronic circuits associated with the tachometer are a velocity discriminator, a phase comparator, the motor drive amplifiers and the disc drive motor.

Each of the four head assemblies used in the disc recorder is moved by an independent stepper assembly that steps the head radially across the surface of the disc. For purposes of identification the heads and their associated signal paths are referred to as head (or channel) A, head (or channel) B, head (or channel) C and head (or channel) D. In addition to recording, each head also functions as a playback and erase head. During operation, Head A steps radially across the top of the top disc, Head B steps across the bottom of the top disc, Head C steps across the top of the bottom disc, and Head D steps across the bottom of the bottom disc.

Each head assembly consists of a ferrite head transducer and two ferrite pads mounted so that the head and the two pads extend perpendicularly from the corners of a triangular platform. The head and the two pads provide a stable three point contact with the disc surface, and are held against the disc by a cantilever spring which bears against the rear of the platform. The head carriage assembly, which moves the head assembly, is mounted on guide rails extending radially across the disc surface. As the head carriage is moved a given distance along the rails, the head transducer is carried across the disc in the same direction and the same distance.

Driving power for the carriage assembly is provided by a stepping motor controlled by logic circuits and by end stop sensors, which provide reversing commands as well. The carriage assembly is coupled to the shaft of the stepping motor through a pinned stainless steel belt. The manner in which the stepping motors move (or step)their associated carriage assemblies is determined by the track format for the mode of operation being used.

Track Format, Normal Record Mode

Each field is recorded on the disc as a circular track; the head is held stationary while the disc makes one complete revolution. When Head A completes recording a single field, Head B starts recording the next field. While Head B is recording, Head A is being stepped to a new position. When Head B has recorded its field, Head C records the next field. While Head C is recording, Heads A and B are both being stepped to new positions. When Head C has completed recording one field, Head D starts recording, Head A erases the track in which it is now positioned, and Heads B and C are stepped to new positions. When Head D completes recording one field, Head A starts recording in the track it just erased, Head B erases, and Heads C and D step to new track locations. In this manner each head records every fourth field, and successive fields are recorded by Heads A, B, C, and D in sequence. Heads A and C record odd numbered fields; Heads B and D record the even numbered fields.

Recording, moving, and erasing follows a definite sequence for each head. For example, during Field 1, Head A records. During Field 2, the stepper assembly moves Head A 0.010 inch radially across the disc (tracks are 0.007-inch wide, 0.010-inch center-to-center). During Field 3, Head A is moved an additional 0.010-inch radially, placing it a distance of two tracks away from where it recorded (during Field 1). During Field 4, Head A erases, with a dc current, any signal previously recorded on the track in which it is now positioned. At the start of Field 5, the erase current to Head A is switched off and Head A is fed the FM signal output of the record amplifier.

Carriage Reversing

During any given field, one head is always recording, one head is erasing, and the remaining two heads are being stepped to new track positions. The heads move in this manner toward the center of the discs until Head A eventually reaches its innermost track. This position of Head A is sensed by a lamp and photocell arrangement positioned so that the photocell detects Head A as it makes its first step from its last record track position. The photocell output, acting through the carriage control logic circuits, prevents Head A from making the second stepping movement. During the two subsequent fields, Heads B and C also reach their innermost point of travel and are similarly prevented from making their second stepping motion. On the next field, Head A records on the track where it was stopped, and Head D steps one track. On the following field, the direction of rotation of all four stepping motors is reversed. The heads then begin stepping toward the outer edge of the disc, following the normal sequence, and recording between the tracks used when the head movement was toward the center of the discs.

At the outer edge of the discs, head travel is again inhibited and reversed by a second lamp and photocell arrangement. Thus, the heads travel continuously until stopped by an operator command. If a stepping error occurs, the head carriage logic circuits detect it and correct at the end stops before allowing the carriages to reverse direction.

Alternate Field Recording

In the alternate field recording mode of operation, head sequencing is the same as for the normal recording mode, except that it is triggered at half the rate. The rotation speed of the discs, the track width, and the track spacing is unchanged and only the odd numbered fields are

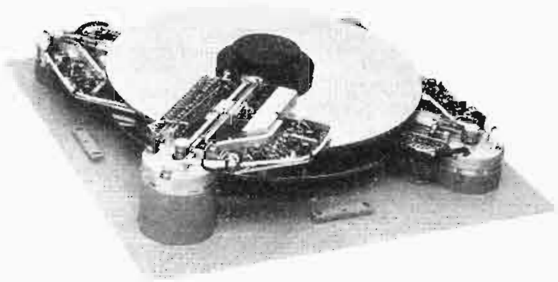


Fig. 98. Disc drive and stepper assemblies.

recorded. During even numbered fields, no steps are triggered and the record amplifier is turned off. Erase current, however, is permitted to flow during the even numbered field intervals.

The record signal path, shown in Fig. 99 contains a modulator located in the electronics signal unit, a record amplifier, and four preamplifiers located in the disc servo unit. The modulator module contains a preamplifier circuit which amplifies the composite video input, a preemphasis network, and a modulator which converts the composite video to an FM signal (RF).

In the record amplifier module, the RF is amplified and divided into four sequentially gated outputs, each of which is applied to a different one of the four preamplifiers. Each preamplifier contains a relay which is energized during the record mode and de-energized during playback. During recording, signals gated out of the record amplifier are applied directly to the head transducer by way of a record current level adjustment potentiometer in the preamplifier and the preamplifier relay contacts. An erase circuit in each preamplifier supplies a dc erase signal to its associated head transducer when commanded to do so by a gating pulse. The same pulses that gate the FM signals out of the record amplifier supply the erase commands for the preamplifiers. The lines carrying the gating pulses are connected in such a way that the pulse that gates the channel A signal out of the record amplifier turns on the erase function in the channel B preamplifier. Similarly, the pulse that gates the channel B signal out of the record amplifier simultaneously turns on the erase function in the channel C preamplifier. This sequence, applied to all four channels, ensures that when one head is recording, the head that will record next is erasing previously recorded material.

In the normal speed forward direction playback mode, the sequence of carriage movement is identical to that used in record. The head connections are transferred, by means of relays, from the record and erase amplifiers to the reproduce preamplifiers. The outputs of the reproduce preamplifiers are sequentially gated through the rest

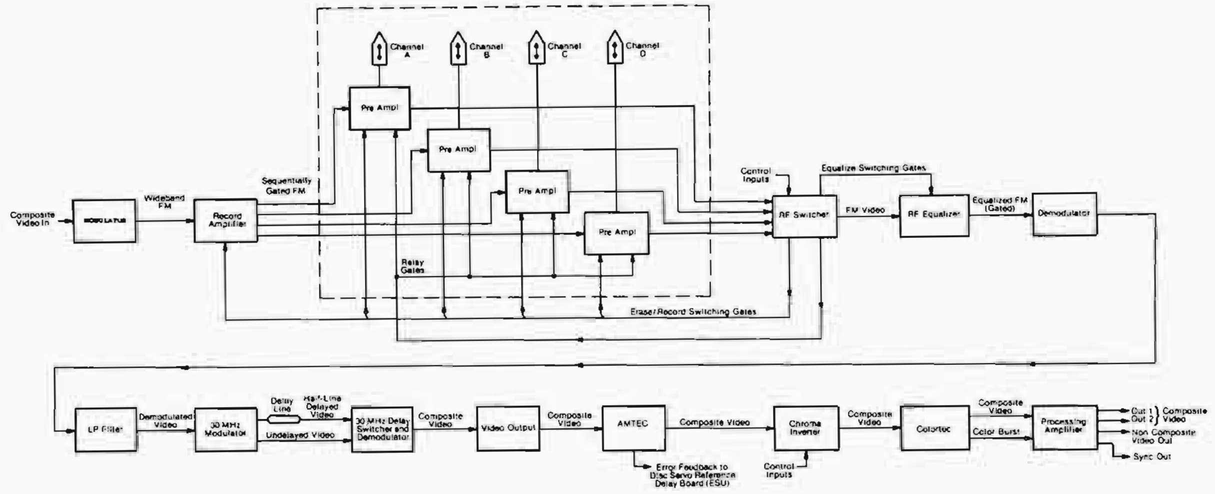


Fig. 99. HS-100 disc record/reproduce signal path simplified block diagram.

of the reproduce electronics in the same manner that the record current was gated to the heads in the record mode. Each field is reproduced in the exact sequence in which it was recorded, so that the demodulated video output is a standard NTSC signal.

In the still frame or freeze mode, the playback sequence is stopped on a particular field, and the system video output is derived from the continuously repeated playback of a single track. In this mode, line interlace and chroma phase are restored by special techniques to produce a standard television signal.

Line Interlace

The normal television video signal is a succession of odd and even fields characterized by a half-line shift of horizontal sync (with respect to vertical) in each field, Fig. 100.

This half-line shift produces line interlace of the two fields, constituting a frame, when displayed on a picture monitor. When, as in the case of still framing, each successive field is derived from the same recorded track, and is therefore identical to the one preceding it, interlace must be restored artificially.

The phasing of the record switcher on the disc recorder is such that each recorded field begins and ends just after the last equalizing pulse of the vertical interval (point A or B' of Fig. 105). Odd

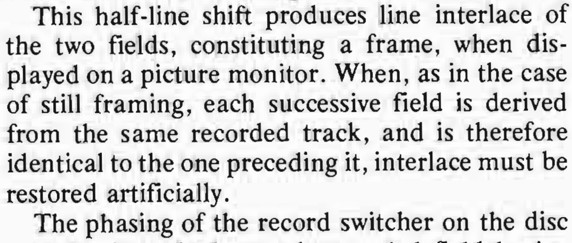


Fig. 100. Odd and even vertical field intervals.

fields, as recorded on the disc by Heads A and C, begin at A' and end at B'; even fields, as recorded by Heads B and D, begin at B' and end at A'.

To produce line interlace artificially, odd fields are changed to even fields, or even fields are changed to odd fields, by insertion of a half-line delay in the video signal during the horizontal scanning interval of each field (i.e., from A to B, or from B to A). The half-line delay insertion is controlled by the system logic. By knowing what type of field is required, by examining reference sync, and knowing what type of field is being reproduced by each head, the logic controls the insertion of the half-line delay as required, always removing the half-line delay during the vertical interval A to A and B to B. Accordingly, when still framing, the half-line delay is inserted during the horizontal interval of alternate fields.

Chroma Phase

In the NTSC color system the frequency relationship between the 3.58 MHz chroma subcarrier and the horizontal and vertical scanning rates are such that the chroma phase advances 180° each line and each frame, dot interlace. This minimizes chroma-luminance crosstalk since the effects are reversed on successive scans.

In still framing, a chroma-phase problem arises from attempts to generate a continuous signal from a single recorded field. In scanning a complete field, the chroma phase at the end of the field is advanced 90° with respect to its phase at the beginning of the field. If the field is then rescanned from the beginning, 90° phase discontinuity appears in the chroma signal at the beginning of the scan. This would not only destroy dot interlace, but in a normal receiver would seriously disrupt the color demodulation process.

The chroma phase shift is further influenced by the insertion or removal of the half-line delay.

Insertion of the half-line delay retards the chroma phase 90°; removal of the delay advances the chroma phase 90°. Thus when the half-line delay is inserted at the beginning of a rescan, its 90° phase-shift adds to the 90° shift caused by rescanning, producing a total chroma phase shift of 180°. Conversely, if at the beginning of a rescan the half-line delay is switched out, its phase shift cancels out the 90° shift caused by rescanning. The combined result when still framing, therefore, is that a 180° phase shift occurs in the chroma phase at the beginning of every second field. This effect is compensated for by a chroma inverter which extracts the chroma signal, including burst, from the composite video playback signal, reverses its phase each time the half-line delay is inserted, and recombines it with the luminance portion of the signal.

Slow Motion

Slow motion is essentially a combination of normal motion and still framing. To produce the effect of slow motion, each recorded track is scanned not once but several times, depending on the slow-motion rate selected, after which the playback signal is taken from the next track. Selection of a particular speed determines the average number of scans per track, even though some tracks may be scanned more often than others. For example, if a speed reduction of 2:1 is selected, each track is scanned twice; at a 3:1 reduction, each track is scanned three times. At a 2.5:1 speed reduction, half the tracks are scanned twice and half are scanned three times. Thus speed control is continuously variable from normal to freeze.

During the time a particular track is being rescanned, the system operates exactly as described for still framing (freeze mode). Carriage motion stops, the signal is derived from one particular head, the half-line delay is switched in or out at the beginning of each rescan, and the chroma phase is reversed each time the half-line delay is switched in. When the playback signal is advanced from one track to the next, carriage movement and head switching progress from one field to the next as in normal motion. Since switching from one track to the next produces a normal transition from one field to the next, the state of the half-line delay and chroma inverter remains unchanged during the transition. That is, if the half-line delay was in the signal path before the switch, it remains in after; if it was bypassed before the switch, it remains bypassed after. Similarly, no inversion of the chroma phase is carried out at this time.

In reverse motion playback, the sequence of carriage motion and head switching is reversed and the carriages are made to move in the opposite direction. Thus,, the fields are played back in opposite sequence to that in which they were recorded.

The head switching sequence, D, C, B, A, preserves the normal progression of fields from odd to even, but loses the track-to-track continuity of the chroma signal. In switching, for example, from Head D to Head C, switching is from the end of one field to the beginning of the one which preceded it in the original recording. This constitutes a 180° chroma-phase reversal, which must be corrected by reversing chroma phase in the chroma inverter. Thus, when switching from track to track in the reverse motion direction, the half-line delay is not altered but the chroma phase is reversed by the chroma inverter.

When rescanning a track in slow motion reverse, the action of the half-line delay and chroma inverter is identical to rescanning in the forward direction.

Recordings made in the alternate field record mode differ from those made in the normal mode in that only odd fields are recorded, the first field of each frame. Since all fields are odd, it is necessary to change the state of the half-line delay, i.e., either insert it or remove it, as the case may be, each time the signal is switched from one track to the next, both in the forward and reverse motion directions. In going from track to track in either the forward or reverse direction, the chroma phase is retarded 90°, which is cancelled out when the half-line delay is removed, and increased to 180° when the half-line delay is inserted. Therefore, in the alternate field record mode, it is necessary to reverse chroma phase by means of the chroma inverter each time the tracks are changed, and at the same time insert the half-line delay. When rescanning a track in the alternate field record mode, either in forward or reverse motion, the half-line delay and chroma inverter are controlled in exactly the same manner as in normal still framing.

Recording of only half the fields otherwise affects the system in the following ways:

a. The storage capacity of the system is doubled, from 30 to 60 seconds.

b. Speed-up of motion is available as well as slow motion. Speed is continuously variable from twice normal speed to freeze action (still frame).

c. Increments of motion from field-to-field are doubled in the reproduced picture. This becomes noticeable as jerkiness in fast-action sequences when played back at very slow speed.

The reproduce signal path, Fig. 99, contains the four head transducers, the four head preamplifiers, and RF switcher module, an RF equalizer module, a demodulator module, a low pass filter, a 30 MHz modulator module, a delay line, a delay switcher and demodulator module, a video output (amplifier) module, an Amtec assembly, a chroma inverter module, a Colortec assembly, and a processing amplifier assembly. The particular functions of these modules and assemblies are discussed in the following paragraphs.

During playback, the relay in each of the preamplifiers is de-energized so that the low level signals picked up from the discs by the head transducers are routed through the preamplifier circuits.

In the RF switcher module, the outputs from the preamplifiers are sequentially gated to the RF equalizer module in accordance with the playback mode, i.e., normal, slow motion, freeze, selected by the operator. The RF switcher also converts the control inputs from the system logic circuits into the gating pulses that control the record, erase, and equalizer switching functions.

The RF equalizer contains a master equalization circuit and four channel equalization circuits. The gating, switching, pulses applied to the RF equalizer select the applicable channel equalization circuit for the signals being gated out of the RF switcher. For example, when the RF switcher applies the channel A signal to the RF equalizer, it also applies a command signal to the equalizer module which routes the signal through the channel A equalizer circuit.

The outputs from the RF equalizer are applied to the demodulator. The circuits in this module convert the FM output of the RF equalizer to a series of identical, in both width and amplitude, pulses with a pulse recurrence frequency twice that of the FM signal.

The pulse outputs from the demodulator module are applied through a low pass filter to a 30 MHz modulator. The low pass filter integrates the pulses from the demodulator and attenuates the FM carrier. The resulting output from the filter is a carrier-free video signal which varies in amplitude in accordance with the pulse recurrence frequency of the demodulator output.

The 30-MHz modulator generates a 30-MHz carrier which is amplitude modulated by the demodulated video output of the low pass filter. The 30 MHz signal is then split into two paths. One path goes directly to the 30-MHz delay switcher and demodulator; the other path is through a delay line to the 30-MHz delay switcher and demodulator.

The 30-MHz delay switcher and demodulator contains a diode switching circuit which selects either the delayed video or the undelayed video, depending on the playback mode. In normal speed playback operation, the undelayed 30-MHz signal is selected; and in slow motion or freeze action operations the delayed and undelayed 30-MHz signals are selected alternately. The purpose of the delay line is to delay the signal by one-half line, approximately 31.4 μsec, to synthetically restore the interlace to the TV picture when repeating fields, i.e., it changes fields into frames. Switching between delayed and undelayed video is controlled by a timing signal originating in the signal switching logic.

The demodulator circuit in the 30-MHz delay switcher and demodulator module demodulates the selected 30-MHz input, delayed or undelayed, to produce a replica, composite video, of the video input that was applied earlier to the 30-MHz modulator module.

In the video output module the composite video signal is amplified and filtered, and the sync pulses are clamped to the required level. A de-emphasis network connected to the video output module compensates for the pre-emphasis applied during the recording process in the modulator module.

The composite video output is fed to the Amtec and reduces signal timing errors and also provides a timing error feedback to the disc servo reference delay. From the Amtec, the video is applied to the chroma inverter and separates the chroma from the composite video, electronically inverts the chroma in accordance with the operating mode, and then recombines the luminance and chroma to form an NTSC color signal. Chroma inversion does not occur during normal playback, or record, modes of operations.

The output of the chroma inverter is applied to the Colortec, which corrects residual signal timing errors. The Colortec output consists of two signals: one, the composite video and two, a time-corrected color burst signal. These signals are fed to the processing amplifier which combines the composite video and the time-corrected burst, added to back porch of composite video, to provide a time-corrected composite video signal.

Fast Search

Fast search is used to move the head rapidly, at about four times normal speed, from one point on the discs to another. In fast search, as in normal operation, the heads must remain precisely in step, otherwise loss of field-to-field continuity would result in subsequent playback. Therefore the sequence of motion is kept the same as in normal speed operation. Because of the inertia of the carriage drive system moving at search speed, it is not convenient to reverse the direction of travel of the carriages at the inner and outer limits of travel. Therefore a lamp and photocell arrangement, located on carriage drive A detects the approach of the heads to the inner and outer limits and briefly slows the carriage speed to normal while carriage direction is being reversed.

The HS-200 computer control console combined with the magnetic disc recorder provides a complete teleproduction and editing system. The

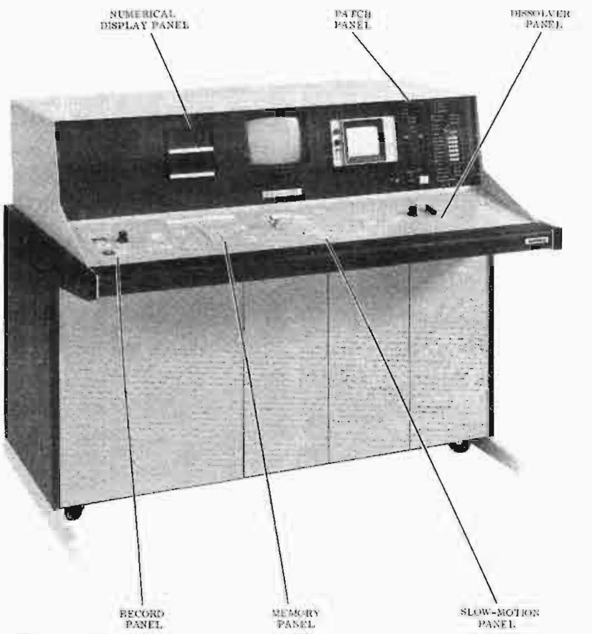


Fig. 101. HS-200 computer system control console.

combined system may now be used for complex electronic editing under the control of computer type logic, permitting automatic editing of complete programs, such as commercial spot advertising and animation sequences. The system can be controlled from the cue track of a quadruplex video recorder, allowing the transferring of video tape programming as desired to the magnetic disc medium for playback, instant replay, freeze frame, time-controlled freeze frame, double speed playback, slow motion, and variable animation assembly.

The main advantage in television production over video tape recorders is in its ability to repeat the same track for hundreds of passes without wearing the magnetic disc surface, and to play back frames in any predetermined order. The two video recording systems, magnetic video tape and magnetic video disc, combine the functions best performed by each and are entirely complementary.

Summary of Magnetic Disc and Computer Control Console Capabilities

Animation. The system has a total capacity of 900 frames. These may be all recorded in one operation or in short passages by alternately pressing the start and stop record buttons. Also, the system can be programmed to record any number of frames from one through 900 each time the start record button is pressed.

Animation can be preprogrammed and requires only two passes of the video tape on the VTR. On the first pass, cues can be recorded at appropriate places on the video tape. On the second pass, the computer control console will automatically compile the animation sequence using cues from the VTR to place the magnetic disc in record for a preset number of frames.

Manual or automatic time lapse. This is an extension of animation. As mentioned previously, the system will record a preset number of frames each time the start record button is pressed. The lapse-timer unit can be preset to perform this function automatically.

Random access to any frame. The machine has a frame counter which gives every frame an address. Using the keyboard numerical entry system, any number from 1 to 900 can be entered into store. When pressing search, the equipment will search out the desired frame and display it in freeze. This frame could be considered as an individual frame or the first frame of a sequence.

Variable-speed playback in forward or reverse. As on the magnetic disc recorder a choice of three speeds is selectable by push buttons. Slow motion 3 position provides continuously variable speed from normal all the way to freeze under the control of a lever. On the computer control console all of these functions are accessible through the patch panel which also enables preprogramming of these functions.

Freeze frame or field. On the magnetic disc recorder a freeze picture is obtained by repeating one recorded field. A half-line delay is used to turn odd fields into even fields and vice versa to produce a frame. Because we are repeating fields, there is a loss of vertical resolution which is subjectively acceptable on most program material.

On the computer control console a freeze picture can also be produced by repeating two adjacently recorded fields to make up the frame. In this way full definition is obtained. These two modes are called the field and frame modes, respectively.

If a freeze picture of some recorded fast action is required, then the field mode must be used because the frame mode would produce a blurred picture due to the fact that it was made of two pictures recorded 1/60th of a second apart.

Stop motion is produced by repeating fields or frames. The same choice of repeating frames or fields is available in slow motion.

Time-controlled freeze frame. Any frame can be accessed and held in freeze for any time period between two frames and 900 frames before another mode such as a switch or forward or reverse motion is actuated.

Automated dissolves of variable length. The computer control console includes a digital dissolver. The dissolve rate can be preset to be any one of the following: Cut, 4, 8, 11, 16, 22, 32, 43, 64, 86, 128, and 256 frames. A dissolve between any two channels (one of which could be the output of the magnetic disc) will take place at the push of a button, at the receipt of a remote cue, or at any frame address in the memory store.

Matting and keying. The matting and keying amplifier in the computer control console allows adjustments of luminance, chrominance, and saturation of the matting signal. This device will key or matt at the push of a button from a remote cue, or from any stored frame address. The time duration of the key or matt can also be controlled. One very useful application is the animation of special keying patterns which can be stored on tape for future use.

Computer logic for sequential preprogramming. A solid-state memory unit stores up to eight switching, mixing, editing, timing, and slow-motion commands and holds them until cued. Once the preprogramming is completely set using the patch panel, an entire sequence can be assembled automatically.

Two-way remote control. The equipment will receive cues from a VTR in the form of logic commands or tone bursts and will act upon them through the patch panel. It will also send signals to another magnetic disc recorder system or VTR. This, for example, permits preprogramming of an A-B roll consisting of cuts, dissolves, and slow-motion effects between the two machines.

Random access slide store. The magnetic disc recording system can be used as a buffer store for a sequence of color slides. Up to 900 slides can be recorded on the discs. The memory store can be programmed to search for up to eight slides, displaying each one for a predetermined period.

Concept of Editing and Special Effects Utilizing the HS-200 Teleproduction and Editing System

The simplest concept of motion picture editing (either film or tape) is that of "assembly": the putting together, in sequence, of various scenes available from prerecorded material, or the production of scenes in the required order at the time of editing. The process of assembly from prerecorded material involves locating the desired sequence and attaching it to the preceding one either physically, photographically or electronically. This is actually the only way it can be done with film with any degree of precision or artistic flexibility. With either tape or disc, however, assembly and recording can be accomplished concurrently by producing the scenes in order and recording each one to its desired timing and making the desired transitions. The HS-200 magnetic disc recorder and computer console adds an order of magnitude to the ease, speed and precision with which this can be done, and progress may be reviewed as the operation is carried out.

Insertion of new material into previously recorded material is a common requirement. Accurate placement of the insertion with regard to preceding and following material requires the ability to determine the "in" and "out" edit points of both the new material and the material into which it is to be inserted. There are two possibilities for carrying out such an operation: (1) the material to be inserted is recorded on the magnetic disc and cued with extreme accuracy to the desired "in" point and then electronically edited into the prerecorded sequence on tape from cues previously placed and precisely adjusted. (2) The original material is recorded on the magnetic disc and the new material inserted at the desired points from any other source, once again with one-frame accuracy of placement.

The "cut" (an instantaneous change of scene) is the simplest of video transitions both physically and subjectively, timing being the only variable. With film, proper timing is accomplished by selecting the frame at which the cut is desired. The magnetic disc control console offers this facility by allowing leisurely study of material at a frame-by-frame rate, and also allows realistic preview of the cut before it is accomplished.

The "dissolve" is a more complex transition requiring the fading out of the first picture simultaneously with the fading in of the second one. Timing again is the critical point, not only as to when the dissolve occurs, but in how long it will last. With film this is done in the optical printer with precise control of the number of frames involved, and is an operation that must be entrusted to the lab technician. With the computer control console and an accompanying video source, dissolves may be achieved with the same accuracy and automatically controlled as to the length. Again the major advantage offered by this system is the ability to preview or rehearse the effect with the possibility of desired adjustments before actually performing the final transition.

The "fade" involves simply fading from picture to "black" or vice versa. It is easily accomplished in a number of ways. It can be done at the time of recording or during the editing process. The advantage offered by the computer control console in this operation is accuracy of timing.

The "A-B roll" technique, commonly used in film production, involves dividing the production into "odd" and "even" scenes. The "odd" scenes are placed in sequence on one video source and the "even" ones on another. With proper timing between the two sources, "odd" and "even" scenes are then combined into the desired final form. With the precision of control available, this is easily accomplished within the computer control console and a second video source.

In keying process, one picture signal is inserted into another, e.g., a title into a background scene.

In film this is a laboratory process requiring time and expense. In television it is achieved electronically by combining two video signals. The main use of the computer control console in this process is as the source of the signal to be keyed. Because of its frame-at-a-time capability in playback, material to be keyed may be recorded on succeeding frames and keyed into the background as desired and changed on cue. Animated titles or products can be recorded on the magnetic disc and keyed into other material with full control of movement and timing.

The time lapse technique, which might also be called "time compression," allows the reproduction of lengthy events to be condensed as much as desired. This effect is accomplished by taking picture frames at selected intervals during the event being recorded, rather than recording it continuously. When the reproduction is played back in a continuous manner, time compression is achieved. In other words, if one frame is recorded every five seconds during a 15-minute process, we will finish with a total of 180 frames. If these frames are played back at the normal rate, 30 fps, the whole event can be viewed in 6 seconds. This is done on film by exposing one frame, either manually or by a timer, at every selected interval. The same technique is possible on magnetic recordings with the magnetic disc recorder. Two advantages accrue: (1) The reproduction is immediately reviewable. (2) Playback is not locked to any particular frame rate (as it is in film), allowing the length of the event to be manipulated to fit any time segment.

Simulated time lapse, which produces the effect of time lapse, is achieved by combining the backward motion and single frame recording capabilities of the magnetic disc. For example, a potted plant may be placed on camera, a series of frames recorded, and between each "take" a little of the plant snipped off until the plant has been cut entirely away. If this sequence is played in reverse, the plant seems to grow before the camera. This can be applied to a number of different subjects.

Slow and fast forward motion have long been available on film. They are achieved by photographing at either a faster or slower frame rate than normal, and playing back at normal speed. The desired speed of replay must be determined at the time of photographing as there is usually little or no flexibility in the speed of film playback. The magnetic disc recorder, however, allows complete control of the speed of playback from stop to normal speed, and these speeds may be varied as desired. For faster-than-normal motion two different techniques are available with the disc recorder. The first is "time lapse," explained previously. The second is a technique in which every other field or frame is recorded. Playback at normal speed then provides double speed action, once again with variable speed down to full stop.

Stop action is an often-used effect in which a normally moving scene suddenly "freezes," and, if desired, subsequently returns to normal motion. In film this can be accomplished in the laboratory printing process. This effect is easily achieved with the magnetic disc recorder and action can be programmed to stop at a pre-selected point and to continue at a pre-determined time. All the flexibility of direction and speed of playback are also available in conjunction with this effect.

Animated titles are created by moving and manipulating the elements of the title. In film this is the job of the "animator" who uses a special camera and associated equipment. With the magnetic disc computer control console, many if not all of the desired title effects can be accomplished in the studio using normal television equipment. Again the frame-at-a-time and reverse playback capabilities of the magnetic disc are useful. The effect of a title "writing itself" is achieved by shooting a complete title, and then on subsequent "takes" blacking out a portion between each frame. This material, once recorded on the magnetic disc, can then be "keyed" through a background.

With the magnetic disc and computer control console, anything that can be animated on film can be animated on tape. The process of taking animated pictures is merely that of one-frame-at-a-time photography, for which the recorder is exceptionally well suited. The important advantages of the system allow the material to be viewed, and if necessary manipulated, before it is photographed, and provides results that can be instantly reviewed after production. These features apply equally to animated "cells," live or static models, and printed art work.

The flash cut technique results in a series of very rapid changes of scene, possibly as many as three or four per second. At a slightly slower rate of scene change it is sometimes referred to as "squeeze action" and gives the effect of jerky animation. In film this can be handled on the animation stand if the picture material is static, or in the printing process if movement is required within each short sequence. With the magnetic disc recorder control the effect is achieved for either kind of subject by simply recording the required number of frames of the first subject, and then repeating the process in sequence for each following subject; this can be done as rapidly as the subjects can be changed. A variation of this technique, which gives an almost subliminal effect, calls for the repeated brief insertion of other material into a continuous scene. This effect is accomplished on the system with only the need to determine in advance the

Fig. 102. VR-3000 portable quadruplex video tape recorder.

intervals at which the insertion is desired. The number of insertions, or flash cuts, and the times at which they occur can be precisely controlled and programmed with an accuracy of 1/30th of a second.

Quadruplex Portable Video Tape Recorded

The Ampex VR-3000 Portable Video Tape Recorder provides for the first time a rotary head quadruplex recording system in a miniaturized light weight, battery operated, portable configuration. The compact unit is switchable between low band monochrome (LBM) and high band (HB) NTSC color or monochrome. Video tapes recorded on the portable video tape recorder are interchangeable with all other quadruplex VTR equipment.

Fig. 103. VR-3000 portable recorder and companion camera.

The compatibility with other broadcast VTR equipment is of paramount importance to accomplish a free flow of video tape interchange in television program productions, remote news programs, on-location features and on-site commercial advertising productions.

Video tape path dimensions cannot be changed without compromising interchangeability; therefore, this recorder meets and complies with all SMPTE recommended practices and USASI standards and at the same time is packaged in a unique fashion and the permissible weight is only a small fraction of that of the smallest existing broadcast VTR machine. As well, hand-held companion cameras have been designed to complement the portable video tape recorder. An overall portable recording system is shown in Fig. 103.

The recorder and the associated camera is portable by a man. There is obviously a limit to the weight that he can carry, particularly if he is asked to exercise an artistic appreciation of the picture he is recording. This limit of weight influences greatly the design of every component of the system, electrical or mechanical. The power consumption of each circuit is optimized very carefully, the size and weight of the battery pack is to be kept within reasonable limits. This equipment must also operate with the variable environment in which recording may be performed. The range of temperature must be at least from that of a skiing resort to that of a mid-summer sun (minus 20C to plus 55C).

More difficult than the temperature problems are those created by all the possible accelerations the equipment may be submitted to, such as operation on back-pack, aboard a car, an airplane or a helicopter. These produce spurious inputs into the various servo mechanism loops, thus creating entirely different problems from those of fixed machines.

The determination of what constitutes a reasonable use of this equipment is in itself a problem. The spectrum envelope of vibrations aboard helicopters, heavy airplanes, and automobiles is well known. A subjective criterion can be established for TV use by saying that the portable recorder should perform for all movements of the camera producing a usable picture.

The tape transport is conceived in such a way that, apart from the transducers, no fixed element is in contact with the oxide of the tape, so that the generation of scratches are minimized. The capstan operates according to the principle of "minimum work" and does not require a pinch roller. The tape path is relatively unconventional, but the critical dimensions determining the position of the recorded information on the tape are exact, conforming to the established recommended practices. The tape transport design for

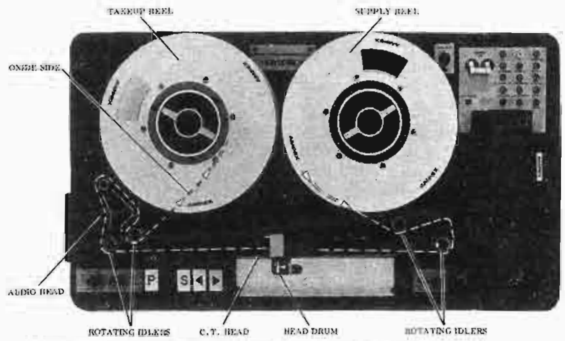


Fig. 104. Portable quadruplex video recorder tape threading path.

the portable recorder shows the tape path and major element of the portable video tape recorder in Fig. 104. The tape is wound "oxide in" on a standard 8-in. reel, permitting about 72 minutes of video recording tape to be accommodated. The tape path used causes the oxide side of the tape to be exposed to a minimum number of path surfaces and elements.

The unusual feature of this transport is the absence of a capstan pinch roller. The capstan without a pressure device depends solely upon the tension of the tape wrapped around it for its grip on the tape. A large tape wrap angle is provided by the transport design. This provides adequate "grip" to permit the capstan motor to remove disturbances in the tape transportation process.

The greatest of these is caused by angular acceleration of the entire package in the plane of the reels. The average work done by the capstan motor (in the absence of disturbances) is held to a minimum by maintaining constant tension at the output of the supply reel. Supply reel holdback tensioning is provided by a magnetic particle brake, where the torque drag is electrically controlled by a tape tension arm near the supply reel. This brake is more efficient than a motor system.

The supply brake is also used for "parking" the supply reel during movement of the machine prior to use. While parked, the take-up motor supplies a slight torque to maintain a tight tape path, and will even restore a tight tape path, if a severe lurch during transportation of the machine should loosen the tape.

Since the capstan motor does minimum work and a brake can do none, it is clear that all tape motion is powered by the take-up motor. The proper choice of this motor is paramount in achieving good overall electro-mechanical efficiency.

A dc motor is most efficient when operating near its maximum speed, and of course has zero efficiency when stalled. Since reels turn rather slowly at 15 in/s, a motor is needed whose unloaded maximum speed is low.

While a dc motor is a logical choice for a high efficiency head drum drive, at high speeds an ordinary dc motor can easily waste 15W or so in brush-commutator friction. To save the 15W is well worth the few ounces of electronics necessary to make what is called a "brushless" dc motor; a motor in which the switching, instead of being done by mechanical sliding contacts, is done by transistor switches using timing information derived from the rotation of the shaft. Since a drum motor tachometer is necessary for servo purposes, timing information is readily available without any weight penalty.

The vacuum guide is engaged and retracted by a tiny dc motor controlled by limit switches so that power is consumed only during movement. This motor, incidentally, is not part of the video head assembly but is affixed to the transport.

A small brushless dc motor drives a diaphragm-type vacuum pump. It is surprising how little air leaks past the seal formed by the tape and the vacuum guide vacuum slots. Such air flow capacity provided is needed to accommodate the occasional wrinkled piece of tape which will not seal properly at the female guide, and to pump away the air contained within the vacuum system in a reasonably short time.

The capstan motor is a small and higher-speed version of the take-up motor. Since it does a minimum of work, the average motor current is small. The motor is servo-controlled, being locked to the drum rotation. A tachometer on the back shaft provides speed information, while damping is provided by a servo loop electrically performing the same function as a flywheel. A flywheel large enough to absorb tape disturbances is too heavy and will not work in a machine subject to angular acceleration because of its great moment of inertia.

Where the power savings justify the extra circuit weight, switching-type voltage changers are used to obtain an efficient dc-to-dc voltage transformation. They are most useful when the voltage ratio is large as in power supply for some of the integrated circuits which operate at low voltage. Four main servo mechanisms are included in this machine: capstan loop, drum loop, and tape-tension loops.

The capstan servo differs from the usual in many ways. Most of the existing fixed machines use a capstan coupled to a heavy flywheel and a low-cutoff frequency loop. No tachometer information is collected in the record mode, and high frequency disturbances are absorbed by the large inertia. Such a solution is not possible in the case of a portable machine for several reasons. First, the inertia of the flywheel would prevent the capstan from following the rotational movement of the transport. Second, the starting time would be longer, an important factor in recording of quick action news events. Third, the weight and volume would be prohibitive. The adopted solution is a low-inertia high-cutoff frequency loop capstan. A high rate of tachometer information is collected by measuring the speed of the capstan with respect to the transport, and by supplying the error to the high frequency loop. A problem associated with such a scheme is that it is difficult to realize an error-free tachometer. Very tight mechanical tolerances and an optical electrical compensation device are used. The cutoff frequency of the capstan servo-loop is at least 100 times that of previously designed VTR equipment.

The head drum servo mechanism function is to drive the heads at a very precise speed and to position them with respect to the tape. The problem is compounded by the movements of the transport with respect to the rotor of the drum motor. Certain applications, helicopter or car, produce vibrations at relatively high frequencies. Some vibrations may have direct rotational components, or their application in certain directions, with respect to the center of gravity of the transport, may transform them into rotation in the plane of the drum. These vibrations would produce timebase and velocity errors that must be eliminated. It is necessary to have a much higher cutoff frequency than is usually required in a fixed machine while in the record mode. High rate tachometer information is again necessary, thus presenting the same problem as with the capstan servo, which is solved by different means, but identical in principle. An electronic tachometer eccentricity cancellation device is as well utilized.

The power consumption is a most important factor in a portable unit. The head drum motor, which requires the largest share of the available power, must be as efficient as possible. The necessary high frequency response of the servo loop is more easily obtainable with a motor having a dc motor transfer characteristic. A brushless dc motor especially designed for this application is used.

The function of the tension-servo mechanism is to maintain the tape tension at a nearly constant value, from beginning to end of the reel of tape, and under any condition of tape friction or guide vacuum variation.

It was mentioned earlier that the capstan operates under the principle of "minimum work." This means that the power to move the tape is supplied by the take-up reel motor that works against the braking action of all frictions in the tape path plus that of a magnetic particle brake attached to the supply reel shaft. Ideally, the capstan does not supply any work when the tape is going at the proper speed, and only addition and subtraction of torque is needed when the tape speed differs from normal. The tension differential between the two sides of the capstan is maintained within limits by the tension-servo loop. The advantage of this scheme is that it leaves a large reserve of torque available to take care of the perturbations.

The only readily available batteries which meet the weight and size requirements are silver-cadmium units. The batteries chosen supply about 3W per ounce of battery over 60-minute operational periods without risking damage due to overdischarge. A battery having a nominal voltage of 33 v was chosen, and a center-tape is provided. This permits an adequate voltage for 12 v regulators even when the battery is at the end of its discharge cycle, at which time its voltage will fall to plus and minus 14 v.

Taking wattage, voltage, age factor, and reserve into account indicates a battery having a capacity of four ampere-hours. The battery in use consists of 10 three-cell units of 3.3 v each. When interconnected and packaged in an insulated container with connector, the completed battery weights seven pounds. Where ac power is available the portable video recorder can be operated from a battery eliminator ac power pack in place of the battery pack. The portable quadruplex video recorder, and companion camera, serve as excellent examples of the weight and size economies to be gained by careful selection of energy convertors and careful matching of those convertors to the work load. The weight of the recorder is 55 pounds including the back pack rack, an additional approximate weight in the hand-held camera is 15 lbs.

The signal system function is to supply the recording heads with the proper frequency modulated current to drive the tape. The recording capability of the portable video recorder signal system produces a final recording equal to that previously described in the VR-2000 video tape recorder/reproducer and with a power consumption of only a fraction of what is required. It uses the technique of square-wave recording signals, presenting the advantage of a less critical optimization of the head current, and less sensitivity to stray magnetic fields. The advantages of integrated circuits have been fully taken, as well as the power consumed per circuit function is generally less.

Verification of recorder performance is provided and playback is accomplished from the demodulator output. This, of course, does not provide for the regular signal processing amplifier. The composite uncorrected video output is of sufficient quality level for audition of recorded takes and good verification in field operations. Video tapes recorded on the VR-3000 portable recorder will provide the same high quality playback level as though they were originally recorded on the VR-2000 recorder/reproducer.

The portable recorder is designed to accommodate European television recording standards by simply replacing a single circuit board in the recorder electronics.

Beyond the fact of compatibility with other broadcast recorders and the interchangeability of video tape recordings, it is essential to preserve the final stability of the recording within a wide range of environmental and motion conditions; such as in flight and mobile field operations. In quadruplex recorders, longitudinal tape flutter is not translated as much into video time base instability since the primary head-to-tape velocity component is transverse to the tape motion. This, and the advantage of the lighter mass, and low inertia of the quadruplex rotary head drum format is most favorable to the realization of the necessary high performance servo system providing better angular error correction and acceptable time base stability particularly critical in color television broadcasting application.

THE STANDARDIZATION OF VIDEO TAPE RECORDING

Before discussing the standardization of video tape recording, it might be useful to review the overall program of standardization handled by SMPTE. Basically, all American standardization goes through the United States of America Standards Institute (USASI), formerly the American Standards Association (ASA). The ASA has since been reorganized and is now a new corporation, the USASI. This organization holds the responsibility in the United States for all national standards which are often generated in many places and through many channels. The SMPTE generates through its engineering committees all of the standards in the motion picture field, and currently many of the standards in the operational phase of the television field.

One may consider that USASI Standards are formed by a seven-link chain. The first link is the origin. Standards do not necessarily originate within SMPTE engineering committees, although this is generally the case. They can originate anywhere.

Once the need for a standard has been established, the video tape recording engineering committee formally takes it under study. If the proposal needs work, it is turned over to a small subcommittee appointed by the main committee, which prepares the first document and circulates it to the full engineering committee for a letter ballot. Once approved, the proposal is then reviewed by the SMPTE Standards Committee, which consists of the chairmen of all SMPTE engineering committees. At this level the committee takes a look at the standard with respect to the overall field. For example, if a standard is generated in the Video Tape Recording Committee, the Sound Committee chairman then looks at it in terms of that committee's responsibility.

Once a draft standard is approved by the SMPTE Standards Committee, it is published in the SMPTE's Journal for a trial period during which time criticism is invited. All comments are reviewed by the chairman of the Reviewing Committee as well as the chairman of the USASI Standards Committee which review the document concurrent with publication. This committee operates under USASI regulations and belongs to the organizations which make up the membership. Here, the voting members speak for their companies and examine the proposal in terms of industrial acceptance. The SMPTE, as the administrative sponsor of the USASI Standards Committee C-98, carries the responsibility for insuring that a balance of membership is maintained by the producers, distributors, retailers and consumers. It further assures that the views of all parties substantially concerned have been considered in the preparation of the standards. As sponsor, the SMPTE also acts as a secretariat for all committee functions and responsibilities.

With the approval of the USA Standards Committee, the SMPTE Board of Governors, as the official voice of the society, gives the society's approval. The document then proceeds to the USASI Standards Board. Once this approval is received, the standard becomes a USA Standard, and is published in the Journal for public information and there first utilized for reference purposes.

Although the society generates standards, it does not provide the document for sale. Once a standard is approved by the USASI, it becomes their property and is published and distributed by the institute.

Another document that the society generates is the Recommended Practices. There is a philosophical difference between the Recommended Practices, and the Standard. They are both generated by the same people but the Recommended Practices are considered more as for good engineering practices to the industry than as basic standards.

A serious area of misunderstanding involves the difference between a standard and specification. Many people come to the society asking for a standard when in reality they want a specification. For many reasons a scientific organization such as the SMPTE cannot write specifications. This is done by trade organizations. For instance, there are many associations in the television field—the Electronic Industries Association (EIA), the National Association of Broadcasters (NAB), and many others. One can say that the difference between the two types of organizations is that the technical society generates the numbers and then the trade association writes these numbers into specifications.

The rapid growth of the field of Electrical Standards has resulted in the problem of borderline responsibilities. These problems are dealt with through a group called the Joint Committee for Inter-Society Coordination, which has representatives from the NAB, the Institute of Electrical and Electronic Engineers (IEEE), the Electrical Industries Association (EIA) and the SMPTE. If a proposal is submitted, which appears to fall under more than one organization, the JCIC decides which of these four should undertake the task.

The SMPTE also works on the International level. Quite recently, a technical committee was organized for the standardization of video tape recording through the International Electrotechnical Committee (IEC). The first meeting of this committee (SC60B) was held in March of 1968 in Paris.

The Video Tape Recording Committee has been functioning for over 18 years. The first meeting was held in June of 1958 under the chairmanship of Howard Chinn of CBS. It has been meeting regularly since then.

Throughout the history of the committee the emphasis, of course, has been on quadruplex recording for broadcast uses. The main assumption underlying this effort is the concern for interchangeability. When a video tape recording has been sent to a user in another location, it should play back on their machine as well as it does on the equipment providing the original recording. In order to illustrate the kind of guidance that the committee has received from the SMPTE Board of Directors, we may examine the charge of the committee. "To propose standards and good engineering practices for the construction, adjustment, operation and measurement of video tape recording and reproducing equipment and for those video tape dimensions or other characteristics which affect performance and interchangeability."

This, of course, is a reasonably general charge, and out of the whole spectrum of problems that arise in the process of developing a technology as complex as video tape, it has been necessary to study certain priority items before others.

The membership in the committee consists of experts—people who operate and manufacture equipment and are most concerned with video tape recording. In terms of their participation in the work of the committee, the members vote as individual experts and not as spokesmen for their companies.

The turnover in membership from year to year has not been great, but the committee has been expanded as the need for entry into various areas of this technology has arisen. Normally VTR Committee meetings are held about every two months in New York City at SMPTE Headquarters. The meetings are open to visitors.

It is worth noting that Recommended Practices are usually less menable to being locked up, so the Recommended Practices technique of expressing a consensus on the way to do something is useful. It allows a more rapid consolidation of information and dissemination of it into the field.

There is a good example of this in the case of RP11. This is the Recommended Practices dealing with the radius of the tape vacuum guide and its position for producing a standard video tape recording. This may seem like a relatively simple document when read, but the variables that were considered in drafting it are quite numerous. One has to compromise head wear and tape wear with dropout activity, for example. The whole question of friction between the rotating head and the tape as it affects servo-stability and tape life had to be evaluated. Data was gathered on both head wear and tape wear. This illustrates what may go into a document that ends up being less than a full page of typewritten material.

The committee is constantly revising or considering revision of existing documents. Automatic review is built into both the USASI Standards program and the SMPTE Recommended Practices program. The documents are reexamined at least every five years.

So far as future committee work is concerned, this depends on the rate of progress that the industry exhibits, and on the problems that are communicated to the committee. International activities will also dictate activity at home. The IEC, the International Electrotechnical Commission, and other groups—CCIR, the Consultative Committee for International Radio, and the EBU, the European Broadcasting Union—are at work on video tape recording standards. In general these reflect our USA documents, but are, of course, adapted where necessary to the fifty-field television systems used in Europe.

VIDEO TAPE RECORDING

"USA Standards"

C98.1	Dimensions of 2-In. Video Magnetic Tape
C98.2	Monochrome Video Magnetic Tape Leader
C98.3	Audio Records for 2-In. Video Magnetic Tape Recordings
C98.4	Speed of 2-In. Video Magnetic Tape
C98.5	2-In. Video Magnetic Tape Reels
C98.6	Video, Audio and Tracking Control Records on 2-In. Video Magnetic Tape
C98.7	Primary Audio Reference Level Recording for Quadruplex Video Magnetic Tape Recorders Operating at 15 In./s
C98.8	Audio Level and Multifrequency Test Tape for Quadruplex Video Magnetic Tape Recorders Operating at 15 In./s
C98.9	Color Video Magnetic Tape Leader
C98.10	Primary Audio Reference Level Recording for Quadruplex Video Magnetic Tape Recorders Operating at 7.5 In./s
C98.11	Audio Level and Multifrequency Test Tape for Quadruplex Video Magnetic Tape Recorders Operating at 7.5 In./s

Note: The above listed "USA Standards" (USASI) may be obtained from the:

United States of America Standards Institute
10 East 40th Street
New York, N.Y. 10016

VIDEO TAPE RECORDING

"SMPTE Recommended Practices"

RP 5	Dimensions of Patch Splices in 2-In. Video Magnetic Tape
RP 6	Reference Carrier Frequencies and De-Emphasis Characteristics for 2-In. Quadruplex Video Magnetic Tape Recording
RP 10	Video Alignment Signal Specifications for Quadruplex Video Magnetic Tape Recording
RP 11	Tape Vacuum Guide Radius and position for 2-In. Quadruplex Video Magnetic Tape Recording
RP 16	Specifications of Tracking Control Record for 2-In. Quadruplex Video Magnetic Tape Recordings
RP 26	Label Specifications for 2-In. Quadruplex Video Magnetic Tape Recordings
RP 29	Video Test Tape for Quadruplex Video Frequency Mag. Tape Recorders Operating at 15 In./s and Practice LBM of SMPTE RP 6
RP 30	Video Test Tape for Quadruplex Video Frequency Mag. Tape Recorders Operating at 7.5 In./s and Practice LBM of SMPTE RP 6
RP 31	Video Test Tape for Quadruplex Video Frequency Mag. Tape Recorders Operating at 15 In./s and Practice LBC of SMPTE RP 6

Note: The above listed "SMPTE Recommended Practices" may be obtained from the:

Society of Motion Picture and Television Engineers
862 Scarsdale Ave.
Scarsdale, N.Y. 10583

BIBLIOGRAPHY

Alden, A.E., Staff Engineer, The Society of Motion Picture and Television Engineers, "The Standardization of Video Tape Recording," (Unpublished).

Anderson, C.E. Ampex Corp., Redwood City, Calif., "The Modulation System of the Ampex Video Tape Recorder," *SMPTE Journal,* **66**, April 1967.

Bounsall, N.F. Ampex Corporation, Redwood City, Calif., "Electronic Editing of Magnetic Television Tape Recording," *SMPTE Journal,* **71,** (2), Feb. 1962.

Busby, E.S., Senior Engineer, Ampex Corp., Redwood City, Calif., "Power Economy Considerations in a Portable Video Recorder," *The Royal Society Journal,* **12**(2), 1968.

Clark, H.V. Staff Engineer, Ampex Corp., Redwood City, Calif., "Inter-Synchronization of Television Magnetic Recorders," presented at SMPTE Conference, Los Angeles, Calif., May 1960.

Coleman, C.H. Ampex Corp., Redwood City, Calif., "Techniques for Multiple Generation Color Video Tapes—Today and Tomorrow," presented at the NAB Convention 1966.

Coleman, C.H. Ampex Corp., Redwood City, Calif., "Part II, The Choice of Frequency Parameters in Color Television," presented at the International Conference on Magnetic Recording, Institute of Electrical Engineers, London, July 6-10, 1964.

Dolby, R.M. "Rotary-Head Switching in the Ampex Video Tape Recorder," *SMPTE Journal*, **66,** April 1967.

Esterly,D. & Skalon, P. Ampex Corp.,Redwood City, Calif., "Video Recorder Head Tip Wear," *Broadcast Engineering.* March 1968.

Felix, M.O. Ampex Corp., Redwood City, Calif., "Part I, F.M. Systems of Exceptional Bandwidth," presented at the International Conference on Magnetic Recording, Institute of Electrical Engineers, London, July 6-10, 1964.

Ginsburg, C.P. Ampex Corp., Redwood City, Calif., "A New Magnetic Video Recording System," *SMPTE Journal,* **65,** 1956.

Ginsburg, C.P. Ampex Corp., Redwood City, Calif., "Interchangeability of Video Tape Recorders," *SMPTE Journal*, **67,** 1958.

King, J. & Anderson, C.E. Ampex Corp., Redwood City, Calif., "Tape Tips and Standards," *Bulletin, Video Engineering, Ampex Corp.*

Lemoine, M.G., Ampex Corp., Redwood City, Calif., "The Particularity of Design in the VR-3000," presented at the Fifth International Television Symposium, Montreux, Switzerland, May 1967.

Minnesota Mining & Mfg. Co., St. Paul, Minn., "Video Talk, Bulletin No. 2," March 1, 1960.

Minnesota Mining & Mfg. Co., Technical Services Magnetic Products Division, St. Paul, Minn., "The Handling and Storage of Video Recording Tape," **1**(2), 1968.

Poole, B.M. Ampex Corporation, Redwood City, Calif., "Television Applications of the Magnetic Disc Recorder," (Unpublished).

Roizen, Joseph, "Modern Methods of Magnetic Video Recording," *Broadcast Journal,* Nov./Dec. 1968.

Stanley, C.B. Ampex Corp., Redwood City, Calif., "How Environment Affects Magnetic Recording Tape," *Bulletin, Ampex Corp.*

Stratton, L. Ampex Corp., Redwood City, Calif., "Reviewing Slow Motion Disc Principles," *Broadcast Engineering,* Feb. 69.

28

Film for Television

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FILM IN TELEVISION PROGRAMMING

From the inception of television broadcasting, the motion picture film medium has been a prime source for the television broadcaster of program materials. The combining of television with the well-established technical and commercial practice of the motion picture medium has benefited each.

In looking for a convenient, economical method of local program origination, television stations and CATV operators find that film meets most of their requirements. At the same time, this medium offers a number of attractive operational advantages, such as excellent image quality, production flexibility, ease of editing, simplicity in program distribution, and worldwide interchangeability.

Television stations make use of film in two broad categories—complete programs produced by others and received by the stations essentially ready for broadcast and local in-house program production utilizing film as the recording medium. These merge as they reach the electronic film reproducing equipment (telecine) for transmission by the stations to the viewing public. Film is utilized extensively by television stations for local commercials, documentaries, public affairs, sports events, and especially for reporting local news events.

Network Film Use

The major networks usually feed their program distribution systems with images originating from 35 mm prints—feature pictures, prime-time productions, and national market commercials. These films are usually produced by large professional motion picture production companies. The large print image size and substantial production budgets produce excellent technical quality characteristics in both pictures and sound. Quality-control personnel representing the networks deal directly with the film production companies responsible for the original photography and also with the film laboratories where the prints are made. This communication between the broadcaster and the laboratory provides the highest possible picture and sound quality. In addition, the networks also make use of large quantitues of 16 mm film for sports, documentaries, and especially for news reporting.

The scope of network operation is so broad, so well staffed and equipped, that it is really a professional motion picture production activity comparable to many large units of the motion picture industry.

Individual Station Film Use

The use of 16 mm motion picture film for broadcasting is almost universal with television stations outside of the network centers. Most of the film programming materials are provided to the stations through film distributing agencies. The 16 mm film format has been and is still widely used for lower budget motion pictures and for the vast number of education, industrial, documentary, and commercial subjects commonly known as "nontheatrical" films which are intended for direct projection for smaller audiences instead of distribution to motion picture theaters.

Most stations shoot their own local news, and many are producing commercials, documentaries, and other program material. Local assignments can be handled by one person, the camera operator; a full crew, including sound and lighting technicians, seldom exceeds three persons. Film cameras can be taken anywhere. Power for the camera motor can be supplied from small batteries carried in a belt. Programs can be produced in black-and-white and color with the same camera—only the recording material, film, has to be changed.

A 16 mm film camera is a relatively simple optical-mechanical device that requires very little maintenance. Most professional cameras are of moderate weight, easily portable by one person, and require only very little setup time on location. The sound is usually recorded on a magnetic stripe on the edge of the picture film (single-system sound), or separate synchronous sound can be recorded on a compact professional 1/4-in. tape recorder (double-system sound).

Overview of Film in TV

The fact that some films do not conform with minimum and maximum densities for TV use has prompted the adoption of automatic signal level control devices in an attempt to maintain white signal level at 100 IEEE units and picture blacks near setup level while disregarding picture content. This automatic approach often changes or defeats the effects that the producer/director may have been trying to achieve.

Signal level compensation is necessary, as some film image densities continue to vary beyond acceptable limits. Industry recommendations give a value for the film minimum density of not less than 0.3, while the maximum density should not exceed 2.5 in any image areas where important picture details are located.[1] Densities between 2.35 and 2.5 will suffer some black compression resulting in less than faithful reproduction of the tonal gradations. The degree of such image degradation depends to some extent on the telecine operating characteristics.

Modern color films are capable of producing excellent television pictures when the film has been correctly exposed and the telecine reproduction equipment has been properly adjusted. In recent years a great deal of time and effort has been expended in investigations of the various factors adversely affecting film reproduction in the television system. Out of these investigations have come recommendations for film program production and for telecine alignment designed to give consistently high picture quality. In the following pages, details of these recommendations are given, as well as practical working methods for the implementation of these recommendations.

[1]SMPTE Recommended Practice RP 46-1972, "Density of Color Films and Slides for Television (final)."

Benefits of Film in TV

The capital cost of film equipment is quite modest compared with all-electronic production facilities. Film offers worldwide program interchangeability, since dimensions, projection rates, image sizes, and sound track locations have been internationally standardized. In addition, film provides visible picture images, greatly simplifying program assembly operations. Films made for television reproduction will also perform satisfactorily on direct screen presentations as well.

TYPES OF TELECINES

There are two common types of light-receiving tubes currently in use in the telecine color camera: the Plumbicon and the vidicon.

Camera-type telecines utilizing vidicon tubes are by far the most popular and are generally used in North America. A vidicon tube translates an optical image into voltage variations that can be retranslated into a TV image. The quality of the television pictures obtainable with properly made films in properly adjusted and maintained vidicon telecines can be very good indeed, comparable with television pictures from other sources.

Television stations are being urged also to provide carefully controlled viewing conditions for television films. When this is accomplished, failure to properly reproduce films in telecine can be readily detected.

Some television engineers feel that telecine cameras should be fitted with Plumbicon tubes to gain additional improvements in the reproduction of films. Telecines have been designed with switchable masking capability to compensate for the characteristics of various film dyes. Electronic masking is employed to make the pictures from film match the pictures from live television cameras.

The Plumbicon tube offers some advantages in this highly specialized type of service. However, for general telecine use, the less costly vidicon tube is capable of giving satisfactory results. Also important are improvements in film production to take full advantage of the excellent television reproducing conditions already available.

FLYING-SPOT SCANNERS

In a flying-spot scanner (Fig. 1), a cathode-ray tube is utilized as the light source. The rapidly moving spot of light at the face of the tube is focused on the film, and the light transmitted by the film images is converted into a video signal by a light-sensitive device (photo-

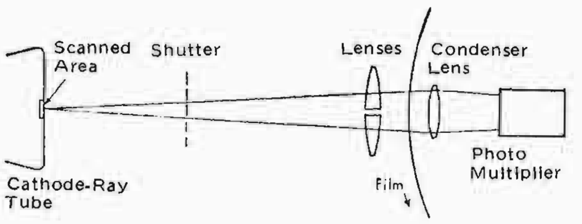


Fig. 1. Essential components of a twin-lens flying-spot telecine. (From *Color Film for Color Television* by Rodger Ross.)

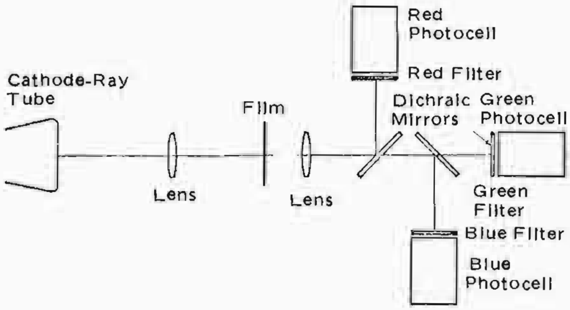


Fig. 2. Essential components of a color flying-spot scanner. (From *Color Film for Color Television* by Rodger Ross.)

cell). In a color flying-spot scanner (Fig. 2) three photocells are used in an optical system with color separation filters.

Another technique for utilizing the flying-spot principle in 30-frame television systems is to pull down the film within the vertical blanking interval and then scan the film while it is stationary, in the familiar 2-3-2 sequence. Pulling down the film in the vertical blanking interval—1.14 msec.—cannot be achieved with conventional mechanical methods. One alternative is to utilize the technique of penumatic film pulldown.

IMAGE ENHANCEMENT AND COLOR MASKING

Resolution and color fidelity of broadcast motion picture color film can be improved through vertical aperture equalization and bandwidth limited color masking. An image enhancer and associated masking amplifier[2] makes it possible for a color telecine camera to produce a picture that is equal to the best obtainable from studio cameras.

Image enhancement is a combination of vertical and horizontal sharpening used to compensate the relatively soft images of color cameras and the color kinescope in the receiver. Subjective tests show that the eye desires overenhancement of average subject matter, so much so, in fact, that a test pattern looks greatly overpeaked.

Color distortions of the Plumbicon cameras can be corrected by the installation of masking amplifiers. Flesh tones and saturated reds show a remarkable improvement with this technique (see Footnote 2).

FRAME-RATE CONVERSION

The standard motion picture filming rate in the United States is 24 frames per second, while 25 frames per second is used in Europe, England, and some other countries. Films have to be reproduced in television systems with different frame rates. In England and Europe, as well as the other countries, the standard television projection rate is 25 frames per second.

In North America and some other countries with a television frame rate of 30 frames per second, the conversion problem can be solved by utilizing telecines with storage-type camera tubes, such as the vidicon, and accelerated pulldown and modified shutter design to allow the 24 frames per second of the film projector to be broadcast at the television frame rate of 30 frames per second.

The vidicon tube has the interesting characteristic that if it is exposed for at least 30 percent of active scanning time and the same area of the photoconductive layer is exposed each time, there will be no noticeable discontinuities in the television pictures. The projectors must be fitted with a shutter having five narrow openings, and the pulldown mechanism must be so designed that one film frame is exposed twice, the next three times, the third twice, and so on.

A very important consideration here is that film pulldown can occur anywhere in the television scanning cycle; that is, pulldown does not have to be restricted to the television vertical blanking interval. This gives broadcasters a great deal of freedom in switching to and from the telecine camera output.

TEST FILMS AND THEIR USE

Alignment of the slide and motion picture projectors to the TV input requires accurate positioning of each projector with the multiplexer. To position the projector accurately, it is necessary to view a projected image while using some sort of an alignment or target device (a slide or a motion picture film).

For slide projector alignment, the registration slide and field-size slides are inserted into the projector and the projector can be adjusted for each slide accordingly.

[2] *Journal of the SMPTE*, 1968, **77**(3).

The motion picture projector should be threaded with a suitable test film—a 35 mm Television Test Film (TV35-AS), a 16 mm Television Test Film (TV16-AS), or Super 8 Television Test Film (RP-32). Adjust according to recommended procedures. (These films are available from the Society of Motion Picture and Television Engineers, 862 Scarsdale Ave., Scarsdale, N.Y. 10583.)

OPTICAL SOUND

The gain and frequency response of the optical sound system is affected by the sharpness of the scanning slit image and the position of that image with respect to the optical sound track.

For this test, thread a film—such as a 16 mm Television Test Sound Focusing Film, Type A, 700 Hz, or a 16 mm Television Test Sound Focusing Film, Type B, 5,000 Hz—through the projector with the emulsion toward the lens.

Optical sound test films are also available from the SMPTE at the above address.

SUGGESTED SETUP PROCEDURES

The setup procedures outlined in this section are of a general nature. Manufacturer's recommendations are supplied with each telecine camera, and these must be followed to achieve peak performance. Even though reference has been made to vidicons, where appropriate, these statements also apply to Plumbicons. It is not necessary to accomplish all of the setup procedures on a daily basis. However, it is recommended that a periodic check, on a scheduled basis, be conducted to make sure that consistent high-quality operation of the telecine camera is obtained. The check procedure should include the following.[3]

A. Check the telecine electronically per the manufacturer's recommendations.

B. Make sure that the exterior optics of the slide and motion picture projectors are clean.

C. Make sure that the telecine camera optics are clean. If not, clean according to the manufacturer's recommendations.

D. Calibrate waveform monitor.

E. Insert Cross Step Gray Scale and follow recommended procedure. (See following procedures.)

F. Check and adjust encoder.

G. Set up color picture monitor.

H. Set telecine camera operating levels, both manual and automatic.

I. Adjust telecine for camera minimum subcarrier.

J. Operating telecine camera in a manual mode, check each projector for proper color and intensity match.

IMPROVING BROADCAST QUALITY[4]

General procedures

At each television station, the color telecine should be closely examined. The *cleanliness of the optical elements* and *the alignment of projectors* require early attention because of the possible adverse effect they can have on the chain's performance. A Cross Step Gray Scale slide can be used to make objective measurements of the condition of the telecine by using one of the 16 mm projectors, running without film, as the light source. The resulting video waveforms can then be analyzed for proper step placement, and where necessary (and possible) adjustments should be made to *correct shading errors, optimize gamma,* and *establish acceptable tracking to obtain proper tone reproduction and a neutral color balance.* Some procedures may differ from station to station because of the differences in telecine cameras and the nature of the problems that might be encountered.

In order to properly display the subjective color test film, set up a color picture monitor and adjust it to produce 6500 K correlated color temperature at a 20-fL peak white brightness. Then run the color print, balanced for 5400 K projection, on the telecine chain and in most cases it will produce a very good picture. Where an acceptable picture is not produced, electronic or optical problems probably exist and usually have been noted in earlier tests with the Gray Scale Slide. The color print can also be viewed by direct projection using a modified projector and special screen to give an open-gate brightness of 40 fL at a color temperature of 5400 K. Under these conditions the projected image should match the monitor image very well.

Procedures for the Color Picture Monitor

Since the setting up or adjustment of almost any piece of equipment in a television station at some time requires a subjective picture evaluation, a high quality, professional color monitor is essential. As yet there is no standard setup procedure for color picture monitors, but there are generally accepted procedures and recommendations that will produce excellent pictures

[3]*Journal of the SMPTE,* 1971, **80** (12).

[4]*Journal of the SMPTE,* 1971, **80**, 973-976.

on a properly functioning monitor. A basically visual approach can be used to establish the various parameters of the color monitor on which results from the film chain are to be viewed.

Before adjusting the color picture monitor, *it is essential to check the precision of the station's color bars and adjust them, when necessary, to the required accuracy.* Also, it is necessary to make certain that the waveform monitor display is an accurate representation of what is actually getting to the color monitor—that is, that there are no level differences through switchers or other devices.

The most critical monitor adjustment is the setting of the color of peak white. This has always been a major problem in matching color monitors and in maintaining their day-to-day consistency. The brightness level of the peak white must also be properly set. Such adjustments can be made quickly and accurately, using a visual comparator. The comparator is a concentric field comparison instrument employing a low-voltage, tungsten-halogen lamp to illuminate the comparison field at an appropriate brightness level to establish a peak white brightness on the picture monitor of 20 fL at a correlated color temperature of 6500 K to within ±2 fL and ±200 K. The device is placed at the color picture monitor so that the 100 percent white from the split-field color bar pattern or from a "window" signal appears in the center of the reference field. The color of the monitor white can be made to match the reference field by adjusting the blue and green drives or, on some color monitors, red and green. The picture monitor brightness is made to match the reference field by adjusting the contrast control.

There are other instruments that can be used to set the peak white of the color picture monitor. Several available photoelectric instruments are excellent for reproducing an established setup, but they should be calibrated for different types of color monitors.

The validity of the subjective evaluation of the color film chain is dependent upon the proper performance of the color monitor. One of the most frequently encountered monitor problems is poor tracking.

Although a color picture monitor set to D_{6500} produces a pleasing color picture, many persons object to the appearance of a black-and-white picture displayed under these conditions because of its reddish hue when compared with the same picture on a black-and-white monitor that has a white comparable to 9300 K white. Some stations change the "color" of their black-and-white monitors with a filter to make them match the lower color temperature color monitor.

Optical Signal Generator

Usually a primary concern is the proper adjustment of the television film chain. Causes of poor quality of television images from good film can be traced to poor film chain performance, lack of color balance uniformity between chains, etc. There are many reasons for these conditions, but uppermost seems to be the lack of well-defined parameters for establishing the optimum condition of the color film chain camera for reproducing color films. Different television stations have different gray scale test objects, or other "neutral" test objects, that are used in a variety of ways. Some stations use selected color films as subjective reference films, although frequently they do not conform to current recommended practices for such reference films. At the present, there is no standard practice for telecine setup.

Cross Step Gray Scale Slide

An important device for the maintenance of good broadcast quality is the Cross Step Gray Scale Slide[5] (Fig. 2A). This slide is intended for use in the checking of the following characteristics of a telecine camera in the color television film chain:

1. Setup and balance of gains and black level.
2. Operation of the gamma-correction circuitry.
3. Amplitude tracking among video signal channels.
4. Light-signal transfer. Light-input, signal-output, transfer characteristic.
5. Compression or clipping in the video signal channels.
6. Shading controls to minimize field nonuniformity.

Requirements for a Light Modulator[6]

The light input to a television film chain is converted to variations of electrical voltage with time. The characteristics of this output signal must be controlled within certain well-specified limits so that a good signal will be available for broadcast. This fact is taken into account in the design of the telecine camera and also in the operational adjustment of certain controls available on the camera.

Necessary to this operational adjustment is a calibrated light modulator that has enough of the optical characteristics of the film input to be

[5]A typical slide is manufactured by Eastman Kodak Company.

[6]*Journal of the SMPTE*, 1971, **80**, 970-972.

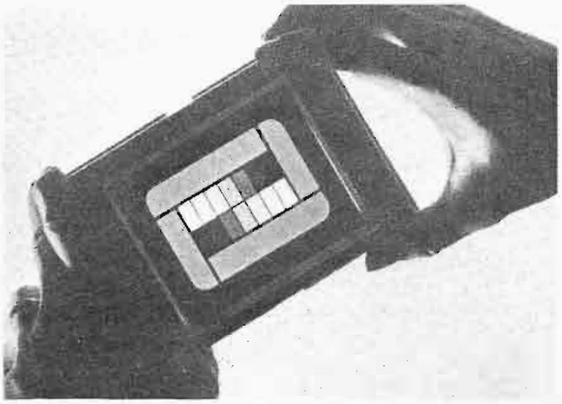


Fig. 2A. Cross Step Gray Scale slide for telecine camera test as specified in RP 27.7-1972. (VIDEO film NOTES, Kodak Publication No. H-40-4, p. 5.)

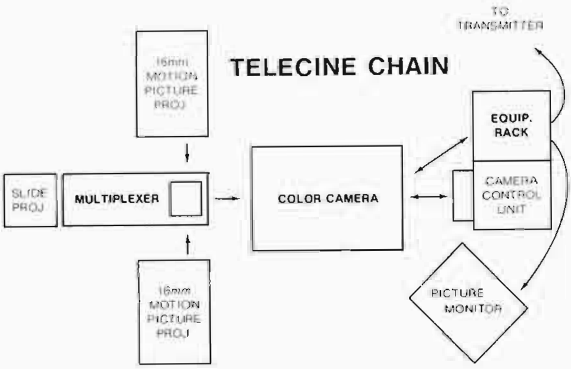


Fig. 3. Basic components of telecine chain. (VIDEO film NOTES, Kodak Publication No. H-40-4.)

valid and that can produce an instrumental display for the television engineer to read and manipulate. Tradition and practice have resulted in a step-scale gray modulator that is displayed on a waveform monitor as a "staircase" in which the "risers" are the voltage increments corresponding to the transmission increments, and the "treads" are the time units corresponding to the horizontal dimension of the steps. By adjusting gain and blanking controls in each of the channels, the proper dynamic range can be obtained, and the three color channels can be made to conform with each other (gray-scale tracking). In addition, a properly designed modulator can be used during the adjustment of the shading (field uniformity) controls.

Position and Size of Test Slide

Most television film chains are multiplexed; that is, several projectors feed one camera (Fig. 3). Usually this combination is two 16 mm projectors and 2 × 2-in. slide projector, with a system of movable mirrors and a relay or field lens between the projectors and the camera. It is desirable that the output of the three optical projectors be matched for color balance, intensity, and shading, as far as possible. It has been customary, as a matter of convenience, to use a light modulator of 2 × 2 in. format in the slide projector of the multiplexed telecine. This means that the chain is adjusted to optimize the output of that projector. Yet the motion picture films used on the other two projectors represent considerably more broadcasting time and usually more critical subject matter. Therefore, it is desirable to be able to use a 16 mm projector as the input source during adjustment. A light modulator in the field-lens position solves this problem, since it can be used to examine and adjust for any of the input sources. This requirement dictates that a slide be large enough to be used in the field-lens position. The standard 3 1/4 × 4-in. slide is adequate for this purpose.

To accomplish these functions, the modulator must have the characteristic of not scattering light. In addition, it must be neutral in color, and it must be stable when exposed to light and heat.

Format

The format of the slide (Fig. 4) depends directly on the oscilloscope display that is desired. The size of the steps is a compromise between a need to confine the entire staircase to a small central area to minimize the effects of shading and a need to have a display large enough to be visible on the oscilloscope. The adoption of the crossed-staircase design is a direct result of the shading problem; the redundancy of the double display is useful in quickly determining if there is a shading problem. The choice of the number of steps is a compromise between the desire for a very simple display and a need to have several data points. An odd number of steps allows the crossover to fall on a step, rather than between two steps.

A mid-density, uniform background serves two functions. It provides an average transmission similar to that of average picture level (APL). In addition, the uniform surround provides the signal at a critical signal level for monitoring adjustment of shading or uniformity controls at both the optical and electrical stages.

Transmission Values

The SMPTE Recommended Practice[7] for such a telecine slide (RP27.7-1972) calls for the steps

[7]SMPTE Recommended Practice on Specifications for Grav-Scale Operational Alignment Test Pattern for Telecine Cameras RP 27.7-1972 (final).

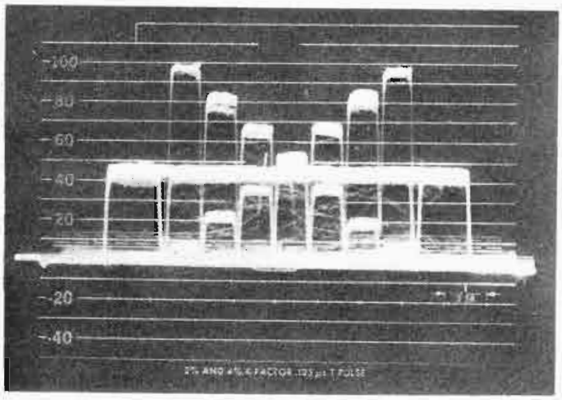


Fig. 4. Waveform monitor display of crossed-step slide in a well-adjusted film chain. (VIDEO film NOTES, Kodak Publication No. H-40-4.)

in the pattern to follow a 2.5 power law increase in transmission over a 40:1 contrast range, from the next most dense step to the least dense step. The most dense step is to fall at a one-half step increment below the adjacent step on the 2.5 power law curve. The intent of the 2.5 power law is to relate directly to the gamma of the display tube.

The least dense step has a value of 50 percent transmission (D=0.3). This corresponds to the least dense end of the tolerance of the recommended density for white objects reproduced on film.

The surround density is specified at 1.14, which satisfies the requirement for average picture level, and puts the waveform display of the surround halfway between two of the gray-scale steps.

The density and transmission specifications for the slide are given in Table 1.

TABLE 1

Density and Transmission Specifications for Slides

Step	Diffuse density	Transmittance, %
1	0.30 ± .01	50
2	0.48 ± .01	32.9
3	0.70 ± .02	19.9
4	0.98 ± .02	10.6
5	1.34 ± .03	4.5
6	1.90 ± .04	1.25
7	2.35 ± .05	0.45
Surround	1.14 ± .03	7.2

Note: ISO Recommendation R5-1955, Diffuse Transmission Density (Photography).

Use of the Slide

Since the slide is not used for geometrical alignment, its location at the field-lens position is not critical. Although theory may call for the slide to be placed in the center of that lens, in actual practice the depth of field at this position is great enough to allow considerable leeway. It is possible to place the slide at least 2 in. from the field lens of several telecine chains and still obtain an image enough in focus to present a well-defined waveform. Ideally, for operational convenience a holder for the slide should be part of the camera equipment so that the slide can be inserted in the optical path during alignment, yet easily stored out of the way during broadcasting.

Inasmuch as the least dense step is intended to correspond to television white level, it is obvious that the gain control of the television film camera should be adjusted to display 100 IEEE units, in each channel. Specification of black level is less certain. On many film chains the best display of film is obtained when the black level corresponds to the absence of light. The opaque border of the slide provides a convenient signal for setting black. Its waveform display should be controlled by setting blanking controls so that it is just above blanking level, which may be a 7.5 IEEE units if "setup" is used.

The waveform monitor display resulting from use of this slide in a well-adjusted film chain is shown in Fig. 4. This is the encoded signal with the monitor in the IEEE response condition. The crossed staircase is clearly defined with each step being easily visible. The horizontal display of the uniform surround, showing between the 4th and 5th steps, illustrates the excellent shading or uniformity of this chain.

Storage and Handling

Remove the slide from the optical path at the field lens position when all of the tests have been completed.

The slide is an optical signal modulator. Since it is made of glass, the two main dangers to the slide are breakage and scratching. Dust and fingerprints should be removed by wiping with a soft, lintless cloth or lens tissue moistened with a suitable lens cleaner. Ordinary exposure to heat and light will not affect the slide. If the telecine camera is equipped with a slide holder that can be moved in and out of the optical path, storage in the holder is adequate; otherwise, when not in use, the slide should be stored in a protective case.

Color Telecine Camera Setup

Shading

The shading of all projector inputs should be adjusted before attempting any camera adjustments. The uniform gray background of a Cross Step Gray Scale slide should be used for making shading adjustments since it is at a very sensitive density level. It is easy to distinguish between projector illumination uneveness and camera shading problems because the former almost always appears as intensity variations in all channels, whereas the latter will show up in only one or two channels, or variations will appear in all channels. If a projector shading problem is evident, telecine camera shading controls should not be used in an attempt to improve it, since those controls were not intended to handle this type of problem and are usually inadequate to correct nonuniform light application. Instead, the projector should be checked to see if it is properly aligned with the other optical elements of the film chain. Improper alignment of projector lamps, reflectors, and condensers is sometimes the cause of shading problems. These misadjustments are relatively easy to locate and remedy. Gross mismatches of projection distances and field lens power can produce a "porthole" shading problem. This occurs where the field lens power is not correct for all inputs. It can be corrected by selecting a lens with the proper focal length to give the projection distance required by the field lens.

Telecine camera shading problems should be corrected by adjusting the horizontal and vertical saw and parabola shading controls in each camera channel. This and subsequent camera adjustments should be performed using the Cross Step Scale slide with light from the most frequently used film projector.

The waveform monitor should show a horizontal line representing the gray background on both the two-frame and the two-field displays. It should occur about the middle of the scale—that is, at 50 IEEE units—but it can vary because at this point the operating levels of the camera have not been established.

Operating Levels

To set the proper operating levels, the waveform monitor is switched to IEEE response. The telecine camera channels are adjusted following the manufacturer's instructions to set the lightest step of the cross step slide at 100 IEEE units and the most dense step just above setup, or just above blanking if the operator is observing the signal before insertion of fixed setup. This establishes the maximum density range that the telecine camera can reproduce properly; that is, densities from 0.30 to 2.35.[8] Tonal gradations in the 2.35 to 2.5 range will be compressed resulting in loss of detail.

It is important that this portion of the camera setup procedure include adjustments to produce equal level settings in both the manual and the automatic operating modes, if used. If, then, a sudden automatic control failure should require the switching to manual operation, such a transition can be made without producing violent level fluctuations.

Some color film chains use electromechanical control of neutral density wedges on the projectors to compensate for the range of density levels encountered in programming slides and motion-picture films. Before undertaking to set up the telecine camera on such chains, the proper position of these wedges, i.e., the amount of neutral density attenuation in the projector light path, should be determined. The proper setting is that which allows the use of normal target voltage on the least sensitive vidicon camera system. The other vidicons can be brought close to the same target voltage by "padding" with neutral density filters mounted on the vidicon camera lenses.

If it is found that this wedge setting does not provide sufficient reserve density (that is, reserve camera sensitivity to accommodate moderately dense films) the projector should be checked to see if it is possible to increase its light output. Failing in this, it will be necessary to raise the target voltages; but rather than raising them to too high a value, the insensitive vidicon should be replaced.

In setting the neutral density wedge in this manner, a film may occasionally be encountered that will be too dense to produce a proper video signal. Such circumstances may require a special camera setup in order to program the film satisfactorily.

Lamp Voltages

It is a mistake to use excessively low projector lamp voltages. While there is some justification for running lamps about 10 percent below rated voltage to increase lamp life, further voltage reductions sacrifice too much light. Another all too common practice that wastes light is that of stopping down projection lenses to unnecessarily small apertures. The excuse offered is the need for depth of field to avoid having to refocus when running the reversed emulsion position on 16 mm films. Too often small aperture (slow) lenses are stopped down one stop below their

[8] RP-46-1972, approved July 1972.

maximum aperture as are large-aperture (fast) lenses, a procedure that seems ill-advised, since an *f*/4.5 lens wide open has the same depth of field as an *f*/2.3 lens stopped down to *f*/4.5, provided they are the same focal length.

Color Balance

The next step in the setup of the telecine camera is to provide precise gamma tracking and color balance. Following the telecine camera manufacturer's recommendations, equal gains are set in all channels so that identical signal levels at the output of the vidicons receive the same amplification. There can be, however, a luminance channel gain difference if a different type of vidicon is used in a four-tube camera.

The blanking, target voltages, channel gammas, and beam cutoffs are adjusted to produce equal response in all channels. This can be done conveniently by selecting, where possible, a sequential display for the waveform monitor. The match can often be improved by superimposing the outputs of the channels to make the touch-up adjustments. The final adjustments of the color channels should be made by nulling subcarrier when viewing the output of the encoder on the waveform monitor with flat response.

Of all the adjustments that should be made to optimize the camera, beam cutoffs are most frequently overlooked. It is recommended that they be set to "beam starve" at about 110 to 120 IEEE units, but at least they should cut off at the same level in the three-color channels so that a color shift will not occur during transitions from a dark or average scene to an extremely light one.

Blanking adjustments are made in all channels to place the bottom step of the cross-step display at a point just above system blanking. Target voltages should be set to establish peak white level by placing the lightest step of the display at 100 IEEE units. The target voltages at this point should be nearly equal. If they are not, neutral density filters should be placed in front of the more sensitive vidicons to allow their target voltages to be brought close to that of the least sensitive vidicon. However, if this latter vidicon's target voltage is considerably above that recommended by the manufacturer, it should be replaced. It is often possible to interchange vidicons in the color channels to avoid rejecting an insensitive one.

Before making the final adjustments on the camera, as noted earlier, the proper gammas should be established in each channel. With the cross-step levels properly set, the gamma circuits in each channel should be adjusted, using a Cross Step Gray Scale slide, so that the middle step of the display is at 55 IEEE units.

With telecine cameras that vary target voltages instead of using a neutral density wedge to change sensitivity, it is necessary to make sure that the subcarrier null in all steps is maintained over an adequate range of target voltages. This prevents a color change with a shift in film density. Careful neutral density padding of the vidicons in the color channels, optimum adjustment of high- and low-target voltage settings, and a good set of vidicons should provide an adequate range of target tracking.

TELECINE MAINTENANCE AND OPERATION

Maintenance of telecine cameras requires the same care and attention given to other electronic equipment in the television station. The quality of the television pictures obtained from film depends not only on the film but also on the condition of the reproducing equipment as well. Too often, poor quality film is given as the reason for poor television pictures, when the real cause of the trouble is in the television system itself.

A routine maintenance procedure should be set up in every television station to make sure that telecine equipment is operating properly at all times. Through the proper use of readily available and inexpensive test films, patterns of good performance can be established in a short time.

Every morning the optical and electronic systems should be checked, including the sound-reproducing channel, with the appropriate test films. Setting up the telecine camera with the gray scale test slide, as described in a previous section, will provide a good deal of information on overall camera performance. This serves also as an excellent starting point for the day's operations.

FLARE

The quality of the broadcast television pictures from motion picture film can often be severely degraded by insufficient or inadequate equipment maintenance. An accumulation of dust, smudges, etc., on the optical surfaces of the telecine equipment may cause flare as light passes through the optical system to the pickup tubes in the camera.

Flare in telecine cameras reduces contrast and causes large errors in color rendition. One method for measuring flare is to make a flare test slide, project this pattern into the camera, and observe the video waveforms obtained from it. Such a slide can be assembled by mounting small patches of opaque material on a 2 X 2-in. glass slide. The black paper used to package

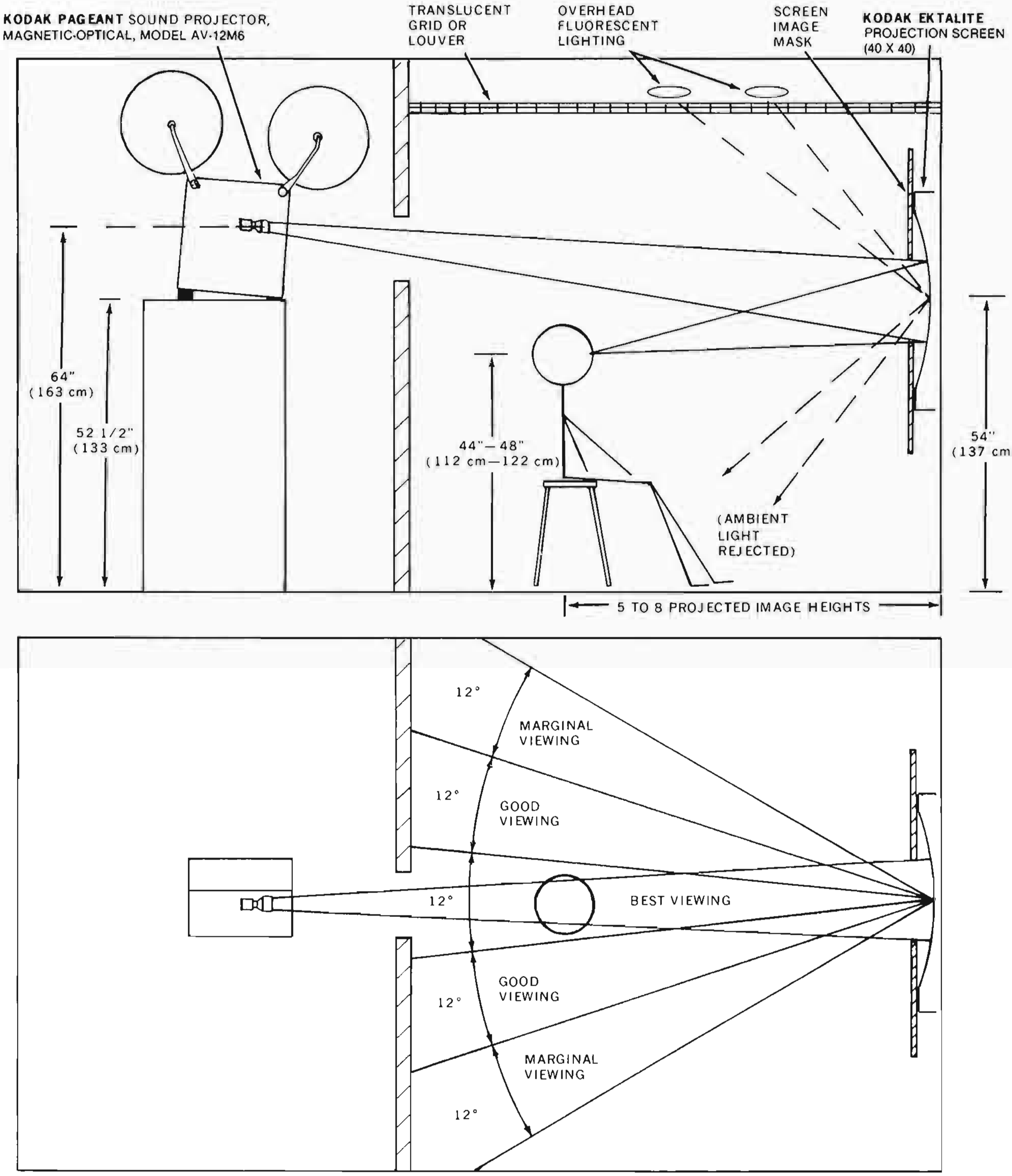


Fig. 5. Typical preview room configuration. (From Kodak Publication No. 5-1 The Television Film Preview Room.)

sensitized materials (film) can be used for the patches. Approximate-size patches can be obtained by using an ordinary office paper punch. These small circles have a diameter of approximately 1/4 in., and several patches can be mounted on the slide—one in the center of the slide and one near each of the four corners.

The waveform produced by this slide will have a very high white level signal caused by the clear glass slide. The white level signal should be adjusted to normal (100 IEEE units). Then the amplitude of the signal in the areas of the waveform, representing the small black opaque patches, can be compared with the signal level when all light is excluded from the camera. The simplest way to make this comparison is to momentarily insert a sheet of opaque material in front of the projector lens.

The black (opaque) patches do not transmit light, and therefore the signal levels in these areas should remain at zero if this is the level at which the light was cut off at the projector. Any increase in the levels for the black patches can be caused only by flare. If the optics in the telecine are not clean, the signal levels for the black patches may be as high as 20 IEEE units or more.

THE TELEVISION FILM PREVIEW ROOM

A film preview room, to be truly effective as a means of evaluating the suitability of motion pictures for television broadcast, must display a picture that closely matches the image viewed on a color television studio monitor.

A method of viewing film that closely simulates the television reproduction is highly desirable, not only to television stations but also to film laboratories and film producers where they are making films destined for release on television. Such a system is described in Kodak Publication No. S-1, *The Television Film Preview Room*. The method permits the use of existing tungsten 16 mm projectors for preview purposes by filtering them to produce an equivalent color temperature of 5400 K at an open gate screen brightness of 40 fL. A high-gain screen is used to offset the attenuation of the filter and to achieve the relatively high screen brightness required. The screen brightness will produce a film highlight brightness of 20 fL, thus matching the highlight brightness established on the studio color picture monitor. The 5400 K color temperature of the direct projection system will give an acceptable match with the film shown on a properly aligned television system whose color monitor is set to D_{6500}.

Films with a rather wide range of color balances will look acceptable when viewed separately in a darkened room. In order to make sure that valid color judgments can be made with this preview room, ambient room lighting is specified that will produce a reflected brightness from the viewing wall of approximately 4 fL with a color to match open screen illumination of the projector. This ambience will prevent the observer's eyes from adapting to different color balances.

It is also recommended that the preview screen be similar in size and shape to a television picture monitor if the preview room is to be used for a small audience. Similar preview rooms are used by the Canadian Broadcasting Corporation.

FILM CHARACTERISTICS

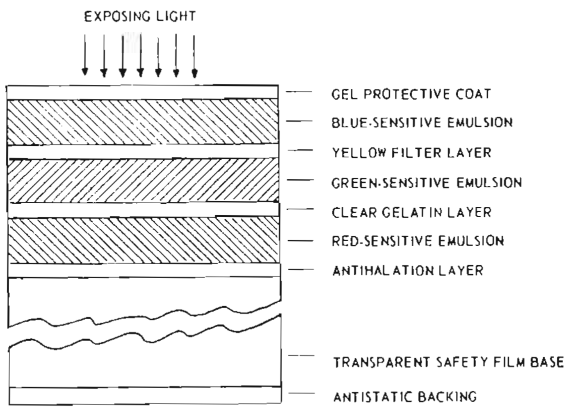
When film is utilized for original television program production, the preferred approach is to consider these two media as parts of a total visual and aural communications system. Film and its associated processes may be classified in several different ways—by the properties of the film itself, by its function in the production of the end product, or by its areas of maximum utility. Various types of films can be described in terms of the following characteristics:

Film Structure. Motion picture film consists of a light-sensitive material, the emulsion(s), coated on a flexible transparent support, the base. The coated base is slit into the desired width, perforated, and wound onto spools or cores in a variety of lengths.

During exposure *black-and-white films*, slight changes take place in tiny silver-halide crystals dispersed in the emulsion and these changes result in latent images on the emulsion, a process that can be considered as a form of temporary storage of picture information. Processing converts the latent images into visible images made of black silver grains packed closely together.

Color films have multiple coatings with three separate light-sensitive layers. Latent images are formed in these layers during exposure in relation to the amounts of red, green, and blue light reflected from the scene. When the film is processed, the latent images are converted into color dye images in a series of complex chemical reactions.

The structure of Kodak Ektachrome films is shown in Fig. 6 as a drawing (not to scale) of a



* This drawing illustrates only the relative layer arrangement of the film and is not drawn to scale.

Fig. 6. Cross Section View of Unprocessed Kodak Ektachrome EF Film 7241 (Daylight) and 7242 (Tungsten). (Reproduced from Kodak Publication H-33, Manual for Processing of Kodak and Eastman Ektachrome Films Using Process Me-4.

cross-sectional view of unprocessed film. Starting with the bottom of the drawing, an antistatic layer is provided to avoid buildup of electrostatic charges. On the other side of the transparent safety film support is an antihalation layer. This layer minimizes the effect of internal reflections of the exposing light from the base. Such reflections could cause undesirable "halo" images and loss of apparent sharpness. Red- and green-sensitive emulsion layers are coated on the support, followed by a yellow filter layer. Although the red-sensitive layer is sensitive primarily to red light and the green-sensitive layer is sensitive primarily to green light, both of these emulsions are somewhat sensitive to blue light. The yellow filter layer absorbs blue light and thus prevents blue light from exposing the green- and red-sensitive emulsion layers. A blue-sensitive layer is coated on top of the yellow filter layer.

Negative or Reversal. Both black-and-white and color films can yield either negative or positive picture images when exposed and processed. It is customary to use negative film in the camera when immediate projection is not required and a number of prints may be desired; reversal films, when processed, yield positive images on the film exposed in the camera. Reversal film is preferable when the original film—that is, the camera film—will be used for projection.

Spectral Sensitivity. Most black-and-white films for camera use are panchromatic—that is, sensitive to all the colors in the spectrum. Color films for camera use are panchromatic—that is, sensitive to all the colors in the spectrum. Color films are available in two[9] different balances—one for exposure outdoors with average daylight; the other for exposure indoors, with tungsten illumination. As a matter of normal practice, television news photographers place conversion filters over the camera lens to permit a tungsten-type film to be used outdoors, so that only one camera film need be carried.

Speed (Exposure Index). The speed of a film can be expressed as a number that indicates its inherent sensitivity to visible light. To enable photoelectric light meters to be used to set the camera lens aperture (*f*/number) for different exposure conditions, each type of film is given an exposure index by the manufacturer. However, film exposure-index values published for use with exposure meters are intended to serve only as guides. The index figures given in the film listings are recommended for use with meters and cameras marked for ASA speeds (ASA denotes American Standards Association which is now entitled American National Standards Institute—ANSI). Exact exposure levels should be determined by tests with equipment that will be used for the production (because of differences in cameras, lighting, equipment, meters, and techniques). The effective speed of a film is also influenced by the particular solutions and processing method employed. Force processing is a common practice. Longer processing times and/or higher solution temperatures can increase the effective speed of a reversal film. If possible, the tests should include an exposure series made with the specific film emulsion selected for shooting, and the test film should be processed in the manner to be used for the production.

EXPOSURE CONTROL

Exposure for motion picture films can be calculated with a photoelectric light meter. Meters measuring either incident or reflected light can be used for exposure determination. The light value indicated by the meter and the exposure index for the film are "programmed" into a small circular calculator attached to the meter and thus provide an appropriate setting for the camera lens.

This method of exposure calculation works very well with average outdoor scenes and subjects. However, many television filming situations are far from average; and in some situations the camera lens aperture must be adjusted to the largest possible opening for news stories that have to be filmed in available light. Excessive contrast may occur and cause a loss of shadow detail in the reproduction of film in the telecine chain. This happens because of the need to control peak white signal levels from the picture highlights.

Fig. 7 illustrates the way a reversal color film responds to exposure. As the exposure is in-

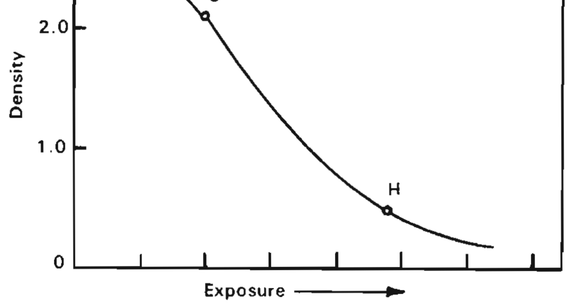


Fig. 7. Typical characteristic curve for a color reversal film. (Illustration from Videofilm Notes H-40-2, p. 4.)

[9]A third color balanced film is available in the 16 mm format. This Type A film is for use indoors with 3400 K Tungsten and is generally not suitable for filtered use outdoors.

creased, the density of the image in the film decreases, as shown in the form of the film's characteristic curve. When a scene with a contrast range of about 20:1 is properly exposed on this film, the lightest and darkest parts of the scene will be located on the curve at points H and S, respectively.

DENSITY CONTROL STARTS AT THE CAMERA

The process of image formation begins at the camera where the film is being exposed. Fig. 8 shows that closing or opening the camera lens aperture can only shift the scene up or down on the characteristic curve of the film. Also, scene content and composition coupled with the camera location and angle of view affect scene density.

It is easy to demonstrate the principle of density control with a test card made of black-and-white bars. However, when the principle is being applied in practice, the properties of real scenes must be taken into account, which makes the task much more difficult.

Every scene has a scale of luminance values. The total amount of light reflected by the various scene areas is dependent not only on their light-reflecting properties, but also on the intensity and distribution of the light illuminating the scene. The simplest example is an outdoor scene illuminated by sunlight. Two areas in this scene can have the same light-reflecting properties, but one area could be in shadow and

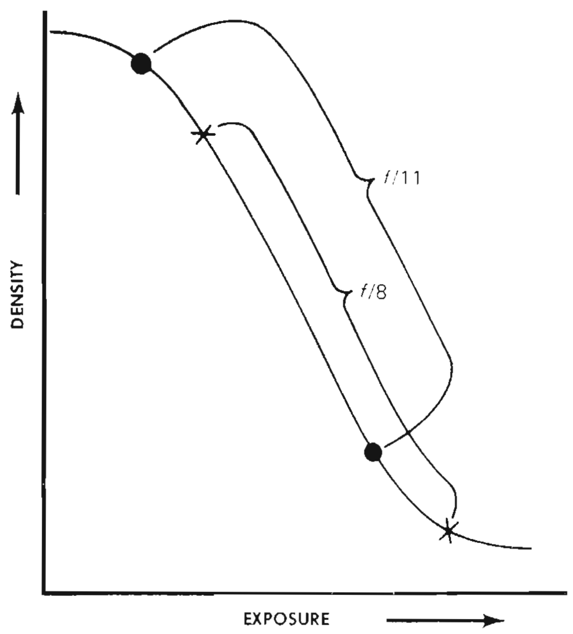


Fig. 8. Effect of camera aperture settings on the placement of a scene on a reversal film characteristic curve. (Illustration from Videofilm Notes H-40-3, p. 6.)

the other fully illuminated. On an overcast day an entirely different image would be obtained on film, since now both areas might be illuminated at the same level. Artificial light or reflectors could be utilized to alter the picture tonal scale. The technique of employing additional light is commonly used in professional motion picture production to avoid excessive contrast and loss of detail in shadow areas, as well as to simulate sunlit scenes.

When it is desired to produce film images that will transmit specified amounts of light into the telecine camera, the film must be properly exposed which means locating the scene correctly on the characteristic curve. In some situations it may be necessary to make use of artificial light to achieve this objective.

Incorrect exposure in the videofilm context means the failure to provide in each scene some well-defined highlight and shadow areas. As stated before, the recommended minimum density is in the order of 0.3 with the maximum density at about 2.5. Subjects of primary interest in the scenes—such as people's faces—must be properly located in the tonal scale of the images, relative to the highlights. As a general rule, faces should have densities in the range of 0.20 to 0.40 greater than the highlights.

The Solution: Density Control

It has been thought that prints found to be acceptable in direct projection should be suitable for television production, and that if these films do not give acceptable television pictures, something should be done to modify the television system.

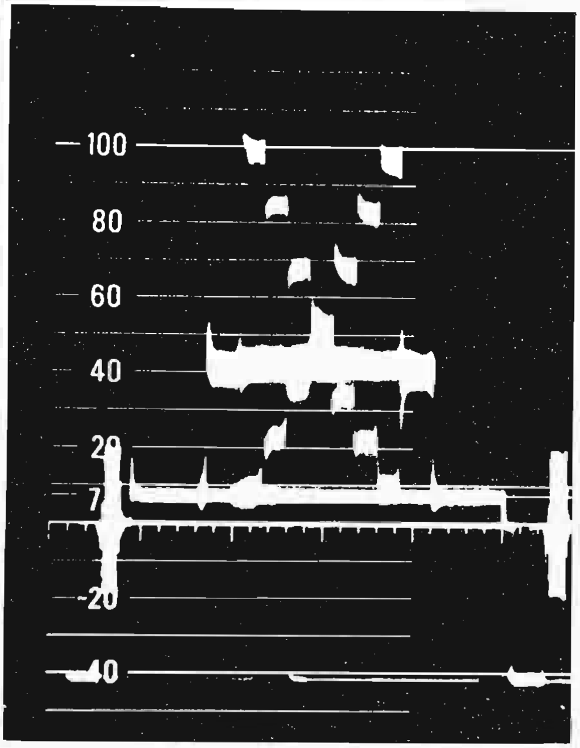
A reason for this attitude can be found in the different terms used by film and television people in describing their image-forming systems. Photographic density has a special meaning; it is defined as the logarithm to base 10 of the reciprocal of the transmittance. That is:

$$D = \log_{10} \frac{1}{T}$$

where T is the ratio of incident to transmitted light.

In photographic work, the light-transmitting properties of images are best and most conveniently described in terms of density rather than transmittance. When density, which is a logarithmic function, is plotted on a graph against the logarithm of the exposure that produced an image, a characteristic curve is obtained. This curve shows how density changes with increasing exposure with different types of photographic materials and processes.

When film is being used a source of television video signals, the amplitude of the signals depends on the amount of light transmitted by the film images. There has been general television industry agreement for many years that the minimum density in highlight areas of the film images should be not less than approximately 0.3; that is, these areas should not transmit more than 50 percent of the incident light. The basic reason for this is the need to avoid nonlinear white compression, as well as a large separation between skin tones and the lightest part of the picture image. It is also necessary to specify a density range outside of which picture information cannot be faithfully reproduced. The density range has been found to be between 0.3 and 2.5. Fig. 9 shows the video waveform obtained with the Cross Step Gray Scale Slide (made by Eastman Kodak Company) after the telecine camera has been set up to properly reproduce the slide. The minimum density of the slide, in the first step that appears in the video waveform at a level of 100 units, is 0.3. In Fig. 9, the densities of all the other steps of the test slide are shown, together with their corresponding transmission values.



Step	Density (Diffuse)	Transmittance, %
1	0.30 ± 01	50
2	0.48 ±.01	32.9
3	0.70 ±.02	19.9
4	0.98 ±.02	10.6
5	1.34 ±.03	4.5
6	1.90 ±.04	1.25
7	2.35 ±.05	0.45

Fig. 9. A typical video waveform with corresponding density and transmittance values from the Cross Step Gray Scale slide made by Eastman Kodak Company. (Refer to SMPTE Recommended Practice RP27.7-1972), *Specifications for Gray Scale Operational Alignment Test Pattern for Telecine Cameras* (approved 7-72) for additional information.

The illustration can provide some insight with regard to using film in television. When films are supplied to the television system in which the desired picture information generates video waveforms similar in amplitude to the test slide, at the peak white-and-black-level lines on the waveform graticule, no steps have to be taken by broadcasters to compensate for variations in video levels.

SELECTING THE TYPE OF FILM

The basic properties of film are used to provide a number of film/process combinations, each deemed most appropriate for a particular purpose. Thus film sensitivity, granularity, contrast, image sharpness, reproduction of colors, latent-image keeping, image permanence, negative or reversal image, spectral sensitivity, and type of support, may have greater or lesser relative importance, depending on where the film fits into the production pattern. Generally, films falls into four broad classes: (1) camera or taking films used for original photography, (2) laboratory or intermediate films used in the printing and processing laboratory to make protection copies, printing masters, special effects (opticals), and changes in image size or format, (3) sound films for use in producing photographic sound tracks, and (4) print films for making copies to be viewed as the end result of the film production.

The many available characteristics are combined in various ways in particular films to produce materials that have a balance of properties most likely to meet the user's needs. For camera films, high speed is desirable, but it must be weighed against the required image structure (sharpness, graininess) and the intended use (to be used for display or to be printed). For instance, for TV news use, high speed is essential because lighting is often uncontrollable. The color balance, contrast or density range, image structure, and image polarity reversal are designed to provide good image quality consistent with the primary requirements of being able to take the picture in a news environment and to use the original camera films as the input to TV broadcasting. For theatrical features, TV entertainment programs, and the like, where lighting on the set can be controlled and the exterior location and time of day and weather can be selected, camera film speed may be less essential, relative to better image quality and the fact that the original, usually a negative, is to be printed rather than used directly.

For laboratory films used to make effects, a specific contrast and excellent image structure are necessary requirements if the duplicate is to resemble the original as closely as possible. Speed and latent-image keeping are desirable but secondary characteristics.

For print films, the contrast must relate to that of the preprint films, and have graininess, sharpness, and color quality satisfactory for the end use of broadcasting or direct viewing. From the laboratory viewpoint, uniformity of the film, ease of processing, and of course cost, are factors.

The choice of a film or a family or group of films for a particular purpose should be approached by first considering the primary end use and working back through the many films, processes, and production options, then selecting the overall production scheme that will most easily produce the desired final product. Sometimes commercial factors, such as local availability of various services, time schedules, or budget provisions, must be balanced against technical factors for the best overall results.

By way of illustration, for TV news broadcasting, rapid access to the processed film, ease of editing, portability and simplicity of the cameraman's equipment, and high sensitivity of the film are usually deemed to be most important. This has led news directors to use a highly sensitive (suitable for new events) 16 mm (portability of equipment) color reversal camera film (rapid processing and ease of editing the original) that can be used routinely for television news broadcasts. The taking sensitivity is balanced for tungsten illumination, and the processed image is color-balanced for 5400 K projection into the telecine equipment. The image sharpness and granularity are adequate for TV use, and the contrast and extent of the tonal scale are balanced between ease of obtaining a good original exposure and the requirements of producing a good video signal.

For secondary uses of the film, there are reversal print films, compatible in processing, which have speed, color balance, and contrast suitable for producing good quality prints from the original news film. A few prints can be conveniently prepared for syndication, or educational uses, or several news stories can be combined into a feature or documentary program to be broadcast later.

If prints are the major objective, a camera film with picture characteristics designed to optimize the print quality would be a better choice. For such originals, different print films are desirable.

At the other extreme, for prime-time, high-budget entertainment programs, prints containing at least simple effects are required, frequently in both 35 mm and 16 mm size. Extra preprint materials may be needed for foreign syndication, and best possible quality is desirable. Such a combination of needs will lead to the choice of a camera film that provides a negative image with incorporated color masking. A material of this type offers excellent picture quality and the opportunity to make duplicate negatives that incorporate special effects. Duplicating and print films, each optimized for a particular function, are available.

The broadcaster who produces his own film programming should consult the film manufacturer, who can provide specific guidance and information about the film best suited to the broadcaster's needs.

FILM PREPARATION AND HANDLING

At the standard motion picture projection rate of 24 frames per second, the total number of frames required for a half-hour time period amounts to 43,200. In the 16 mm film size there are 40 frames per foot, so that a total length of 1,080 feet would be needed. In comparison, there are 16 frames per foot in the 35 mm film size, or 2,700 feet, for a 30-minute period, while the super 8 film format has 72 frames per foot, requiring a total of only 600 feet for the half-hour period.

The length of time allowed at half-hour intervals for station identification and local commercials varies from station to station and from one program to another. When a station's schedules are being prepared, these time periods must be calculated to the second, and copies must be given to the film editors showing all spaces that have to be filled and the materials to be put in these spaces.

For example, a station's program director may have made arrangements to obtain a print of a feature film, and information provided by the distributor may show that this film has a running time of 90 minutes. However, a space of only 60 minutes is available in the station's schedule. The film editor then has the task of removing portions of the film to reduce its length to fit into the allotted time period. In addition, spaces have to be left for the commercials. In a one-hour program there may be as many as 10 or 15 or these items, varying in length from 10 seconds to one minute.

First of all the feature film has to be screened to measure its actual length, while a log is made up indicating the portions that can be removed with the least disturbance of story content. Footage totals for the portions to be retained, together with the commercials to be inserted, are then prepared, and the final length is adjusted to take up exactly the full scheduled time period.

In some stations, the film commercials are spliced into the film program proper at points in the story where breaks can be made conveniently. Other stations splice all of the commercials for a day's operations on one or two 1200-foot reels; then the program film is placed on one projector of a telecine chain while the reel of commercials is placed on the other projector. Different methods can be used to insert film commercials into the program. Sometimes lengths of black leader are spliced into the program film at the points where the commercials will occur. With this arrangement, the projector carrying the program can be allowed to run continuously for the entire program period, while the projector carrying the commercials is started and stopped at the times the commercials are called for in the station schedule. Short lengths of leader between commercials permit the projector to be started a few seconds prior to the time the first pictures are to appear. Then at exactly the scheduled time, the multiplexer mirror—and the sound output as well—can be switched from the program projector to the commercial projector.

Alternatively, the program projector can be shut down while the commercials are being shown and then started up again a few seconds before the last pictures from the commercials are to appear. This procedure also calls for the insertion of short lengths of leader or waste film at the points in the program where that projector is to be stopped. Sometimes metallic cue dots attached to the edge of the film are used to stop the projectors. Projectors could be restarted automatically also, if desired, using metallic cue dots and an appropriate switching control system. In fact, all projector operations as well as video and audio switching could be timed automatically by an electronic counter actuated by the perforations in the films.

When films are being prepared for telecine, a good deal of handling is involved—screening of the films in a projector (See Television Preview Room, Fig. 5), measuring the lengths in a footage counter, cutting, splicing and winding on reels, attaching cue marks, etc. All of this work has to be performed on the prints that will be released on-air to the public. Care must be exercised so that the film is not damaged.

LEADERS AND CUING METHODS

The SMPTE Universal Leader, intended for both motion picture theater and television use, has a frame marked "Start" which is placed in the projector gate, followed by number counts from 8 to 2 at 1-sec. intervals (24 frames). A second projector can be started from the motor cue on the film running in another projector and a smooth changeover can be made from the first reel to the second by means of dowsers in the projector light beams.

These operations are complicated still further by the need to provide cues for starting videotape machines to insert recorded materials into film programs.

Electronic cue dot detection is far superior, and at the same time offers the possibility of partially automating telecine operations. Small dots of aluminum foil can be applied to the film outside of the picture frames. Equipment is available for easily applying the dots. A sensor in the projector detects the dots and gives some kind of visual or aural signal for the operator or initiates an action automatically.

A common practice is to make use of cue dot systems in the programming of reels of commercials, mainly for stopping the projector at the end of each commercial. When all of the commercials for a day's operations are assembled into a large reel, a short length of waste film, equal to the average distance the projector carries the film by its momentum after the cue dot shuts off the motor, can be spliced between commercials. In this way the film is located automatically in approximately the correct position for the projector to be started for showing the next commercial on the reel.

Some stations have adopted the practice of starting telecine projectors on 10-second cues, mainly because it is very easy to make countdowns on the clock in the coordinating studio or control room. For those stations, the SMPTE Universal Leader is too short—only 8 seconds. Other stations prefer 5-second cues; for them the leader is too long. In news operations, it is a common practice to make use of 3-second cues only, especially with modern 16 mm projectors that have a quick run-up to operating speed. In the Eastman 16 mm Television Projector, Model CT-500, for example, the motion of the film is stabilized in less than one-third of a second—8 frames.

One very important advantage of the SMPTE Universal Leader, however, is that it provides a count in seconds to the start of the program from whatever cue start that has been selected. When the telecine projector carrying the program is punched up in the "show" mode, the leader number placed in the projector gate can be seen everywhere in the station on picture monitors showing telecine output.

CLEANING AND LUBRICATION

The following steps should be taken when cleaning film: (1) wind the film onto a take-up reel; (2) rewind onto supply reel, drawing the film between two cloths that have been moistened with a cleaner/lubricant; (3) exert constant light pressure with one hand to provide continual contact between surface and cloths; (4) perform the operation slowly so that cleaner evaporates completely before the film reaches the take-up reel; (5) remoisten the cloths frequently because the solvent evaporates rapidly; (6) refold the cloths often (or replace when necessary), so that only clean areas are used, thus avoiding scratching of the film by accumulated dirt particles. If the cleaner does not contain a lubricant, the film should be relubricated.

Streaks that may appear after lubrication can usually be removed by buffing the film with a soft cloth. Any color that appears on a cloth used for cleaning Kodak color film can be disregarded provided materials and methods recommended by Kodak are used. It is a film-surface accumulation, not part of the dye in the image.

SPLICING MOTION PICTURE FILM

Splicing motion picture films is not a complicated procedure, but a great deal of damage can be caused to film and to projection equipment by poorly made splices. A good splice can be made by either of two common methods: tape splicing, in which a transparent adhesive tape designed especially for the purpose is used; or cement splicing, in which the ends of the film to be spliced are overlapped and fused together.

Either tape or cement splicing, properly done, produces a satisfactory splice. For occasional nonproduction splicing, tape splicing is convenient, trouble-free, and economical. However, cement splicing is required for most professional applications.

Film Cements

Film cement is a chemical solution containing solvents that partially dissolve, and then fuse together, the film ends. Two such cements are available: The first type is formulated primarily for splicing films having an *acetate-propionate* base, such as KODACHROME 40 Film and EASTMAN Reversal Color Print Film 7387. The second type is a professional film cement, which has a slightly different composition. KODAK PROFESSIONAL FILM Cement is suitable for all films on a *cellulose-triacetate* base plus those on an *acetate-propionate* base. In other words, it can be used on almost all professional and amateur motion picture films.

Motion picture films having a Kodak Estar Base cannot be spliced with either of the above cements because the Estar base is not dissolved by the cement solvents, as are the *cellulose-triacetate* and *acetate-propionate* bases. At the present time Estar Base films, and other *polyester* base films cannot be successfully spliced with any readily available commercial film cement. These films can be spliced with a tape splicer, such as the KODAK PRESSTAPE Universal Splicer, or with a splicer that uses a high-frequency current to melt and fuse the film ends. Estar Base films are used primarily in the fields of instrumentation, engineering, and science.

Cement-Splicing Equipment

There are many commercial cement splicers available today, ranging from simple models for the amateur to units designed specifically for specialized professional applications.

For example, some splicers have built-in scrapers (necessary for preparation fo the film to be spliced), often with adjustable guides to control the depth and width of the scrape. One type of splicer, the hot splicer, has a heating element under that portion of the splicer where the film cement is applied. This element reaches approximately 100° F and the heat, by increasing the evaporation rate of the solvents in the film cement, decreases the drying time of the splice from 15 or 20 seconds (conventional splicer, film cement but no heat) to 8 or 10 seconds. Choice of splicing equipment will depend upon the type and amount of splicing to be done.

Splicing Motion Picture Film with Cement

It is a good idea to practice making splices with scrap film; this is an inexpensive way to learn the "feel" of the splicer and to recognize the pressure necessary for proper scraping.

WARNING: Film cements and their fumes are mildly irritating, and they should be kept away from the eyes.

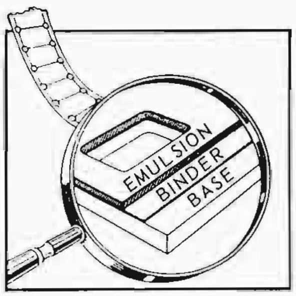


Fig. 10. Magnification of a section of motion picture film indicates that the film is made up of more than one layer. (In the illustration, the thickness of each layer is exaggerated. Kodak Publication No. S-38, p. 2.) Splicing Motion Picture Film with KODAK Film Currents.

The solvents used in film cements are volatile and can burn rapidly. While modern film bases are not fire hazards, the film cements can be.

Film cements can damage enamel and other finishes, and the man-made fibers in clothing.

Structure of Motion Picture Film

Motion picture film contains three major layers (see Fig. 10) of interest:

1. An *emulsion* coating, consisting chiefly of gelatin. In this layer of processed film is suspended the silver or dye that forms the photographic image.

2. The *binder,* a microscopically thin layer between the base and the emulsion coating, binding these two layers tightly together.

3. A flexible film *base* that provides a strong, durable support.

Width of Splice

Shown in Fig. 11 are the two splice widths most common in film editing and repair. They are the *positive* splice (1/10-in. overlap) and the *negative* splice (1/16-in. overlap). These names do not refer to positive or negative film, nor do the names imply a degree of splice reliability—both splices are highly reliable when made properly. The positive splice was developed first; unfortunately, it is quite visible when the film is projected. Therefore, positive splices are suitable for film that will not be used for printing (workprints, for example). The negative splice is narrower, and overlaps a different portion of the projected picture. It is less visible but just as reliable. The professional must make a negative splice if he is conforming original film for A- and B-roll printing. Many splicers can be ordered to provide scraping widths of 1/10 inch or 1/16 inch, as desired.

Removing the Emulsion

For a good splice, the two top layers—emulsion and binder—must be removed completely

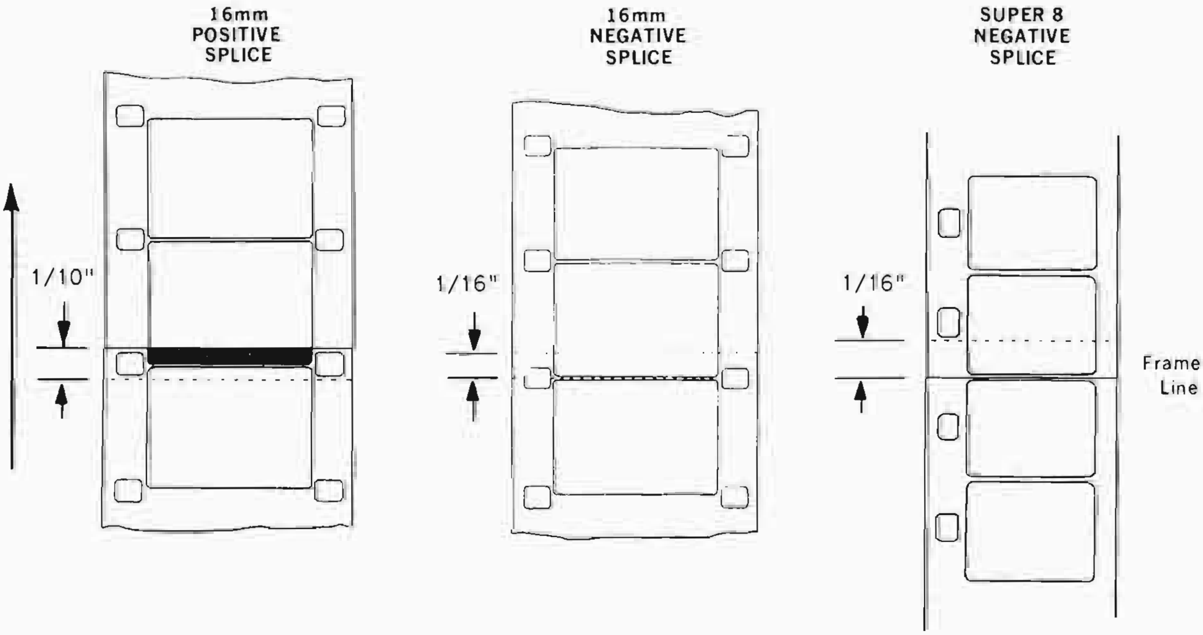


Fig. 11. Two splice widths most common in film editing and repair. (Kodak Publication S-38, p. 3.)

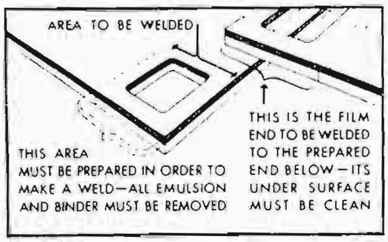


Fig. 12. Preparation for splicing. (Kodak Publication No. S-38, p. 3.)

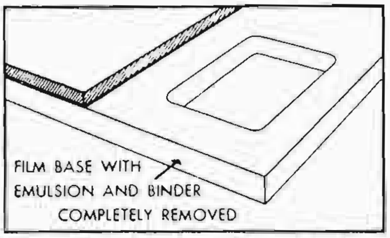


Fig. 13. Film ready for splicing. (Kodak Publication No. S-38, p. 3.)

from the section of film that will be overlapped in the splicer. The base of the bottom film must be bare and ready for contact with the overlapping film. (See Figs. 12 and 13.)

Splicers with a built-in scraper are available.

The scraper is equipped with guides that control the depth and width of the cut—on other splicers, however, the amount of pressure and the number of scrapes determine the depth. In any case, it is best to scrape the film with light strokes at first, then gradually increase the pressure until emulsion and binder are completely removed. If the pressure is too great, or uneven, the base may be torn, gouged, or just scraped too deeply. This produces a weak spot in the base, and a weak splice.

Preparing the Base Side

The base side, or undersurface, of the film that will be overlapping in the splicer may have oil on it, picked up in projection; also, some films are made with a thin coating on the back. If a good splice is to be obtained, any oil or base coating must be removed.

To remove oil and other coatings, wipe the back of the film with a dry cloth. Further rubbing with a cloth moistened with alcohol is often helpful, although many film editors prefer to apply a moderate amount of film cement to the base and then quickly wipe it completely off with a soft cloth. If these simple measures fail, lightly scrape the splice area of the base side. Be careful not to leave abrasive particles on the back of the film, since there is a possibility that they will spread through the roll and scratch the film.

If the film is old, it may be necessary to treat the back surface of the film base with film cement before splicing. As film ages, it becomes dry and sometimes brittle. An application of film cement acts as a conditioning agent, to help prepare a good splice.

Applying Film Cement

As mentioned previously, film cement is a chemical solution that dissolves film base. In addition to a solvent, it contains chemicals that stabilize its action. If film cement is exposed to the air, the solvent will evaporate, the cement will become thick and gummy, and usually it will not make a satisfactory splice. For these reasons, and for convenience, your bulk supply should be kept in the original container, and a quantity sufficient for immediate use transferred to a well-stoppered working bottle.

Cement should be applied by brush to the prepared surface—enough to wet the complete splice area, but not so much that cement will run outside the splice when the two films are pressed together. It is important that you close the splicer and bring the two films into contact as soon as possible after cement has been applied (time counts!) and keep the film under pressure for 15 to 20 seconds (8 to 10 seconds for a hot splicer).

The body and viscosity of most available film cements are such that little or no cement will be squeezed out of the overlap when splices are made properly; but if any is, the excess must be wiped off immediately with a soft cloth. Otherwise, it may adhere to and leave a smear on the preceding or following convolution of film in the reel, causing damage, distortion, or wrinkle.

Films that have become very dry or that have been rolled on small-diameter reel hubs can develop so much curl that splicing becomes difficult. Such films should be held under pressure in the splicer 30 seconds or longer (15 seconds with a hot splicer) after the cement has been applied, to allow the splice to develop adequate strength.

Checking the Cement Splice

A good splice has sufficient strength after 20 seconds to allow the film to be removed from the splicing block and wound onto the reel at normal tension.

Examine each splice for quality. A good splice is fully transparent; bubbles and hazy areas indicate a poor splice. No freshly made splice

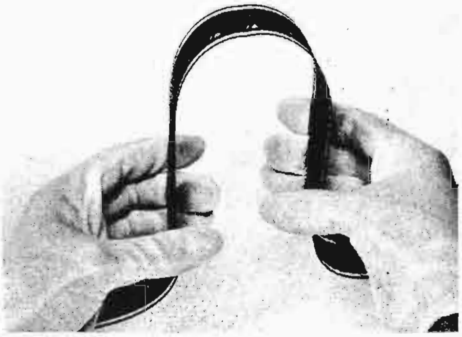


Fig. 14. To test the splice, gently flex the film in this way. (Kodak Publication No. S-38, p. 4.)

should be tested by scraping or pulling at the weld; instead, test the splice by flexing it as shown in Fig. 14. The splice should be slightly stiffer than the single thickness of film.

Splicing Film that Has a Magnetic or Optical Sound Track

Cement splices on film that has a recorded magnetic sound track may cause a momentary loss in signal level at the splice; if the magnetic head of the projector bounces at the splice, the head loses contact with the film for an instant. To minimize this effect, make sure the butt of the splice is toward the tail end of the film so the head will drop off the splice, not run into it. The correct method of lapping the film ends is illustrated in Fig. 15.

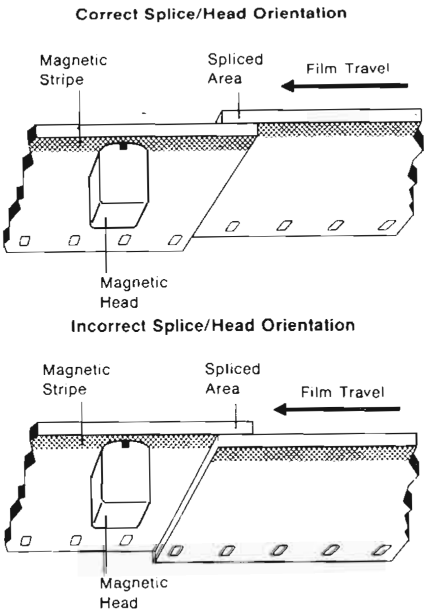


Fig. 15. Lap the film ends so that the butt of the splice is away from the magnetic head. (The "step" in the splice is greatly exaggerated for clarity.) (Kodak Publication No. S-38, p. 4.)

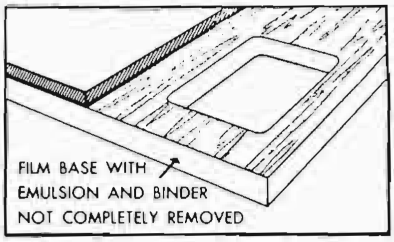


Fig. 16. Incomplete splicing preparation. (Kodak Publication No. S-38, p. 5.)

If the metal in the splicer becomes magnetized, a noticeable click may be heard in films that have a magnetic sound track. If this proves to be a problem, the splicer must be demagnetized.

Film that has an optical sound track can be spliced without any special attention to the direction of the splice butt, because the optical sound track is essentially a part of the film emulsion. Use blooping ink on optical sound film splices to eliminate pops and clicks caused by abrupt changes in the sound track modulation at the splice.

Causes of Unsatisfactory Cement Splices

Some of the most common causes of unsatisfactory cement splices are:

1. Insufficient drying time.
2. Emulsion or binder remaining on the base in the prepared area (Fig. 16), causing an incomplete or poor weld.
3. Excessive scraping, scratching, or gouging (Fig. 17) of the film base, which weakens the base and causes the film to break.
4. Too much delay in bringing the film ends into contact after the cement has been applied.
5. Applying too much cement, causing the film to buckle. After a short time, this will create difficulty when the film passes through the projector gate.
6. Applying too little cement, resulting in an incomplete weld over the entire area of the splice. Such splices should be made again, or the film edges will come loose and tear easily.
7. Using the wrong cement for a particular film base.

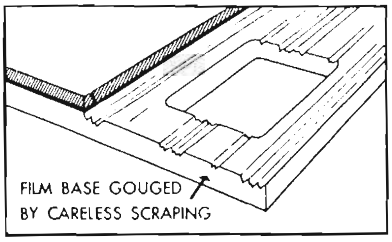


Fig. 17. Weakened base caused by excessive scraping. (Kodak Publication No. S-38, p. 5.)

8. Poor mechanical alignment of the splicer. (This can cause misalignment of the film ends and inadequate or uneven pressure on the splice area.)

9. Old or partly dried cement from which essential solvents have evaporated.

Editing Equipment

The selection of the most efficient editing equipment for the type of work to be done is very important. If the volume of editing to be done is low, then elaborate equipment may not be necessary. However, if the volume of film to be edited assumes the proportions of a professional production, then equipment designed for professional production should be used.

The organization of editing equipment on a suitable table is also very important. If it is arranged efficiently, the handling of film to be edited can be done in a routine manner.

Editing Table

Many hours of mechanical and creative effort are spent at this table, and it should be designed and arranged in such a manner that each piece of equipment can be utilized with a minimum of effort and the maximum amount of efficiency. Rewinds are positioned at opposite ends of the table near the front edge. The splicer, viewer, and other equipment (such as a footage counter and sound reader, if used) will be positioned in between.

The table surface must be smooth and clean to protect against scratching the film. An illuminated glass panel or a strong adjustable light is also helpful for viewing film.

STORAGE AND CARE OF *EASTMAN* AND *KODAK* MOTION PICTURE FILMS

The sensitometric characteristics of virtually all photographic materials gradually deteriorate with age. There may be a loss in sensitivity, a change in contrast, a growth in fog level, or all three. Various physical defects can also result from improper storage. In color films, the rates at which the various color-sensitive layers change may differ and thus upset the color balance of the material. Sensitized films (raw stock) should be protected from excessive: (1) moisture, (2) heat, (3) harmful gases, (4) x-rays, and radioactive materials, and (5) physical damage.

Storage of Raw Stock in Original Package

Relative Humidity

All motion picture raw stocks should be kept in the original taped cans to prevent any exchange in moisture between the rolls and their surroundings up to the time that they are to be exposed. The taped cans are relatively water-vapor-tight and will provide good protection for the film *as long as the seal remains unbroken.* However, storage at very high relative humidities (70 percent or higher) should be avoided because of possible damage to labels and cartons from moisture and mold, and to cans from rust. Low humidities are not harmful prior to breaking the package seal.

Note. It is the *relative* humidity, not the *absolute* humidity, that determines the moisture content of films. Relative humidity is best measured with a sling psychrometer. In a small storage chamber, a humidity indicator, such as those sold for home use, is satisfactory.

Temperature

In general, the lower the temperature at which a film is held, the slower will be the rate of change of its sensitometric properties during aging. For periods of storage up to six months, both color and black-and-white motion picture film should be stored at a temperature of 55° F (13° C) or lower. This temperature should not be exceeded during the entire storage period, if optimum film properties are to be retained.

Store raw stock at 0 to -10° F (-18 to -23° C) in a freezing unit if it must be kept longer than six months, or if the film is intended for critical use requiring the most uniform results. Sensitometric deterioration will not be prevented completely by such storage, but it will be minimized.

IMPORTANT. After the film has been removed from cold storage, it should be allowed to warm up until its temperature is above the dew point of the ambient (surrounding) air before the can is unsealed; otherwise, moisture, condensation, and spotting of the film may occur. For film in standard packages, the following table can be used as a guide for warm-up time:

Film package	Warm-up time (hours)	
	25° F rise	100° F rise
8 mm	1	1½
Super 8 cartridge	1	1½
16 mm	1	1½
35 mm	3	5

Any moisture condensation that may occur *inside* a factory taped can of film when it is refrigerated is harmless. The only possibility of damage from moisture condensation occurs when the can

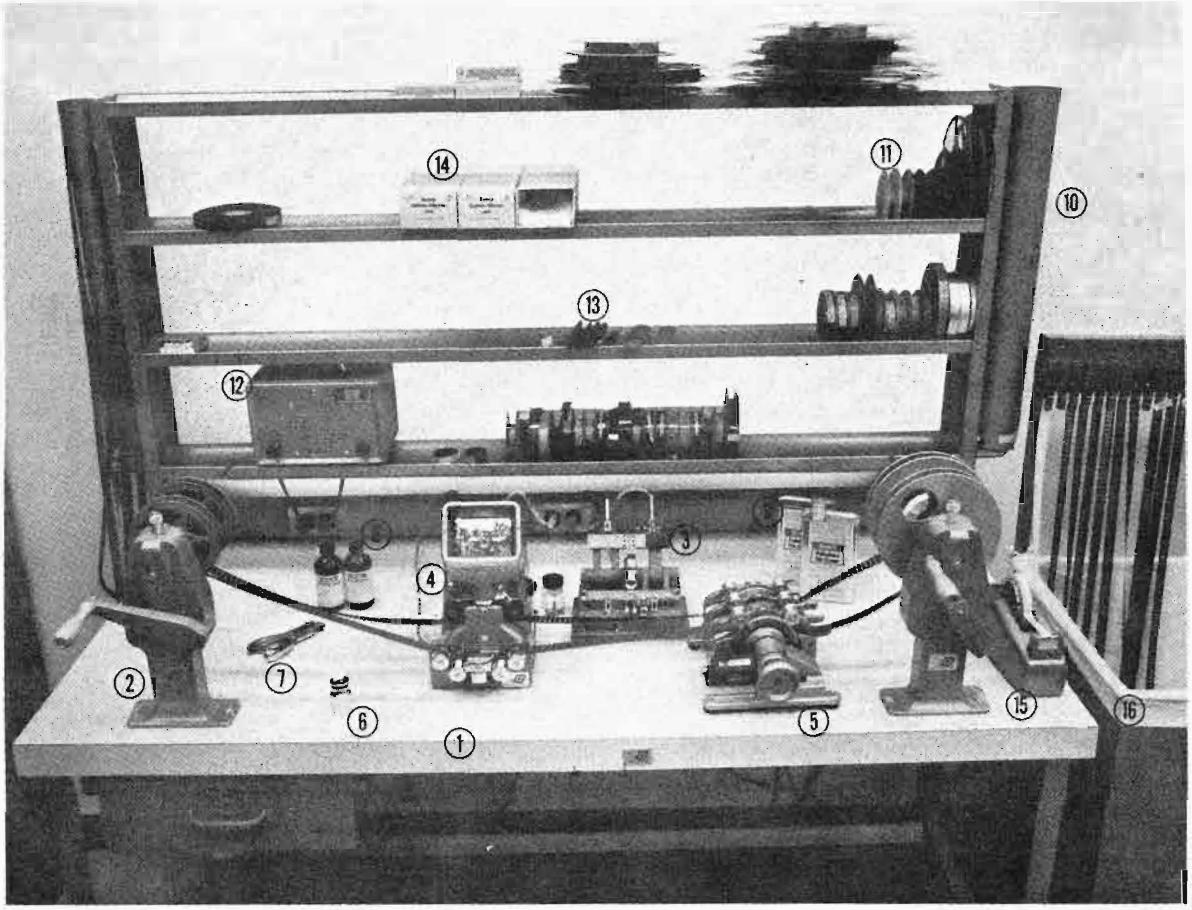


Fig. 18. Editing equipment: 1. Editing table; 2. Gang rewinds; 3. Splicer; 4. Viewer with sound head; 5. Synchronizer; 6. Magnifying lens; 7. Punch; 8. Professional Film Cleaner (with Lubricant); 9. Professional Film Cement; 10. Storage shelves; 11. Additional reels; 12. Speaker; 13. Pens; 14. Cotton Gloves; 15. Tape; 16. Film bin. (Kodak Pubication, *Film Systems for Color Televsion*, Videofilm Notes No. H-40-2, p. 5.)

is removed from the cold storage and is not allowed sufficient warm-up time.

Protection Against Harmful Gases and Rays

Gases such as formaldehyde, hydrogen sulfide, sulfur dioxide, ammonia, illuminating gas, exhaust from motors, and vapors of solvents, mothballs, cleaners, turpentine, mildew or fungus preventives, and mercury can damage photographic emulsions. The cans in which motion picture film is packaged provide protection against some gases, but others may slowly penetrate the adhesive tape seal. It is safest to keep film away from any such contamination. Raw stock should not be stored or shipped near x-rays or other radioactive materials unless proper precautions are taken. Special storage precautions should also be taken in hospitals, industrial plants, and laboratories where radioactive materials are in use.

Physical Damage

Storage rooms for motion picture raw stock should be designed so that accidental flooding from storms, water pipes, or sewers cannot damage the product. All film should be raised at least 6 in. off the floor for storage.

Rooms that are artificially cooled should be constructed and insulated so that moisture does not condense on the walls. If the building is not fireproof, sprinklers should be installed. As indicated, relative humidity control below 70 percent is unimportant as long as the film cans remain sealed. The *temperature* should be maintained as uniform as possible throughout the storage room by means of adequate air circulation, so that the sensitometric properties in each roll of film will remain the same.

Film should not be stored near heating pipes, or in the line of sunlight coming through a window, regardless of whether the room is cool or not.

Storage of Unprocessed Film Before and After Exposure

After a film package has been opened, the film is no longer protected from the outside atmosphere. High relative humidities and high temperatures often cause undesirable changes in the latent image. Exposed film, particularly color, deteriorates more rapidly than unexposed film. *Film should be exposed and processed as soon as possible after the package is opened.*

Film should not remain in the camera magazine longer than necessary. Loaded cameras or magazines and carrying cases containing film should be protected from direct sunlight, even in temperate climates. Film in loaded cameras, magazines, or even in original packages should never be left in closed spaces that may trap heat from the sun or other sources. The temperatures in closed automobiles, parked airplanes, or the holds of ships, for example, can easily reach 140° F (60° C) or more. A few hours under such conditions either before or after exposure, can severely impair the quality of the film image.

The films must be kept away from the harmful gases mentioned earlier. Since the vapors from mothballs and mildew or fungus preventives can cause deleterious effects on film, keep all films away from clothes closets and drawers containing these preparations.

Satisfactory drying of motion picture films by means of desiccation is not possible because of the slow transfer of moisture through a large roll. It is easier, therefore, to avoid excessive moisture take-up when handling motion picture film at high relative humidities than it is to do an adequate job of removing the excess moisture once it has been absorbed. If there are delays of a day or more in shooting, a magazine containing partially used film should be removed from the camera and placed in a moisture-tight dry chamber. This will prevent any absorption of moisture by the film during the holding period. Immediately after exposure, the film should be returned to its can and retaped to prevent any increase in moisture content over that picked up during exposure. If processing facilities are not immediately available, exposed films should be stored at 0° F (-18° C).

Storage of Processed Film

Storage of processed motion picture film differs from the storage of raw stock because the film is no longer photosensitive, and much longer storage periods are generally involved.

Processing is one of the most important factors contributing to the ultimate permanence of photographic records. A thorough washing is particularly important because thiosulfate salts (hypo) left in the processed material can fade the silver image of black-and-white films by converting it partially to silver sulfide, especially under conditions of high humidity and temperature. Thiosulfate salts allowed to remain in color film can also fade the dye images. In color films, it is likely that one dye will be affected more than another, causing an undesirable change in color balance and deterioration of the image.

The following suggestions pertain specifically to the storage of *color* films; however, some may also be applied to black-and-white films:

1. Each film should receive adequate washing to remove residual chemicals. It is important to make sure that the residual hypo level does not exceed the recommended maximum.
2. Film should be treated in the recommended stabilization bath for the amount of time required to provide optimum stabilization of the dye images.
3. Wetting agents for prevention of water spots, and detergents for cleaning processed film should be selected with great care. Antimold compounds in some wetting agents may also be harmful to the dyes. KODAK Movie Film Cleaner (with Lubricant) has proved to be a satisfactory cleaning material for these purposes.
4. If alkaline or detergent solutions are used for cleaning, the film should be rewashed and relubricated if it is to be used again.
5. Film should not be stored in an atmosphere containing acid vapors, or fumes of sulfur dioxide, peroxide, or hydrogen sulfide.

For short-term storage of processed *black-and-white* motion picture film, the temperature should be kept below 75° F (24 ° C), and the relative humidity should be kept below 60 percent. For long-term storage, the film should be stored at a temperature below 70° F (21° C), and at a relative humidity of 15 to 50 percent. Very low storage temperatures are desirable (0° F or below) when infrequent use of the film is expected and maximum useful life is the primary concern.

IMPORTANT. Storage at relative humidities below 15 percent can cause curl and brittleness in film.

For short-term storage of processed *color* motion picture film, the temperature should be kept at approximately 70° F (21° C), and the relative humidity should be kept between 40 and 50 percent. There are several methods employed for long-term keeping of color film images. Although these methods are too detailed to be covered adequately here, information concerning this subject can be found in the following article: Adelstein, P.Z., Graham, C.L., and West, L.E., "Preservation of Motion Picture Color Films

Having Permanent Value," *Journal of the SMPTE,* 79:1011-18, November 1970.

Film Cans

Films should be stored in film cans or boxes. These containers protect films from damage, dirt, and dust.

Storage Cabinets

All modern 16 mm films are on a safety base and can be stored on wooden shelves or in wooden cabinets. However, most libraries store film on metal shelves or in metal cabinets made especially for this purpose.[10] Such metal cabinets are usually supplied with adjustable shelving for standard-size reels. The can of film should be stored on edge for easy access. Films that are to be used infrequently should be stored in cans that are placed horizontally on the shelf rather than on edge to minimize film distortion.

Storage Conditions

Storage cabinets should be separated enough to permit free circulation of air on all sides. Storage areas should be located on the intermediate floors of buildings, never in damp basements or on the top floors of uninsulated buildings, or on radiators, hot-air ducts, and other sources of heat and humidity.

Film storage and handling areas should be kept as free as possible from dust and dirt. Ideally, such rooms should be supplied with conditioned and filtered air. Precautions should be taken to prevent the entrance of dust and dirt through ventilators, heating ducts, and windows.

Care of Processed Films

After the primary consideration of first-quality processing by a reputable processor, long service of films depends on proper care. The following suggestions are offered for the promotion of long film life:

1. The projector gate and other parts that guide the film through the projector should be kept clean.
2. Film should be threaded correctly, and the projector should be operated properly.
3. Films should be inspected (and repaired if necessary) before use.
4. Films should be cleaned and lubricated properly.
5. Splices should be made with care and accuracy.
6. A long leader should be attached at the start of a reel, a trailer at the end.

[10]Manufacturers of such equipment include: General Fireproofing Co., 413 E. Dennick Ave., Youngstown, Ohio 44501; Lyon Metal Products, Inc., 1933 Montgomery St., Aurora, Ill. 60505; Neumade Products Corp., 250 West 57th St., New York, N.Y. 10019.

COMMERCIAL MOTION PICTURE LABORATORY SERVICES

It is most important that the TV photographer or producer become acquainted with, and use, the facilities and services of one or more motion picture laboratories. The selected laboratory should be the "silent partner" in the production of a motion picture. It can assist and simplify endeavors of the TV motion picture producer if he will take the laboratory into his confidence, and keep it informed of what he is doing, his objectives, and his problems.

A laboratory can relieve the TV station of much tedious work and of investment in space and equipment for facilities that are not utilized full-time. As experience is gained, some of the operations can be assumed by the TV or photographic staff. Titling, editing, and conforming are good examples of services available at many laboratories.

Following is a list of some of the principal services offered by commercial motion picture laboratories. Few laboratories will offer all the services listed, but most of them will provide a major portion.

Processing. Developing color or black-and-white camera film. (Special overnight, pickup and delivery, or weekend service is available in some places.)

Furnishing advice to help with technical or even aesthetic problems.

Printing and duplicating from camera films for workprints or release prints. Most laboratories will print or duplicate the camera film after it is processed. They may also hold the original in their vault and forward the print to the photographer for use as his workprint. The original is thus protected from damage in handling until it is needed for final conforming.

Black-and-white printing from a color original to produce a workprint or a release print.

Edge numbering of originals and workprints to facilitate editing.

Editing, cutting, splicing, and assembling as directed by the producer.

Conforming. Matching the original camera film to the workprint as edited by the producer.

Optical effects. These include dissolves, wipes, fades, freeze frames, etc.

Sound production, including recording, narrating, editing, obtaining cleared music, adding sound effects, rerecording, magnetic striping, and optical track production.

Titling as required, including design of artwork, lettering, and photography.

Animation, including design and production of artwork and photography.

Stock library, provides footage of standard scenes and events for use in the producers' film; i.e., plane in flight, ship at sea, mob scene, sports event, street scene, monuments, parks, out-of-season weather scenes, etc.

Special photography requiring facilities or equipment not available to the photographer.

For some purposes, it may be preferable to make prints from the edited originals, the sound being reproduced in the form of optical tracks. This work can be done by most commercial motion picture laboratories.

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Audio and Video Special Effects

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VISUAL EFFECTS

Electronic Switching Special Effects

In television video practice, the term "special effects," by accepted usage, is applied to techniques for creating visual effects which are beyond the capabilities of an elementary video switching system which provides only signal selection and additive superimpositions, or "lap dissolves." The purpose of special effects may be either to achieve an artistic objective or to aid the communication of information. Electronic special effects can also be of economic advantage when they permit realistic simulation of pictorial material that would otherwise be prohibitively expensive.

The major category of electronic special effects is the use of electronic switching, or "keying," for simultaneous display of portions of two or more video signals by a pattern division of the raster. Other types of visual special effects are largely techniques for introducing distortions of the picture image, by either optical or electronic means.

Keying Techniques

Since the television picture is transmitted by time-sequence scanning, it is evident that appropriately timed instantaneous switching between two video signals can produce the visual effect of a geometric division of the raster area so that portions of each picture are displayed. Conventional electronic switching techniques readily permit the switching interval required. Methods of using this technique are categorized by the source of the signal which determines the pattern of the display. In the most elementary application, the "wipe," keying waveforms are generated by pulse circuit techniques to create geometric patterns. It is also possible to obtain keying waveforms of any desired pattern by processing video signals from conventional camera equipment. The simplest form of this technique uses an independent camera trained on silhouette art work of the desired pattern, so that the resulting video signal closely resembles a pulse keying waveform and requires a minimum of processing. The most advanced application is matting, in its most popular form, "chroma-key," where the keying signal is derived from one of the two video signals to be combined. This permits placing a subject visually into any background scene desired.

The arrangement of equipment components for these three forms of electronic switching effects is shown diagrammatically in Fig. 1.

Keying Amplifier

The circuit which is fundamental to any special-effects switching system is the keying amplifier circuit itself. Functionally, this circuit takes three input signals, the two video signals and the keying pattern signal, and produces an output video signal which combines the two video signals in accordance with the area division established by the keying pattern signal. The keying pattern signal is assumed to be a two-valued function, or pulse signal. Switching circuits usually, however, include a clipper in the key-signal input channel to remove any noise or shading components that may be present. This permits the use of camera-generated signals developed from silhouette artwork without further prior processing.

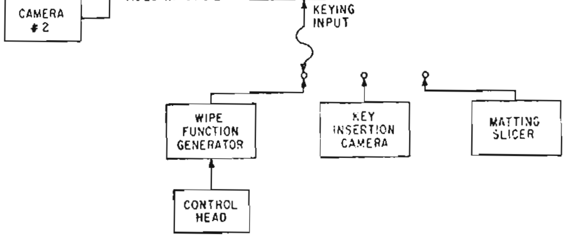

Fig. 1. Electronic switching special-effect system.

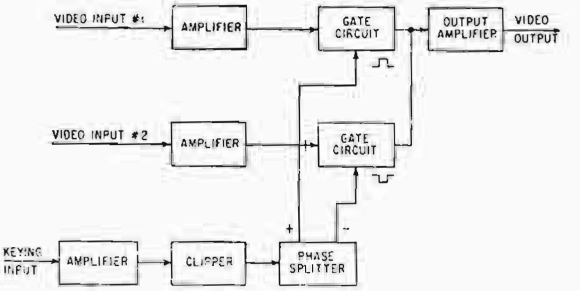

Fig. 2. Electronic switcher-typical circuit plan.

A typical circuit arrangement (Fig. 2) employs a pair of solid-state switches as gate circuits. The keying signal, after clipping, is phase split so that it can be applied in opposite polarity to each of the two gate circuits. The gate outputs are paralleled and fed to the output amplifier. Auxiliary circuitry for clamping is essential to ensure constant clipping levels. The opposed-polarity keying pulses must be precisely matched to avoid a gap or overlap at the instant of switch; this is one of the key problems facing the designer.

Until the early 1970s, the history of keying amplifier design development was one of striving for the fastest possible transition, so that the boundary between the two portions of the signal would be sharp and invisible. As a corollary to this objective, the keying signal is derived from a very narrow slice of the keying video signal. A disadvantage of this inherently high gain gating approach is, in the chroma-key application, when the keying video signal is noisy or in any way ambiguously defines the location of the keying boundary, a severe and unpleasant edge-noise or "boiling" effect is evident at the keying boundaries in the chroma-key output signal. The availability of improved semiconductor components and circuit techniques in the early 1970s has made possible a better approach to keying amplifier design, in which the gate circuits of Fig. 2 are replaced by a two-input linear transfer circuit of equivalent performance. With such a transfer circuit, the keying action in the chroma-key application can be derived on an essentially proportional basis from the keying video signal, and the resultant output chroma-keyed picture is free of edge-noise effects even where the edge is ambiguously defined. An effective illustration of the performance of such a circuit can be shown by the keying of cigarette smoke. Another advantage of the proportional keying approach is that it permits the option of a "soft wipe," in which the boundary between two signals, instead of being sharp, provides a dissolving effect or soft edge of any desired thickness. The system architecture of video switching systems employing proportional keying, furthermore, is considerably simplified, since the proportional keying element is used for lap dissolves also, thus avoiding the need for the switched selection of alternative processing paths which characterized earlier designs.

Wipe Function Generation

A wide variety of keying patterns can be electronically generated by conventional pulse circuit techniques. Such signals are applied in two general ways: (1) for a transition from one picture to another and (2) for a static display of portions of two (or more) pictures.

The term "wipe," which originated as the description for the most elementary form of geometric transition (in which a dividing barrier sweeps across the raster with the new picture appearing behind it as it progresses), is applied as a generic term to any system for electronically generating patterns of raster division. A "split-screen" is, in effect, a stationary wipe. Transition wipe effects include not only a linear sweep of the inter-picture boundary, but also the iris form of motion, in both single and multiple patterns, and in more elaborate systems, rotating boundaries are also provided.

For the transition application, a variety of patterns are commonly employed, the simplest being the horizontal (Fig. 3) or vertical wipe. Diagonal wipes (Fig. 5) are also common. More complex wipes are possible with wedge and irregular shapes. The box (Fig. 6), the diamond, and the circle are the most common shapes for the iris type of motion. A wide variety of more complex patterns can be electronically generated, including "venetian blind," "checkerboard," multiple circle, star, triangle, etc.

Of the static patterns which are employed to display portions of two or more pictures simultaneously, the horizontal split screen (Fig. 3) is the simplest and is frequently used. Another popular pattern is the wedge (Fig. 4), in which a rectangular segment in one corner of the picture is keyed off, usually for insertion of the face of a commen-

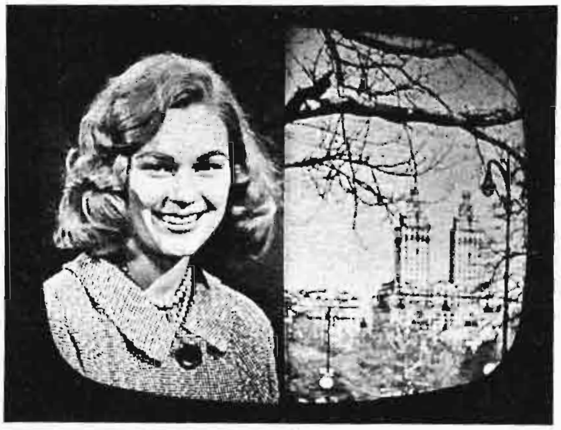

Fig. 3. Horizontal wipe or split screen.

Fig. 4. Wedge insert.

Fig. 6. Wipe and split-screen effects.

tator. A vertical split screen is sometimes employed to insert written material in a strip at the bottom or top of the picture. On occasion, for planned news coverage, more than two signals have been combined, and as many as five pictures have been combined to display simultaneously the faces of news commentators or public personages from widely scattered locations. When pictures are so combined from different locations, it is, of course, necessary to phase-lock the sync generator at the coming location. When pictures from more than two points are combined, the sync generators from each contributing source must be phased and held in synchronism with that of the final mixing facility. In the earlier years, this was achieved by a chain system whereby all contributing points beyond the first processed the signal, adding its contribution and phasing its sync generator to the incoming feed. More modern practice is to employ one of the available remote feedback techniques for individually controlling the phase of each remote sync generator from the mixing facility, so that all signals are fed directly to the mixing facility and are processed there.

Circuitry for the generation of wipe keying signals usually employs certain principles that are common to all practical designs. A block diagram is shown in Fig. 7. In the typical system, vertical and horizontal waveforms are generated as elements for the synthesis of keying signals. The simplest patterns use horizontal and vertical sawtooth and triangle. The typical commercial wipe function generator also employs multiple-frequency and parabolic waveforms for a variety of complex wipe function patterns. The wipe pattern is generated from a master waveform, which may be a combination of basic horizontal and vertical waveforms, by double clipping (or "slicing") to develop a pulse signal whose timing will depend upon the clipping level. The motion is thus imparted to the pattern for transition effects by manually changing the clipping level through the amplitude range of the entire master waveform. Some patterns require independent clipping of two waveforms with following mixing and clipping (in effect, logical mixing) of the two resultant pulse signals. Additional combinations of mixing circuits and basic signals make possible an extremely wide variety of patterns. In elaborate systems, the major design problem becomes the switching arrangement for selection of a large number of signal combinations. Fig. 8 shows a typical selection control panel for a contemporary wipe function generator.

A frequently included convenience feature is a positioning system by which horizontal and verti-

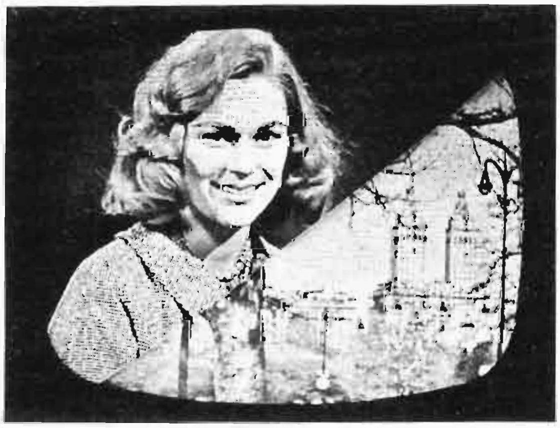

Fig. 5. Diagonal wipe.

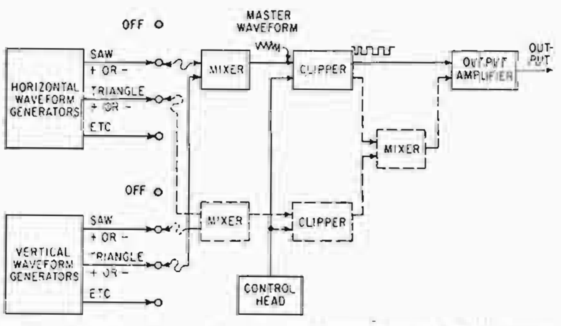

Fig. 7. Wipe function generator-typical circuit plan.

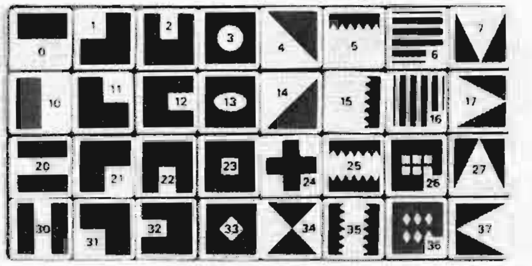

Fig. 8. Typical wipe selection controls (Courtesy Grass Valley Group, Inc.).

cal drive pulses are delayed under manual control, typically with a joy-stick, to locate the wipe pattern easily on any part of the raster. An occasionally employed technique for elaborating on the conventional wipe pattern is to phase-modulate the keying signal at an audio frequency rate by a few microseconds, producing an animated shimmering effect in the final pattern. Special modes of operation are often built into wipe keying systems, such as a "soft wipe" option, which is feasible when the proportional keying technique is used and "borderline," in which a prominent boundary line of deliberately visible thickness (either black or at a specified luminance and chrominance level) is substituted for the normally invisible keying boundary. Fig. 9 shows a typical repertoire of controls for a variety of special functions in a special effects system.

Keyed Insertion

Where there is desired a split-screen or wipe pattern of an irregular shape that cannot readily be generated electronically, it is necessary that the keying signal be produced by an image-scanning process. Conventional camera equipment can be used for this, either live or film.

The major application of keyed insertion has been for trick "split-screen" effects. There has been limited use for transitions, generally using a live camera with a zoom lens to produce the pattern motion. Film animation is another possible source for moving patterns, but its cost has seldom been considered justifiable. Fixed keyed-insertion patterns are usually derived from live cameras with silhouette artwork or with film cameras using projected slide or opaque material.

Any camera signal requires double clipping, or "slicing" to eliminate noise and shading components before use as a keying signal. The switching circuit will normally include sufficient clipping, but in some systems the key-insertion signal is fed through a portion of a wipe signal generator circuit to process it adequately.

The component pictures and results of a key insertion process are shown in Figs. 10 to 13. Fig. 10 is the background camera, showing a map of the United States. Fig. 11 is the key-insertion camera, a silhouette outline of the state of Missouri. Fig. 12 shows the picture from the subject camera. In the final product, the subject appears within the state outline in Fig. 13.

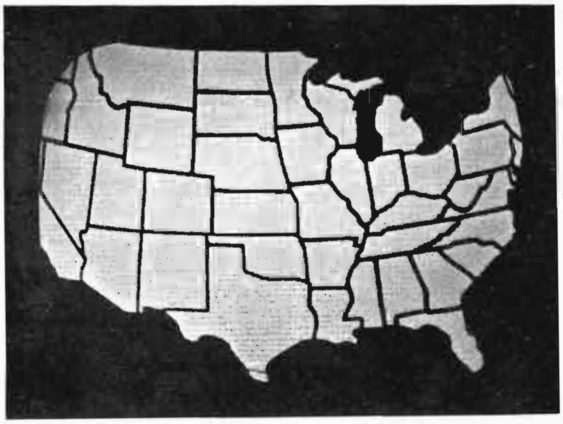

Fig. 10. Background camera picture.

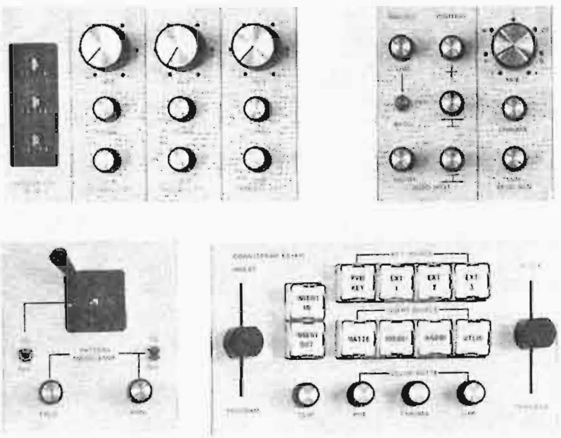

Fig. 9. Electronic special effects auxiliary function controls (Courtesy Grass Valley Group, Inc.).

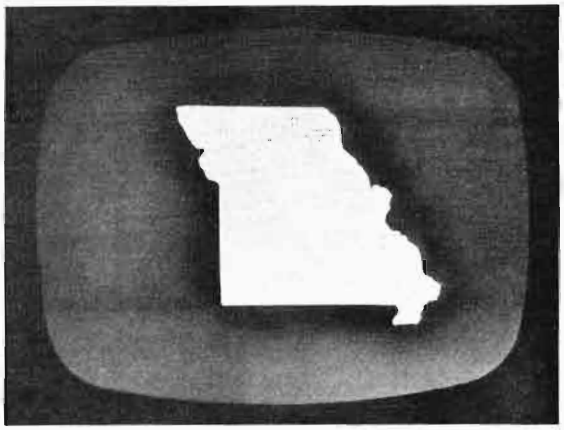

Fig. 11. Key-insertion camera picture.

Fig. 12. Subject camera picture.

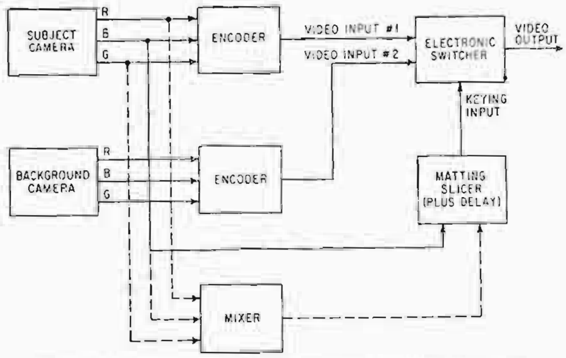

Fig. 14. Color matting system-block diagram.

Matting and Chroma-Key

The object of the matting process is to insert a subject (usually human) into a background scene, sometimes for a trick effect but usually for the purpose of creating the illusion that the subject is actually in the scene. When skillfully applied, the process can offer an advantage of economically creating effects that would otherwise be prohibitively expensive.

In the era of monochrome broadcast television, matting was achieved occasionally by placing the subject against a black background and slicing the resulting video signal. The process was, however, very difficult to control, requiring extreme care in lighting, costuming, and staging to produce a scene with reflectance values adequate for key slicing. With the advent of color, however, the added dimension of chrominance proved to be a crucial aid to the process, and the chroma-key technique has since come to be widely used in commercial television broadcasting.

The usual practice is to use a backdrop of a bright primary color, sufficient to produce full "white" level in the corresponding channel of the system. The primary to be used is selected on the criterion that it be complementary to the predominant color of the subject. Since human subjects are most often used, blue is usually the optimum backdrop color. With mixing techniques, color other than primaries, such as cyan, can also be used. An essential precaution is to avoid any use of colors approximating the backdrop color in the costume of the subject.

Fig. 13. Final key inserted picture.

The matting-system layout in color differs from monochrome only in the keying-signal source and processing, as shown in Fig. 14. The two video inputs to the electronic switcher are the encoded signals of the subject and background pictures. Instead of the subject signal itself as an input to the slicer, however, the desired primary component, before encoding, is used. This may be either an actual primary, such as the blue signal, or a matrixed combination.

In the diagram of Fig. 14, it will be noted that the unencoded RBG signals are routed directly from the camera to the chroma-key equipment. It is essential that the signal input to the slicer be of sufficiently wide bandwidth to permit the accurate definition of the keying boundary (although this requirement is somewhat alleviated if proporportional keying is used). This means that cameras which deliberately reduce the bandwidth of the chroma signal, such as certain types of four-tube cameras, cameras which employ special signal transmission techniques to operate with miniaturized camera cable (such as "Triax"), and the low cost two-tube and one-tube cameras used in low-budget closed-circuit applications, do not lend themselves well to chroma-key application. Another consideration relates to the need which may sometimes arise to chroma-key into an encoded signal, where access is not possible to the original camera RBG video outputs, such as at a point remote from the camera location, or with a tape-recorded signal. The RBG outputs of a conventional decoder are typically not of sufficient bandwidth to permit chroma-key. With

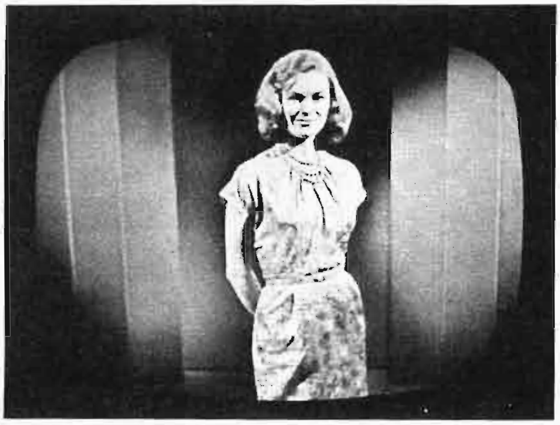

Fig. 15. Normal picture.

wideband decoding employing the comb filter technique, however, sufficient bandwidth is obtained to permit "in-line" chroma-keying, and equipment for this purpose became commercially available in the early 1970s.

Camera-Induced Effects

Horizontal and vertical scanning are easily reversible by the installation of DPDT toggles switches directly in the yoke circuit of a camera. The effects made possible are the geometric inversion of the picture and horizontal reversing, which can be used for superimposition of mirror images. There is a basic design problem in color television cameras for the achievement of this effect in the maintenance of registration; typically, some registration setting controls must be duplicated if registration is expected to be maintained without readjustment between the two conditions.

Ripple

The superimposition of an audio-frequency component on the camera horizontal scanning current causes a rippling motion in the picture which can be used dramatically to suggest dreams, fading of consciousness, etc. A frequency close to 60 Hz or its harmonics produces a suitable motion effect. The effect is illustrated in Figs. 15 and 16 showing normal and rippled pictures, respectively.

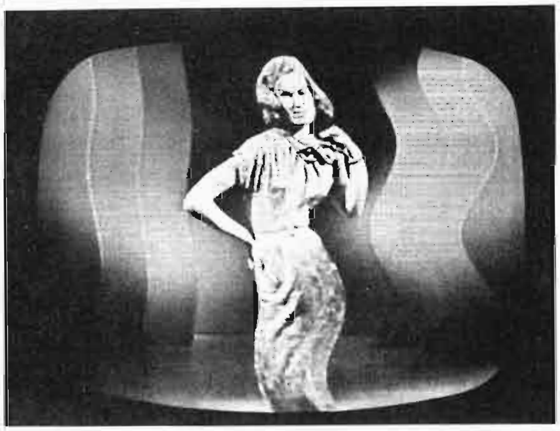

Fig. 16. Rippled pictures. (Figs. 15 & 16 The ripple effect.)

Deliberate Signal Distortions

Nonstandard operation of camera controls provide a limited capability for special video effects. With photoconductive pick-up tubes, "puddling" from beam starvation will generate an odd-looking lag effect, and simple underexposure with excess gain will produce smear. Such effects were more readily available and more frequently employed in the monochrome era, when the image orthican tube offered much more versatility in that regard. Another type of distortion which may be achieved electrically is the manipulation of the color signal. A device called the "colorizer" permits transformations of chrominance and luminance values so as to produce a transformed, unnatural appearance. Another technique sometimes employed for a dreamlike, or psychedelic effect, is "video echo," wherein a camera is trained on a monitor displaying its own output. By adjustment of framing, this can be arranged to produce a variety of multiple image effects, which, particularly if combined with chroma-key, can produce a wide repertoire of surrealistic images. A film produced on videotape for theater release entitled "200 Motels" was a virtual *tour de force* of video special effects, employing all the techniques mentioned herein.

Electronic Title Generation

The continued lowering of costs for digital electronics in the 1960s introduced the feasibility for economic generation of alphanumeric characters for television titling purposes. Such equipment was introduced on a limited scale in the period 1964-1966, and was first implemented as a commercial product in 1968.

The earliest versions of such equipment, for economic reasons, were able to offer character font styles considerably short of that desirable for ideal graphics quality, but nevertheless adequate. Likewise, the earliest versions employed a fixed character matrix, instead of the more desirable proportional spacing. By the 1970s a variety of classes of character generation equipment had become available, ranging from the lowest cost class offering the features of the earlier-introduced equipment, to the most sophisticated class offering high-quality or variable-choice fonts with

Fig. 17. Low resolutions (Courtesy of Datavision, Inc.).

Fig. 19. High resolution, proportional spacing (Courtesy of CBS Laboratories).

proportional spacing. Figs. 17, 18, and 19 show, respectively, representative fonts available in the three classes of equipment, in ascending order of quality and cost.

In addition to display of static titles, sometimes on call from random-access digital memories, electronic titling equipment can include certain special animation features, such as the horizontal "crawl" effect, where a continuous, long message travels in a single line across the screen from right to left, or a vertical "roll" effect, where a continuous page copy travels upward through the raster.

The insertion of titles into the video signal in monochrome television was achieved in the most elementary fashion by direct superimposition, followed by white clipping to remove the necessity for reducing the level of the primary signal to avoid excessive combined signal level. Since color telecasting and the use of keying amplifiers have become commonplace, titles in contemporary practice are invariably inserted by keying, and most systems provide means for selecting any desired brightness level and color for the inserted title.

An important enhancement of the visibility of inserted titles is through the use of edging, which is achieved on an "all-around" basis by using horizontal line delay techniques such as are employed in vertical aperture equalization equipment. The most elaborate editing systems permit a choice of all-around, horizontal, vertical, or "drop-shadow" edging. Figs. 20 and 21 show the improvement achieved by the application of all-around edging.

Electronic Graphics Generation

As an adjunct to electronic titles, there have been limited efforts to use similar digital tech-

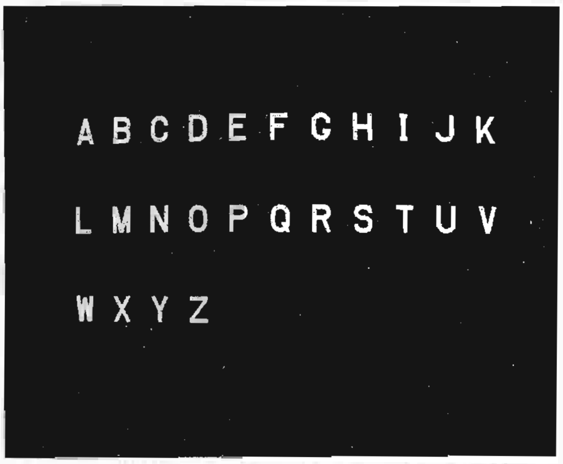

Fig. 18. High resolution, nonproportional spacing (Courtesy of CBS Laboratories).

Fig. 20. Without edging (Courtesy CBS Laboratories).

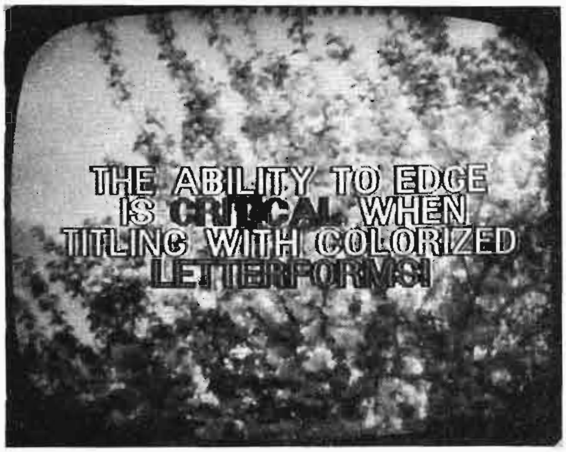

Fig. 21. With edging (Courtesy CBS Laboratories). (Figs. 20 & 21 Edging enhancement of electronic titles.)

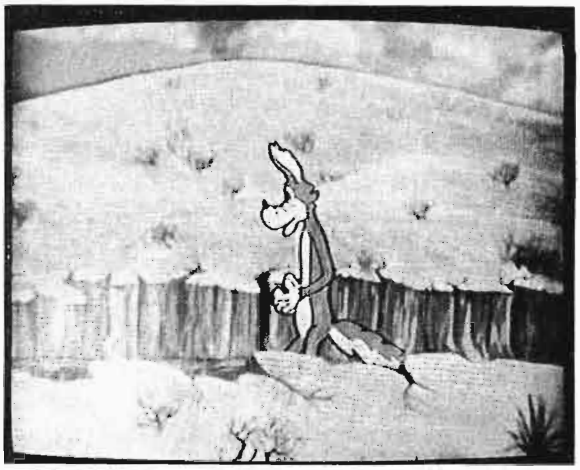

Fig. 23. Computer-generated cartoon character (Courtesy of Computer Image Corp.).

niques for the generation of graphic material. Such technique can be used, and has to a limited degree, for such presentations as maps, bar charts, and graphs.

A technique available to broadcasters for animated graphics generation employs raster scanning manipulation to produce animated and preprogrammed geometric distortions and transformations of prepared artwork and visual images. This system has been widely employed in television commercial production and for program billboards. Fig. 22 illustrates a typical appearance of an image processed by this system. Perhaps the ultimate in video special effects is represented by systems which generate full-scale animated action entirely under computer control. Such systems had been speculated upon in theory for many years and were beginning to make their appearance in broadcasting by the mid-1970s. Fig. 23 illustrates a typical product of such a system as of that time.

Fig. 22. Raster manipulation title effect (Courtesy of Computer Image Corp.).

Optical Effects

Many very interesting effects can be achieved by interposing various optical devices between the subject and camera lens. Images can be multiplied, rotated, inverted, flared, distorted, and arranged in a variety of different patterns. Among the devices used to perform these effects are several types of prisms, kaleidoscopes, and etched lenses.

Multifaceted Prisms

One group of prisms is referred to as the "multifaceted" prism because of the multiplicity of plane surfaces on the face of the optical element. These prisms are placed between the subject and camera lens and produce one subject image for each plane surface on the face of the element and in a pattern corresponding to the arrangement of the surfaces. A diagram of a simple prism which produces these images is shown in Fig. 24. The center Section C consists of an optical flat which passes reflected light rays from the subject S without deviation to the camera objective lens, which in turn focuses it in the normal manner on the focal plane at C'. Rays from the subject S are redirected by the wedge section at A at such an angle as to be received by the camera lens and focused on the focal plane at A'. In a similar manner, the subject is redirected by the wedge

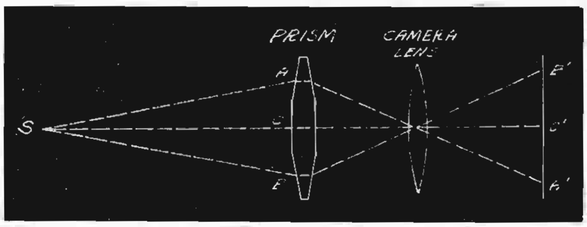

Fig. 24. Three-faceted prism.

Fig. 25. Multifaceted prism.

Fig. 27. Kaleidoscope.

section at B to focus a third image on the focal plane at B'. Fig. 25 shows a picture taken with a little more complex prism of this type, with five wedges surrounding the central facet.

Dove Prism

Another effect is produced with the Dove prism. It is placed in front of the camera objective lens in such a manner that its longitudinal axis coincides with the optical axis of the objective lens. Rotating the Dove prism around its longitudinal axis will then cause the image in the focal plane to rotate. Fig. 26 shows this rotation in progress. It is interesting to note that for every degree that the Dove prism is rotated, the picture image rotates 2°. In this manner, turning the Dove prism through 90° will cause an upright picture to rotate 180° and become upside down. Another 90° rotation of the Dove will complete the 360° rotation of the image and bring it back to its original upright positions.

Kaleidoscope

One of the oldest optical effect devices is the kaleidoscope. By utilizing the basic arrangement of the two mirrors which form a V and shooting through the V with the leading edge of the intersection (bottom V) framed in the center, studio scenes and performers may be shown in a variety of kaleidoscopic configurations. The number of images produced will depend upon the angle formed by the two mirrors and can be determined by dividing 360° by the angle. For example, if the angle is 60°, six images will be formed. Fig. 27 shows a picture taken with a kaleidoscope whose mirrors formed a 45° angle. While smaller angles will produce more images, it should be noted that there will be a greater difference between the sharpness and contrast of the unreflected image at the top and the last generation of reflected images or image at the bottom. Even though front-surfaced mirrors were employed in the kaleidoscope used to produce the

Fig. 26. Dove prism.

Fig. 28. Hartley lens.

illustration, there is a noticeable difference between the top and bottom images.

Etched Lenses

Another type of effect can be produced with etched lenses, Fresnel lenses, and fine-meshed screens. Ordinarily, great care is taken to avoid scratches on the lenses, but in this particular case, lenses or optical flats are etched on purpose with some pattern such as a series of concentric circles, dots, or crosshatching. The etching is fine enough to cause little interference with picture quality but yet deflect highlights in such a manner as to produce odd patterns of light flare. The picture shown in Fig. 28 illustrating the effect was taken with a Hartley lens attachment.

Projected Backgrounds

Projection can be used to provide backgrounds where photographic authenticity are essential, and on news and special-events types of shows to produce graphic or pictorial illustrations. In this latter group, the purpose is to "tie in" narrator and picture illustrations in one camera shot.

Rear and Front Projection

Projected backgrounds are both rear projected and projected from the front. When they are front projected, the projector is placed overhead and directed down on the front of the background screen at an angle. While this eliminates the need for space behind a screen, it results in some loss of playing area immediately in front of the screen where the actors cannot play without interfering with the beam of projection, as illustrated in Fig. 29. In addition, some "keystoning" will result from the axis of projection forming less than a 90° angle with the plane of the screen, and this may require a compensating predistortion of slides or provision for an optical correction.

While rear projection must of necessity be used with translucent screens, front projection can and customarily is used with opaque screens. These are often matte screens, and because of their superior diffusive characteristics, the "hot-spot" problem normally associated with rear projection, in which the center is bright, is not experienced. Cameras can dolly from one side to the other without apparent change in the light distribution of the projected picture.

Projection Lenses

To present the camera with the most uniform distribution of rear screen illumination requires the use of projection lenses of long focal length. Unfortunately, these lenses require long paths of

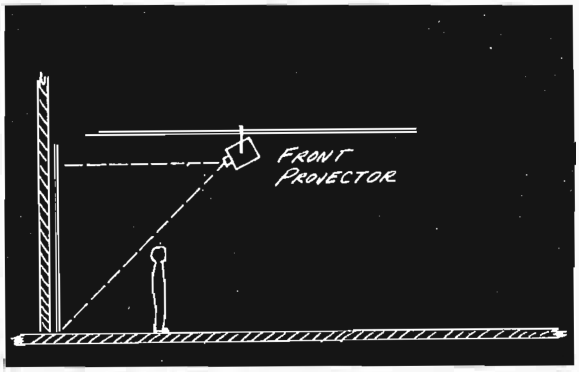

Fig. 29. Front projection setup.

projection and consume much space behind the screen. When space limitations make this impractical, front projection may provide a better solution.

Slide Sizes

The most commonly used slide sizes for studio projection are 3¼ X 4 in. and 4 X 5 in. Generally, larger slides are easier to cool but the difference here is not significant. Equipment employing slides smaller than 3¼ X 4 in. is generally intended for the visual-aid field and, except for use with the miniature screens, has little application for background projection.

Screen Materials

The picture quality of rear projection depends to a considerable extent upon using the proper screen material. Fig. 30 shows characteristic gain curves for three different materials. These were derived by directing a collimated light source perpendicularly onto the rear surface and measuring brightness on the front surface at angular inter-

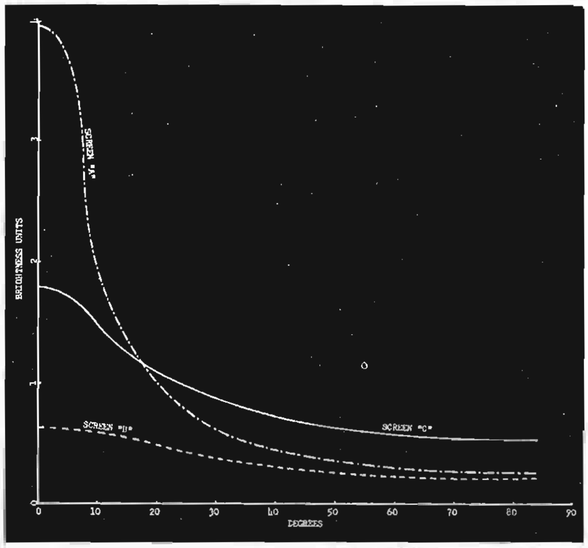

Fig. 30. Diffusion characteristics of screen materials.

vals from the perpendicular to the plane of the screen. Inasmuch as all three materials exhibited symmetrical characteristics, the curves are applicable to angles in all directions from the perpendicular to the plane surface of the screen.

From these curves it can be noted that Screen "A" will produce the brightest picture and with narrow-angle lenses on both the projector and camera, this quite obviously is the material to use. Should it be necessary to use a wide-angle lens on the projector and shoot the screen at short-range with a wide-angle camera lens, a severe "hot-spot" will result. If the camera is moved laterally, the "hot-spot" will follow, centered around the projection lens if it could be seen through the screen from the camera lens position. To minimize this "hot-spot problem, it may be necessary to use Screen "C" material with less gain but a smaller brightness change with change in angle. If the "hot-spot" is still troublesome, it may be necessary to resort to Screen "B" material with less than unity gain but minimum change with change in angle. Screen "B," however, will require about five times as much projection light as Screen "A," and if this is not practical, certain trade-offs may have to be made, such as reducing the size of the projected image.

Another consideration is reflectance. It is quite obvious that the reflectance must be diffuse, or nonspecular, to prevent the camera from picking up set lights, but in addition, it is desirable that the reflectance be kept low in order to maintain picture contrast. To reduce reflectance, a black bobbinet is sometimes placed in front of the screen. While this reduces reflectance, it also reduces transmittance, but in a ratio of 2:1, inasmuch as the reflected ambient must pass through the bobbinet twice compared with once for the rear projected illumination. Whether this is good practice depends to a considerable extent upon the ultimate use. If the screen is used where spill light can be controlled, adequate contrast may pose no problem and the higher light transmittance would be preferred. Where this control over spill light cannot be maintained, then the sacrifice of transmittance for lower reflectance may be a good trade-off.

Beyond the optical requirements, the physical characteristics of the materials are of some consequence. It is customary to expect rear screens to be shifted around like studio scenery, and for this practice it is desirable that screens be made of light-weight, reasonably rugged materials. Some of the plastics have been found suitable. Another excellent material is latex, but it is somewhat more fragile than the plastics. Just how durable the material must be is something that can best be decided after the actual application is known.

Lighting for Rear Projection

In addition to good equipment, the proper employment of studio lights is also essential to the successful use of rear projection. It is important that "key light" be kept off the screen. To do this it is necessary for the actor to play a distance at least equal to his height in front of the screen just as he would—or should—with other background scenery. Barn doors or other light-blocking means should be used to keep backlight off the screen and efforts made to minimize the impingement of fill light.

Shooting Rear Projection

Good projection and screen equipment having been used and the set lighted properly, there still may be evidences of the "hot-spot" which will prove troublesome unless the screen is shot properly. Referring to Fig. 31, the best way to shoot a scene from Projector A is along the axis of projection with Camera A. To Camera B, the right side of the screen would appear bright and the left side dark. If it is known that the preponderance of shooting must be done with Camera B, then Projector A could be moved to the location of Projector B. Focus would have to be split, and keystoning might have to be corrected. The same rule also applies to elevation.

AUDIO EFFECTS

One of the most critical requirements of sound effects in television is synchronization with the picture. Lack of synchronization may detract from the credibility of the effect as well as the performance. This may result in an ineffective scene and even annoyance to the audience.

For radio, the critical requirement is realism. With only the help of dialogue, the effect must sound sufficiently authentic that there can be no doubt left in the listener's mind as to what is happening.

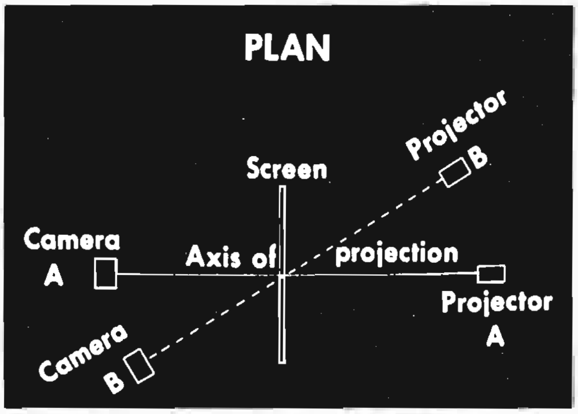

Fig. 31. Shooting on axis of projection (plan).

In television, there are four basic types of effects which must be considered. First are the on-camera effects—effects one would expect to hear with a picture. As the picture would show the telephone bell or handset, the audio would transmit the bell ringing and, when the telephone is answered, the sound of the cradle being lifted. There are many other such on-camera effects which may have to be performed by sound effects.

Second are the effects that are off camera. These effects are very much like radio effects, and must be quite creative in themselves. They must paint a picture strictly by audio. For instance, perhaps a scene calls for the arrival of a person in a car. Let's assume that one of the actors might be looking out a window from inside a house. The viewer hears an off-camera car drive up, actually a sound effect. The actor reacts and the camera stays with him. The car stops; the car door opens and closes; the car drives off. The next things that are heard are footsteps and a knock on the door. So far everything that was heard was done by sound effects. When the actor opens the door, a second actor is standing in the doorway. The actor had been there all the time, but the audience got the story. It was all done with sound effects.

The third type of effects are those that are used for background or to set a scene. For instance, if a scene opens outdoors or on a street, one would expect to hear some traffic sounds—especially if it is a city street. It might be a side street, and a car might never drive past, but as long as the camera is outside, the viewer would expect some sound. In a night scene outdoors in the country, night sounds such as crickets would be heard. All these various effects help to set the scene.

The fourth type of sound effect in TV which is completely different from radio is the type where the sound man must create a sound track for a silent film. This is done on programs such as documentaries, utilizing a number of clips of film and/or tape. It is up to the sound-effects man to get a viewing of this film and then put in these effects while the film is taped or aired "live." Quite obviously, synchronization is very important. Often, time is short and so the sound-effects man needs equipment that is considerably flexible. In the following pages some of this equipment is described.

Sound-Effects Console

Television and radio production requires a wide variety of sound effects. Some of these effects are produced manually, some electrically, and some from recordings of the actual sound. In order to reproduce and amplify these various effects, turntables, amplifiers, and associated equipment are necessary. An example of a console (Fig. 32) designed for this purpose is one used at CBS.

Fig. 32. Sound-effects console (Courtesy of CBS).

The Turntables

The console consists of three variable-speed turntables and four pickup arms. The variable speed is very desirable for sound-effects use. Most of the sound-effects records are cut at 78 rpm, but by being able to change record speed it is possible to get a variety of effects from the same disc. For instance, with a sound-effects record of a car running, the variable speed allows the sound-effects man to vary the speed during a chase scene or to even slow down and stop the car. Records played at 78 rpm can give other effects at slower speeds. For example, a waterfall record can be made to create an explosion at slow speeds.

The Pickups

The four pickups used are so designed and installed that any two arms will work on at least one table, so that all four arms can be used at once. This is valuable for cross fading and continuing the same effect for a long period of time such as a car running, a train-wheel click, etc. In addition, two different cuts of the same record can be played at the same time or quickly cross-faded. Another effect is to play a smaller record of one effect on top of a larger record, in essence, having a fourth turntable. Still another effect is to place two pickup arms in the same groove. By so doing an echo can be obtained, as one arm is one-quarter turn behind the other arm. The type of pickup used is a crystal with a replaceable steel needle.

Amplifiers

Each pickup is equipped with its own preamplifier with a self-contained equalizer. The equalizer can raise or lower the treble end. This is useful for sound effects to be able to change response to suit arising conditions. It is possible with this setup to play voice cuts of records made overseas and

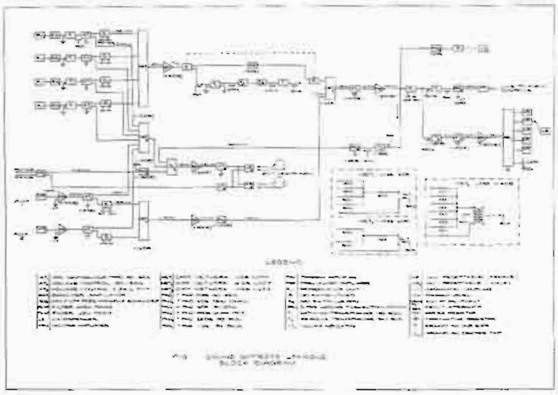

Fig. 33. Sound-effects console block diagram.

make them more understandable than if they are played on so-called Hi-Fi reproducing equipment. These preamplifiers are fed to a mixing network along with two other inputs. The two other inputs can handle a microphone for acoustical or manual effects such as doors, telephones, bells, etc., or one of these other inputs can use an input coil instead of a preamplifier. Then it is possible to use additional high-level inputs such as other turntables, and audio tape cartridge units. The individual controls have a cueing position on the fader so that a cue can be found rapidly even though the console is feeding other effects on the air. This is very useful when last-minute changes have been made or a marked cue has been lost during an air show. As shown in the block diagram, Fig. 33, there is a booster amplifier between the mixing network and the master volume control.

Filters

A sound-effects filter of the low-pass—high-pass type is used for an overall effect. This device has roll-off frequencies of off-100-250-500-1,000-2,000-3,000-4,000-5,000 on the high-pass and off-5,000-4,000-3,000-2,000-1,000-500-250-100 for low pass.

Conclusion

To show how a sound-effects man is actually set up to do a show using this turntable, see Fig. 34. First of all, the output of his console is fed on a line directly to the control-room audio console. He checks levels by using a tone record when he checks in. Usually his fader in the control room is left open, and he is responsible to see that only those sounds that go to the control room are the correct sounds. The line that feeds the control room carries all his effects—recorded, acoustical, or electronic. In order to work this equipment remotely from the studio, the sound-effects man needs first of all to wear earphones so that in one

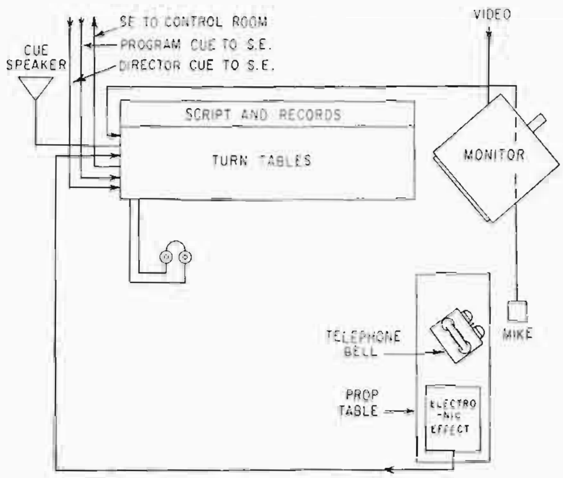

Fig. 34. Simplified circuit showing how a sound-effects console is connected to control room.

ear he hears program cues which includes his own effects. In the other ear he can select either director's cue or boom cue, as he must anticipate every cue. He has to be ready for it when it appears on the screen and synchronize with the visual effect. At this point he could use several heads: one to watch the monitor, one to watch the script so as to prepare the up-coming effects, one to watch the VU meter, one to watch what he is doing at the moment he is making a particular effect. He must ride all his own gain including his own mike and be able physically to fade on and off manual effects. He must make sure the level to his speaker is enough so the actors can hear the effect but not so high as to cause feedback to his own mike.

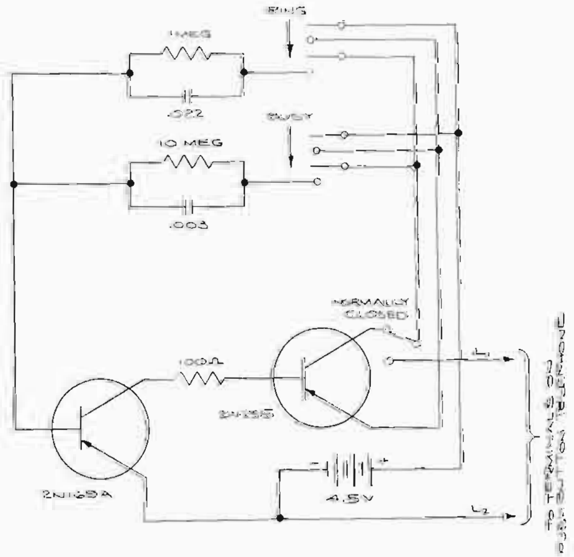

Fig. 35. Internal telephone sound circuit with busy and ringing effect.

The Telephone

Telephones are widely used in TV dramas as well as in radio. In Figs. 35 and 36 we see a sound-effects telephone which has gained wide acceptance in the industry. This design accomplishes the following effects:

Telephone Ringing in the Line or at the Other End. Here there is no bell sound, but it is the sound the caller would hear in his earphone as the second party's telephone is being rung by the telephone company. It is operated by the sound-effects man.

Various Types of Clicks. The clicks are used to indicate connecting parties together or a distant receiver being hung up. This sound would be heard by the caller who would be on camera. It is operated by the sound-effects man.

Busy Signal as Heard by Caller. This is operated by the sound-effects man in any rhythm the director desires.

Additional Telephone Effects. In addition to the telephone device shown, the CBS sound effects department has recently developed additional methods of generating and amplifying the necessary effects for telephone use with transistors. Circuit data are given in Fig. 37 shown when a battery supplies the power for the two-tone generator circuits, key click, and bell-ringer effect (Fig. 38). This is all contained in a modern handset with the handset mounted on the batteries. This particular type of bell set sounds very modern, so it can really be used only with a modern telephone prop. All the above effects are performed on the sound-effects microphone, and it is up to the sound-effects man to achieve the right perspective according to the picture. This is done not only by a change in volume as the picture gets tighter on the telephone ringing but also by bringing the instrument closer to the sound-effect microphone. Other telephone effects are achieved in a variety of ways.

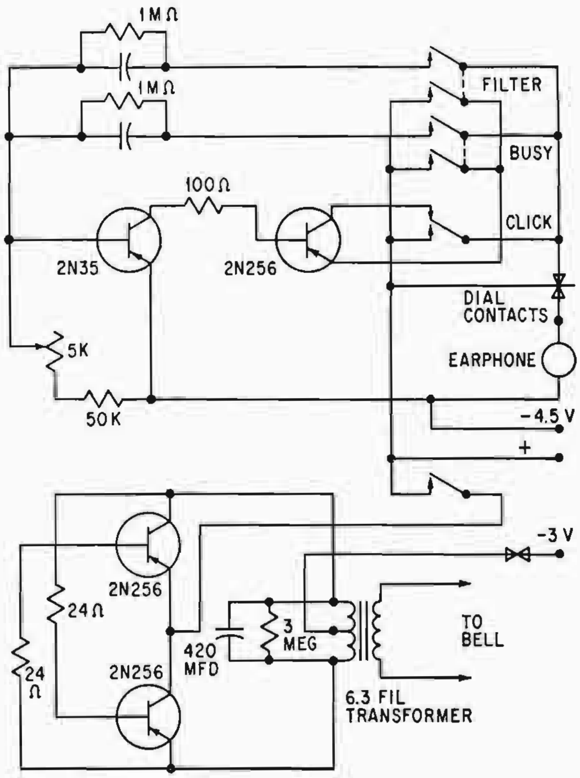

Fig. 37. Circuit of electronic telephone.

Fig. 36. Push button telephone with interval telephone sounds.

Fig. 38. Electronic telephone.

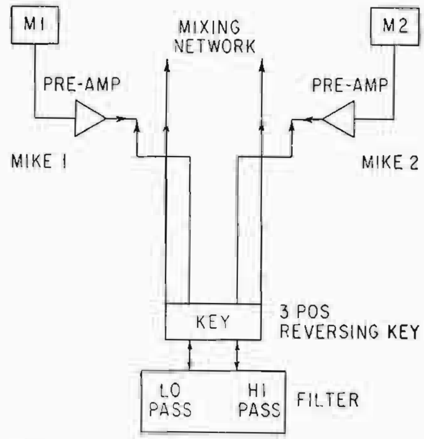

Fig. 39. Circuit showing hookup of two-way telephone filter effect.

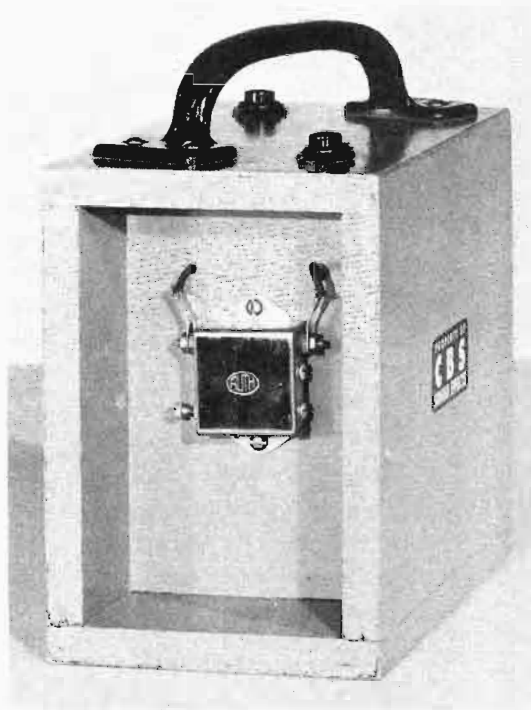

Fig. 41. Doorbell with self-contained batteries.

Telephone Filter. For instance, a so-called telephone filter uses a normal microphone which is fed through a sound-effects filter. The sound-effects filter is usually a low-pass—high-pass type which in essence then becomes a bandpass filter. This means that the low frequencies and extreme high frequencies that can be heard normally are cut off with the sound-effects filter, so the effect is that a person is talking over a telephone or the voice is "filtered." Quite often in TV as well as radio the actors switch places or reverse their "on" and "off" camera positions, in which case the filter mike has to be reversed also by the audio man. This can be done with one filter unit and a reversing key that requires the output of the two mikes that are being used to be reversed. The reversal takes place at the output of their respective preamplifiers (see Fig. 39). Another possible method is that the filter is switched by the switcher on certain camera takes. This is a video interconnecting system with the audio filter. This would actually be set up for each program as needed. This method helps eliminate errors.

Practical Telephones. Another device that is needed in TV is a "practical" telephone for the actors talking on the telephone—both on and off camera. These telephones are made practical by actually (Fig. 40) connecting the receiver part of the telephone handset to a cable that can connect directly to program cue. So the actors then can hear themselves as well as all the program and the other end of their telephone conversation even though they may be quite a distance apart. Occasionally a switchboard can be used in a show which is not practical except for inserting the telephone plugs. In this case, the sound-effects man would have to supply all the necessary buzzers and bells that the switchboard sound might need. It usually is simpler to add the sound effects than it is to try to make the switchboard practical.

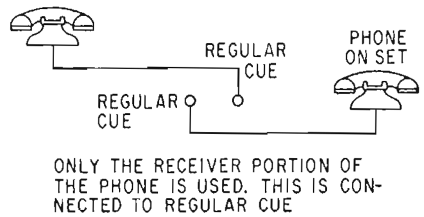

Fig. 40. Circuit showing hookup of practical telephones.

Bells, Buzzers, Chimes

A device that is widely used in TV is the sound of a doorbell or door buzzer and occasionally a chime. Once a particular bell or chime is selected for a set, this unit has to be always available whenever this particular set needs it. Door buzzers are made up in such a way that a selection of various ones is available (see Figs. 41 and 42). The buzzers and bells are mounted on wooden boxes which also contain the operating batteries. They are shock-mounted on rubber also. Several types of chimes, door chimes especially, are always in demand. Fig. 43 shows one type.

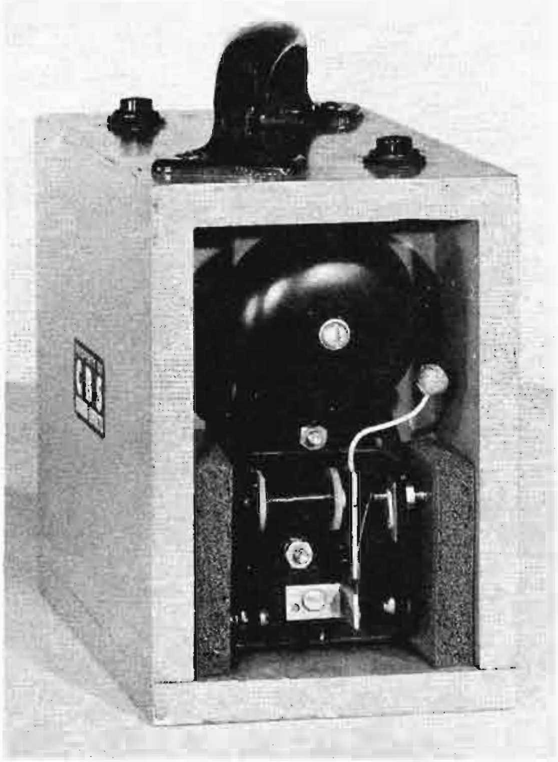

Fig. 42. Door buzzer with self-contained batteries.

Reverberation

Definitions

There are various ways of producing "echo" and reverberation. These two terms are used synonymously, but actually they are different. Echo is a distinct delay that reproduces the original sound once or several times over. Reverberation is a continuation of the original sound with no separation between the original sound and the continuation.

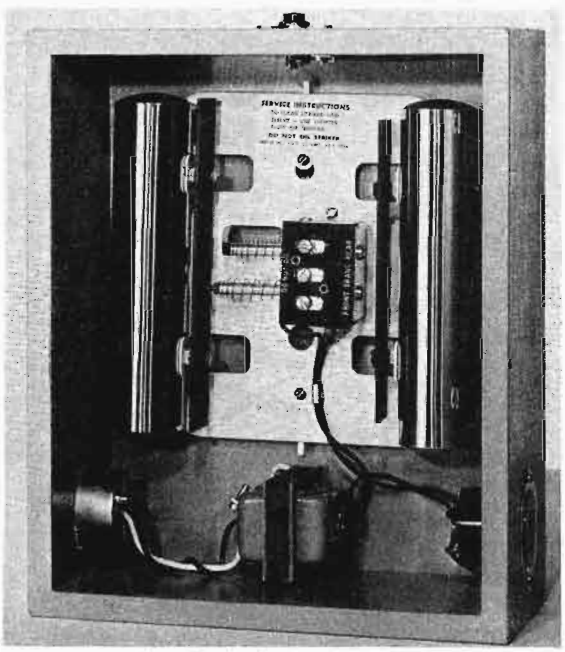

Fig. 43. Dual electric chime.

Reverberation Units

Devices for the creation of artificial reverberation have been developed which replace the traditional acoustic echo chambers used heretofore in television, radio, film, and recording studios. They utilize the physical properties of metals to achieve their effect.

It is known that a steel sheet, excited by an impulse setting up oscillations, will deliver reflections which increase in density with time, and that sound reflections in a three-dimensional room become more dense as a function of the square of the time. It is also known that the human ear is unable to recognize the difference between these two operating modes.

Through the use of appropriate steel and critically chosen dimensions, it is possible to produce a plate which possess an adequate number of self-resonances. The length and frequency response of the decay time produce an artificial reverberation effect, which is not possible to differentiate from that obtained from a three-dimensional room. One such device is the EMT Reverberation-Unit (Fig. 44).

Cartridge Tape Machines

Cartridge tape machines are now playing a major role in sound effects mixing and postproduction sweetening.

New cartridge machines that have gained wide industry acceptance are machines using "NAB" cartridges. Another type which is in use is the Mackenzie unit as shown in Fig. 45. These devices permit easy mixing, tightly-cued synchronized effects, such as audience reactions, thunder, gunshots, explosives, etc.

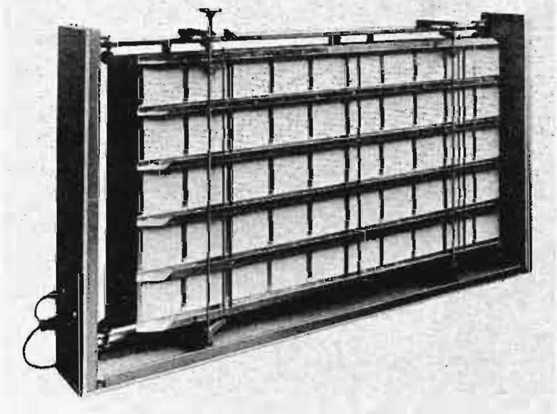

Fig. 44. Reverberation Unit (Courtesy of Gotham Audio Corp.).

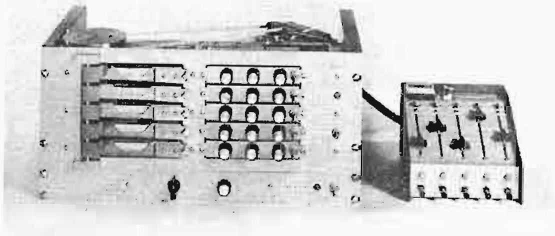

Fig. 45. Mackenzie cartridge unit.

Fig. 46. LP turntable.

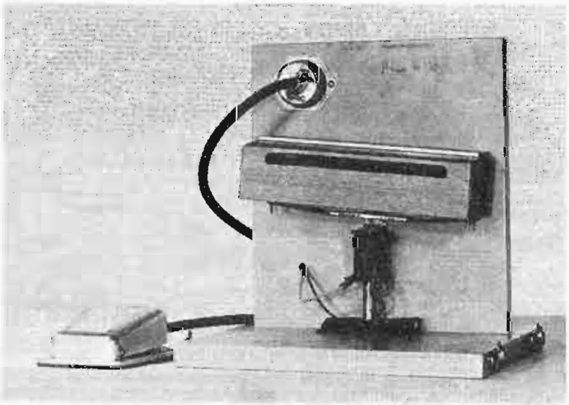

Fig. 47. Electric "bat crack" showing foot pedal.

Other Electronic Effects

With LP records, a more desirable type of turntable was designed to be used by the sound-effects man. Inasmuch as sound-effects men are called on to play various types of music records as well as sound-effects records, especially for backgrounds, cafes, nightclubs, etc., this particular design was a must. This table uses a good four-speed turntable and a properly balanced and weighted arm so that LP and EP's can be played with good quality. For cueing purposes it is equipped with a transistorized amplifier that feeds a small speaker encased in the turntable case. This is shown in Fig. 46.

The "Boing"

One type of electronic "boing" that is widely used is in effect a guitar string that is stretched over a magnetic pickup. The pitch is varied by a handle on one end. Fig. 48 shows this device. Another type that is used is the ordinary Jew's-harp. This takes an artist to play it, however.

The Electronic Bat Crack

During the baseball season a good bat crack for sound effects is a necessity. The electric bat crack

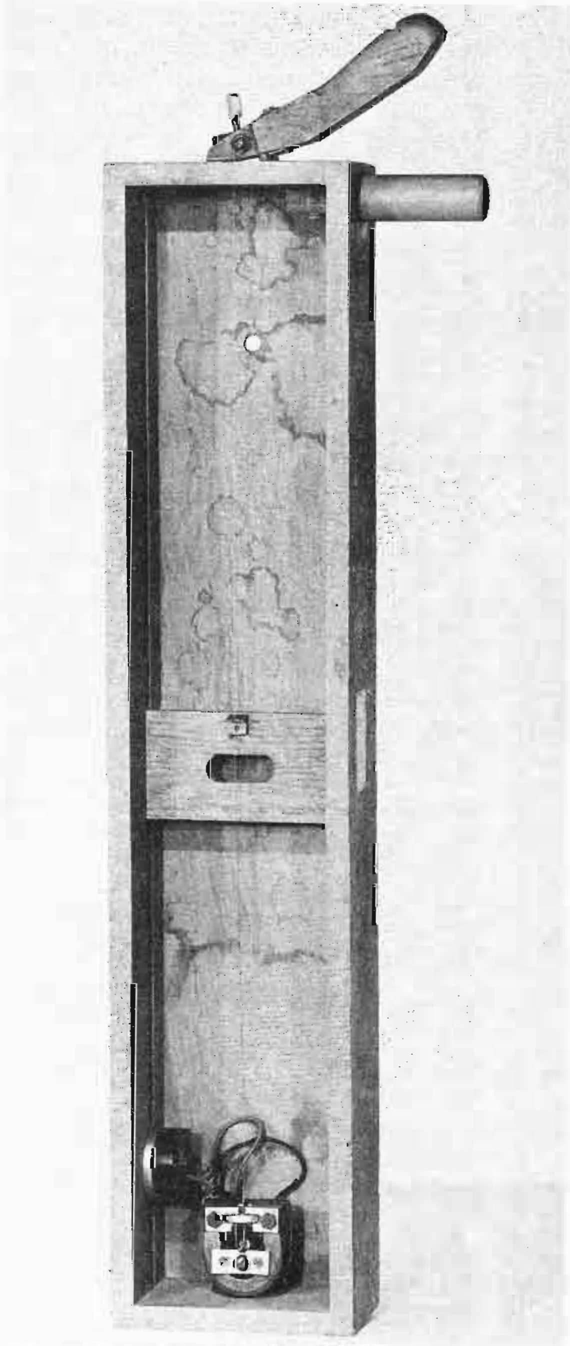

Fig. 48. Sound-effect "boing" showing steel string.

(Fig. 47) is a device using a solenoid and tempo block operated by a foot switch. All the sound man must do is watch the monitor, and by stepping on the switch at the precise moment, he gets an effect of a bat crack. At the same time he hand operates his crowd-reaction records.

Oscillators

Various types of oscillators are used in sound-effects work. Usually there is a demand for tones of all types. So everything from beat-frequency oscillators to single-tone self-operated types are called for. One type that found favor was the neon oscillator, shown in Fig. 49. This particular device was used mainly because it would not change pitch over a program but would remain on pitch. This was important as it blended with organ music.

Manual Sound Effects

The Door

The sound-effects door (Figs. 50 and 51) plays a major role in TV production. Since this is a visual medium, the sound effects might look unnecessary. However, this is not the case. Quite often a door will open and close which will not be "on camera." Consequently the sound should be heard as indicated in the script. Otherwise, the story will not have continuity or meaning. Then quite often a door that is on camera or is visual may not sound like a door, or it may have the wrong latch on it or may be too far away from a mike to pick up the actual sound. In this case, once again the sound-effects door has to "fill in" the vacant sound. Occasionally a simple effect such as a knock on a door may cause a set to move or shake while on camera. Here once again the sound-effects man does the actual knocking, even though the actor may go through the motions.

Fig. 50. Sound-effects door (front) showing door latch, chain, and acoustical chamber for resonance.

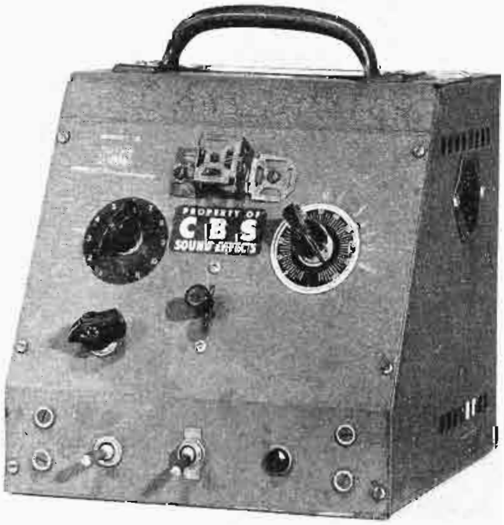

Fig. 49. Neon oscillator for sawtooth tone.

Horses' Hooves

Coconut shells are used as much in TV as in radio depending on the script. Almost any effect which lends realism and can be controlled is actually much better done "live." Rubber plungers can also be used. Actually making a horse effect calls for good rhythm and coordination, and only a few people are gifted this way. When used with dirt or gravel as shown in Fig. 52, dirt should be wet down to avoid dust.

Door Squeak—Wooden

A wood squeak is caused by two dry pieces of wooden material rubbing together. A form of one type is shown in Fig. 53. Actually one end is in a

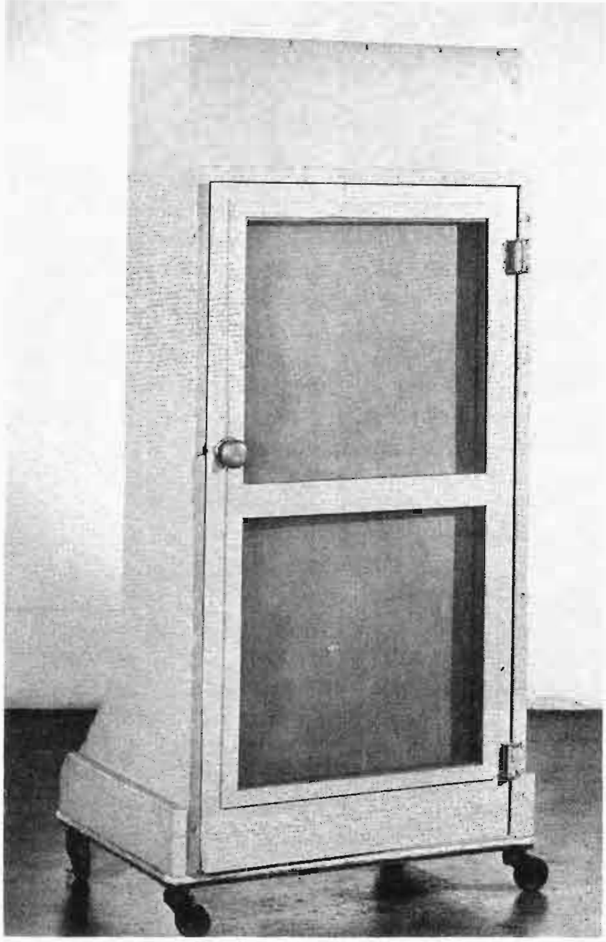

Fig. 51. Sound-effects door (rear) showing screen door.

dowel shape. This is moved in another piece of wood, preferably hardwood, and the squeak is adjusted by tightening down on the dowel. This must be adjusted to get a proper squeak. The whole assembly can then be put on a door with a

Fig. 52. Horses' hooves in dirt box—using coconut shells.

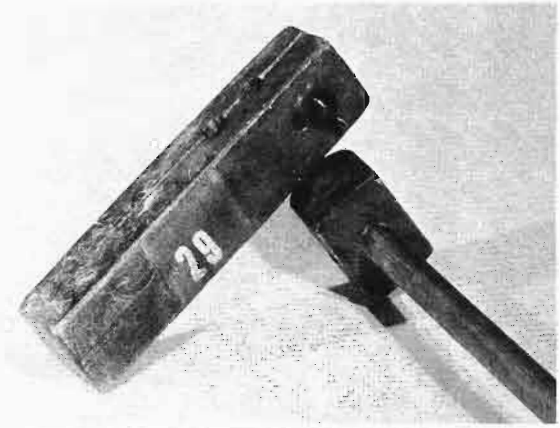

Fig. 53. Wood squeak for sound effects.

temporary C clamp. This squeak can then be operated by a sound-effects man as in Fig. 54. This way the squeak does not have to follow any rigid pattern but can be different each time. One door for *Inner Sanctum* was actually built for just that show. So that no other show would use this door, it was kept locked. When the show moved from one network to another, the door traveled with it.

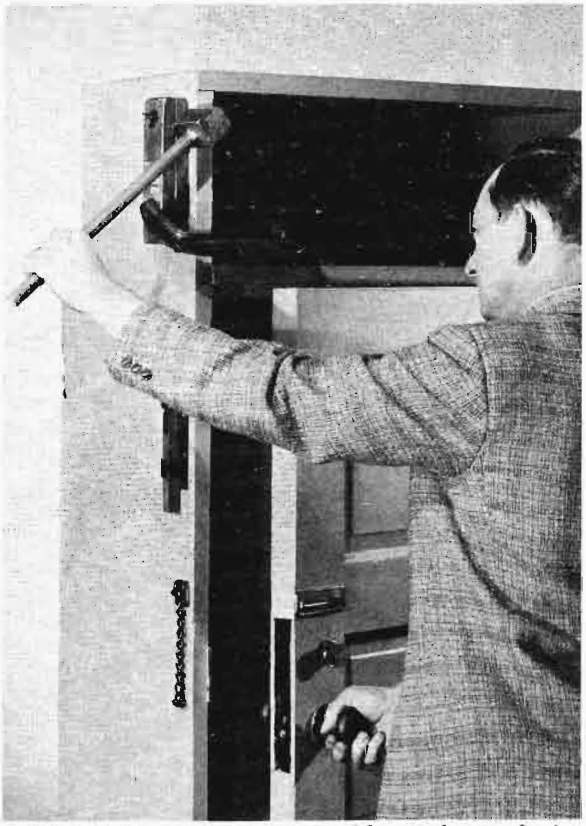

Fig. 54. Sound-effects door with wood squeak attached.

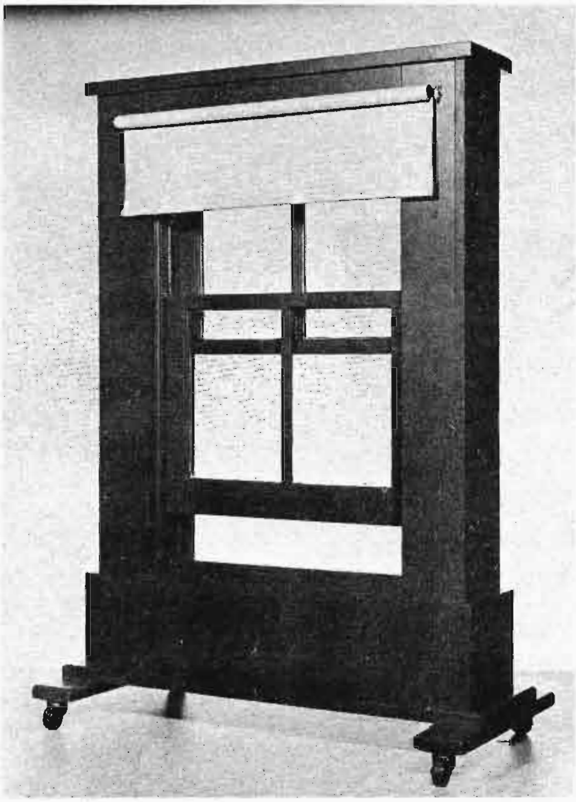

Fig. 55. Sound-effects window showing shade.

Audio and Video Special Effects

The Window

A device which is used quite frequently is the window. This is shown in Fig. 55. One window is hung with regular sash cord while the other uses chains to give a different effect. There is also a place for a window shade, as occasionally such an effect is needed.

Floor Boards

Most studios use concrete floors and tiles. There is also a demand and need for wooden floor boards that are portable. A wooden floor board is used, of course, to emphasize footsteps, especially when there is no dialogue present (see Fig. 56). Quite a few directors insist on footsteps, so all sound men carry an extra pair of shoes for sound effects with hard leather heels. Footsteps are not used so much in TV as radio, however, as it is possible to see movement, and any fast movement such as running can actually be picked up with the actor doing the effect.

In addition to wooden floor boards, sound-effects men are called on to simulate walking on sidewalks. A marble slab about 12 by 24 in. can be used for this as shown in Fig. 57. Movement is expressed by walking in one spot up and down. Sound-effects men are also called on to do footsteps on gravel, sand, snow, metal floors, brush—and you name it. Note in Fig. 58 steps on a gravel bag. The gravel is contained in a double canvas bag so that the sound will come out but not the gravel. This way there is no mess or spilled gravel on the studio floor. However, if the director insists, the bags can be opened easily and the gravel can be spread out on a canvas over a larger area. In a similar manner bags can also contain cornstarch to get an effect of walking on snow, or a small cardboard box of cornstarch well wrapped can give the same effect very close to the sound-effects microphone. The box is squeezed by hand.

Fig. 56. Footsteps on a wooden floor board.

Fig. 57. Footsteps on a stone slab.

Fig. 58. Footsteps on gravel (in bag).

Fig. 60. Footsteps on a slanted board for stairs effects.

Occasionally an effect of walking in brush or through trees is called for, in which case broom straw is used. This can be done by hand or can actually be walked on if there is sufficient room.

Stairs

Wooden stairs are called for occasionally, and a set is shown in Fig. 59. If these are not available, there is a simulated effect which it can get from a floor board or a slanted board as shown in Fig. 60. Since the board is slanted, it is impossible to walk flat on it, so the foot slides onto it, as in the case of stairs, and the heel sound is not heard—only the sole of the foot.

Prop Table

A very important item that is used on practically every show is a prop table. Prop tables have been designed in a number of ways. This table has a cork top so that it is quiet and durable. The height is a matter of practical mike placement on one side and the height of the sound man on the other. Besides holding props, this table can be used for such things as a body fall with elbows and arms landing on it.

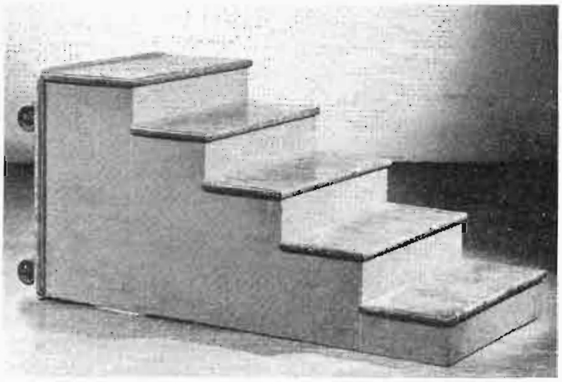

Fig. 59. Sound-effects stairs (portable).

Glass Crash

This shows a type of manual glass crash that actually breaks a piece of glass. Window glass is supplied in an 8 by 10 size, and when one or two sheets are placed in this frame, it can be broken by pushing down the lid of the machine (see Fig. 61).

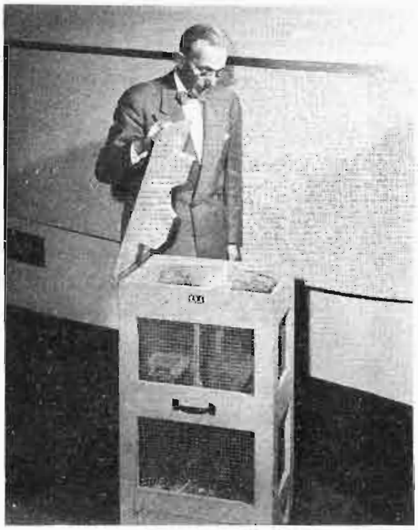

Fig. 61. Glass-crush machine.

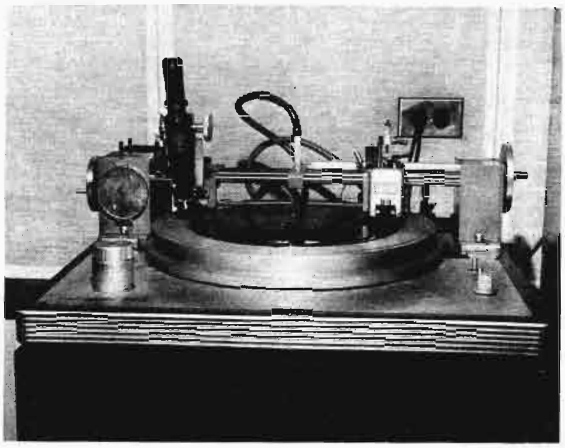

Fig. 63. Cutting lathe.

RECORD LIBRARY

With the successful Apollo space flights, the sounds of outer space are with us, and a great deal of work has been done to preserve them for use in future television shows. Miles of tape will be evaluated and new records will be made. However, the sounds of the past, although disappearing from the scene, must also be retained. Rarely do we hear a steam train's mournful whistle, the rattle of a horsedrawn wagon, the clanging of a trolley car, and many more mood-setting sounds. These records have to be stored (Fig. 62) and be readily available for immediate use. Since tape allows a great deal of information to be kept in a small area, entire master libraries have been made up. Everything is catalogued and numbered so that, whenever necessary, a disc can be cut on the lathe (Fig. 63). Use of tape and the lathe makes it possible to blend combinations of records to a desired form. Acetate discs are not as permanent as pressed discs, but if cared for and handled properly, a great amount of use may be obtained.

30

Radio on Wheels

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Programming away from the main studio has become a way of life for many broadcasters both large and small. It is a method whereby the audience meets the air personalities, a device for the sponsor to assemble large crowds at his place of business, and a method whereby the station can add substantial income and program material not otherwise available. In planning such facilities, the broadcast engineer is faced with a myriad of problems and decisions. When considering the purchase of a permanent type remote broadcast facility, one must consider many possibilities both in choosing the equipment and the mobile unit in order to provide optimum performance. This article will provide the reader with an insight into what the prospective user needs to know in order to successfully carry out remote broadcasts on a continuing basis, and so far as practical, independent of telephone line circuitry. The more self-contained and independent the remote broadcast unit is for the job to be done, the greater will be its value to the station.

TYPES OF REMOTES

There are many types of remote broadcasts. However, they can be broken down into the following categories:

1. Disc jockey plus record spinning (commercials inserted at main studio);
2. Disc jockey plus record spinning plus commercial origination at remote;
3. All of No. 2 plus local live interviews;
4. All of No. 2 plus local pretaped interviews;
5. All of No. 2 plus local live music (band, orchestra, etc.);
6. All of No. 2 plus interviews or presentations by wireless microphone;
7. Sports events (continuous or short report type);
8. Public affair (fairs, speeches, conventions, etc.).

Most remote broadcasts fall into one of the above categories, and each one requires its own special type of hookup. Successful remote broadcasting requires equipment so arranged that it will handle all probabilities with little or no changes. Of course, if program requirements call for only one particular type of remote, extras need not be included. For example, if the programming calls for just a local appearance by an air personality at some location, a microphone and amplifier to feed a telephone line may be all that is needed. However, as the complexity of the remote grows, more equipment will be needed. If the programming calls for a disc jockey, an operating console with turntables will be required.

If commercials are to be inserted from the remote location, cartridge machines will be necessary, and the console must have additional inputs. Live interviews from the remote location will require additional microphone inputs for the console. Locally recorded interviews on cassette recorders, etc., also must have a feed into the console. When broadcasting live music, a microphone mixer is recommended for the proper audio-mix. Wireless microphones may be desirable when working in crowds since this eliminates the possibility of cables being pulled loose, or of tripping a passerby.

The broadcasting of sports events may range from simple to complex, depending on how many announcers are used and where, the cue involvement, and the commercial origination. On a local level, though, a microphone and an amplifier may be all that is necessary. Public affair events are perhaps the most challenging of all remote broadcasts due to their unpredictability. Preplanning is an absolute essential.

CHOOSING A LOCATION AT THE REMOTE SITE

When a remote broadcast has been scheduled, it is necessary for a member of the engineering department to visit the site. If it is to be a sponsored event, check with the manager or other person in charge, and, if possible, before the day of the event. The greater the knowledge of what can be expected to happen, the less the chance of errors during the actual program. Ask such questions as: preference of equipment and mobile unit location but do not hesitate to raise questions if the location is not the best. For instance, note the layout of the sponsor's location. Is he on a busy highway? Is the parking lot large enough? These questions are very important for obvious reasons; a good view of the remote from the highway is always an advantage so that it will catch the attention of those who pass by. Large crowds can create a hazard to passing automobile traffic, or even worse, restrict ready public access to the sponsor's place of business. In many cases, one must choose the best compromise. Some of the more simple but obvious questions are the most important. Are electrical outlets conveniently available for the equipment? If so, determine what else is on the circuit. Are high current appliances on the circuit and will the addition of your remote facilities perhaps cause an electrical failure in the middle of the program? Where is the fuse panel location just in case such happens. Are spare fuses available? Is the area served by adequate telephone facilities? Will additional personnel be needed for crowd control or to give cues, etc., during the show? Choosing the remote location is important, and it must be carefully checked prior to program time if trouble is to be avoided.

WHAT TO USE FOR YOUR REMOTE UNIT

This is obviously based on the programming needs. If the remotes are occasional with only an announcer, a microphone and line amplifier is adequate. However, as the scope of the stations' remote activities increases, more permanent facilities are required. This can run the gamete from a converted station wagon all the way up to a completely self-contained motor home. Experience dictates a medium to large trailer, or motor home, is highly desirable.

The following questions will help to determine what will be needed:

1. What type of remotes will be performed and what equipment will be needed?
2. How much room will be required and what type of vehicle will provide it?
3. Will the vehicle selected accommodate the modifications needed to best suit the programming requirements?
4. Is the vehicle approved for driving on state or secondary roads?
5. Will the unit be adequately soundproof?
6. Can the unit provide its own AC power?
7. Does the vehicle have provisions for announcer comfort such as air conditioning, water cooler, etc.?

Fig. 1. WDON mobile studio on location for coverage of a golf tournament. Unit is self-contained with raised antenna.

8. Can the vehicle be locked and secured easily?
9. Can the unit be painted so that it can be recognized as an extension studio?
10. Does the vehicle have adequate storage space?

In the case of station WDON, a motor home was chosen. Since a wide variety of remote programs are engaged in, a large self-propelled unit with built-in soundproofing, power generator, air-conditioning, refrigerator, etc., was selected that would require a minimum of modification.

A console and turntable package were purchased from a commercial manufacturer complete with cueing and monitoring facilities built into one unit. An auxiliary microphone mixer was purchased for mixing additional microphones for live programming external to the unit. Two seats were removed from the vehicle and the console was installed adjacent to the side window so that the equipment and the control operator could easily be observed from the outside.

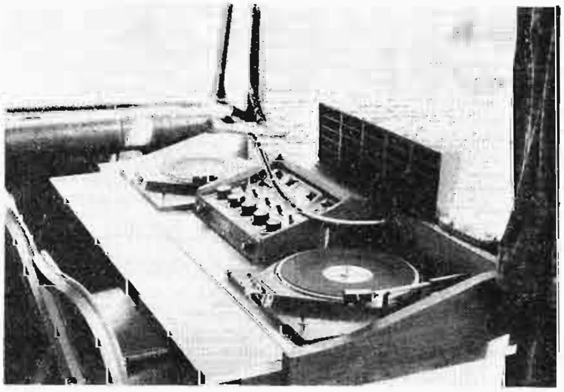

Fig. 2. A commercially available console was utilized with plug-in provisions for cartridge tape equipment. Two chairs are provided for side-by-side interviews.

CHOOSING A METHOD FOR RELAYING THE AUDIO SIGNAL BACK TO THE STATION

There are several choices of relaying the audio signal back to the studio; the simplest method is with an ordinary telephone line. The phone company provides an audio coupler so that the output of a mixer or console may be fed directly into the telephone dial system. At the station end, the same device can be used to couple directly into a console input from the station telephone. A check with the local telephone company should be made to determine rates and installation. This type of interconnection is most handy and convenient for local remotes when the dial telephone lines do not traverse through more than one or two exchanges. The fidelity is quite good for speech or music and minor frequency discrepancies may be compensated for by an inline equalizer at the station. If a bad or noisy line is encountered merely hang up and dial again. This type of interconnection is satisfactory for AM stations, but it lacks the wide dynamic frequency range for FM requirements. One arrangement is to get an extra station telephone line with an audio coupler attached, including a plug and jack arrangement. The telephone can then be taken to remote locations and the only installation at the remote site is to plug-in the unit. If remotes are performed frequently at the same sponsor's location, the jack can be left in permanently for this purpose.

Another type of phone service generally used is the direct metallic nonequalized pair. This again is suitable for local remote use. The frequency response attenuates rapidly with distance as does signal level. The advantage, though it costs more, is the fact that the line is solely for the station's use and removes the possibility of having "dialed-up" phone line problems such as someone accidentally picking up an extension on the same line used for broadcasting. Phone companies also restrict signal levels that are fed into their lines to fixed maximums. It is therefore best to check with the phone company for their particular requirements.

A third type of basic line is the equalized loop. This is a dedicated pair from one site to the other. The line is equalized for frequency response, and line amplifiers are used to make up for line losses. At the main studio termination point, facilities should be provided so that a proper match is affected between the audio equipment and the telephone company line, thus, providing the best utilization of the incoming audio. Usually at the receiving point a 600-ohm repeater coil is provided by the phone company to work directly into the station equipment. An additional note on nonequalized circuits is to provide a 150-ohm to 600-ohm transformer for a better match. At the remote end on nonequalized circuits, the phone company merely provides the termination point of the pair.

If a station's studio is outside the major center from which future remote broadcasting may take place, quite often the phone company will install a permanent equalized single pair from the telephone exchange nearest to the sources of occasional remote to the station. Then, as the equalized circuits are ordered, the telephone company will connect to the permanent terminal into their exchange office, for the ordered period of use. This saves longer run lines, with resultant savings in installation time, with the knowledge that the permanent line from the exchange to your station can be frequently checked and corrected if noise or distortion should develop. The only disadvantage is that back-to-back programs from different points may not be cleared through the phone company exchange as fast as it may be necessary.

At the remote location prior to telephone line installation, make sure that the termination site is labeled for the telephone installer. Since the appearance of an installer is not predictable, a tag saying "Put line here" makes things run much smoother. Telephone lines are usually quite reliable, however, the longer the lead-time (within reason) that you can provide, the better. There can be a substantial time lag between placing your order and installation, as time is required by the company to choose good lines, setup amplifiers, equalization, etc. Also in some locations there are areas where no facilities for having an equalized line exist, and other arrangements will have to be made.

Another method of interconnection between the remote and studio location is via radio. The Federal Communications Commission has allocated the following frequencies for remote pickup purposes:

(1)

Group A (kHz)
[1]1606
1622
1646

(2)

Group D (MHz)	*Group E (MHz)*	*Group F (MHz)*	*Group G (MHz)*	*Group H (MHz)*
[2]25.87	[2]25.91	[2]25.95	[2]25.99	[2]26.03
26.15	26.17	26.19	26.21	26.23
26.25	26.27	26.29	26.31	26.33
26.35	26.37	26.39	26.41	26.43

(3)

Group I (MHz)	*Group J (MHz)*
[2]26.07	[2]26.09
26.11	26.13
26.45	26.47

(4) Group K (MHz)

[3]152.87	[3]153.17	[5]161.64
[3]152.93	[3]153.23	[5]161.67
[3]152.99	[3]153.29	[5]161.70
[3]153.05	[3]153.35	[5]161.73
[3]153.11		[5]161.76

(5)

Group L (MHz)	Group M (MHz)
[4]166.25	[4]170.15

(6) Group N (MHz)

450.05	450.55	455.05	455.55
450.15	450.65	455.15	455.65
450.25	450.75	455.25	455.75
450.35	450.85	455.35	455.85
450.45	450.95	455.45	455.95

[1]Subject to the condition that no harmful interference is caused to the reception of standard broadcast stations.

[2]Subject to the condition that no harmful interference is caused to the reception of broadcasting stations.

[3]Subject to the condition that no harmful interference is caused to stations operating in accordance with the Table of Frequency Allocations.

[4]Operation on the frequencies 166.25 MHz and 170.15 MHz is not authorized (i) within the area bounded on the west by the Mississippi River, on the north by the parallel of latitude 37°30' N., and on the east and south by that arc of the circle with center at Springfield, Ill., and radius equal to the airline distance between Springfield, Ill., and Montgomery, Alabama, subtended between the foregoing west and north boundaries; (ii) within 150 miles of New York City; and (iii) in Alaska or outside the continental United States; and is subject to the condition that no harmful interference is caused to government radio stations in the band 162-174 MHz.

[5]These frequencies may not be used by remote pickup stations in Puerto Rico or the Virgin Islands. In other areas, certain existing stations in the Public Safety and Land Transportation Radio Services have been permitted to continue operation on these frequencies on condition that no harmful interference is caused to remote pickup broadcast stations.

[6]The following frequencies are allocated for assignment to remote pickup base and mobile stations in Puerto Rico and the Virgin Islands only:

(MHz)	(MHz)	(MHz)
160.89	161.07	161.25
160.95	161.13	161.31
161.01	161.19	161.37

Note 1: These frequencies are shared with the Land Transportation Radio Service.

Equipment may be purchased which, when fed remote audio signals, will transmit them back to a studio receiver. Using this method requires a different setup from a telephone line and naturally has a few problems of its own. The use of radio does provide the instant remote possibility therefore, it is best to purchase equipment made by a reputable manufacturer. Using homemade equipment can reduce the reliability of your system. Remember, this equipment will be carrying your programming. Most remote pickup equipment uses FM modulation thus providing all the inherent features, with its resultant high quality signal. Since such a system is portable, a remote broadcast can be performed anywhere within signal range of the system.

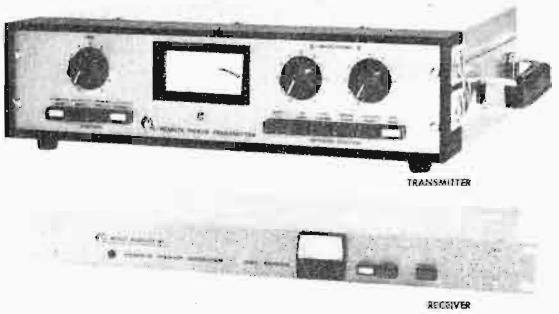

Fig. 3. Typical radio remote equipment. (Photo courtesy of Moseley Associates, Inc.)

It is usually necessary to utilize a directional antenna at the remote unit in order to provide maximum signal-to-noise at the receiving end. Since the remote unit's transmitting antenna (usually a Yagi, with high directivity) must be aimed accurately at the station (assuming that the receiving antenna is mounted on the station's tower), one simple method of determining direction is by using a small portable AM receiver with a loop antenna. Since the general direction of the main station from the remote site is always known, i.e., whether north, west, south, etc. The exact "direction-of-aim" of the Yagi (or dish, or other directional antenna) at the remote site can be obtained by utilizing the loop characteristics of the receiver, namely, to

Fig. 4. View is left front side behind the driver. A short rack has been installed containing the remote pickup transmitter mounted on a shock absorbing pad. The rack also contains a small patch panel and public address amplifier.

Fig. 5. The transmitting antenna is mounted to rotate 360 degrees and can be raised 10 ft. above the vehicle. The transmission line is attached to a reel inside the van to provide the additional length.

null out the AM signal, having in mind that the exact direction of the station is at 90° from the nulled direction of the receiver's loop antenna. The null process provides a much sharper and more precise orientation of direction than working with signal maximums which are quite broad in response.

Of course, when the station's tower(s) or other receiving location can be clearly seen, the remote transmitting antenna can be aimed visually toward the receiving point. At the station, the relay receiver antenna may be made directional for maximum pickup from the remote unit, and at the frequencies employed can be easily rotated from the ground by the more common TV antenna rotators.

To go to the opposite extreme, when distances are short and the path unobstructed, a remote may be carried out with just a remote transmitter, a microphone, and a beam or simple ring type antenna mounted on a floor type mike stand.

Relay broadcast frequencies are fast being used up and are not granted on an exclusive basis to any station. The use of the channels must be shared.

Cooperation between station licensees solves many problems, but in and near large communities, the use of these relay frequencies have become so extensive that the unexpected can happen more often than the expected. For this reason remote broadcast relay frequencies should be carefully chosen. Also, a station may be assigned more than one frequency in the band in which it operates. To have at least two crystals and ready capability to immediately use either channel in the case of unexpected interference on the frequency normally being used is both prudent and good insurance for uninterrupted program transmissions.

CUEING

In order to coordinate the remote broadcast, adequate communication between the studio and the remote unit is necessary. This may be carried out by a number of methods.

1. *By Radio.* A separate transmitter at the main station and a receiver at the mobile unit can be used for cueing. However, if the frequencies are close to each other, care must be taken to avoid interference which may occur when transmitting from the van and receiving instructions at the same time.

2. *By Telephone.* An ordinary telephone can be installed at the remote unit for cues and instructions.

3. *Via On-Air Cue.* A portable radio at the remote broadcast site can be used to receive cut back cues over the air from the main station, and at the main station from the mobile unit. During such time as the mobile unit is not sending program material it can, of course, keep the main station advised of any necessary changes, although this is not a two-way convenience.

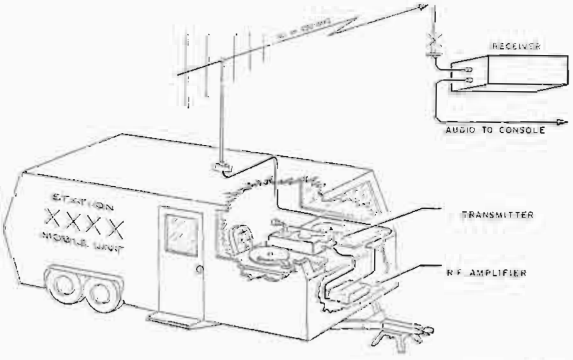

Fig. 6. Another example how the equipment may be installed in a commercial vehicle. (Drawing courtesy of Moseley Associates.)

Fig. 7. Public address speaker is mounted on side of van and is capable of being rotated 180°.

PUBLIC ADDRESS SYSTEM

This is a vital part of the remote system. Before purchasing a system decide what range and what area you need for sound coverage. Then decide what sound reproducers will serve the purpose. In some instances only two outdoor horn type speakers on a rotating mount are adequate.

A high quality audio amplifier should be chosen with power to spare and with a switchable input for being fed from (a) the console, (b) off-the-air monitor, and (c) a local microphone for announcing separately over the public address system without directly interfering with programming from inside the mobile unit. It is advisable to have the speakers mounted so that they could be turned and adjusted up or down to minimize any type of feedback. The volume control should be conveniently mounted so adjustments by the announcer can be quickly made, if necessary.

CART MACHINES AND TAPE RECORDERS AT REMOTE SITES

When the decision is made to insert the commercial spots at the remote site, provision must be made on the console for accommodating the cart machines. Also this means that the cartridges will have to be either duplicated or brought from the station for the event. If taped reel-to-reel shows are to be played, it is usually a good idea to dub them onto a quality cassette tape deck, which can conveniently be used in the remote unit and not take up room, while providing more than adequate fidelity.

AC GENERATING FACILITIES

The installation of a 110-v ac generator in a vehicle is a "must." The noise developed by such a generator does not prove to be a handicap for promotional activities when the vehicle is in motion (Fig. 8). Such a generator also is available in case of failure of commercial power while on semipermanent location.

The size of the generator depends, of course, on the load developed by the equipment and display lighting attached to the studio on wheels. Most commercial generators guarantee one percent frequency accuracy when the generator is operated within load limits. This is particularly important for proper operation of tape recorders or turntables when the generator is used as the power source. In planning a generator installation, manufacturers caution about oversizing. If the load is not sufficient, the engine driving the generator does not work hard enough which could raise the maintenance costs.

Should the station engineer choose to install a 110-v ac generator in the vehicle, care should be taken to allow for sufficient ventilation. If the available space is small, supplemental forced air should be installed to guard against excessive heat building up. A fixed-position 110-v ac fan will work satisfactorily to force out any excessive heat.

Since the generator is a gasoline-driven device, provision should be made to obtain gasoline from the main tank of the vehicle. This permits the personnel to use the gasoline gauge of the vehicle as a guide for sufficient fuel at all times. A separate supplemental tank can be used, but generally there is no gauge for judging the amount of fuel in the supplemental tank.

Normal winter and summer protection for the cooling system must be observed, just as with the vehicle engine.

While the installation of a power-distribution panel will undoubtedly raise the initial cost of installation, the safety factor, particularly for generator protection plus protection of off-air time, should make the cost and effort worthwhile.

WHAT TO DO WHEN THINGS GO WRONG

As with any type of remote broadcast you are out of your controlled environment and away from the convenience of your normal maintenance facilities. You must plan ahead for contingencies. The obvious problem is the interview where an indiscretion may get on the air. This of course can be solved by a tape delay at the station. If the console fails, a backup amplifier at least for the microphone is a good idea. Spare fuses are important items. A general rule-of-thumb is "DO NOT PANIC." Most problems are simple and solved rapidly. If handled properly at the remote site, neither the sponsor nor the listener will be made aware of the problem that developed.

SPOT NEWS COVERAGE

In addition to the mobile studio concept, remote pickup equipment can be installed in conventional type automobiles and used extensively

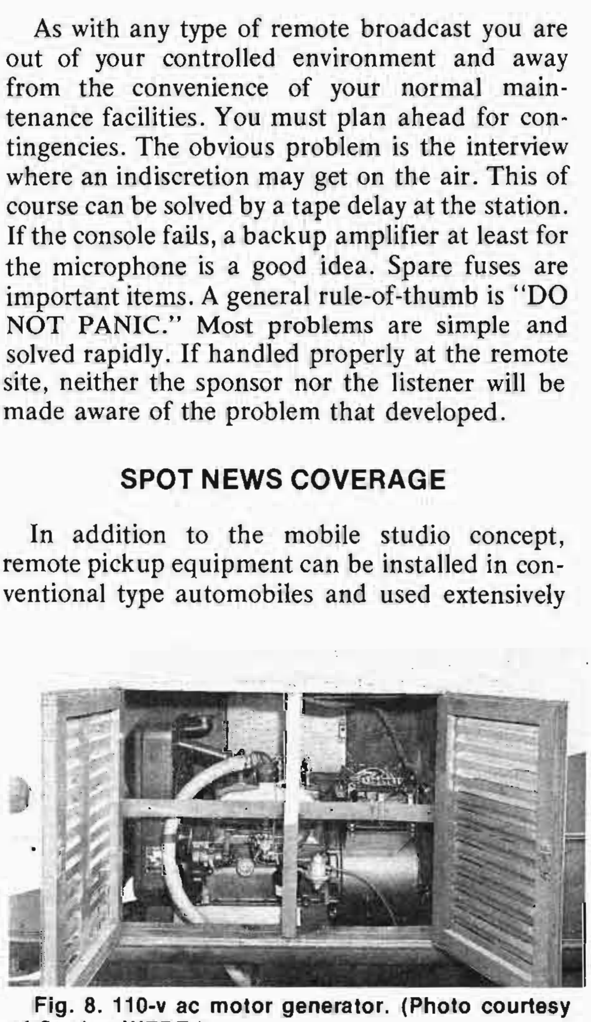

Fig. 8. 110-v ac motor generator. (Photo courtesy of Station WERE.)

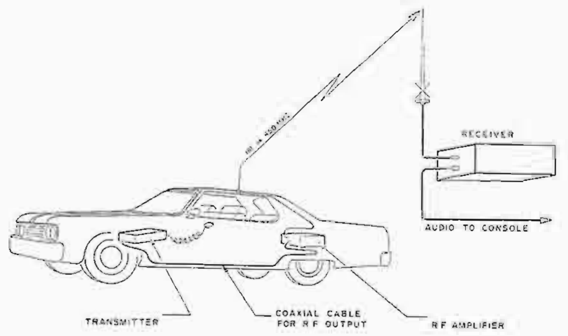

Fig. 9. A typical remote pickup system for the coverage of spot news. (Drawing courtesy of Moseley Associates, Inc.)

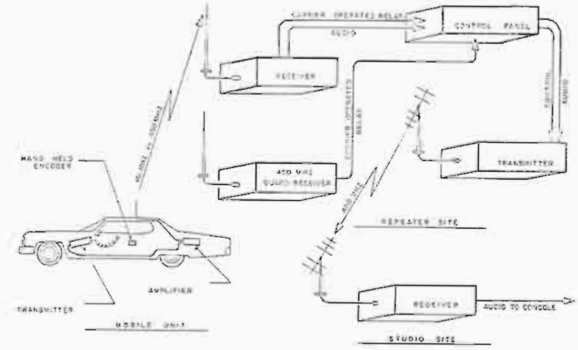

Fig. 10. Remote pickup equipped automobile for unattended automatic relay. (Drawing courtesy of Moseley Associates, Inc.)

for "on-the-spot" news coverage. Fig. 9 shows a mobile unit with direct communications to the studio. The automobile is equipped with a transmitter and optional RF amplifier. Although not shown in this drawing, additional audio sources besides the microphone shown may be fed to the transmitter.

As illustrated in Fig. 10, it is possible to install and use unattended automatic relay systems. Typically, such installations are usually on mountain top locations (or on high towers) to extend the coverage of remote pickup broadcasts. This enables stations located in areas where terrain factors are a hindrance to realize substantial increases in the usable range of the remote pickup system. Note that the relay repeater system, as shown, is activated by a two-tone hand-held encoder. This is accomplished by holding the encoder to the microphone and transmitting the keying tones to the relay receiver, and then to the remote control panel. The remote control panel is used to activate the relay transmitter. To meet FCC requirements, a guard receiver is required to monitor the output frequency of the repeater. If the guard receiver detects another signal on the assigned frequency, it will not activate the repeater transmitter until the channel is clear. Once the repeater is activated with the encoder, it will stay on the air until such time as the remote transmitter removes its carrier from the air. At this time, remote control panel senses the loss of carrier from the remote and removes the relay transmitter from the air.

These systems, mobile, repeater or base stations, are licensed under Part 74, Subpart D of the Commission's Rules and Regulations. Such systems can be licensed whether telephone land line service is or is not available. The systems shown are just some of the possible configurations. As an example, mobile repeaters in a mobile studio or news vehicle can extend the usable range of a system on a moment's notice. Also, it can be relocated easily to suit changing requirements. Systems also have been used from helicopters, airplanes, blimps, boats, and even atop flag poles.

31

Television Remote Program Originations

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As an independent broadcaster in the City of Chicago, WGN Continental Broadcasting Company relies heavily on remote pickups in its television operation. The following chapter reflects the information that has been acquired by WGN-TV in making television remote program originations.

Our discussion necessarily will be about facilities used at this station and will also include facilities considered for the future. It is to be understood that remote pickups take on many forms. These include sporting events, on-the-site commercial recordings, community affairs public interest programs, closed circuit originations, news events, and even presidential speech originations.

The diversity and frequency of remotes, naturally, is a vital factor in the type of equipment used. If, for example, a station is to provide baseball coverage of two major league teams, it would be wise to have equipment comparable to a normal studio control room, where reliability of facilities for daily operation was present and where comfortable working quarters for the mobile unit crew are provided. For these reasons, the primary color mobile unit, if more than one mobile unit is employed, will handle the day-to-day originations, or those that require the greater facility with the more complex production.

A second color mobile unit can be judiciously employed where a one or two camera on-the-site commercial recording is to be made prior to post-production work at the studio, where coincidence of more than one remote pickup per day is a frequent factor, where a generator need be employed for a self-powered feature, or where equipment utilized in that mobile unit can be disengaged and rolled into the pickup quarters. Other reasons, such as the need for videotape playback equipment, or the involvement of the station in electronic news coverage, may also necessitate the use of two or more mobile facilities.

WGN-TV is currently using two mobile units to satisfy its remote requirements. The station has always stressed versatility in its remote handling capabilities. Features that are built into its remote mobile units emphasize this point.

This discussion can be outlined as follows: (1) principal features of the primary mobile unit, (2) additional features worth considering in a primary unit, (3) a secondary mobile facility, (4) video taping and remotes, (5) lighting and remotes, (6) electronic news, and (7) remote operational considerations.

PRINCIPAL FEATURES OF THE PRIMARY MOBILE UNIT

The primary facility that will be described in great detail is a semitrailer, 40 ft. in length, 8 ft. wide, and 12 ft. 6 in. in height (Fig. 1). 1974 was the first full year of service for this unit, and 200 remote program originations emanated from this vehicle. Of the two mobile units to be discussed, this is the deluxe facility.

The trailer layout shown in Fig. 2 identifies the principal operating areas of the trailer, and will

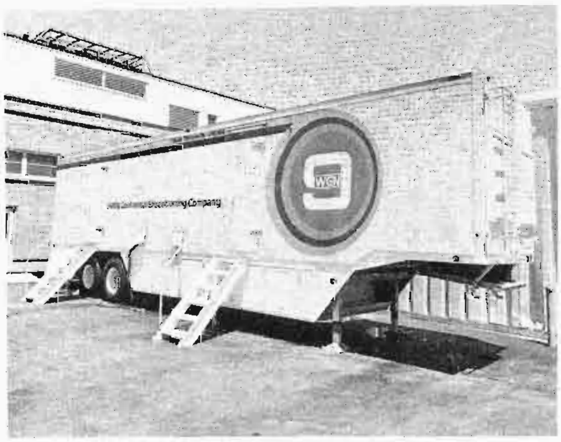
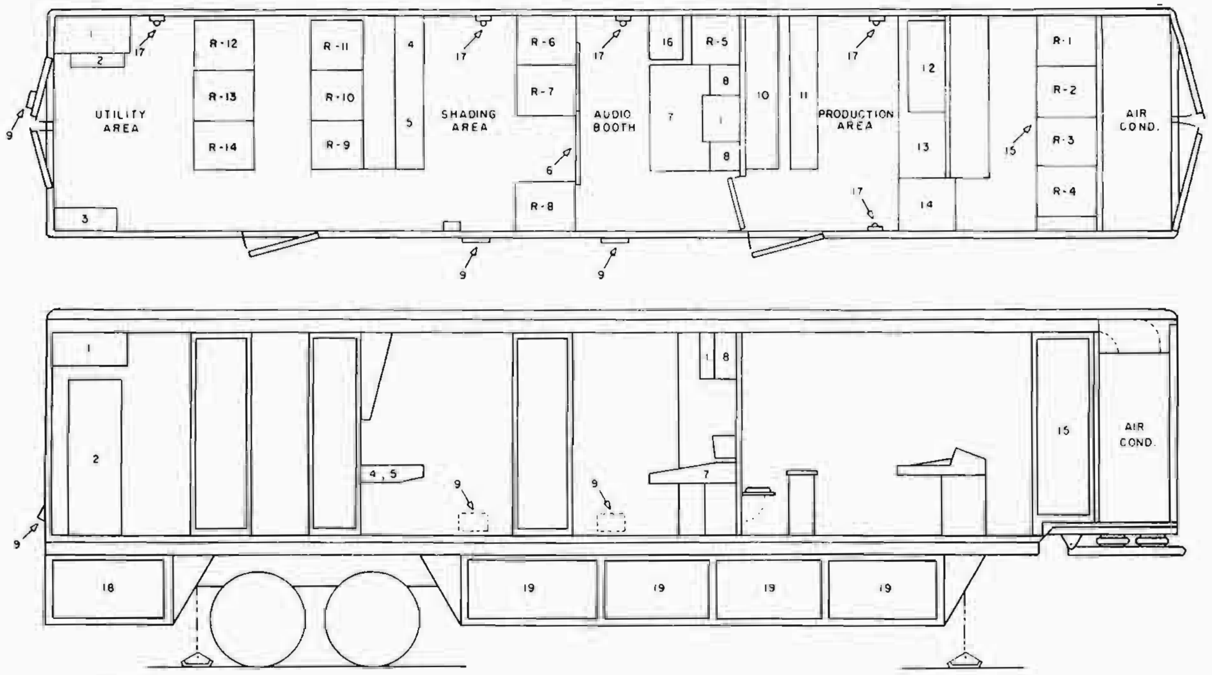


Fig. 1. WGN-TV primary mobile trailer.



1 STORAGE
2 SLO MO
3 POWER DISTRIBUTION
4 SLO MO CONTROLS
5 CAMERA CONTROLS
6 SLIDING DOOR
7 AUDIO CONSOLE
8 SPEAKERS
9 CABLE ACCESS DOORS
10 FOLD-DOWN PRODUCTION BENCH
11 FOLD-DOWN PRODUCTION TABLE
12 SWITCHER
13 PRODUCTION CONSOLE
14 ALTERNATE SLO MO CONTROL
15 RACKS 1,2,3,4 MONITOR BAY
16 DROP-LEAF COUNTER
17 BUSINESS TELEPHONES
18 ELECTRICAL BULKHEAD CONNECTOR PANEL
19 BELLY STORAGE COMPARTMENTS

Fig. 2. WGN-TV color mobile trailer—equipment layout.

be referred to as these areas are further described. All principal equipment racks are accessible from the front and rear. Racks are identified with the "R" designation. Note that personnel can walk through the entire length of the trailer without going outside; this is appreciated by the crew during bad weather.

All cabling for cameras, audio, video, and telephone facilities enter the vehicle by way of the cable access doors (No. 9 of Fig. 2), and terminate on the two bulkhead panels located inside of the unit itself on either side of R-8. This feature, we feel, is very important for two reasons. First, it is more trouble-free because all of the bulkhead chassis connectors are not subject to corrosion due to weather. Secondly, at the remote unit end, any troubleshooting of lines can be done inside the comfortable quarters of the mobile unit.

Fig. 3. Production control area.

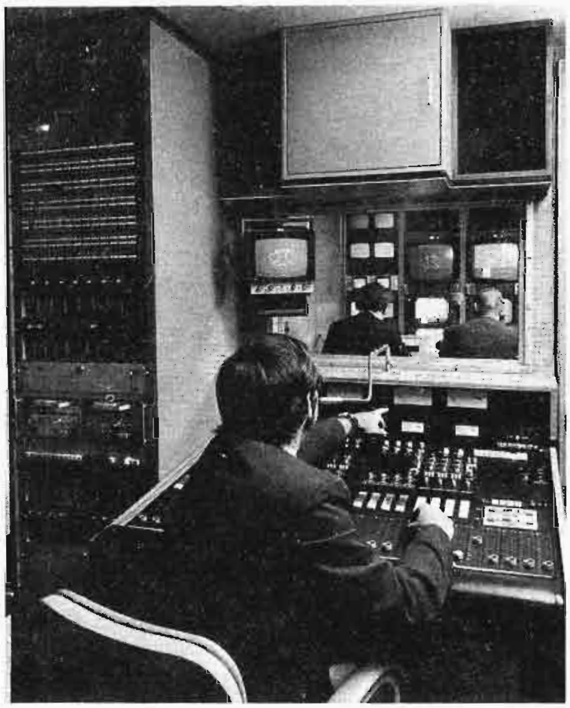


Fig. 4. Audio control booth.

Fig. 5. Audio bulkhead panel.

The principal operating areas are: production control, audio control booth, camera shading, and the utility area. Storage provisions, communications, and other features of the interior and exterior of this mobile unit will also be described.

Production Control Area

A 10 ft. 4 in. X 8 ft. area is used for the production area. A switcher, director, and slo mo operator sit side by side at the front control desk, some 4 ft. 8 in. away from the monitor bay (Fig. 3). Behind them in the control area is a foldaway table and cushioned bench for use by additional production personnel.

The switcher (Central Dynamics) has 20 inputs, two special effects systems, chroma key, modulator, downstream keyer, quad split, and color matte on eight switch busses (two at the shader area and one in the audio control booth). Isolation busses feed the network and the slo mo disc recorder.

Essential to the production area are program and preview aural monitoring, a dual tally system on the visual monitors for air and slo mo record, talkback system, color monitors for line and preview, interphone facilities, and business telephones for studio communication. This control area is lit with dimmable, low-wattage spots above the control room desk for optimum monitor viewing during air time.

Audio Control Booth

A 6 ft. X 8 ft. area is utilized for the audio control booth. A custom, 16 input, four-channel console features a reverberation unit with echo send/receive on each input, equalizers, compressor, preview system, two aural monitoring systems and remote control of two cartridge record/playback machines and one reel tape machine (Fig. 4). It is of solid state construction, using vertical attenuators. The audio console was designed so that it could be removed from the trailer and installed elsewhere. This would allow the audio operator to have eye contact with a stage performance or other pickup that has this requirement.

Front and rear doors to the booth allow for complete isolation from other areas in the vehicle. A large front window provides full viewing into the production area. An important feature is the small visual monitor included in the booth; the audio operator has a full-switcher-input-selector bus feeding this monitor.

All external audio cables and telephone lines enter the vehicle through a curbside access port and terminate on the audio bulkhead connector panel (Figs. 5 & 6) inside the vehicle. This panel provides an entrance for all console inputs, outputs from all four channels of the console, talkback to studio, and business telephones. Microphone inputs enter by way of individual Canon XLR connectors, numbers 1-16, or through two multiple-pair harness connectors. These feed the A and B preselectors, respectively, of each of the console's mixers. A large patch bay is located in the utility rack to the left of the audio console. Also included in the rack are the cartridge machines, reel-to-reel tape machine, intercom amplifiers, visual monitor selector, and motor-driven monitor pads used throughout the mobile facility.

Camera Shading Area

To the rear of the audio booth is the camera shading area. Here each of three custom-made racks (R-9, 10 & 11 of Fig. 2) contain necessary control equipment for four color cameras (RCA TK/44). Two additional camera chains are completely wired and have the necessary visual monitoring equipment already installed. It is a relatively simple transition for the addition of some studio equipment to make the mobile unit a six-camera facility. The slo mo control unit can be

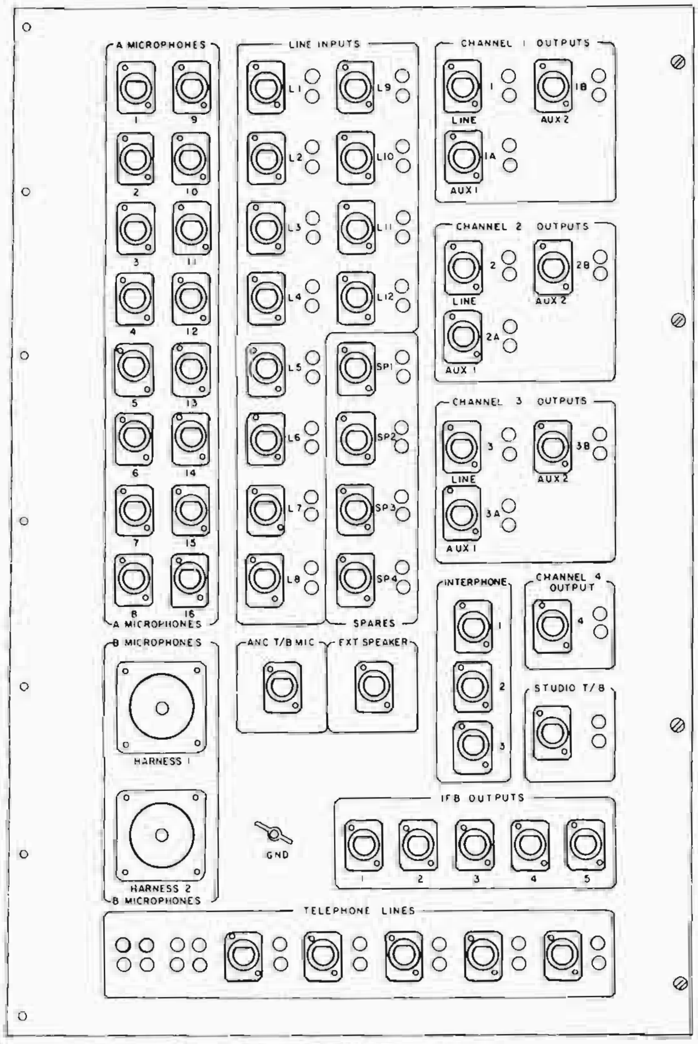


Fig. 6. Audio bulkhead panel.

operated from the console housing the fifth and sixth camera control units by employing a cover shown in Fig. 7. In order to effectively allow for containment of two camera chains in a rack, the upper portion of each camera control rack was extended forward and its front surface angled downward 12 degrees to improve the shader's viewing angle of the visual monitoring equipment. The side view of the shading consoles is seen in Fig. 8.

Convenient to the technical operation in the camera shading area is the needed switching equipment for video monitoring with the vectorscope, line scopes, and two color monitors. Total video patching for the trailer, with more than 300 video jacks, is located in the same rack as the video bulkhead panel, two process amplifiers, a VIT signal generator, and 30 video distribution amplifiers (Fig. 9). In this same area is the rack housing the video switcher (R-6 and 7 of Fig. 2), all encoders, and power supplies for the camera chains. Figs. 10 and 11 show the arrangement of video connectors and camera cable connectors on the video bulkhead panel.

Utility Area

In the rear portion of this primary mobile unit is the utility area (Fig. 12). Housed in this area is the slow motion disc recorder (Ampex HS/100). This recorder is primarily kept in this vehicle, although it is also used in a small van when it becomes necessary to supplement the operation of our second mobile unit. Internal wiring, plus patching, allows the flexibility of using the slo mo control unit at three different locations within the trailer, or even in an adjacent mobile unit.

Three utility racks contain pulse generators, pulse amplifiers, off-air receiver, modulator and additional audio and video monitoring equipment. Space has been left, and internal wiring provided, for a microwave control unit, auxiliary handheld camera chain, and character generator in these auxiliary racks. A tally patch board

Fig. 7. Camera shading and slo mo control.

provides the flexibility of tally needed to accommodate the needs of the many production people that are involved in this vehicle's remote assignments.

The main power distribution rack contains all circuit breakers and distribution of ac to the 14 equipment racks, utility outlets, and lighting and air conditioning equipment (Fig. 13). Metering of current, voltage, and frequency is provided. All utility outlets on the trailer exterior, belly compartments, and camera chains are protected by ground-fault breakers.

Power enters the trailer through two four-wire cables to the power connectors located on the lower rear curbside bulkhead panel (No. 18 of Fig. 2). Directly behind this panel, and accessible from the rear through the roadside belly compartment

Fig. 8. Camera shading area.

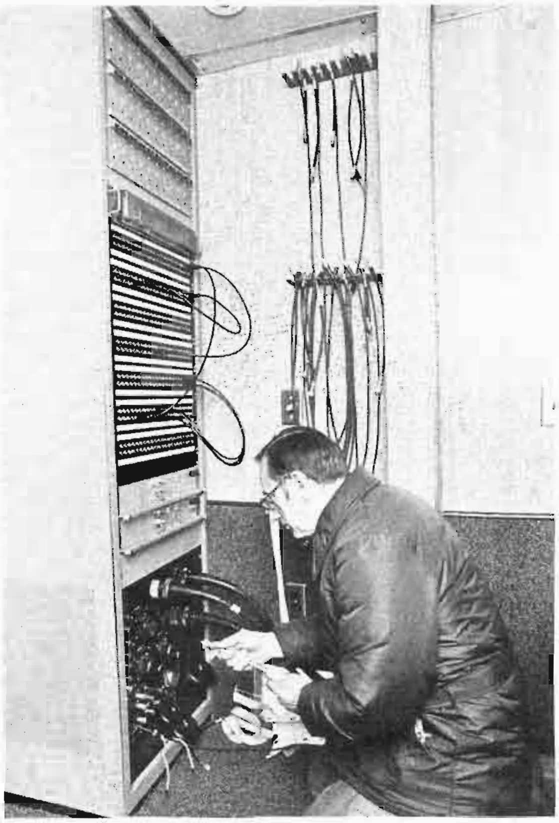


Fig. 9. Video patching and video bulkhead panel.

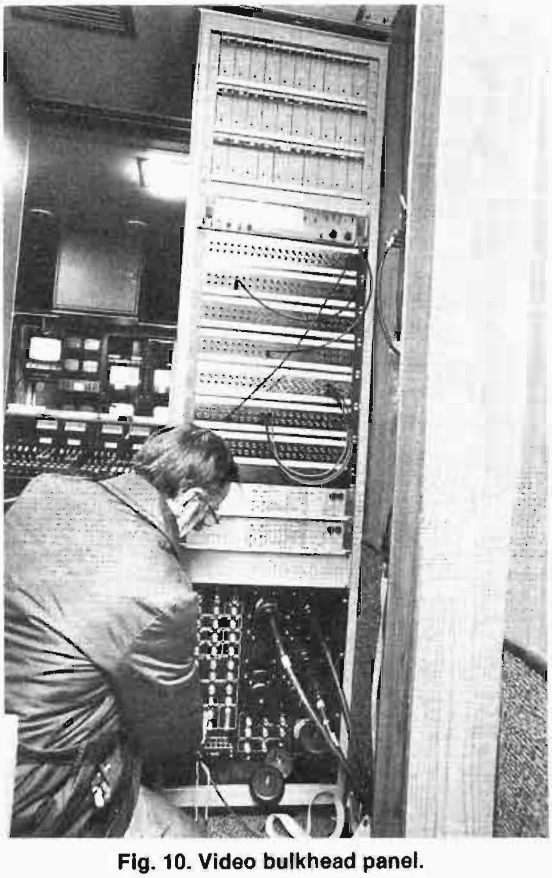


Fig. 10. Video bulkhead panel.

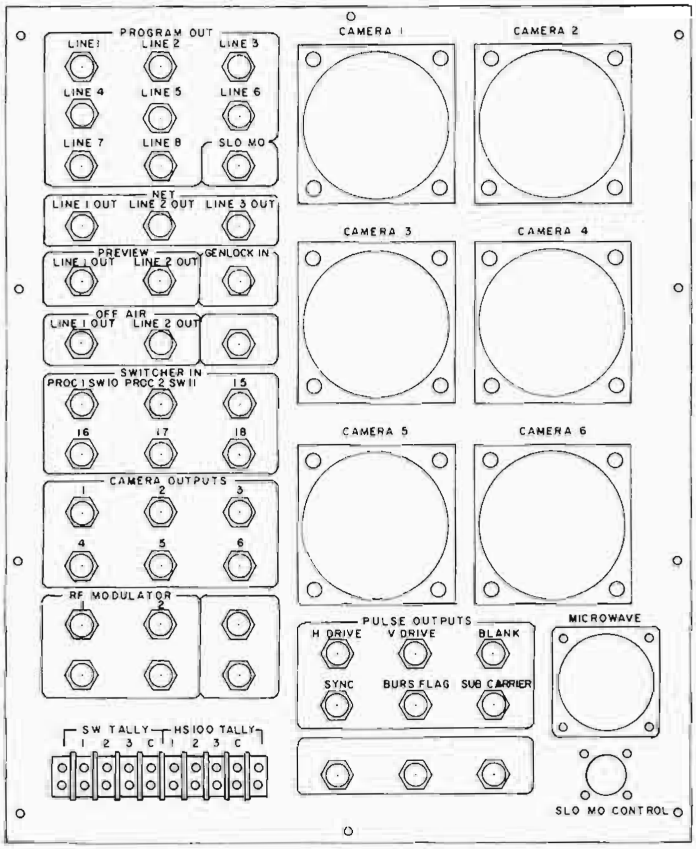


Fig. 11. Video bulkhead panel.

door, power is fed through manual disconnect switches and on to two 15-KVA input transformers for the technical equipment and, also, to one 30-KVA transformer for the mobile space conditioning units. On the panel are utility outlets and connectors. A grounding lug completes facilities on this panel (Fig. 14).

Fig. 12. Utility area.

Within the rear power compartment, the technical load is fed to two 15-KVA voltage regulators that will assure constant voltage to the technical equipment. Please refer to the diagram shown in Fig. 15. You will note that the tapped primary winding allows for input phases of 208-240 volts. No neutral is included in the input wiring. In this

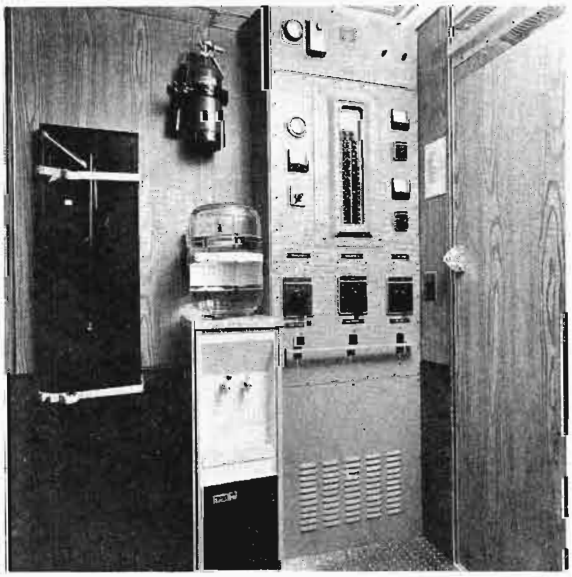


Fig. 13. Power distribution and space conditioning control.

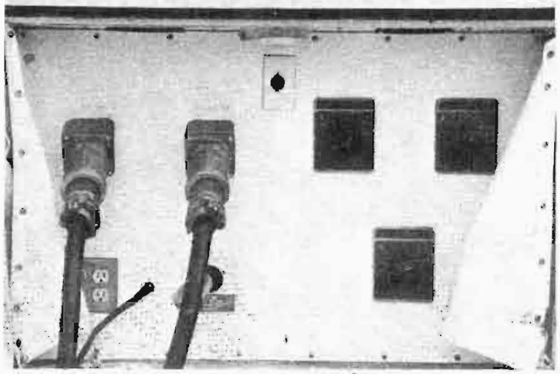


Fig. 14. Power bulkhead panel.

same general area are the battery and charger that provide dc for a number of ceiling lights, as well as the roof hoist. Telephone company distribution and key equipment for the five wall-mounted business telephones are also located in this rear compartment.

Communications

Each of the four basic operating areas in this vehicle is in full communication with each other via a microphone/speaker talkback system. In addition, all stations may converse with the studio, cameramen, and assistant directors. Five "IFB" key positions are also on each talkback panel. These are used principally to feed program, interruptible by cues, to sports announcers or talent when on camera. The latter generally utilize the small ear plug on these circuits. Each IFB position has a choice of two program sources, selectable in the audio booth.

Outside communication is accomplished through five jack-equipped wall-mounted business telephones, each capable of receiving five business lines and hold.

A headset interphone system also interconnects all working areas on three selectable busses—engineering, production, and isolate. The camera cue bus can also be heard on local panel speakers in the production and shading areas. Controls are mounted on this panel in order to attain desired levels. For the director who prefers privacy with the cameramen, the speaker may be turned off. In order to maintain desirable levels on the production busses, all interphone positions in the trailer and in the cameras are equipped with send and receive amplifiers.

Storage

Remote mobile units never seem to have enough storage area. In order to avoid any such problem, our primary mobile facility has ample storage in each of the operating areas. Cabinets are provided under the production visual monitors in the front of the trailer, above the audio console in the audio booth under the production desk, and, also, above the slo mo disc in the rear of the trailer. Where possible, slide-out drawers are also included in some of the utility racks. The inside cabinets are used for microphones, adapter cords, test charts, spare parts, hand tools, hardware, and manuals.

Larger items are stored beneath the floor and accessible from the outside in eight large belly compartments (Fig. 16). Each compartment has its own ac-dc ceiling light fixture. Outlets are also provided in these areas. Cameras are stored on

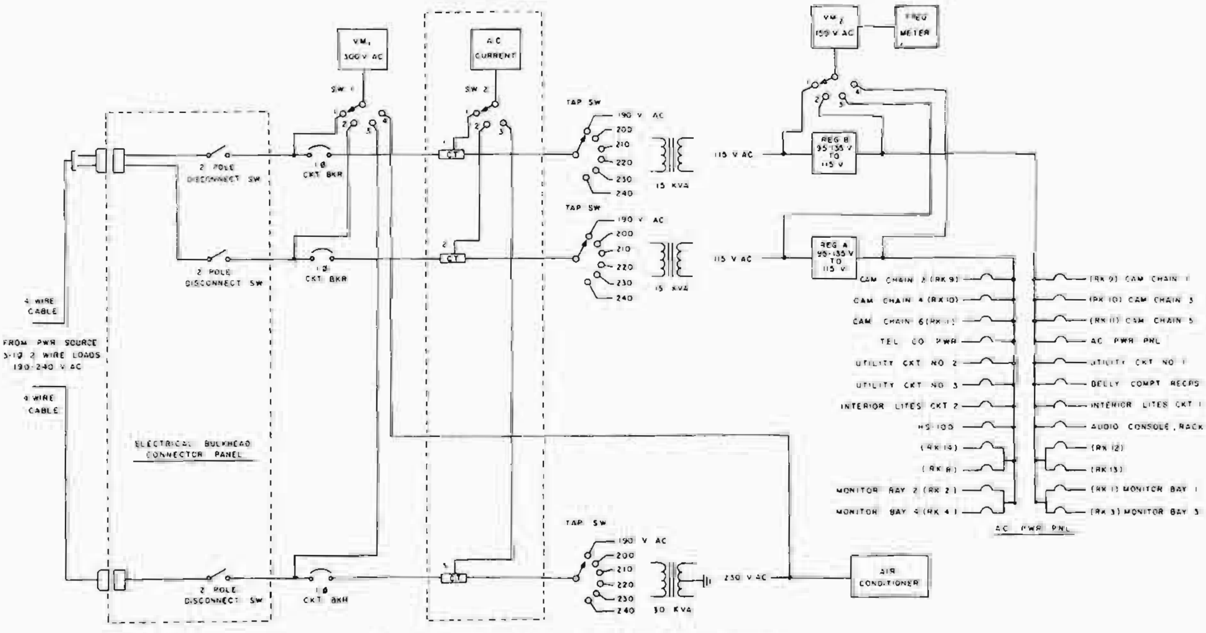


Fig. 15. Single line drawing of ac power system.

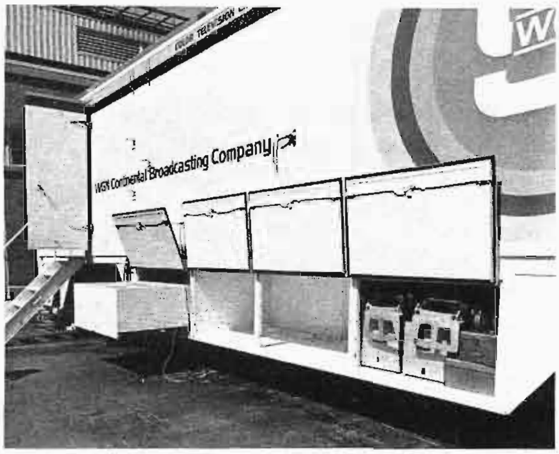


Fig. 16. Curbside belly compartments.

their own transport dollies, two in a compartment. Zoom lenses in their individual lens cases, plus cameramen's utility cases, are stored in another belly compartment.

The fourth curbside storage area has a slide-out drawer, 4½ ft. X 3½ ft. X 15 in., which is subdivided into five cubicles (Fig. 17). In this cable drawer are stored harnesses, rope, and various small audio and video cables which are categorized for quick accessibility. On the road side of the mobile unit, four more storage compartments are used for the storage of other remote equipment, such as camera tripods, dollies, camera cables, power cables, hoist extension boom, harnesses, ladder, ramps, ropes, and hoists.


Fig. 17. Cable drawer.

The outside staircases for each of the three trailer doors are stored during travel on the inside of the doors by means of special bracketing that is attached to the inside surface of these doors.

Other Features of the Trailer Interior and Exterior

The Midwest climate and the year-round operation of this particular remote unit necessitate a heavy floor, ceiling, and wall insulation in order to maintain a proper comfortable temperature for the operating personnel. The floor is completely carpeted by a durable indoor/outdoor carpet having antistatic characteristics. The carpet extends up the side walls to a height of 30 in.

A wood grain laminate surface extends to the ceiling. This same surface was used in the production desk and audio console. Within the off-white laminate ceiling surface are the ac-dc work lights for general illumination and the strategically placed dimmable spotlights for on-the-air lighting.

Two five-ton mobile space conditioning units are located in the front of the trailer. These units provide a combination of heating, cooling, ventilating, and dehumidifying. Maintenance of the space conditioning equipment is simplified because there is full accessibility to these units through the full-length double doors at the very front of the trailer. A dc-operated hoist (Fig. 18 and 19) operating within the curbside center wall, may be used to raise and lower cameras or other equipment to the roof of the trailer. A secondary use of the hoist is to "fly" overhead cabling used on many of the remotes.

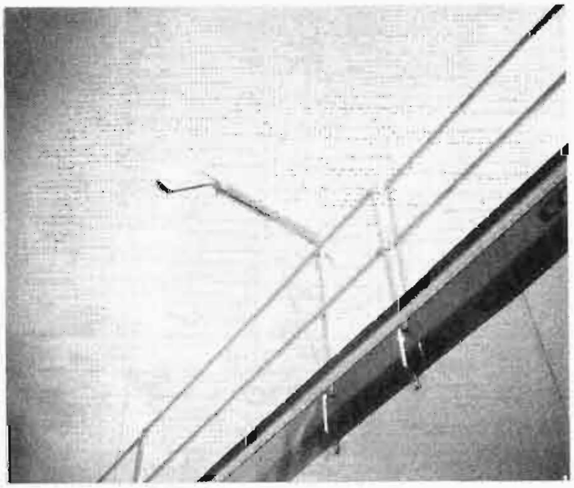


Fig. 18. DC-operated hoist.

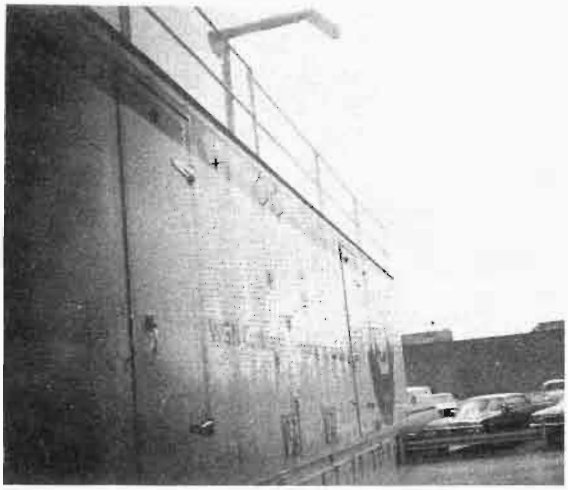


Fig. 19. DC-operated hoist.

Fig. 20. Primary unit at Chicago's Christmas parade.

Fig. 21. Parade commentators atop the primary mobile unit.

Fig. 22. Camera transport dolly.

The 40 X 8 ft. expanse of roof is accessible via two attached ladders located on the front and rear sides of the unit. The roof surface is constructed to support cameras and personnel for on-the-spot reporting of parades, etc. You will note in Figs. 20 and 21, a scene at the annual telecast of Chicago's Christmas Parade, that two commentators, an assistant director, stagehands and cameraman (plus a few guests) have the excellent vantage point for the television parade coverage. There is a protective metal railing, which is 96 ft. in total length, mounted on the outside edge of the trailer roof. The roof surface is a one-piece aluminum skin painted with a nonskid carborundum particle paint.

Finally, this primary remote facility is supported by eight 10:00 X 20:00 12-ply tires mounted on tandem axles. The rear axles and the front coupler are cushioned on air bellows affording the best road performance possible.

ADDITIONAL FEATURES WORTH CONSIDERING IN A PRIMARY REMOTE FACILITY

Protection of Cameras and Lenses

The cameras used on remotes are handled more frequently and are subject to more abuse than the typical studio camera. Care should be taken to minimize possible damage to this expensive equipment.

A picture of the custom-made transport dolly used at WGN is shown in Figs. 22 and 23. The cameras are stored, two to a compartment, with their dollies. When setting up a remote, they are rolled as close to the camera operating position as possible. Heavy durable covers are kept on the cameras in storage and while they are moved on their dollies. The dolly shown is large enough to carry the camera tilthead as well.

An outer plastic cover is used as a second covering when our cameras are left in position at the

Fig. 23. Camera dolly being hoisted to football booth.

baseball parks overnight. A steel cable within the second cover allows the cameraman to lock the outer cover in place and provides some security of his equipment. Special plastic covers are provided for protection against light rainfall.

Lenses are always removed from the color remote cameras before transporting the cameras and are always restored to their respective cases. The cases are generally taken to the camera location during setup and remain there until teardown.

Multipaired Harnesses as an Aid to Setups

Around 1960, we had a prominent cable manufacturer provide us with a multiconductor cable that had ten shielded audio pair, one coaxial cable and, also, an ac pair all in one cable. Lengths of 100, 150, 200, and 300 ft. terminated in MS connectors are still used regularly on one-time-only remotes.

We have found this cable to be a real time saver in remote setups. It is used almost without exception on all of our remote originations. Incidentally, the coax in the multiple-pair cable is used principally for a visual monitor feed at the announcer's or sportscaster's table. Even the ac pair with its five ampere limit has proven advantageous when no power is available or when the normal service blows a fuse or breaker.

Business Telephones and the Voice Coupler

In recent years, the Western Electric Type 30A voice coupler has really come into its own as a valuable aid to broadcasters. Many broadcasters use the coupler attached to the business telephone as a means of sending programs back to their studios rather than ordering a broadcast circuit.

Our primary mobile unit incorporates the voice coupler on two of its business lines. Business Line 1, which is called our production line, is used by the director or other production people in the trailer for studio coordination. After dialing is completed and the circuit is established, the voice coupler key is thrown. The voice coupler on this line gives the director the option of using his headset for private studio conversations or, with the voice coupler key engaged, allows for a more public communication with the studio.

The engineering business line (line 2) can be used as a backup aural program circuit should the primary audio circuit fail. This is accomplished by providing an audio output dedicated to feed the second voice coupler. Panel toggle switches mounted on the voice coupler telco panel are easily accessible to the audio engineer in the audio booth area.

It should be noted that at the studio master control, similar facilities are needed to couple designated business telephones into the studio talkback system or on patch for use as an emergency program circuit.

Disc Recorder (Slo Mo) and Features Necessary to Its Operation

The disc recorder that is used for slow motion and stop action has become an essential tool for replays in sports telecasting. Improvements made in head and disc construction, coupled with a reasonable amount of care in their routine maintenance program, will certainly provide many hours of trouble-free performance. Needless to say, the slo mo unit should be firmly secured in the remote facility, yet allowances should be made for its easy removal from the vehicle.

The desired versatility in the operation of the remote control unit should be emphasized. For day in and day out routine baseball pickups, we have found it quite satisfactory for the second shader to also function as a slo mo operator. Isolated camera selection is switched on the switcher slo mo bus. The remote control unit is shown on a panel which covers cameras five and six control units (Fig. 7).

There are times when it becomes necessary to have the slo mo operator located adjacent to the director, using the fold-up counter of the production desk (No. 14 of Fig. 2). An external portable switcher bus, paralleling the slo mo bus of the main switcher, is plugged into a connector at the base of the production console. This, with the remote control unit, gives the slo mo operator control of the special isolate requirements from this location. The control unit is patched at the base of R-13 (Fig. 2).

In connection with the slo mo operation, it is important to include a secondary tally on the cameras and the camera monitors that are activated when the particular camera is being recorded either by a disc or by a videotape machine.

Inside Bulkhead Connectors for External Audio, Video and Camera Cabling

Attention is once again called to Rack 8 in Fig. 2 and its relative placement to the side-wall cable-access ports. Reference is also made to illustrations six and nine.

Past experience with bulkhead connector panels, when located in the belly compartments, has proven that corrosion of connectors will occur, especially when exposed to the Midwest winters. Continuity checks during setup can be done more comfortably in the environment within the trailer. Audio and telco connections within the audio booth, and camera cable and coax connections in the video shading area, have also proven a time saver during the setup period.

Hoists and Cargo Nets

To avoid hand-carrying all camera equipment to the sometimes lofty camera locations, a hand-operated or power-operated chain hoist can be very useful. There are some occasions where a 40-ft. load chain is a necessity. At the Chicago Stadium, two power-operated hoists (Figs. 24 and 25) are employed in order to elevate the cameras and lenses to their "basket" locations (Figs. 26, 27, and 28). One hoist connected to the steel-ceiling beams is used to lift the cargo vertically, while a second wire rope hoist pulls the load up on an angle in order to reach the otherwise difficult camera locations. Cameras are often lifted while still on their transport dollies, as shown in Fig. 26. Lenses, tripods, test charts, etc., are hoisted by using a specially fabricated cargo net. Such a net is shown in Figs. 29, 30, and 31. The Chicago Stadium camera basket locations are of such a nature that particular effort needed to be made to minimize the possibility of cameras and cameramen blocking the view of spectators behind. A special swivel chair mounted on angled casters was devised for the cameramen (Figs. 32 and 33).

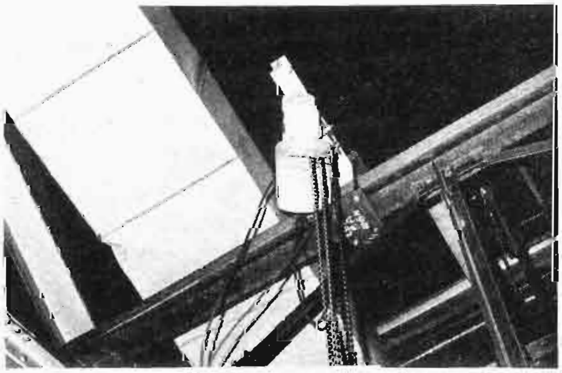


Fig. 24. Power chain hoist at the Chicago Stadium.

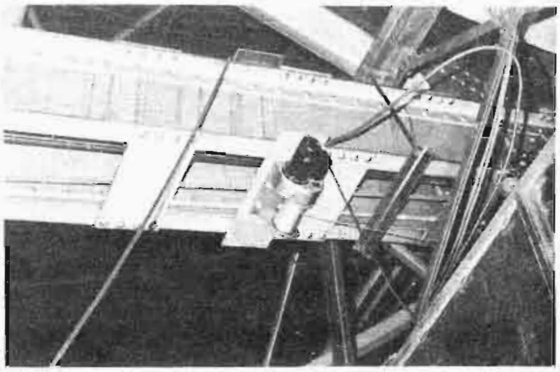


Fig. 25. Power cable hoist at the Chicago Stadium.

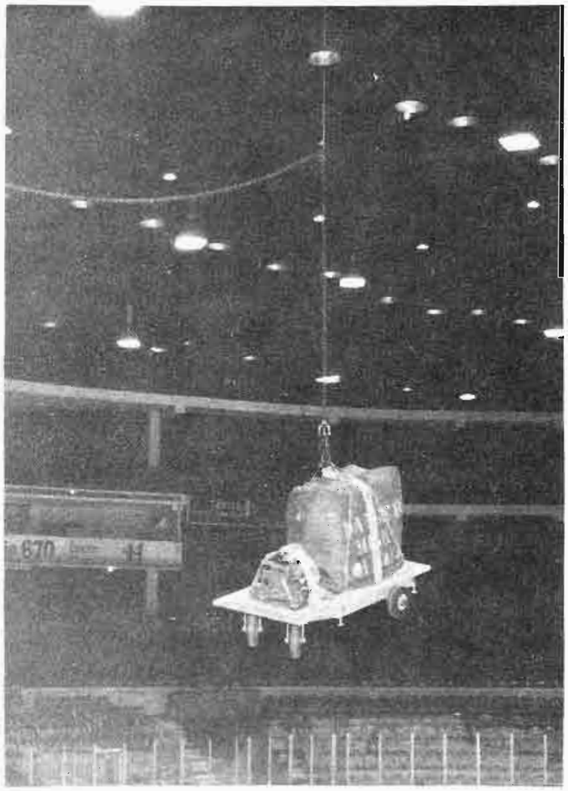


Fig. 26. Camera being elevated using stadium hoists.

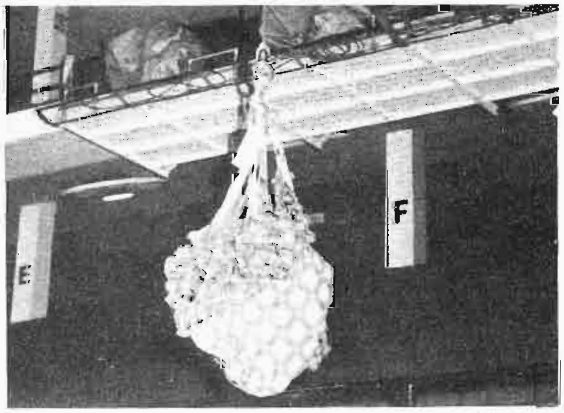


Fig. 27. Cargo net being hoisted to camera positions.

Fig. 28. Hoist operator and cargo.

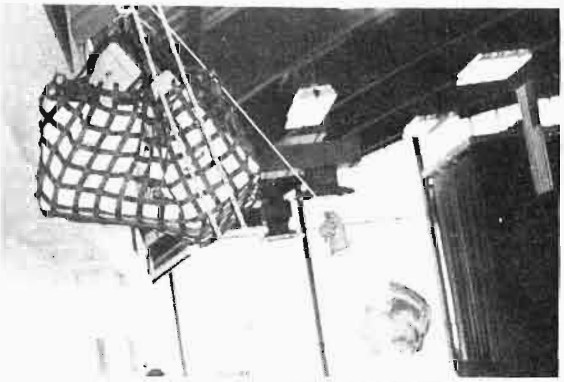


Fig. 29. Cargo net carrying lens cases.

Fig. 30. Cargo ready to be raised.

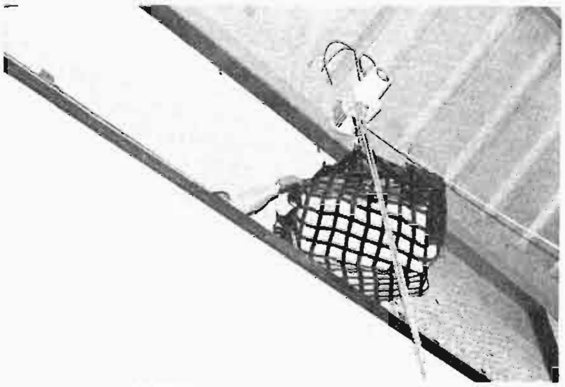


Fig. 31. Cargo arrives at top.

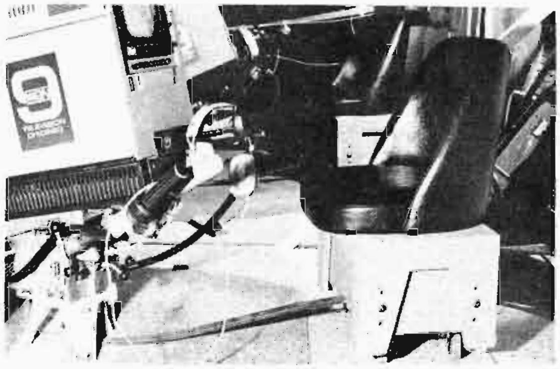


Fig. 32. Special swivel chairs at basket camera location—Chicago Stadium.

Fig. 33. Cameramen ready for hockey game.

Handheld Cameras and Mobile Carts

Handheld cameras are being used with greater regularity as a production tool on sports telecasts. There is no question that a handheld unit has the maneuverability that cannot be attained with a typical tripod/dolly remote camera.

Prolonged operation of a portable camera, however, must nearly always be supplemented with the use of a unipod or some nearby tripod, for cameramen do tire. Effective usefulness of these cameras is where air operation can be in relative short takes or where the picture content, by its unique nature of not being reachable by any fixed camera, enhances the overall capturing of the sports activities.

Very often a tripod-mounted camera on a battery-operated mobile cart will accomplish similar results. Fig. 34 shows a type of cart used to telecast the sideline activity at the Illinois High School Association Football Tournament. Three people were needed for the camera operation, a cameraman, cable puller and the vehicle driver. Note the rain covers and camera-mounted microphone used for pickup of field noise.

SECONDARY OR AUXILIARY MOBILE UNIT

The advantages of having a second TV mobile unit are, naturally, dependent upon what facilities are included in the unit.

The small van shown in Fig. 35 was initially designed for on-the-spot videotaping of commercials. Taped sequences would be recorded at the remote site and brought back to the studio for assembling and editing. It is equipped with a 5-kw gasoline generator. The two racks that house the control equipment (Fig. 36) for the three color cameras (Ampex BC-230) are mounted on wheels so that they can be rolled out of the remote vehicle and rolled into a building when required. This feature has proven extremely beneficial when pickups are being made in tall buildings, etc.

When the van is used for commercial production work, the portable quad head type videotape recorder (Ampex VR3000) is principally used.

Approximately 50 remote originations were made with this unit in 1974. Figs. 37 and 38 show scenes from the Community Affairs series, "Ark in the Park." Two cameras were used for a series of visits to Chicago's Lincoln Park Zoo. Note the use of a mobile cart for the second camera.

Each year, on the eve of the opening of the Chicago Automobile Show in immense McCormick Place, this unit is used to record several hours of videotape on two portable recorders (Ampex VR3000x). The mini truck (our secondary unit) moves from one exhibit to another as it records all the impressive features of the newest automobile models. The 20-minute reels are shuttled back to the studio through the night and next morning where they are screened and prepared for final editing.

Fig. 34. Sideline camera on battery-operated mobile cart.

Fig. 35. Secondary or auxiliary mobile unit.

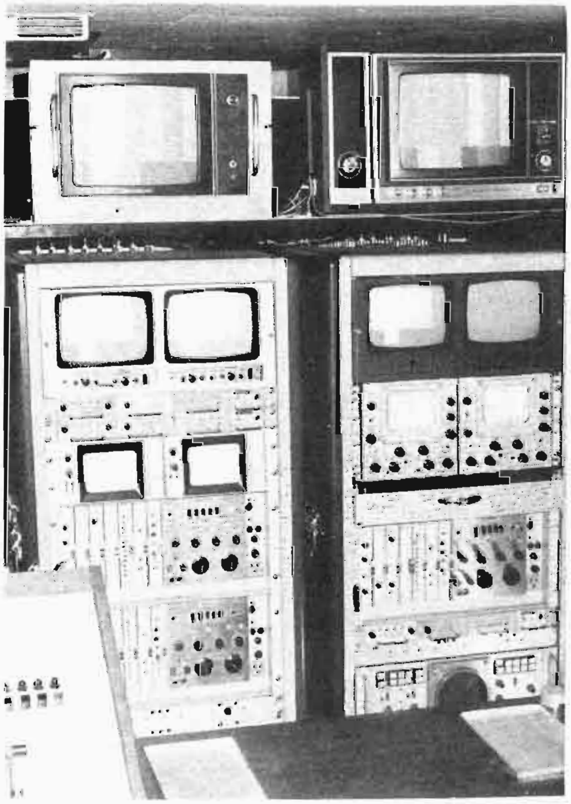


Fig. 36. Camera control equipment for secondary mobile unit. (Racks are removable from van.)

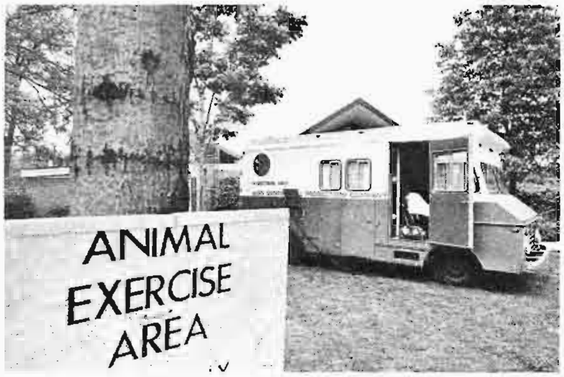


Fig. 37. Secondary unit at the zoo.

Our secondary mobile unit also doubles as a sports pickup facility when two sports telecasts occur on the same day. Should the need for a slo mo arise in connection with the mini-truck operation, the slo mo from the larger trailer is removed and installed in an equipment van and operated from the mini truck using an external control cable.

VIDEOTAPING AND REMOTES

Mobile units which have been designed principally for network originations or for production companies will, most likely, include the incorporation of videotape equipment. This is due to the need of commercial spot playbacks as an integral part of the remote production or where there is the requirement of recording and editing at the remote location.

The independent broadcaster is caught in the dilemma of making this very difficult choice. If he chooses not to include VTRs in his mobile fleet, he will occasionally have to rent costly mobile units which have tape machines in them. If the choice is to include VTR facilities, then there is the risk of too little productive use of this valuable asset. Another direction, of course, is to borrow several VTRs that are normally a part of the studio facilities. This can be a problem, also, since the total tape involvement at the station may not allow for the disappearance of several of its machines.

Fig. 38. Recording an interview for "Ark in the Park."

At WGN-TV, we have rented VTRs which are normally housed in the supplier's vehicle and have, on a number of occasions, rented the VTRs and installed them in our own "tape trailer" that was specifically constructed to house rental or future-owned VTRs. This trailer has cooling and/or heating necessary for a comfortable tape area. Future plans include provisions for audio and switching facilities, utilizing the roll-in color camera control units (Ampex BC-230) from the secondary mobile unit previously described.

The advantages of having an independent vehicle for tape equipment need to be mentioned. First, this affords a facility which can team up with either of the two pickup units. Second, the original design of the primary remote vehicle, having excluded videotape, allowed for roomier areas for all operations within that unit, a feature that is especially important considering that most of our remote telecasts do not require videotape facilities. Finally, this choice of not including tape in the primary unit provided better serviceability of equipment racks. Most racks could be arranged for accessibility from either side, which is very often not the case when VTRs are housed in the same total area.

Television broadcasters principally have been using quad videotape machines in their remote units. With the introduction of the time base corrector, VTRs using the slant track format are appearing on the scene and can be expected to be a part of television remote program originations.

LIGHTING AND REMOTES

To generalize, remote lighting usually falls into two categories: the fixed, planned arena type of installation and the temporary situations found in the one-time-only remote locations. These applications are to be considered here.

First, however, acknowledgment must be made of the tremendous advantage the newer cameras offer. With their improved response to lower light levels, the remote lighting job is no longer the monster it used to be. Whereas sufficient power was a problem at most sites, existing amperage now usually proves adequate. More emphasis then can be made on quality of light rather than attempting to reach 300 or 400 F.C.

In the course of the year, Robert T. Stebbins, Manager, Arts and Facilities, WGN Continental Group Stations, indicated that WGN-TV will handle a great variety of remote locations under varying conditions of ambient light. Our approach probably parallels the procedures of most in that an initial survey is made with such personnel as the producer, director, engineer-in-charge, and the chief electrician of the stagehand crew who will make the installation. During the survey, the scope of the performance will be laid out. A conference with location representatives will normally include the house electrician and, in some cases, power utility personnel. At this point, the method of installing and positioning will be determined. If no building or site plans are available, measurements are taken and existing power sources located. This information is assembled and incorporated into a ground plan (and elevations, if necessary) showing camera and lighting positions, types of instruments to be hung, expected light level, cable runs, junction and distribution boxes, etc.

Normally, on the OTO television remote, most installations are made several days in advance of the actual event. This is done primarily to allow time for changes or replacement of gear that may prove faulty, or if advanced rehearsals are planned.

Each location is treated for its own problems; that is, the lighting approach is tailored for the limitations of a particular location and often special lighting rigging may be built from the notes and photos taken at the preliminary survey. As one may surmize, this might include many variations. Where a low ceiling exists above bleacher audiences, this may take the form of outriggers off columns, as in Fig. 39 (Illinois State High School Swimming Championships). Probably the most common device is the trapeze, a 5 to 10 ft. section of 1½ in. diameter pipe (preferably aluminum) hung on hemp lines or cable dropped through ceiling openings. Often this system is the only practical method in hotels or public buildings.

Luminaires used on remotes are separate and apart (in the WGN procedure) from studio instruments; in fact, most of the remote gear is chosen specifically for remote usage even though it may have studio application. Here in Figs. 40 and 41 is a representative part of the WGN inventory. More often than not, the multiple par is the workhorse. Its ability to cover large areas from considerable distance and the availability of the various lamp configurations make these a must in the television station's inventory. Along with this unit, the single par is also a good item. A variety of lensless quartz instruments with barn doors and focusing in the 650W/2000W range are also useful. When quality of light is an important factor on the job, our remote gear will include a number of 2K spotlights. Softlights can be especially useful in covering situations where glass is a factor. Outdoor work done in daylight frequently will require a certain amount of shadow filling. This might be achieved with any of the units mentioned above

Fig. 39. Swim finals—lamps mounted on out-riggers off columns.

equipped with dichroic filters. If sunlight is convenient, reflectors on stands (long a Hollywood item) will do the job.

If special remote situations are to be a part of your operation, it is well to have a "collection" of hanging devices which should include beam clamps, 1/2 in. hemp, 1/8 in. aircraft cable, 1-1/2 in. OD pipe of various lengths from 4 to 10 ft. along with stands, booms, and adapters.

Speaking of adapters, it is important that remote cabling be able to enter any type of connection. In many instances, connectors at the site will not fit directly into gear being introduced. Hence, electrical adapters are a must. Naturally, in the larger demand remote, connecting is done directly from the bus bars of the electrical service cabinet at the site to the "bull boxes" and then to distribution boxes. The cable route is fused, probably several times. First, an in-line fuse is

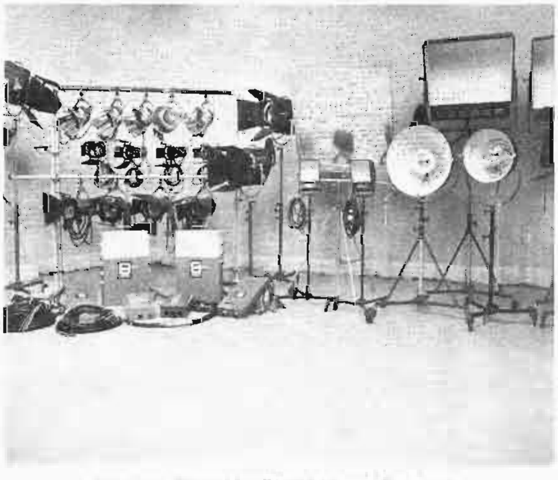


Fig. 40. Remote lighting equipment.

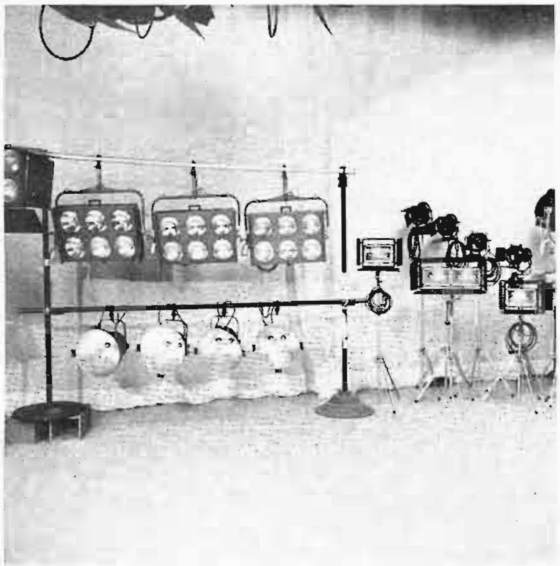


Fig. 41. Remote lighting equipment.

Fig. 42. Lighting circuit breaker panel and disconnects.

introduced (Fig. 42). Second, another at the bull box and once more at the distribution point. All equipment is grounded for safety. All of the cabling gear pictured can be assembled from available parts. Those shown are made to our own specifications.

If remotes include a healthy number of exterior originations, a generator will solve the immediate power source problem. Of course, lighting control, though not as important as in studio operations, is needed in most instances, if not as dimming, certainly as a means of balancing.

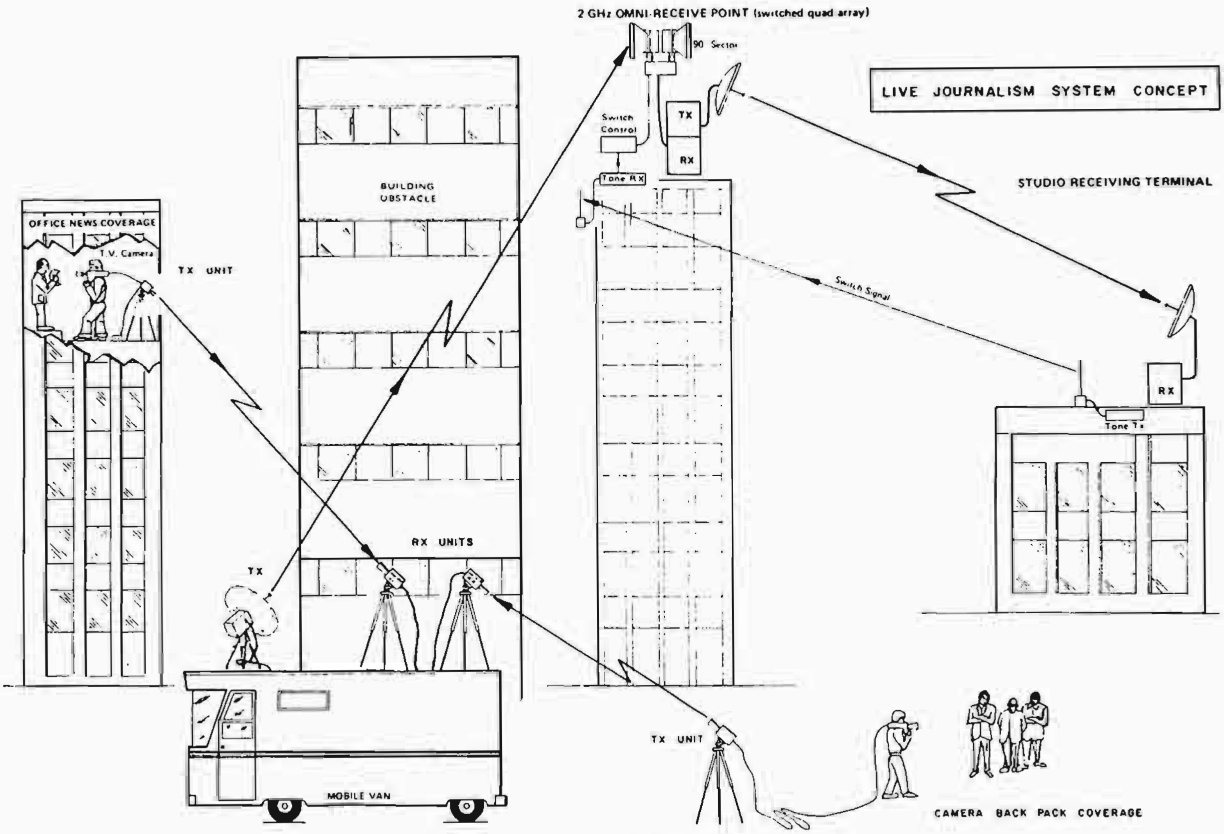


Fig. 43. Electronic journalism, microwave concept.

Finally, flexibility is the key in any acquisition program of remote lighting gear. The ability to cover almost any set of conditions in your respective community governs just how extensive one's inventory should become.

ELECTRONIC JOURNALISM

A discussion of television remote program originations would not be complete without some reference to the changes that have begun in the methods used by broadcasters in obtaining their news stories—that of "electronic journalism."

The traditional system of gathering news has generally been by using 16 mm. motion picture cameras. With this system, news events are photographed, the film is delivered for processing, the processed film is edited, and then it is played on a telecine camera chain for broadcast.

Since late 1971, a new system has made its appearance, that of electronic journalism or electronic news gathering. In 1974, a number of television stations had converted completely to the all electronic system and all of the networks were involved in this new system in varying degrees. This new system employs a portable electronic color camera for the pickup of the news event. The color signal is either recorded on videotape in the field or is transmitted by microwave directly to the studios. Here the signal can be aired live or may be recorded, edited, and played back as an insert into news programs.

There are a number of reasons why this new method of gathering news is being used by a growing number of broadcasters.

1. The speed in which the recorded material can be put on the air. Time is lost in the processing of film which, in the end, may delay editing and judgment of the final news product. Live news break-ins are now possible.

2. The cost of raw film stock and processing of that film is a significant expense.

3. Recent developments in reliable, lightweight, portable color cameras; portable, lightweight videotape recorders; microwave systems and time base correctors make the new method of an all electronic system even more favorable.

4. Less lighting is required due to the greater sensitivity of the portable color cameras.

Whatever the advantages, it is apparent that without the recent electronic developments, we would not be witnessing the changes that are occurring today in the broadcasters' news gathering operations.

There are a substantial number of handheld color cameras available for the news pickups, but their individual virtues will not be identified at this time. Certainly, the broadcaster who is ready to embark into electronic journalism must consider these factors before making the choice of camera:

1. *Performance and picture quality.* Does the final product measure up to the criteria for acceptable picture quality of the station's air product?

2. *Reliability.* Will the camera perform with regularity with minimum or no setup adjustments?

3. *Serviceability.* Is the construction rugged enough to endure the treatment typified in the news operation? Are the setup adjustments easily accessible? Is factory service available? Are service manuals complete? Are parts readily procurable?

4. *Portability.* Is the camera light enough in weight for extended periods of operation?

5. *Cost factor.* If the total change to electronic journalism is to eventually take place, will the final capital expenditure for the total number of cameras be within the budgetary allowance?

One of the primary advantages of electronic journalism is the ability to air news segments live. A number of stations using electronic journalism schedule live segments in their news programs to increase viewer interest. This means that microwave systems need to play an important role in the overall electronic news gathering picture.

A concept of relaying news happenings to the television studio is shown in Fig. 43, as suggested by Microwave Associates. Three different microwave links are employed to deliver the final picture and sound to the news editors in the studio building.

Several battery-operated, seven-pound miniature microwave transmitters, utilizing a circularly polarized horn antennae, beam their signals to the roof of the mobile van. Operating in the 12.7 GHz to 13.25 GHz range, the units typically have a range of up to one mile. With the use of a two- or four-foot parabolic antenna, their range may be increased up to five miles.

At the mobile unit, the camera signal is monitored and either recorded or retransmitted. For this retransmission, the sketch shows a portable, 2-w, 2 GHz transmitter aiming its signal to the central omnireceiving site. Here a four sector, switchable quad array is utilized for the receiving antennae. The selection of the antennae covering the proper direction and the best of four antennae polarizations is effected from the studio building. The signal path is completed by including a fixed microwave link to the studio where the news sequence is aired live or recorded for later editing and playback.

An equally important method of electronic news gathering is to record on videotape the remote news pickup using a portable, lightweight, helical scan recorder, reel to reel, or cassette. The hand portable unit can be on the scene with the camera while a second recorder may also be used in the mobile van. Line level, battery-operated microphones are being used for sound pickup in the simpler news recordings.

Essential to the use of this recorded material is the time base corrector. Variations in timing of the playback signal of the helical scan recorder can be corrected to broadcast standards. It should be noted that the TBCs cannot improve picture quality that is not related to time base instability. Nevertheless, with the insertion of the time base corrector, it is now possible for recordings made on the lightweight portable helical machines to be aired directly or to be dubbed up to a quad VTR.

Those entering into electronic journalism will want to consider the use of both methods of gathering news—by recorder and by microwave. The broadcaster will also want to look closely at the station's videotape editing facilities in order to better complement the electronic news gathering process.

TELEVISION REMOTE OPERATIONAL CONSIDERATIONS

Surveys

Remote pickups which are of the one-time-only variety will require an advance survey, no less than two weeks in advance of the remote. Usually, representatives from production, facilities and engineering are present at this survey which is made at the site of the remote origination. The remote engineer-in-charge making the survey for the Engineering Department will gather all detailed engineering data and will enter it on a remote survey report form.

Included in this report form are the following:

1. Power source and location of power cabinets.
2. Length of camera cable runs and camera cable routings.
3. Mobile unit location, stating requirements with regard to parking permits.
4. Camera locations, specifying any need for hoisting equipment, camera risers, etc.
5. P.A. requirements.
6. Audio requirements with regard to microphones needed (six omnidirectional, six cardioid, and four headset microphones are normal complement), multipaired harness location and cable lengths.
7. Visual monitors or receivers needed external to mobile unit (seven is the normal complement).
8. Microwave possibilities following a line-of-sight check. Recommended microwave location, if any.
9. All contacts; i.e., electrician foreman, PA man, building supervisor, electrical contractor, if needed, security contact, etc., and their telephone numbers.
10. Telephone and business line requirements.
11. Security needs.
12. A sketch of the relative placement of all facilities, including cable runs, parking site, camera locations, etc.
13. Whenever possible, the engineer-in-charge will take photographs (Polaroids) to supplement the survey data.

The Facilities Department would determine the need for lighting, camera platforms, props, risers, rental equipment, snorkels, etc. Production would secure any information they need to prepare for programming, would establish the necessary contacts for talent procurement, credentials, script information and would advise people at the remote location of the scope of the program and its special requirements as pertaining to them. Notification of the remote crew arrival time should be given to the necessary personnel at the remote site prior to the program date.

Using the completed survey form, the administrative engineering personnel would schedule the required remote crew for the setup day, when required, and, also, for the operational day. Detailed arrangements for electronic equipment rental, hiring of security personnel, mobile unit drayage, parking permits, electrical contractor or power utility services, will be concluded by administrative engineering personnel.

Setup

What entails the setup? Just about everything short of the rehearsal and the actual program itself.

Setups will vary considerably in the amount of work required. Hopefully, this work has all been analyzed before the remote setup date. The crew time is scheduled accordingly. No two setups are alike, but all have some very common tasks included in their agenda.

These include unloading of equipment, camera setups, cabling of cameras, power hookup and cabling, audio and video cabling, microphone placement, antennae setup and communications lines and TV monitors installed.

Figs. 44, 45, 46, 47, and 48 illustrate very well some of these setup tasks. These are scenes from the Chicago Christmas Parade taken shortly after the primary mobile trailer arrived on the scene for the annual telecast. Cable runs were at a minimum for this setup, but the trailer roof work and the snorkel setup made up for it.

Basically, setups can be divided into two main categories: those that are repetitive, such as the baseball and hockey pickups, and the one-time-only type.

Setup time for repeated sports pickups at baseball parks, hockey stadia, etc., can be substantially reduced if permanent facilities are installed.

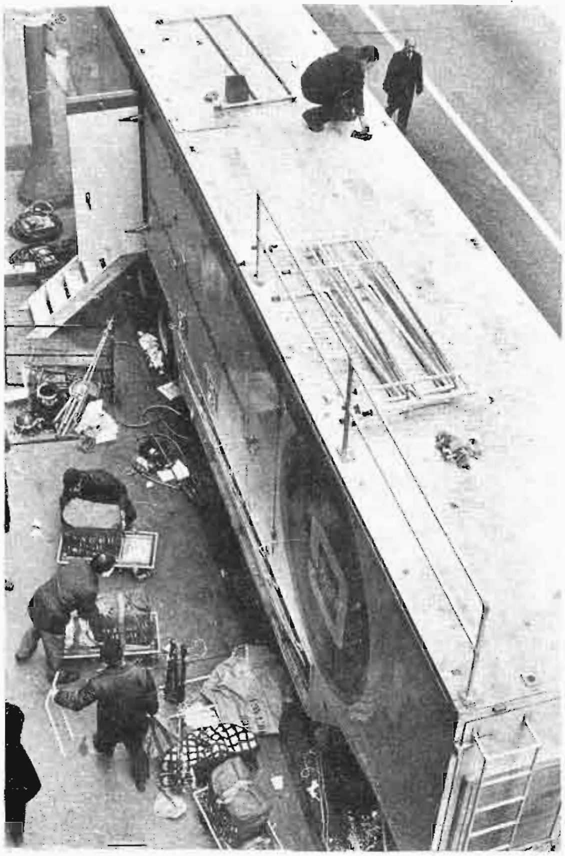


Fig. 44. Setup—unloading and roof railing installation.

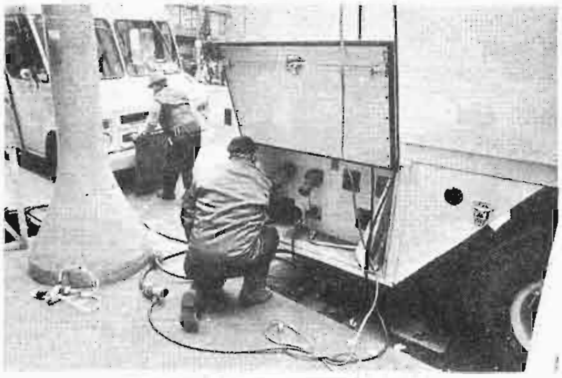


Fig. 45. Setup—power hookup.

Fig. 46. Setup—lighting on the trailer roof.

Fig. 47. Setup—raising equipment to the trailer roof.

Fig. 48. Setup—checking out the camera snorkel.

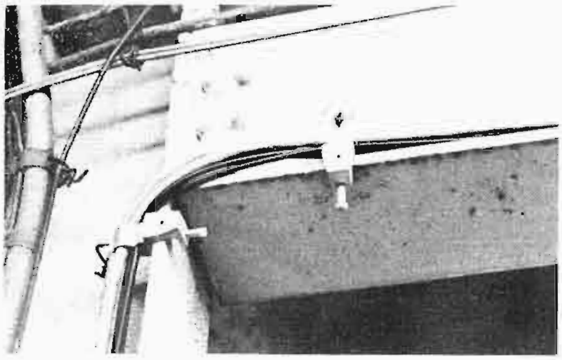


Fig. 49. "I" beam clamps for cable tie-downs.

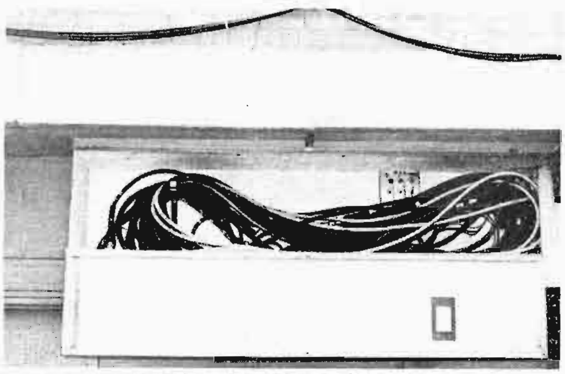


Fig. 50. Cable box at mobile unit location, Chicago Stadium.

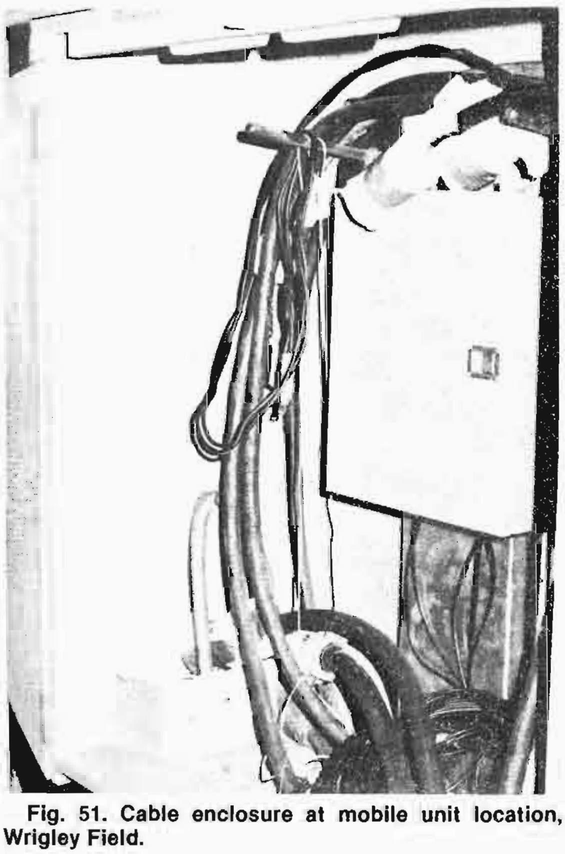


Fig. 51. Cable enclosure at mobile unit location, Wrigley Field.

Fig. 52. Audio/video terminal box at mobile unit location, Wrigley Field.

At such locations, cabling for all camera positions is permanently installed. Cables are routed in such a way as to avoid vulnerable areas where cable damage could occur, especially if mini camera cable is used. "I" beam clamps and adequate tie down of all cabling is recommended (Fig. 49). Sufficient length is provided in order to anticipate possible cutbacks of cables due to connector problems or due to repeated flexing of cables. Also to be considered is to provide enough cable length to reach a second camera that may be located on the adjoining camera mount; this is for the purpose of quick troubleshooting of cables and cameras.

At the mobile unit parking site, all cabling may be coiled inside a protective enclosure to keep connectors out of the weather. Loops of cable are of sufficient length to reach their normal mobile unit terminations. This enclosure may be a painted wood enclosure as large as 5 ft. X 6 ft. X 18 in. used at the ballparks, or, as shown in Fig. 50, used at the Chicago Stadium. Large spindles or brackets protrude from the back inside surface of the enclosure. Cables generally are coiled together around the outer edge of the brackets. Those shown in Fig. 51 have connectors which have been wrapped for winter protection.

Each location where permanent facilities are installed should also include a lockable power disconnect box. It can be located within another enclosure that is of sufficient size to include the power cables that are extended to the mobile unit when in use.

Permanent audio and video tie lines to the remote vehicle from all parts of the Chicago Cubs Wrigley Field terminate in the distribution box located within the cable enclosure at the mobile unit site (Fig. 52). This includes lines to the principal broadcast booth, visiting team booths, dugouts and center field camera locations. Very often the visiting team will have its own sportscaster utilizing the video signal from the mobile unit which supplies the program for telecasting to the local TV audience. This necessitates that all booths be interconnected permanently with audio and video tie lines. Patching can be made in the local booth audio/video connector panel (Fig. 53) to the truck terminal enclosure.

When the remote crew reports for duty at the reoccurring remote pickup site, they most generally find all cameras cabled and in position (but covered and secured). All audio, video, and camera cables are connected to the mobile unit (perhaps from the previous day's use).

At WGN-TV, it has been the custom for the remote crew to check all systems immediately after arrival, making certain that all equipment is functioning. Early corrective measures are sometimes needed and an experienced crew makes the necessary repairs, substitutes with spare equipment, or notifies the studio that a replacement is needed.

Power is first applied to all equipment in the mobile unit. The broadcast positions or booths are prepared for broadcast, including the setting up of all microphones, headphones, and monitors. Similarly, all mikes, headphones and monitors are installed on the field or dugout in the case of baseball, or on the ice level or courtside in the case of hockey or basketball, respectively. Continuity checks of all operational equipment are then made.

Generally speaking, this includes voice checks of all microphones—those used by talent as well as those used as crowd noise for baseball, field noise for football, and backboard noise for basketball. Visual monitors used at the announcer locations are checked for picture quality and the source signal properly identified. All headphones and ear plugs are checked for level and clarity of signal.

Cameras are uncovered, power is applied, and a number of preliminary operational checks are made prior to a warm-up period. Cameramen and camera shaders work together at the camera and camera control, respectively, each determining that all systems are functioning. A quick check of signals from each of the three plumbicons in each camera is a necessity.

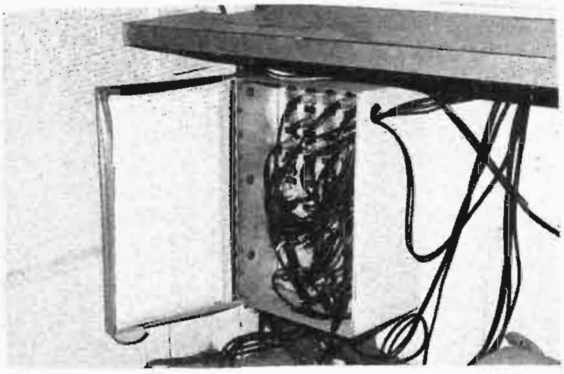


Fig. 53. Booth audio/video connector box, Wrigley Field.

The cameraman is concerned about lens performance, clarity of viewfinder picture, tilt/pan head operation, camera cue and program continuity on his headset and tally continuity on both tally circuits.

The shader(s) checks all monitoring equipment on each camera console. He is concerned with the overall performance of the camera chain, which includes registration, color balance, focus tracking, video levels, aperture setting and peaking of the video signal and encoder check out.

In addition, the switcher or audio engineer checks continuity of all telco facilities (broadcast circuits, PLs and business telephones). An early call to master control for check-in and time check for clock synchronization is always in order.

After time has been allowed for equipment to warm up and the crew lunch break has been taken, a detailed camera alignment is made along with the final color balancing of all cameras. Audio and video levels to the studio are set and verified. Color bars from a camera control unit are used to substantiate the performance of the telco video circuit or microwave circuit to the studio location. The variable tone oscillator used in the audio console is a source feed for checking the audio circuit levels and response. A voice quality check is usually required to assure master control that peak distortion is not occurring. Any suspicions of distortion in that regard may require a more detailed check of headroom capabilities of the audio circuit. Both the color bar signal during setup and the vertical interval test signal during air time assure master control that the telco video loop or the microwave transmission is functioning properly.

One-Time-Only Remotes

These remote originations involve considerably more setup time. It would probably be more accurate to define one-time-only remotes as those which do not have permanent cabling installed. Since camera locations may be as far as 1000 ft. away from the mobile unit, cable installation time can be considerable. On such a setup, the entire remote crew with proper supervision and preplanning can be involved in the running of cables.

Care must be taken to avoid leaving any hazards for the public in these installations. Camera cables are usually flown overhead in order that tripping accidents may be avoided. When it is required for cables to lie on the ground where traffic is expected, cable ramp covers or bridges are provided. At the very least, a heavy, wide carpet tape should be employed.

Frequently, the one-time-only remote will require a microwave setup. Microwave installations are usually established as being possible by line-of-sight checks on the earlier survey date.

The setup of microwave equipment on the top of the mobile unit is not always possible. At times, the transmitting gear must be carried or hoisted to the rooftop of a nearby building where the only line-of-sight vantage point is available. If the survey indicates that the microwave check be made before the day of setup, this precaution should be taken. A minimum of a week's advance notice might still leave time for a telephone video facility to be ordered. Needless to say, microwave usage adds to the total time needed for setup. Depending upon the degree of difficulty of installation and antennae orientation, three engineers on the crew could be occupied for one to two hours.

In order to avoid long operating days for the crew on this type of remote origination, it is sometimes prudent to make a partial setup on the day before the program day. Prior commitments at assembly halls, stadia, and churches may also dictate working around these events. On the setup day, power tie-in and power cable installation should be accomplished, camera cable runs completed, microwave gear set up and continuity checked, and long audio harnesses and microphone cables installed.

It should be noted that on these preliminary setup days, all scaffolding and camera platforms ought to be similarly installed by the Facilities Department.

An early setup day not only reduces the call for the crew, but may provide the additional rehearsal time required of that program. Depending upon the length of the rehearsal and program itself, final tear out of all facilities can be either after the program or on a future day.

The remote survey for the one-time-only remote pickup, hopefully, included methods of obtaining power for the mobile trailer. It is usually advantageous to have these arrangements made prior to the day that power is first needed.

A useful facility for this purpose is the portable dual disconnect box(es) shown in Figs. 54 and 55. The lower box is used for utility power (fused at 200 amperes per leg) in the trailer, and the top box is used for equipment power (fused at 100 amperes per leg). The input of each disconnect box has 15-ft. pigtails of No. 1-0 wire. Across the output of the disconnect units are short cables outfitted with power cable connectors—mates for the 50- or 100-ft. extension cables to the mobile trailer.

The power boxes, which are permanently mounted on a hand truck, are delivered in advance to the remote location where a qualified electrician or power utility personnel ties in the input pigtails. The remote crew on the setup day

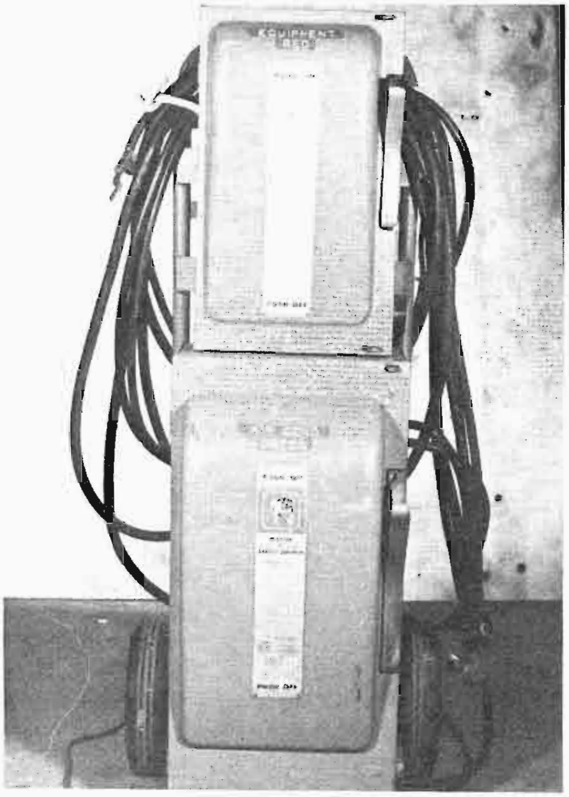


Fig. 54. Portable dual disconnect boxes.

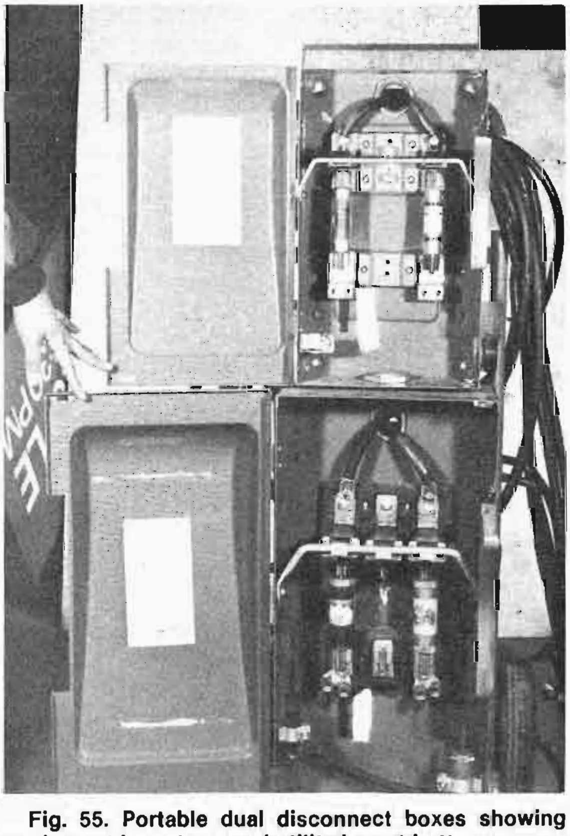


Fig. 55. Portable dual disconnect boxes showing equipment box at top and utility box at bottom.

cables in the extension cables to the trailer and activates the portable disconnect switches.

Advance preparation needed for out-of-town remote pickups can become quite extensive, especially if the program extends beyond several days. Such is the case of the television coverage of the two Illinois High School Association basketball tournaments.

A little background would be helpful in better understanding the scope of the preparation required for these telecasts. The tournaments are held each year at the University of Illinois Assembly Hall in Champaign, Illinois. Quarter final, semifinal, consolation and championship games are played for small schools (Class A) and larger schools (Class AA) in the state. These 16 games are telecast to a statewide network on Friday and Saturday of two successive weekends.

At the remote location, a studio, called Tournament Central, is set up in the lower level of the Assembly Hall. On-camera commentary and interviews originate in this area and supplement the courtside activities of the games where three or four sportscasters provide the play-by-play and color commentary. Fan and cheerleader interviews are conducted and inserted frequently into different positions in the program script.

A videotape spot reel with as many as 75 taped segments is played back from a tape mobile unit at the remote site. Included on the tape reels are commercials, prerecorded interviews and highlights of earlier games. The primary mobile unit is used to coordinate the production, which utilizes six cameras, two VTRs, slo mo, character generator, and an assortment of 20 microphones. Team and player backgrounds, foul information, scoring data, and other pertinent statistics are inserted throughout the course of the telecasts. Total air time for each tournament is approximately 12 hours.

Engineering preparation by administrative engineers for this annual tournament is done over a three-month period. The agenda for this preparation follows:

1. Administrative engineer, in the company of producers, facilities supervisor and agency personnel, meets with Assembly Hall staff to review upcoming tournament.

2. Guard and electrician's needs are listed and a schedule of these needed services is left with the Assembly Hall superintendent.

3. Motel reservations are made for the total personnel who will be assigned to this pickup.

4. Engineering reviews remote personnel assignments of past years for this pickup, reviews recent performances of its personnel and submits selected crew members to the Production Department for the purpose of credential procurement.

5. Business telephones, private lines and broadcast circuit needs are submitted in writing to the telephone company along with a tentative list of television stations due to receive tournament telecasts.

6. Correspondence is written and final arrangements are made for the following:

a. Rental equipment.

b. Temporary help that is to be used at the remote location.

c. Truck or vehicle leasing.

d. Notification of the FCC for use of auxiliary broadcast equipment (handi-talkies) in the downstate area.

e. Business lunch and meeting arrangements during tournament weeks.

7. Review equipment needs with the two engineers-in-charge who are to be assigned to the remote. Check last year's equipment list and ascertain if any purchases have to be made to meet this year's requirements. Orders for needed cabling, connectors, etc., should be submitted at least six weeks in advance of the tournament.

8. Post remote crew assignments about four weeks in advance of the tournament. List vehicles to be used for personnel travel, supply motel information, details of expense money advances and travel directions.

9. Arrange for drayage of mobile trailer and tape trailer for trips to and from the remote location.

10. Delegate engineer-in-charge to prepare information booklet for crew members. Ask that data be included regarding cable runs, audio and video interconnects between trailers and the Assembly Hall, camera placements, power hookup information, rehearsal and videotape recording times, and information supplied by the Engineering Department Office regarding lunches, the use of company blazers, etc.

11. Arrange for catered food for crew lunches on the tournament days.

12. Provide crew and master control with the listings of all business telephone numbers, PL interconnects and broadcast circuit identifications.

13. Work with the Production Department in scheduling studio time for advance preparation of the videotape spot reels. All segments will be placed into their proper position on this reel. The tape engineer making the recording will be one of the engineers eventually assigned to the tape mobile unit at the remote.

14. Advise the Auditing Department of the advance monies needed for engineering personnel.

15. Send memo to the Program Department reminding them of the use of two cameras and the character generator on remote location and indicating the times this equipment will not be available for studio use.

16. Advise the News Department that Engineering will be utilizing its handi-talkies for com-

munication purposes during the two weeks of the tournament.

17. Submit a final reminder to the remote engineers-in-charge that they should be prepared, along with the administrative supervisor, to submit a critique of the engineering operation following the telecasts.

Two and one-half days are devoted to travel and the total setup of this remote origination. The engineering crew schedule is staggered over three days in order that the later arrivals may bring with them any equipment that was overlooked or has become needed due to breakdowns. Although the nature of the telecast of the basketball games cannot provide a complete "rehearsal," all crew members are thoroughly checked out and must be available for system checks well in advance of air time. The videotape recording in Tournament Central on the afternoon preceding the telecast date allows for a good system checkout in that area.

Air time with this remote, or any other remote, exemplifies the teamwork capabilities of a remote crew. Directors and cameramen who work together on sports pickups can attain a degree of perfection for which the home viewers are most appreciative. Conversely, it can be quite obvious if crew members are not in tune with each other's actions because they are not accustomed to working together.

In all cases, the director should run the show at air time. Responsiveness to his cues on the part of the switcher, the audio engineer, the slo mo operator, and the cameramen is essential to the final effectiveness of the remote telecast. A good director will allow certain freedom on the part of the cameramen as long as it is within the general bounds of their coverage responsibility. By this is meant, the principal coverage camera should have certain responsibilities such as following the play action where another camera may principally be employed for close-ups of the pitcher, quarterback, hockey net, etc.

The final air product will always show whether the teamwork was achieved. Whether it be proper iris settings, a well-balanced sound, punctual and accurate switching, good color balance, effective use of the slo mo, smooth zooms, proper framing, or a good choice of close-ups, all will contribute to the culmination of a final product—that of a successful television remote program origination.

32

"Live Journalism" Antenna

Thomas J. Vaughan
President, Micro Communications, Inc.
Manchester, New Hampshire

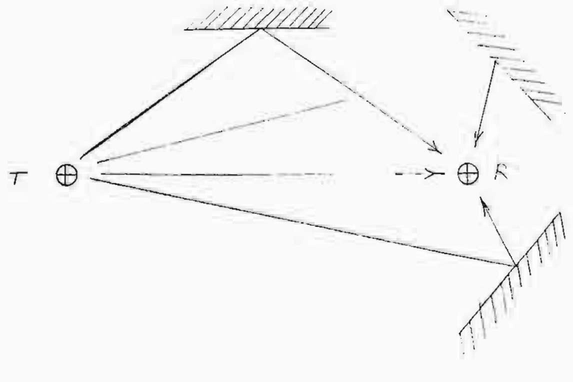
Live Journalism (ENG)—Requirements

Live Journalism requires the use of a receiving antenna that can be "seen" electrically from anywhere in the metropolitan area.

Because of the proximity of tall buildings, it is not possible to have direct line of sight from the antenna on the transmitting van to the receiving antenna for all locations.

It is therefore necessary to use a receiving antenna that can make use of signals that are reflected from nearby buildings.

A second requirement is that some form of filtering be incorporated into the antenna to eliminate or minimize multipath signals—the cause of ghosting.



Multipath Discrimination

There are two useful techniques that can be used to discriminate against multipath reflections:

1. Pattern Directivity
2. Circular Polarization

Pattern Directivity

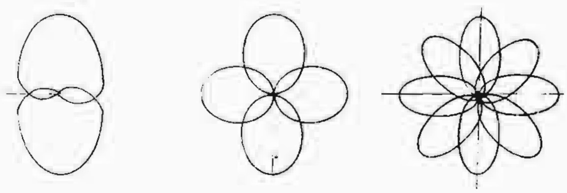
An omnidirectional antenna would be an ideal receiving antenna in that signals could be received from any azimuth direction. The disadvantage is that all multiply reflected signals would be received equally well and the ghosting problem would be greatly aggravated. The obvious solution is to use a circular array of more than one antenna and take advantage of pattern directivity.

The array can be composed of any number of individual radiators and a switch used to select the radiator pointing in the direction of the maximum signal.

It is quite possible that the maximum signal is not in the direction of the transmitting antenna. For example, if a large building is located in the path of the signal, it may be desirable to use the best quality reflected signal. The selection process in this case would be done by the operator.

The criteria for determining the individual antenna properties in the array are based on ± 2 dB ripple factor, e.g., the cross over level of any two adjacent antennas be down no more than 4 dB from the peak or point of maximum gain.

This will permit most signals to be received on more than one antenna.



Two Antennas	*Four Antennas*	*Eight Antennas*
$BW_{AZ} = 180°$	$BW_{AZ} = 90°$	$BW_{AZ} = 45°$
$BW_{EL} = 13.2°$	$BW_{EL} = 13.2°$	$BW_{EL} = 13.2°$
Gain = 12.3 dB	Gain = 15.4 dB	Gain = 18.4 dB

$$\text{Gain} = K\,\frac{4\pi\left(360/2\pi\right)^2}{\theta_1 \times \theta_2}$$

Where θ_1 = Beamwidth — Azimuth Plane
θ_2 = Beamwidth — Elevation Plane
K = Efficiency Factor of Antenna

The greater the number of antennas, the higher the gain and the greater the discrimination to reflected signals.

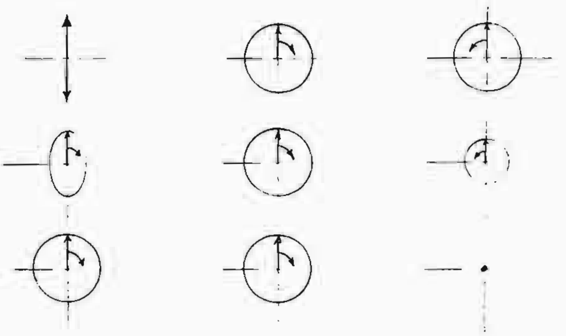
Circular Polarization

Cross polarization has been used as a means of filtering unwanted signals for many years.

By having one TV station radiate horizontal polarization and the other vertical polarization (England), it has been used to space cochannel stations closer than the table of allocation would normally permit.

Circular polarization has been used in television in (Mexico and South America) and recently in the USA. One advantage is that improved signal reception can be obtained regardless of the orientation of the receiving antenna. A second and more important advantage is that many of the unwanted reflected signals will be cross polarized. These can be filtered if a circular polarized receiving antenna is used.

This can be explained as follows. An elliptically polarized wave is composed of two circularly polarized signals one left-handed and one right-handed. When the elliptical wave reduces to a linearly polarized wave the right- and left-handed signals are equal. When the signal is right handed, the left handed signal is zero.

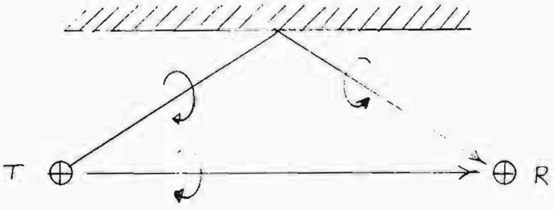


RADIATED SIGNAL   RIGHT CIRCULAR SIGNAL   LEFT CIRCULAR SIGNAL

If a circularly polarized receiving antenna is used, it will only receive that component of the signal that is the same sense. The other will be cross polarized.

A feature of circular polarized transmission is that the reflected signal will be of the opposite sense of the direct signal.

The degree of filtering is a function of the axial ratio of the transmitting antenna, magnitude of the reflected signal and the axial ratio of the receiving antenna.



$$\text{Axial ratio} = 20 \log \left(\frac{E_v}{E_H}\right)$$

Since;

$E_V = E_R + E_L$ $\quad$ E_R = right circular

$E_H = E_R - E_L$ $\quad$ E_L = left circular

Therefore;

$$AR = 20 \log \left(\frac{E_R + E_L}{E_R - E_L}\right)$$

The ghost rejection ratio when the reflection coefficient is one will be;

$$\text{Ghost rejection} = 20 \log \left(\frac{E_R}{E_L}\right)$$

Therefore;

$$\text{Ghost rejection} = 20 \log \left[\frac{1 + 10^{AR/20}}{1 - 10^{AR/20}}\right]$$

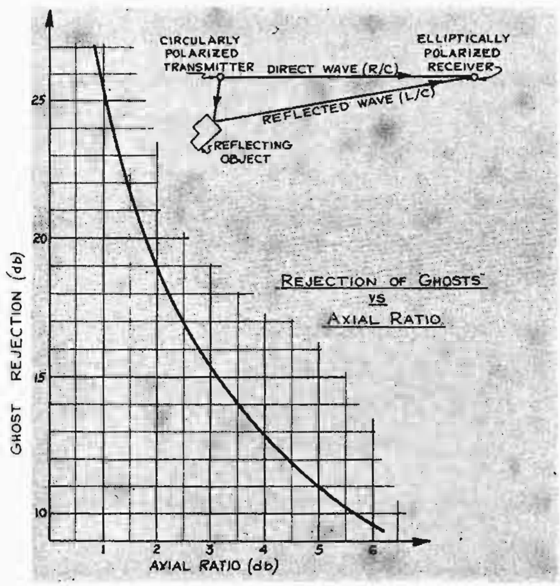


Fig. 1. Rejection of ghosts versus axial ratio.

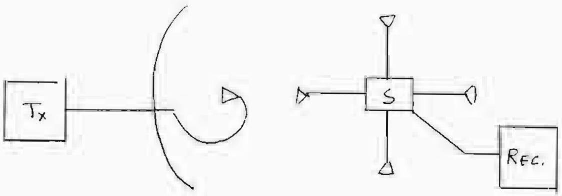


Fig. 2. A 4-ft. parabolic dish with a right circular feed as the transmitting antenna and a four antenna receiving antenna.

For Electronic News Gathering applications it is possible to have:

1. The antenna in the van transmit right circular and to receive horizontal or vertical, right circular or left circular.
2. The antenna in the van transmit horizontal, vertical right circular or left circular while receiving right circular.

The law of reciprocity permits, the role of the transmitting and receiving antenna to be interchanged. Therefore there is no loss in information if fixed polarization is received and multiple polarization is transmitted. It should be noted that a circularly polarized signal of either sense can be received by a linearly polarized antenna of any orientation but it will be reduced by 3 dB.

$$E_H = .707\ E_{CIR}$$

$$E_V = .707\ E_{CIR}$$

Type of Antenna

Most of the ENG systems uses a 4-ft.-parabolic dish with a right circular feed (some capable of being manually switched to left circular) as the transmitting antenna and a four antenna receiving antenna.

The receiving antennas are of two types.[1]

1. Four element phased arrays
2. Flared horns

Each is capable of remotely controlled multiple polarizations and have the same azimuth and elevation beamwidths. They differ in the following respects.

[1]A third type of antenna makes use of a parabolic antenna mounted on a X-/Y pedestal. The antenna can be remotely positioned in azimuth and declination. Although this system has higher gain, it suffers from disadvantages; (a) being side mounted on a tower approximately 90° of azimuth orientation which is blocked by the tower; (b) the drive power available with commercial pedestals cannot drive in winds greater than 45 mph; (c) many insurance policies will not permit a moving antenna on the tower.

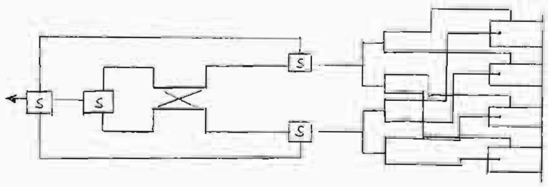


Fig. 3. Four element array module.

Four Element Array

The array consist of four waveguide horns spaced one wave length apart. Each horn contains a dual polarized feed. By processing the horizontal and vertical components through a solid state switching matrix it is possible to receive horizontal, vertical, left and right circular polarizations.

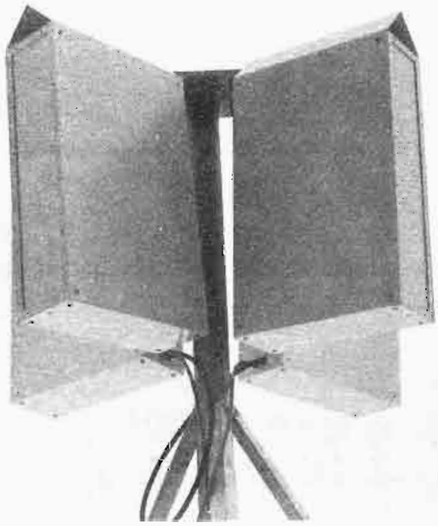
An advantage with this construction is that any amplitude and phase distribution can be placed across the array and null fill and beam tilt can be obtained.

A second advantage is that since a near uniform distribution can be placed across the antenna a near 100 percent aperture efficiency can be obtained. The resultant antenna can be made very small and compact (Photo 1).

The solid state switching permits polarization and quadrant selection to be done live, e.g., with programming on line since switching speed is on the order of 200 nanoseconds.

Flared Horns

The flared horns uses a single dual polarized feed (Fig. 4). The azimuth and elevation beam widths are essentially the same as the four element array. To obtain these beamwidths, it is necessary for (L) to be very large (approximately



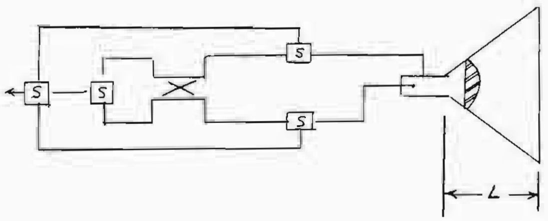


Fig. 4. Flared horns module.

70 in.). To reduce this to reasonable figures (like 30 in.), it is necessary to mount a phase correcting lens in the throat of the horn. This will delay the energy at the center of the horn a greater amount than the energy at the edge resulting in a more uniform phase front.

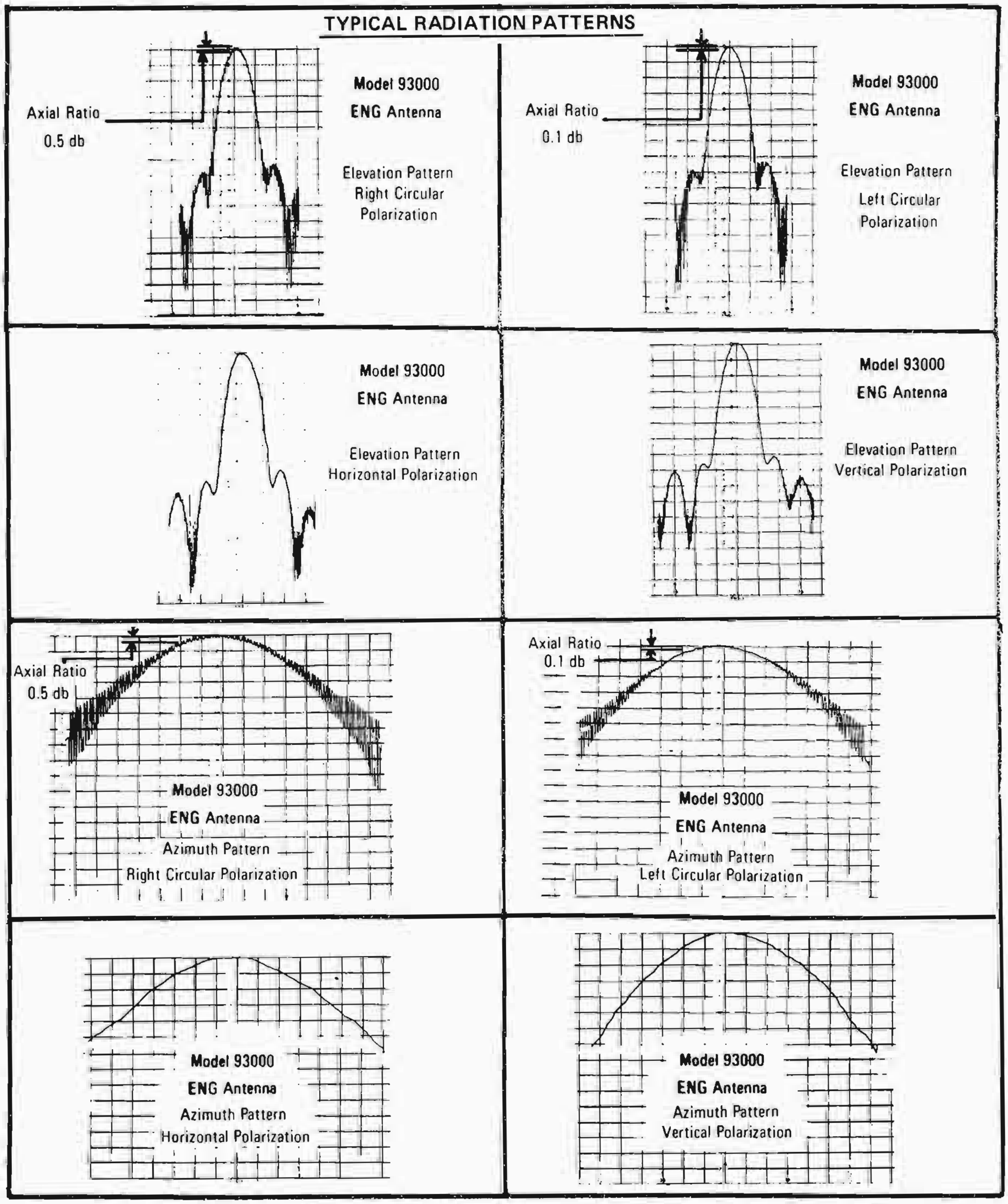


Fig. 5. Typical azimuth and elevation patterns.

Siting Considerations

Typical azimuth and elevation patterns are shown in Fig. 5. An important consideration in the choice of locations is the height of the receiving antenna.

For TV and FM transmissions, the signal level at a point above the ground will increase proportional to height. This increase is due to the reflected signals,[2] adding in-phase when a low gain antenna (dipole) is located at one end of the link.

The ENG antenna uses a high gain (25 dB) parabolic dish at the ground location and the reflected signal will not contribute to an increase in field. Therefore, increase in height will not increase signal level.

In fact the reverse is true. As the height of the receiving antenna is increased, the near in signal will decrease because we are moving further down on the elevation pattern. In addition, the nulls close to the tower will move out.

This can be seen in the enclosed plot of signal to threshold level versus distance for a typical system (Fig. 6).

As can be seen there is no improvement if the antenna is increased from 500 ft. to 2,000 ft. at distances beyond 10 miles although there is considerable reduction for near in signals.

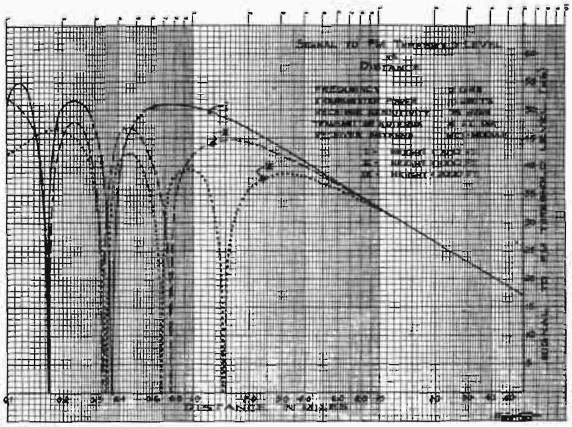


Fig. 6. Plot of signal to threshold level versus distance for a typical system.

The conclusion is that the antenna should be located no higher in height than necessary to obtain *reasonable* line-of-sight paths.

Where high heights are required for line of sight reason, it may be necessary to provide null fill. At a 1,000 ft., no signal will be obtained at 0.8 miles from the receiving antenna. The first null can easily be filled with the four-element array by providing an amplitude taper across the array.

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[2] "*Transmission of Circular Polarized Waves between Elevated Antennas,*" By T.J. Vaughan and R. Pozgay.—*IEEE Transactions Publication* September of 1974, Volume BC-20 Number 3.

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Translators and Boosters in the Broadcast Services

TELEVISION TRANSLATORS

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TELEVISION TRANSLATORS

There has been a need for an automatic unattended device to rebroadcast television signals to shadowed communities since the inception of television broadcasting.

Translators get their name from their function of receiving an "Off-the-Air" signal and converting (translating) it to a new channel in the VHF or UHF Television Band.

The translator is comprised of a television receiver and television transmitter integrated into one equipment with the necessary ancillary circuits. Translators range in power output from 1 to 1000 watts.

The translator station is usually located on a hill or mountain, where available, that offers a "Line of Sight" path to the community to be served while simultaneously providing a good "Off-the-Air" primary signal to the translator input.

FCC Licensing Requirements

Translators are licensed by the Federal Communications Commission under Part 74 Subpart G of the Commissions Rules and Regulations. Applications for new translator stations are filed using FCC form 346 for Construction Permit. Such application may be filed by any individual, public group, civil governmental body or broadcaster. The application requires that the applicant make a brief showing of his financial capability to promptly and properly construct and operate such a station in addition to the necessary legal and engineering information.

While both VHF and UHF channels are available to translators, the FCC encourages the use of UHF channels by giving more "latitude" to UHF translators. As an example, UHF translators are

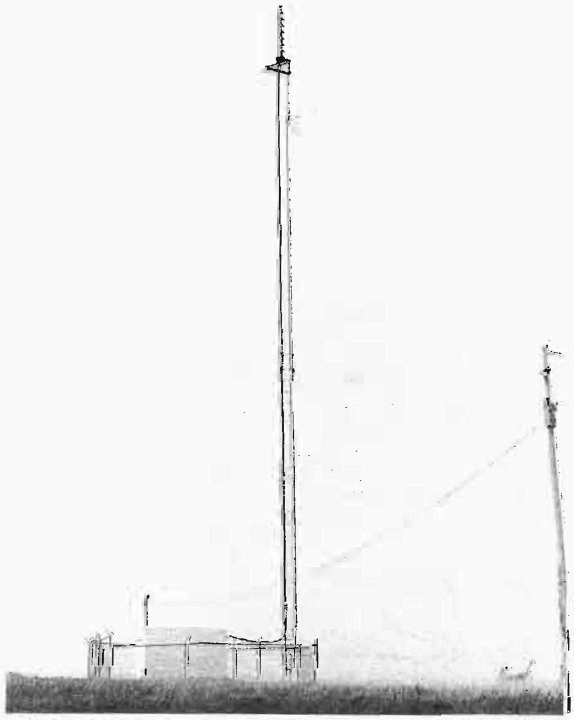


Fig. 1. 2,000 watt ERP, UHF, TV translator station. (Photo courtesy of WVIA-TV.

TRANSLATOR STATION COVERAGE CHARTS

HOW TO SELECT THE PROPER TRANSLATOR AND TRANSMIT ANTENNA

STEP 1) Determine Output Band
A. CH-2 to CH-6 (Band I)
B. CH-7 to CH-13 (Band III)
C. CH-14 to CH-83 (Bands IV, V)

STEP 2) Determine Height "H" of transmitting antenna above community (s) to be served.

STEP 3) Determine desired Distance "D" from Transmitter/Translator to furthermost boundary of community to be served.

STEP 4) On appropriate Coverage Chart (either Band I, Band IV, V or Band III) locate curve approximating Height "H" determined in Step 2.

STEP 5) On same Chart locate Distance "D" along horizontal axis and draw a veritical line intersecting the appropriate "H" curve selected in Step 2.

STEP 6) Draw horizontal line from the above intersection tc the left hand vertical axis indicating required "Effective Radiated Power" (ERP).

STEP 7) Locate the appropriate horizontal antenna pattern which will encompass the community to be served.

STEP 8) Select the antenna which offers this horizontal pattern with the necessary Power Gain (above a dipole) to deliver the "ERP" (in Step 8) when used with the selected transmitter.

NOTES: (APPLICABLE TO BOTH GRAPHS)

A. ERP is determined by multiplying transmitter or translator power output by antenna power gain (relative to halfwave dipole). P × G = ERP (expressed in watts). Do *not* use gain expressed in dB.

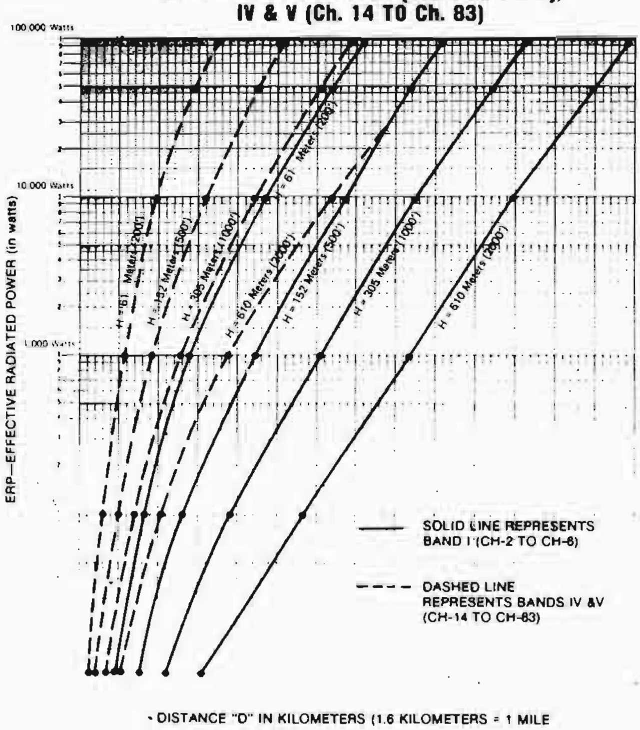
B. For purposes of simplicity, transmission line losses have been ignored.

C. H = Height of transmitting antenna above area to be served, in meters (1 meter = 3.28 feet).

D. Coverage specified is defined as follows:
BAND I (50-88 MHz): +47 dBU (relative to 1 microvolt per meter) field intensity
BAND III (170-230 MHz): +56 dBU (relative to 1 microvolt per meter) field intensity
BAND IV, V (470-890 MHz): +64 dBU (relative to 1 microvolt per meter) field intensity

The above field intensities are sufficient to deliver a satisfactory picture taking into account receiver noise, cosmic noise, receiving antenna gain and line loss.

COVERAGE FOR BANDS I (Ch. 2 TO Ch. 6), IV & V (Ch. 14 TO Ch. 83)



COVERAGE BAND III (Ch. 7 TO Ch. 13)

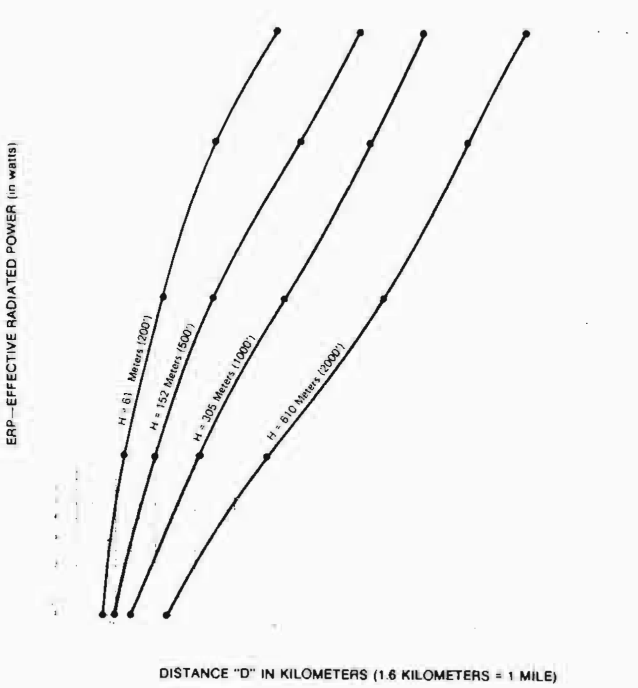


Fig. 2. Translator station coverage charts.

allowed to originate local 30-sec. advertisements once each hour to help defray the cost of operation. At present there are bills pending in Congress to further enhance and exploit the television translator. UHF translators may be operated at power outputs of 1000 watts maximum while

VHF translators are limited to 1 watt east of the Mississippi, 10 watts west of the Mississippi, and 100 watts on unused channel assignments.

The television translator may rebroadcast the "Off-the-Air" signal of

A. The primary broadcast transmitter
B. Another translator station
C. 2000 MHz Translator Relay station

Only translators that are FCC Typed Accepted are licensable by the Commission for the translator broadcast service.

Translator Relay Station

The FCC has provided for the use of 2000 MHz (see Table of Frequencies) microwave relay stations under Part 74 Subpart F of the FCC Rules and Regulations. FCC form 313 is used for applications in this service. These stations are intended to provide an A5F3 microwave feed for translators that do not have adequate signal from the primary broadcast station or another translator.

The relay is designed to pick up an "Off-Air" signal and retransmit it, via a heterodyne process to a distant translator, at microwave frequencies.

Translator Station Design

A. *Site selection.* The site should be chosen such that:

1. It affords a line of sight path to the community to be served.
2. There is adequate primary received signal available for the translator input.
3. There is adequate road access wherever possible.
4. There is reasonable availability of primary power wherever possible.
5. There is adequate space and soil conditions for the needed antenna supporting structure.

B. *Tower height.* Tower height, when added to the site height above the average terrain should be such that when combined with the chosen ERP (effective radiated power) and plotted on the FCC (50, 50) curves provide the desired coverage. It is obviously advantageous to minimize tower height by exploiting available terrain elevation.

C. *Transmitting antenna.* The transmitting antenna should be selected to deliver the necessary gain in those directions where coverage is needed thereby maximizing the signal in the coverage area. Many variations of pattern are available from omnidirectional through highly directive. Wide bandwidth antennas are available for multiplex operation of several translators using only one transmission line and antenna to reduce cost and load on the tower. Both electrical beam tilt and null fill should be available, where needed, by the antenna manufacturer.

Antenna gain when combined with the translator output power determines the ERP and

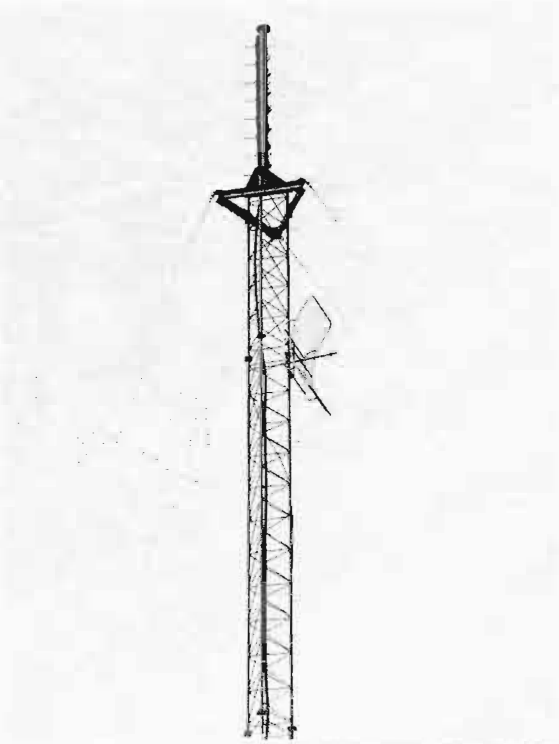


Fig. 3. Close-up view of cylindrical parabolic receive antenna and Bogner slot array transmitting antenna.

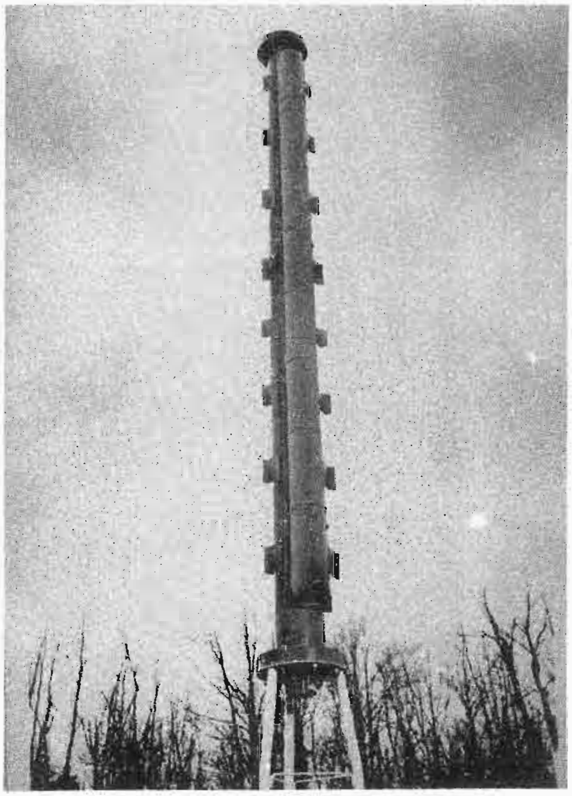
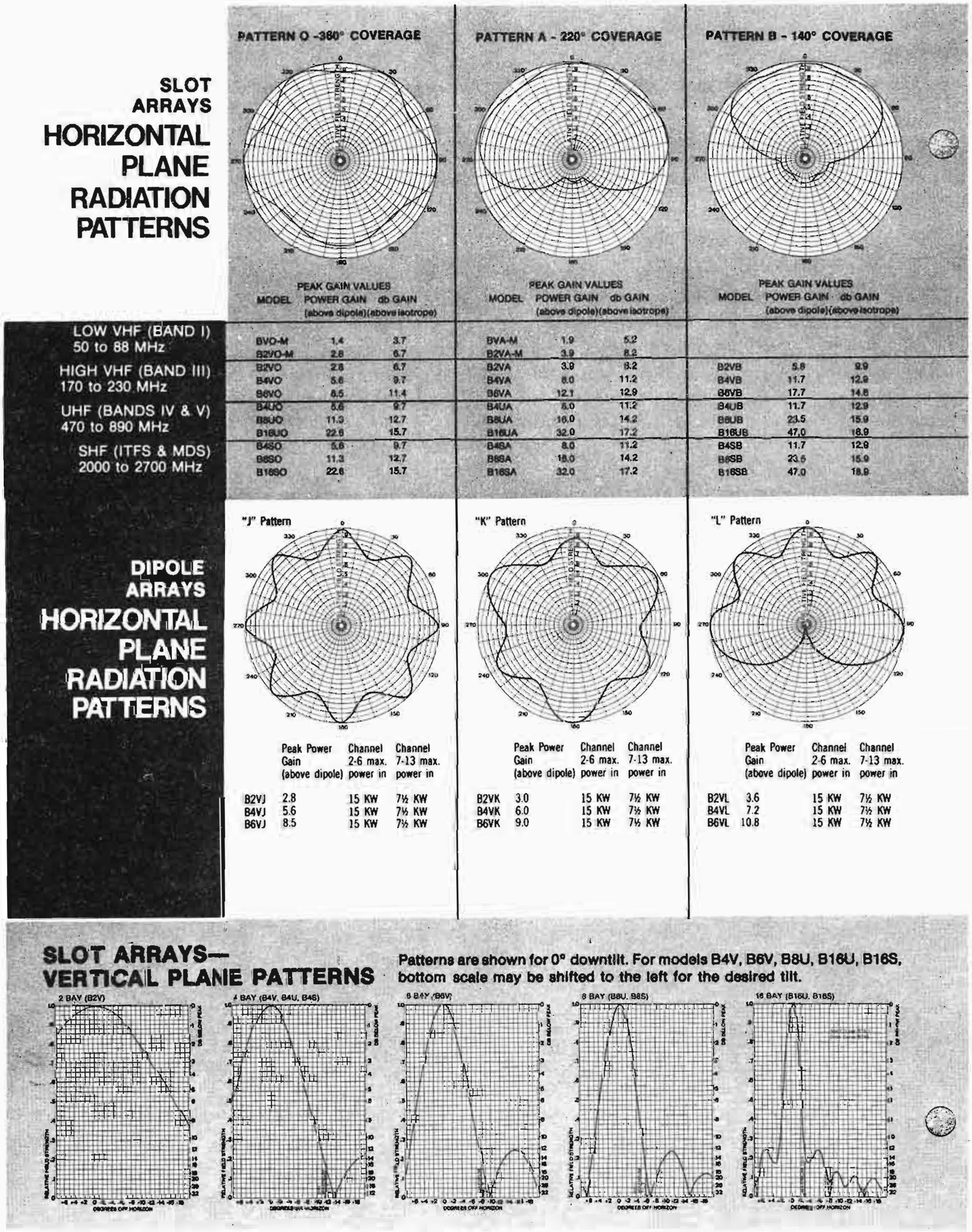


Fig. 4. Detail of Bogner, eight-bay UHF, slot array transmitting antenna.



Band	Pattern O Model	Power Gain (above dipole)	db Gain (above isotrope)	Pattern A Model	Power Gain (above dipole)	db Gain (above isotrope)	Pattern B Model	Power Gain (above dipole)	db Gain (above isotrope)
LOW VHF (BAND I) 50 to 88 MHz	BVO-M	1.4	3.7	BVA-M	1.9	5.2			
	B2VO-M	2.8	6.7	B2VA-M	3.9	8.2			
HIGH VHF (BAND III) 170 to 230 MHz	B2VO	2.8	6.7	B2VA	3.9	8.2	B2VB	5.8	9.9
	B4VO	5.6	9.7	B4VA	8.0	11.2	B4VB	11.7	12.9
	B6VO	8.5	11.4	B6VA	12.1	12.9	B6VB	17.7	14.8
UHF (BANDS IV & V) 470 to 890 MHz	B4UO	5.6	9.7	B4UA	8.0	11.2	B4UB	11.7	12.9
	B8UO	11.3	12.7	B8UA	16.0	14.2	B8UB	23.5	15.9
	B16UO	22.6	15.7	B16UA	32.0	17.2	B16UB	47.0	18.9
SHF (ITFS & MDS) 2000 to 2700 MHz	B4SO	5.6	9.7	B4SA	8.0	11.2	B4SB	11.7	12.9
	B8SO	11.3	12.7	B8SA	16.0	14.2	B8SB	23.5	15.9
	B16SO	22.6	15.7	B16SA	32.0	17.2	B16SB	47.0	18.9

Model	Peak Power Gain (above dipole)	Channel 2-6 max. power in	Channel 7-13 max. power in
B2VJ	2.8	15 KW	7½ KW
B4VJ	5.6	15 KW	7½ KW
B6VJ	8.5	15 KW	7½ KW

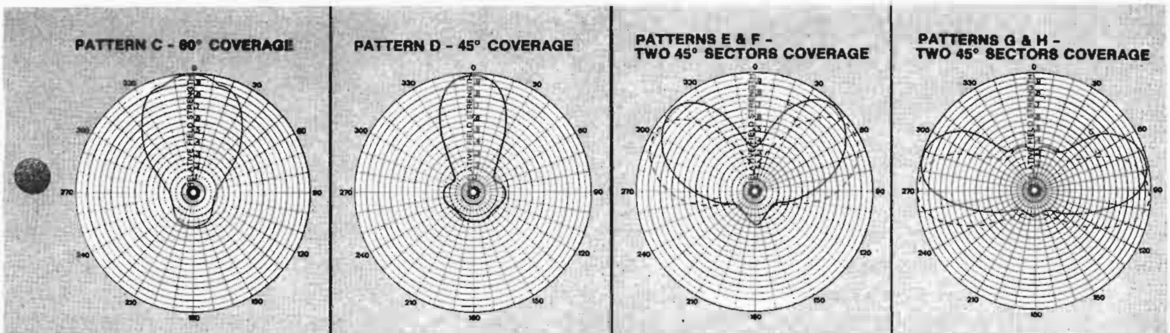
Model	Peak Power Gain (above dipole)	Channel 2-6 max. power in	Channel 7-13 max. power in
B2VK	3.0	15 KW	7½ KW
B4VK	6.0	15 KW	7½ KW
B6VK	9.0	15 KW	7½ KW

Model	Peak Power Gain (above dipole)	Channel 2-6 max. power in	Channel 7-13 max. power in
B2VL	3.6	15 KW	7½ KW
B4VL	7.2	15 KW	7½ KW
B6VL	10.8	15 KW	7½ KW

Fig. 5a shows slot arrays horizontal plane radiation patterns and dipole array horizontal plane radiation patterns.

coverage as determined from the FCC (50, 50) curves for a particular height above average terrain. (See Fig. 2 for coverage estimates.)

Typical maximum VSWR of 1.1 to 1 for single channel operation and 1.3 to 1 for three alternate channels are desirable.



Pattern C – peak gain values

MODEL	POWER GAIN (above dipole)	db GAIN (above isotrope)
B2VC	9.7	12.1
B4VC	19.7	15.1
B6VC	29.8	16.8
B4UC	19.7	15.1
B8UC	39.5	18.1
B16UC	79.0	21.1
B4SC	19.7	15.1
B8SC	39.5	18.1
B16SC	79.0	21.1

Pattern D – peak gain values

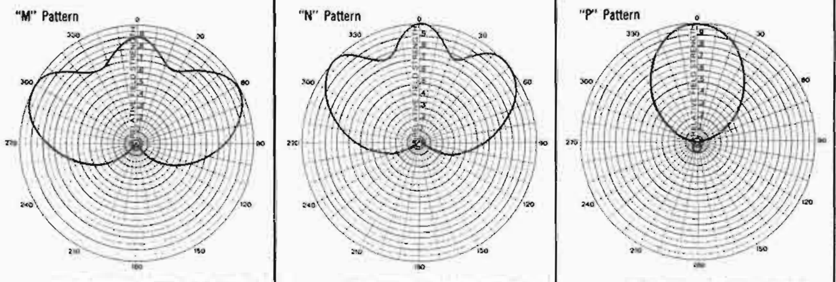
MODEL	POWER GAIN (above dipole)	db GAIN (above isotrope)
B2VD	13.6	13.6
B4VD	27.8	16.6
B6VD	42.5	18.3
B4UD	27.8	16.6
B8UD	55.4	19.6
B16UD	110.9	22.6
B4SD	27.8	16.6
B8SD	55.4	19.6
B16SD	110.9	22.6

Patterns E & F – peak gain values

MODEL	POWER GAIN (above dipole)	db GAIN (above isotrope)
B2VE or F	6.9	10.7
B4VE or F	14.1	13.7
B6VE or F	21.3	15.4
B4UE or F	14.1	13.7
B8UE or F	28.2	16.7
B16UE or F	56.4	19.7
B4SE or F	14.1	13.7
B8SE or F	28.2	16.7
B16SE or F	56.4	19.7

Patterns G & H – peak gain values

MODEL	POWER GAIN (above dipole)	db GAIN (above isotrope)
B2VG or H	6.9	10.7
B4VG or H	14.1	13.7
B6VG or H	21.3	15.4
B4UG or H	14.1	13.7
B8UG or H	28.2	16.7
B16UG or H	56.4	19.7
B4SG or H	14.1	13.7
B8SG or H	28.2	16.7
B16SG or H	56.4	19.7



"M" Pattern

	Peak Power Gain (above dipole)	Channel 2-6 max. power in	Channel 7-13 max. power in
B2VM	5.0	12 KW	6 KW
B4VM	10.0	15 KW	7½ KW
B6VM	15.0	15 KW	7½ KW

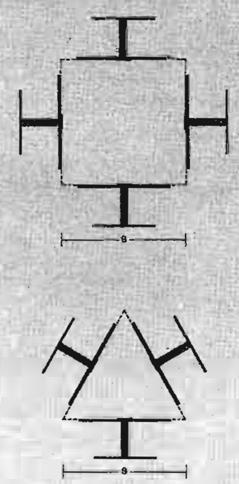
"N" Pattern

	Peak Power Gain (above dipole)	Channel 2-6 max power in	Channel 7-13 max. power in
B2VN	5.4	12 KW	6 KW
B4VN	10.8	15 KW	7½ KW
B6VN	16.2	15 KW	7½ KW

"P" Pattern

	Peak Power Gain (above dipole)	Channel 2-6 max. power in	Channel 7-13 max. power in
BVP	3.2	3 KW	1½ KW
B2VP	7.0	6 KW	3 KW
B4VP	14.0	12 KW	6 KW
B6VP	21.0	15 KW	7½ KW

OMNI-DIRECTIONAL DIPOLE ARRANGEMENTS



Range of S values to obtain performance shown:

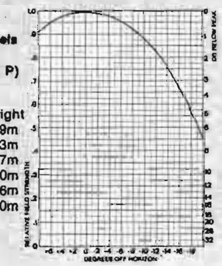
	S (meters)
Ch. 2	3.2 to 3.8
Ch. 3	2.9 to 3.5
Ch. 4	2.6 to 3.2
Ch. 5	2.3 to 2.8
Ch. 6	2.1 to 2.6
Ch. 7-13	.9 to 1.3

See Bogner Dipole data sheet for directive arrangements.

DIPOLE ARRAYS: VERTICAL PLANE PATTERNS AND OVERALL ARRAY HEIGHTS

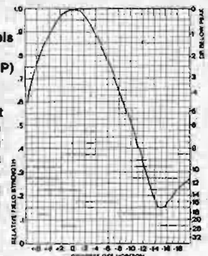
2 Bay Models (B2VJ or K, L, M, N, P)

Ch.	Height
2	6.9m
3	6.3m
4	5.7m
5	5.0m
6	4.6m
7-13	2.0m



4 Bay Models (B4VJ or K, L, M, N, P)

Ch.	Height
2	12.2m
3	11.0m
4	10.1m
5	8.8m
6	8.2m
7-13	3.5m



6 Bay Models (B6VJ, or K, L, M, N, P)

Ch.	Height
2	17.4m
3	15.8m
4	14.4m
5	12.6m
6	11.7m
7-13	5.1m

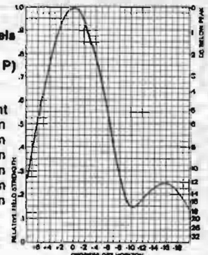


Fig. 5b shows omnidirectional dipole arrangements and dipole arrays: vertical plane patterns and overall array heights.

D. *Transmission line.* Semiflexible transmission lines are preferred for their lower cost and lower installation costs. Modern semiflexible lines offer low VSWR and attenuation.

One-half inch and 7/8 in. lines are most commonly used for VHF transmission and 7/8 in. and 1-5/8 in. lines are used for UHF transmission. The diameter determined by the length of the line. Seven-eights EIA and 1-5/8 EIA connectors are preferred due to their relative immunity to damage during the construction phase. VSWRs of 1.05:1 are available and desirable in the transmission system.

E. *Receiving antenna.* The receiving antenna should be of heavy-duty construction able to withstand icing and wind conditions while providing the necessary gain for a snow free picture. Where high gain narrow beamwidth antennas are contemplated, adequate provisions should be made for supporting the receive antenna to prevent rotation in high wind conditions.

F. *The equipment building.* The building should provide the following:

1. Protection against rain, snow, sun and wind.
2. Adequate filtered air into the building sufficient to match the air flow requirements of the translator.
3. Provision for ducting exhaust hot air outside of the building.
4. Sufficient electrical service for the translator, test equipment lighting and building heater. Electrical service should be adequately grounded and protected against transients (both direct and induced).

Note: Transient operation cannot be overemphasized for high reliability operation.

5. Adequate space for maintenance and storage of spare parts and test equipment.

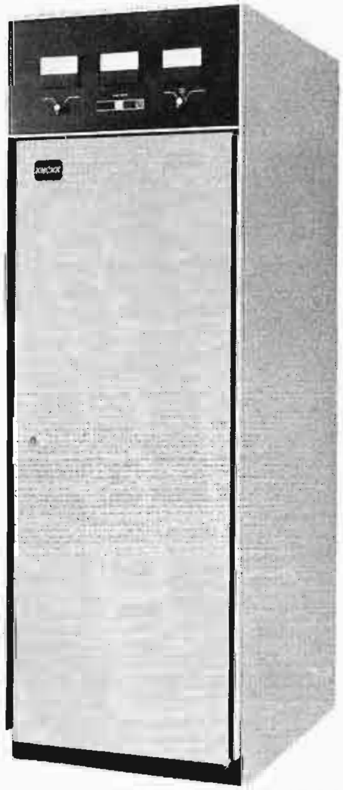


Fig. 6. 100 watt UHF Translator (EMCEE Type TU-100UA).

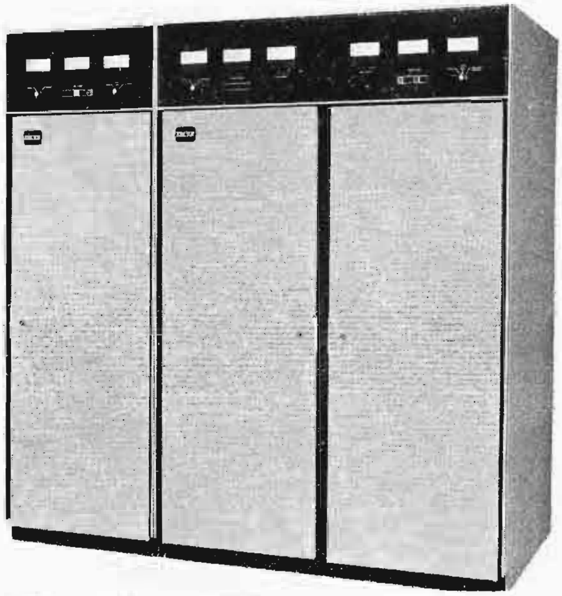


Fig. 7. 1000 watt UHF translator (EMCEE Type TU-1000U).

System Considerations

Once the input and output channels and the site location have been selected, it should be determined if a sufficient input signal level is present. Input levels on the order of 700 microvolts into 75-ohms or more are desirable for best noise

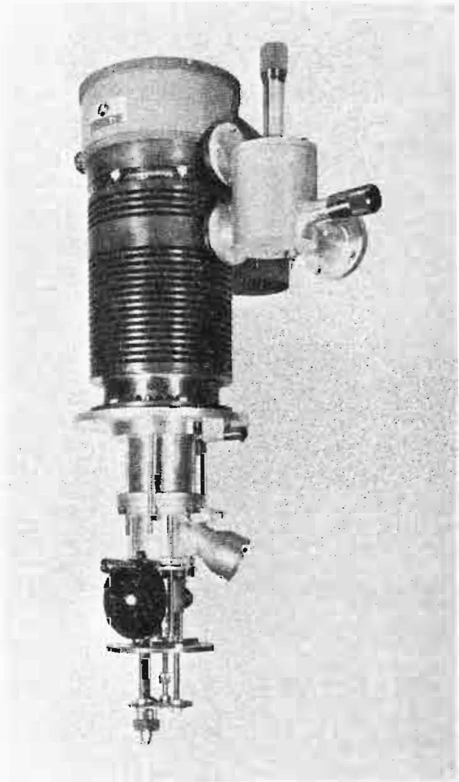


Fig. 8. 1 kilowatt, UHF, cavity (EMCEE).

characteristics but 150 to 200 microvolts will also prove adequate in many cases. Signal-to-noise ratio of the translated output signal is determined by the input S/N and the receiver's noise figure. Of course, if the input signal has a poor S/N due to the noise characteristics of originating transmitter, the translator's output S/N will be poor. However, if the input signal was transmitted with a high S/N, the received signal's S/N will be determined by the effective noise power of the receiver antenna system, and the receiver will degrade the S/N by an amount known as its NOISE FACTOR or its decibel equivalent to Noise Figure. The Noise Figure will typically have a value ranging from 3.0 to 10 dB and is *primarily* dependent on the noise characteristics of the receiver's input circuitry.

Typical practice is to employ a low-noise preamplifier at the receive antenna to minimize losses and optimize noise performance. The overall noise figure of the translator can be found by use of the following formula:

$$F_T = F_1 + \frac{F_2-1}{G_1} + \frac{F_3-1}{G_1G_2}\ldots$$

where F_1 is the noise factor of the preamplifier;
F_2 is the noise factor of the receive line;
F_3 is the noise factor of the receiver;
G_1 is the gain of the preamplifier;
G_2 is the loss of the receive line.

Note: For this case where G_2 is a loss

$$G_2 = \frac{1}{F_2}$$

As can be seen in the following calculation, the overall noise performance of a translator is primarily but not completely determined by the preamplifier's noise figure:

F_1 = 2.5 (4 dB noise figure preamp)
G_1 = 40 (16 dB gain in preamplifier)
F_2 = 4 (6 dB loss in down-lead)
G_2 = 0.25 (6 dB loss in down-lead)
F_3 = 10 (10 dB receiver noise figure)

$$F_T = 2.5 + \frac{4-1}{40} + \frac{10-1}{(0.25)(40)}$$
$$= 2.5 + .075 + .9$$
$$= 3.475$$

converting to decibels

$$10 \log_{10}(3.475) = 5.4 \text{ dB Noise Figure.}$$

The noise figure of a translator can be utilized to determine the S/N of the translated signal by calculating the effective input noise power, determining the input S/N and then reducing the S/N by the Noise Figure.

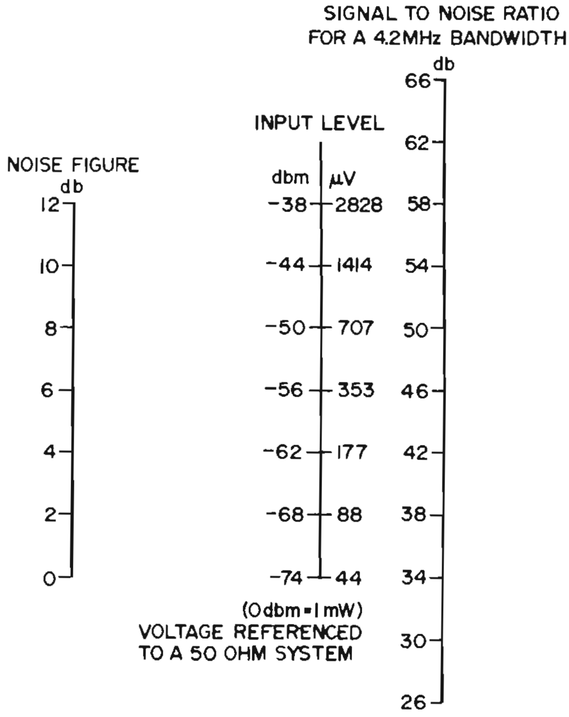


Fig. 9. Noise figure nomogram.

The effective input noise power is

$$N = kTB$$

where k is Boltzmann's constant, B is the bandwidth, and T is the effective temperature in degrees Kelvin.

This formula can also be expressed in its more convenient form:

$$\text{Noise input in dBm} = -198.6 + 10 \log B + 10 \log T$$

As an example, for a receiving system with a noise figure of 5 dB and a 4.2 MHz bandwidth:

$$\text{ENI} = \text{EFF. Noise Input} = -198.6 + 10 \log 4 \times 10^6 + 10 \log 298\,°\text{K} = -107.6 \text{ dBm}$$

If the input signal is 300μv (−57 dBm), the input S/N is:

$$(-57 \text{ dBm}) - (-107.6 \text{ dBm}) = 50.6 \text{ dB}$$

and the output S/N is

$$\frac{S}{N}(\text{in}) - NF = 50.6 \text{ dB} - 5 \text{ dB} = 45.6 \text{ dB}$$

The nomogram (see Fig. 9) of Noise Figure and Input Signal will be useful in determining the output S/N. It assumes a 4.2 MHz bandwidth.

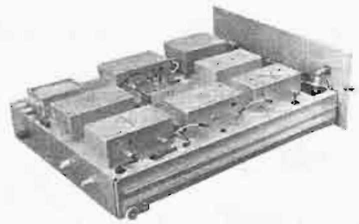


Fig. 10. Receiver drawer assembly showing modular construction.

It should be clearly understood that the S/N of the translator output is also dependent on the input S/N and that cascading of translators will further degrade the S/N of the signal.

This effect can be seen by looking at the equation for Noise Factor of cascaded networks, shown earlier to be:

$$F_T = F_1 + \frac{F_2-1}{G_1} + \frac{F_3-1}{G_1G_2} + \ldots$$

Multihop Translators

If two translators are cascaded, the total system F_T is:

$$F_T = F_1 + \frac{F_2-1}{G_1} + \frac{F_3-1}{G_1G_2}$$

where F_T is the system noise factor;
F_1 is the noise factor of the first translator;
F_2 is the net combination of the antenna gains and the path loss;
F_3 is the noise figure of the second translator;
G_1 is the overall operating gain of the first translator;
G_2 is the net gain of the antennas and path loss (usually a loss).

In general for multihop translator service, it can be shown that, if each translator has the same input level and the same noise figure (a reasonable case in system design), then the overall S/N will degrade by 3 dB each time the number of hops is doubled.

Determining effective radiated power. Selection of the output power is based on several factors, the primary one being the size of the area to be covered. Of course, coverage area, terrain, antenna gain, and tower height are interdependent, and the best approach is to estimate field strengths in the coverage area using the FCC (50, 50) curves and to plot several path profiles to a sample of receive sites. The necessary effective radiated power (ERP) can then be estimated and the necessary antenna pattern can be determined. It may be found in the process that beam tilt and null fill are desirable and these can normally be supplied by the antenna manufacturer.

Typical output powers for translators range from 1 watt to 1000-watts peak visual power. Average aural output power is usually 10 percent of the peak visual output power. Other site restrictions may influence the choice of operating power; e.g., availability of ac power. The combination of antenna gain, line losses, and output power will determine the ERP.

Modern television translators use transistors in all but the highest level amplifier stages. Completely solid-state translators are available up to 100 watts on VHF channels and up to 10 watts on UHF channels. Additionally, units are available for operation from thermoelectric power and storage batteries employing various charging means.

Translator Circuit Description

The general approach used in translators is to receive a VHF or UHF input channel through a low-noise preamplifier-filter combination, mix the signal with a local oscillator in a balanced mixer, filter and amplify the signal at the Intermediate Frequency, and then convert the signal to the desired output channel in another balanced mixer for amplification and retransmission.

Preamplifiers. Since the preamplifier operates in the proximity of the translator output antenna, its input must be well filtered. Normally a multisection bandpass filter of low insertion loss is ahead of the amplifier stage or stages. The preamplifier stages must utilize transistors capable of handling the largest input signals expected while providing the lowest practical noise figure. Either 50 or 75-ohm preamplifiers are available. Power is usually duplexed onto the preamplifier output cable, and is supplied by the receiver or by a separate power supply.

Input cable. The cable interconnecting the preamplifier and the translator need not be of exceptionally low loss type as long as the loss is much less than the gain of the preamplifier.

Receiver. The receiver performs a variety of important functions. It receives the input signal either directly from a receiving antenna or from a preamplifier and provides input selectivity before heterodyne conversion to an IF. This conversion is usually accomplished in a balanced mixer to

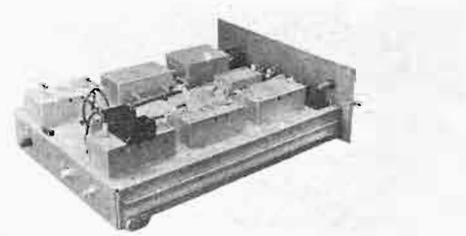


Fig. 11. One watt, UHF upconverter amplifier drawer.

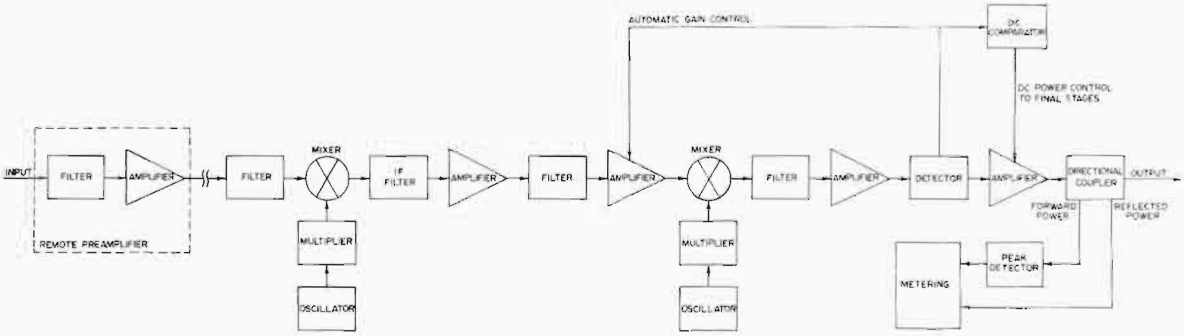


Fig. 12. Typical functional block diagram.

maximize local oscillator isolation. The output of the mixer at IF is filtered to remove undesired mixing products and amplified in a low-noise amplifier stage or stages before further processing. This is necessary to minimize the receiver's input noise figure. Extensive filtering is then usually performed to reject energy outside of the desired channel. This is usually done in a multistaged bandpass filter, and often includes an aural trap for reducing the amount of aural power present if desired. Automatic gain control of the level is then performed. This is done in a broadband cascode current controlled stage which is capable of 50 dB of gain variation. Use of a broadband amplifier insures that the frequency response of the IF strip is not level dependent. The level control voltage or AGC voltage is derived from a following amplifier stage, which is either at the IF output of the receiver in the UHF output translators or at a VHF low level stage in the VHF output translators. The technique utilized in the AGC detector is to sample and peak detect the signal and compare the resulting detected dc voltage to a reference voltage in a high gain comparator/integrator. The reference voltage is manually adjustable and temperature compensated. The output of the comparator is the AGC voltage, and has the effect of continuously adjusting the gain of the gain controlled IF stage to maintain the detected dc voltage, and therefore the output signal, at a constant value independent of input signal level. In the translator, the detection process also involves frequency selective circuitry which is tuned to the visual carrier IF or VHF frequency.

Automatic operation. The AGC voltage is dependent on the presence of an input on visual carrier frequency, and this voltage is compared to a reference voltage in another comparator/integrator which controls a relay. After the reference voltage has been exceeded for the time constant of the integrator, the relay actuates and begins the turn on sequence of the higher level stages of the translator output circuitry.

Up-conversion. The IF signal is converted to the desired output channel by another balanced mixing process and is filtered and amplified.

Amplification.' The amplifier stages in the translator output section must provide linear stable amplification of the signal. Class A amplifier stages are used extensively, even at the 1 kw output level, to insure distortion free performance. Transistor power amplifiers employ negative feedback bias control circuitry to insure reliable performance over a wide temperature range. This normally takes the form of the circuit in Fig. 14.

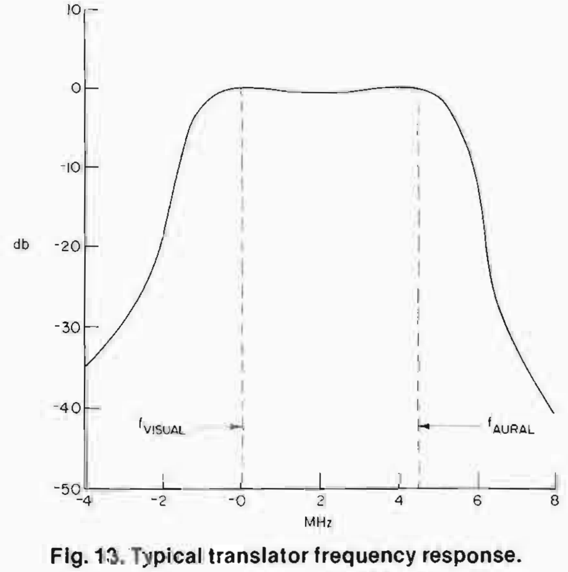


Fig. 13. Typical translator frequency response.

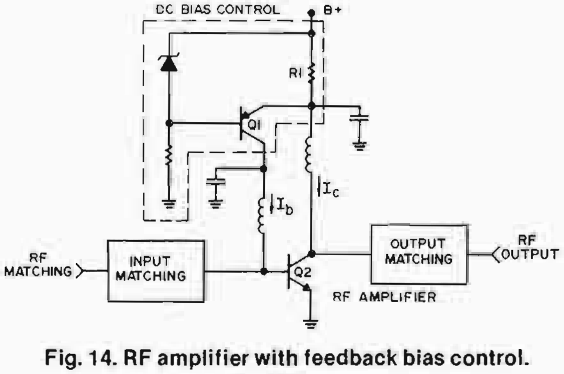


Fig. 14. RF amplifier with feedback bias control.

Bias circuit description. In this circuit the base of the bias control transistor is fixed at a dc voltage below that of B+ by the zener diode. Since the base-emitter drop of the device is reasonably constant, the voltage across the resistor R_1 is constant. This results in a constant current flow through R_1. This current flow is divided between emitter current of Q_1 and collector current of Q_2. Since the emitter current of Q_1 is approximately equal to its collector current and since its collector current is also the base current of Q_2 we have:

$$I_b + I_c = \text{constant}$$

where I_b is Q_2s base current and I_c is Q_2s collector current, but

$$I_b \cong \frac{I_c}{\beta}$$

where β is the transistor beta.

Since β of RF transistors is reasonably high, I_b is relatively small and we have:

$$I_c = \text{constant.}$$

High power amplifications. Higher power solid-state amplifiers often employ parallel amplifiers with appropriate combining circuitry. Eight Class A VHF amplifiers operate in parallel in the EMCEE Model TV-100-VA television translator. A significant advantage of this arrangement is that, in case of a component failure in one of the amplifiers, the remaining amplifiers will continue to operate and the translator will remain on the air.

Vacuum tube amplifiers are used at the 1 kw level and their gain is sufficient to allow a 100 watt translator to be used as the driver. Since these higher power stages must operate reliable at unattended sites, extensive use is made of voltage regulation and protection circuitry. The EMCEE Model TOA-1000A UHF 1 kw amplifier utilizes a Thompson CSF TH-331 ceramic tetrode in a double-tuned coaxial cavity. This tube operates Class A for optimum linearity and requires only 60 watts of drive. Forced air cooling is employed and fault detection circuitry with five automatic reset steps protects the tube and power supplies.

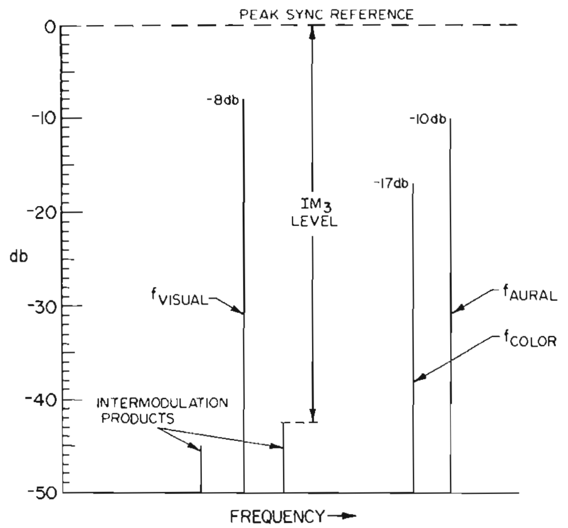


Fig. 15. Three tone intermodulation test.

Monitoring. Measurement of important voltages and output power is done on VHF and UHF amplifiers. Peak visual output power, combined visual and aural power, and reflected power is normally monitored. In the solid-state amplifiers emitter ballasted transistors are employed which are capable of operating under high output VSWR conditions. Higher power tube amplifiers employ VSWR sensing circuitry to protect the tube from high reflected power conditions.

Distortions

Several forms of distortion can be seen on a signal after passage through a television translator. An understanding of these distortions and their respective causes will aid in proper adjustment, operation, and planning.

Linearity distortions. Since all amplifiers have some degree of nonlinearity in their transfer function, some amplitude and phase distortion will occur on a translated signal. Classic video distortions such as differential gain, differential phase, and sync compression normally occur in linear amplifiers as they are driven to higher powers. Since most translators employ common visual aural amplification in final stages, intermodulation distortion is present to some extent. Modern television translators are designed to handle color television signals, and maintain extremely low distortion products. As in the case of noise addition in cascaded translators, distortion levels are also affected by cascading translators, and this often places a new constraint on the tolerable level of distortion in an individual translator. It has been found, for instance, that the 920-kHz intermodulation distortion level generated on one translâtor is often in phase with the intermodulation level generated in a second, cascaded translator.

Since reduction in output power usually results in substantial reduction in distortion products, operation of cascaded translators below their rated power should be considered.

Delay distortions. Translators normally have steep frequency response skirts which result in phase variations near the passband edge. Additionally, the ripple in the passband response is related to the phase variation versus frequency characteristics.

The derivative of the phase with respect to frequency is time delay and can be measured to some reasonable accuracy by observing the waveform of the demodulated 2T and 12.5T pulse. (See Figs. 16 and 17.)

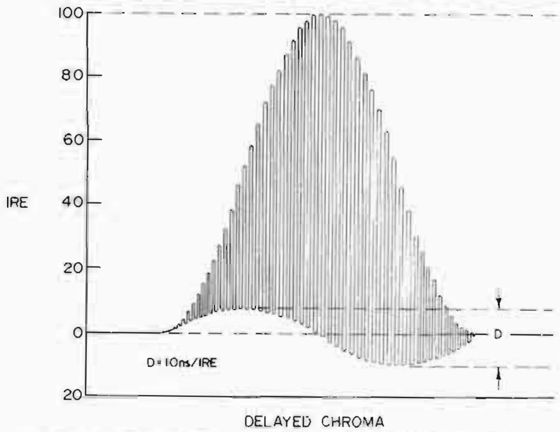


Fig. 16. Delay distortion of a 3.58 MHz modulated 12.5T pulse.

Minimizing delay distortion. Adjusting the frequency response of a translator for a reasonable "flat" bandpass characteristic will normally minimize delay variations. Delay distortions are additive in nature and the cascading of translators will tend to increase the amplitude of the delay variations across the television channel.

Conversion Accuracy

Another consideration in cascaded translators is frequency accuracy. Use of oven controlled oscillators in all translators in a system will tend to maintain conversion accuracy. Since crystal aging tends to diminish after the first year of operation, it is wise to reset the oscillator frequency of new translators several times during the first year of operation then only as needed to multihop systems. Phase lock techniques have been developed to maintain frequency accuracy in 2 GHz translator relay systems.

The translator has, in recent years, proved itself as a valuable tool to the broadcaster. It offers the broadcaster the opportunity to fill in coverage "Holes" as a "Crest Effective" alternative to CATV.

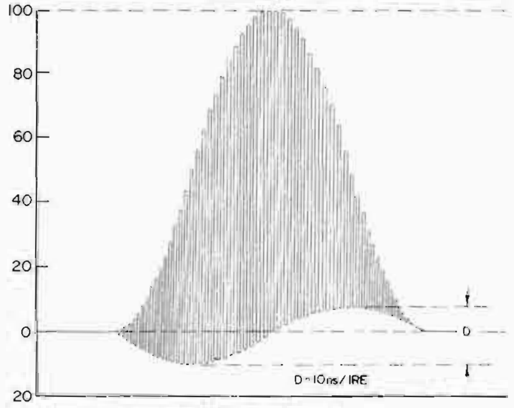


Fig. 17. Delay distortion of a 3.58 MHz modulated 12.5T pulse.

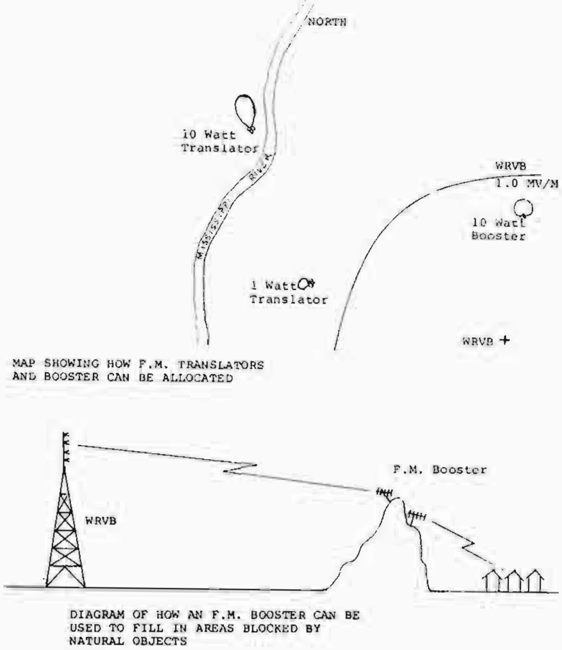


Fig. 18. FM translators and boosters.

FM TRANSLATORS/FM BOOSTERS

FM Translators

Unlike TV translators, FM translators have only been legal in the United States since 1970. But, in Haiti, Missionary Dave Hartt had pioneered and had utilized FM translators since the early 1960s.

Through the efforts of FM Broadcasters, the FCC was persuaded that a need for low cost repeaters did exist in the FM aural service. Just as with TV, FM being a line-of-sight transmission, poor service was being rendered to remote areas as well as to areas affected by hilly or mountainous terrain (Fig. 18). In many ways the FCC attempted to duplicate the TV Translator Rules, but the two services are not the same. The FM translator may well be the last new electronic broadcast service ever granted by the FCC.

An FM translator is really a combination of an FM receiver coupled to an FM transmitter, being designed to extend the coverage of the originating station by amplification of the primary signal and rebroadcasting same (Fig. 19). The receiver part of an FM translator receives the signal transmitted by the FM broadcast station. It then changes the frequency of the incoming signal down to some intermediate frequency. The IF signal is then fed to the transmitter section of the FM translator. In the case of TV translators, the FCC found that it is more practical to employ a different output than input

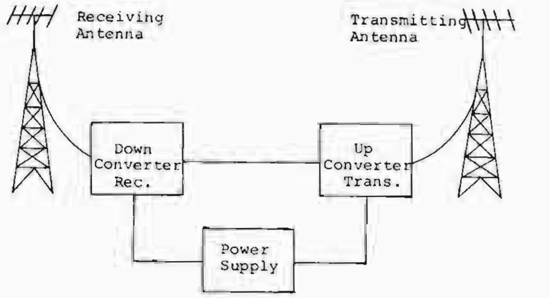


Fig. 19. FM translator block diagram.

frequency to avoid feedback problems. The transmitter section of the translator then converts the IF signal back up to the FM band. The FM Booster differs from the FM Translator in that its input and output frequencies are identical.

FCC Rules Covering FM Translators/FM Boosters

Any FM broadcaster, licensee, civil government, association or individual is eligible to apply for a license to erect and own an FM translator. The basic concerns are that the applicant be legally and financially qualified.

An FM translator is intended to serve the general public and is not intended as a vehicle to relay programs or special services from one station to another. Operations are subject to the FCC rules, as enumerated in Subpart L, Section 74.1201 thru 74.1284. Below is a brief synopsis of these rules.

1. Licensing Policies

a. FM translators may be used only for the purpose of retransmitting the signals of an FM station or another FM translator.

b. Transmissions are intended for direct reception by the general public. Any other use shall be incidental thereto.

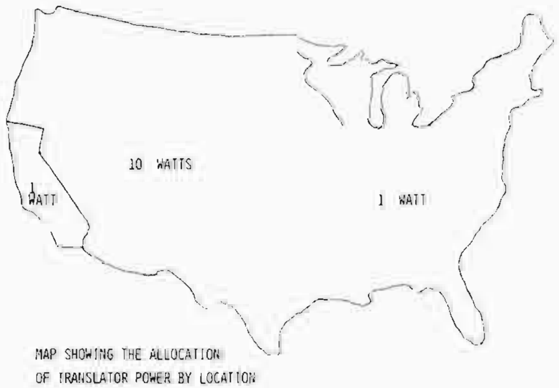


Fig. 20. US map of power limits.

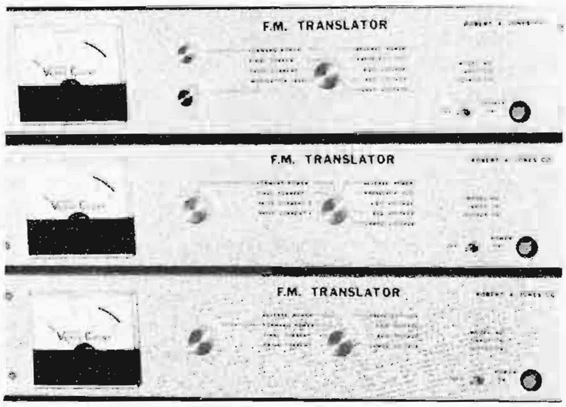


Fig. 21. 10-watt translator (RA Jones).

c. The technical operation of a translator shall not deliberately alter the characteristics of the retransmitted FM signal including stereo and SCA.

d. FM Booster stations will provide a means of extending service to areas of low signal intensity within the primary station's predicted 1.0 mv/m contour.

2. Eligibility and Licensing

a. An FM translator license will be issued to any qualified individual, organization, FM licensee, or civic governmental body.

b. More than one FM translator may be licensed to the same applicant, even though they may serve substantially the same area.

c. FM translators will not be licensed to FM licensees if they are located beyond their predicted 1.0 mv/m contour and within the 1.0 mv/m contour of another FM station.

d. An FM booster will be licensed only to the primary FM broadcast station.

e. Unattended operation is permitted, providing certain requirements are met.

f. Power limitations are 10 watts except FM translators serving areas east of the Mississippi River and in Zone 1-A. These will be limited to 1 watt.

g. No limit is placed upon the effective radiated power or antenna polarity that may be used. There is no requirement that horizontal polarity must be used, as there is with regular FM stations.

h. Only FCC type accepted equipment will be licensed.

3. Other Requirements

a. Written permission must be obtained from the FM station to be rebroadcast.

b. The FM broadcaster may contribute financially, may render technical advice or maintenance to a translator station operated by another licensee. But, he cannot provide technical assistance or provide financial help to cover the costs of a license application, or the purchase and installation of equipment.

c. An unlicensed operator may observe the operation of an unattended FM translator. An attended FM translator shall be operated by a person holding at least a valid restricted radio telephone operator permit.

d. Local origination of spot announcements is permitted, as long as they do not exceed 30 secs. in any one hour period. Aural material transmitted shall be limited to solicitation of contributions to defray expenses. A contributor may advertise his own business or service.

e. Antennas and transmission lines are not FCC type accepted. Translators, boosters, and multiple amplifiers are FCC type accepted.

f. Station identification may be given by the primary FM station, three times per day, with the exception that translators of 1.0 watt or less require no identification. Ten watt translators can employ mechanical identification. Boosters require no identification.

g. Rebroadcasting of an FM station is not permitted without written consent. Translators are limited to the retransmission of a single FM broadcast station and may not retransmit other stations of other classes.

Design Consideration of an FM Translator Station

Service Area

A study should be undertaken of the area to be served. This should include population data, available FM service from other broadcast stations, and a topographic study of the area. It is wise to also obtain topographic maps of the area between the originating station and the translator site.

Site Consideration

It is important to carefully consider the selection of a potential FM translator site. The most important factors are these:

1. The site should be as close as possible to the intended service area.

2. Where natural elevations such as hills or mountains exist, advantage should be taken of them. Advantage can also be taken of existing towers, tall buildings, grain elevators, etc., as possible FM translator sites.

3. The proposed site should have a clear path back to the originating station. Where possible, it is recommended that 6/10 first Fresnel Zone clearance be achieved.

The selection of an ideal site is not always possible and often compromise is necessary. In the consideration of the various site availabilities, they should be visited to ascertain ease of access, right of way, existence of all weather roads, electric power, proximity of other radio towers or services, etc. Other considerations are the necessity of clearing trees from the site, soil problems associated with tower or building erection, and other environmental factors. Sites where boulders have to be moved, guy anchors blasted in solid rock or swampy areas, may prove to be uneconomical sites.

The next step, once the site is selected, is to determine the path clearance back to the primary station. By use of a 4/3 earth "profile" graph paper and topographic maps a profile can be plotted of the path between the primary stations' tower and the FM translator site. The reason we employ 4/3's earth radius for these graphs is to account for normal atmospheric bending of the FM signal. (Fig. 22)

The height of the originating stations' transmitting antenna is drawn on the profile graph at zero miles. This is normally the left-hand edge of the graph. By drawing a straight line from the center of radiation of the originating stations' antenna to the FM translator site, the various path obstructions can readily be seen. In order to calculate the first Fresnel Zone radius, the following formula can be used:

$$R_1 = 2280 \left(\frac{d_1 \, d_2}{(d_1 + d_2)\, F} \right)^{1/2} \qquad [1]$$

Where R_1 = first Fresnel Zone radius in feet
d_1 = distance in miles, obstruction to FM station
d_2 = distance in miles, obstruction to FM translator
F = signal frequency in MHz

The minimum path clearance for satisfactory results should be at least 6/10 R_1. It should not exceed 13/10 R_1, for within this range one can expect the signal received at the translator to be equal to a free space path. Keep in mind that extra clearance must be allowed for trees, buildings, etc., at each path obstruction point. Usually a figure of +50 ft. will account for such objects.

If the above study reveals that inadequate path clearance exists to the FM translator site; then the receiving antenna can be elevated by installing it on a tower, high enough to overcome the path obstructions. This height can be determined from the path profile plot. In some cases it is impossible to elevate the receiving antenna high enough to achieve 6/10 R_1 clearance. Lower heights will result in some additive loss in the received signal. These losses

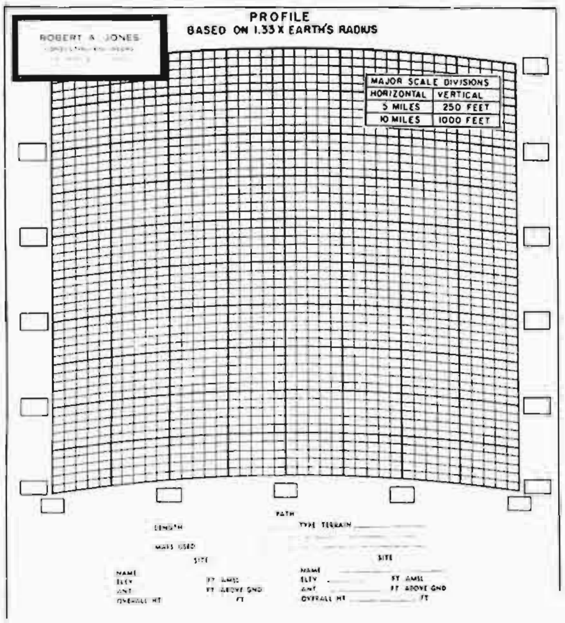


Fig. 22. 4/3 Earth profile graph.

will increase from 0 dB at 6/10 R_1 to —19 dB at 0/10 R_1.

It is often possible to receive a satisfactory FM signal under conditions of less than adequate path clearance. This is particularly true when the primary station employs very high ERP. These "over the horizon" signals are more susceptible to fading, and may be dependent upon weather conditions. FM reception is not affected by selective fading as is TV reception. For this reason several FM translators are in use today having no path clearance. This results from a propagation phenomenon termed the "knife edge" effect.

The next step is to study the path clearance from the translator site to the area to be served. This analysis should be undertaken in the same fashion as the above primary station—translator site path studies. Because normally one chooses to serve a wide area, rather than just a single path, it is best to consider several path profiles, at say 30° to 45° intervals. Care should be taken if special terrain features are present. The necessary minimum height of the transmitting FM translator antenna may be selected from the results of these profiles. The FCC has not established service area contours for translators nor defined minimum or maximum reception requirements.

The proposed translator transmitting antenna should be high enough to clear all objects which would be illuminated in the immediate foreground, such as trees, houses, etc.

As with the erection of any tower, notice of applicable FAA rules or local zoning requirements should be met.

Output Channel Selection

The FCC rules call for the output channel to be one of the 20 Class "A" channels. There is an exception if the originating station is an educational FM station operating in the spectrum between Channel 201 and 220. Then the translator applicant has a choice. He can select either a Class "A" channel or one of the educational channels as his output channel.

Those FM translator stations located east of the Mississippi River or in Zone I-A (southern California) are limited to 1 watt output power. Ten watts of power are allowed west of the Mississippi River, in Alaska, and Hawaii.

In selecting the output channel, engineering judgment must be used to pick a channel that is clear. That is, one that is not presently in use within 45-65 miles cochannel, or three channels either side of the desired class "A." In some parts of the country there is actually a shortage of class "A" channels. In the absence of a usable Class "A" channel, the FCC can grant a waiver to utilize a Class "B" or "C" channel. Care should also be taken to select an output channel that is not 10.6 - 10.8 MHz removed in frequency from the input channel. This of course would result in IF interference.

Output Requirements

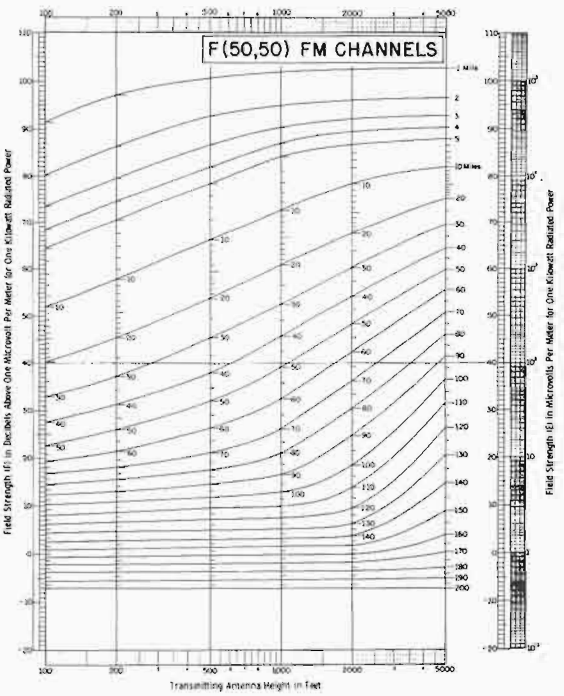
The translator power output when multiplied by the antenna gain, less the transmission line attenuation, yields the effective radiated power (ERP). Knowledge of the output power is necessary in order to calculate the effective coverage of the translator.

There have been two common methods of determining the true coverage to be expected. The first method depends upon use of the FCC's *F*(50, 50) curves. These show the estimated field strength exceeded at 50 percent of the receiver locations for a minimum of 50 percent of the time, based upon an assumed receiving antenna height of 30 feet. The assumed transmitter ERP is 1,000 watts, for this FCC curve. (Fig. 23)

The next logical question is what is a minimum usable FM field intensity for acceptable coverage? In the FM rules the FCC has stated that primary stations are limited to their 1.0 mv/m contour (60 dBu). Experience has shown that with FM a signal for 34-40 dBu will achieve satisfactory reception, even with a stereo signal. If the FM listener has an outside antenna, having some "gain," he could very likely receive a 20 dBu signal and enjoy good receptive quality. Since almost all FM translators are located in small cities or remote areas, where there is a scarcity of outside FM signals, what would otherwise be considered a weak signal is accepted by the listener as a strong signal.

To utilize the FCC $F(50, 50)$ curve you must first determine the transmitting antenna height above average terrain, between 2 and 10 miles. This would be from the FM translator site along the above path profiles. Keeping in mind that the $F(50, 50)$ curve is based upon 1 kw ERP, for radiated powers other than 1 kw, the curves should be scaled up or down. This is borne out by the following example.

Assume the area to be served extends from 5 to 15 miles from the translator site, and that the site is on a hill 1,000 feet above mean sea level. The average elevation, as determined from a path profile thru the desired listening area for 2 to 10 miles, shows 600 ft. above mean sea level. This yields an FM translator antenna height of 400 ft. above the average elevation. Using the curves of Fig. 23, the distance to the 34 dBu contour for 1 kw ERP would be 42 miles. Let's assume we have a 10 watt FM translator with an antenna gain of 10, or 100 watts ERP: we then look up a chart value of 44 dBu (34 + 10 dB) at height of 400 ft., to find the correct distance to the 34 dBu contour. In this example we could expect to serve to a distance of 29 miles. If we encountered a situation where the ERP was not adequate to serve all the desired area, then the ERP required can be determined from the chart. Once having determined the ERP it is then necessary to work back to determine the translator power output and the antenna gain. The following generalized formula can be used:



F.M. CHANNELS
ESTIMATED FIELD STRENGTH EXCEEDED AT 50 PERCENT OF THE POTENTIAL RECEIVER LOCATIONS FOR AT LEAST 50 PERCENT OF THE TIME AT A RECEIVING ANTENNA HEIGHT OF 30 FEET

Fig. 23. FCC (50,50) graphs.

$$ERP = dBw + G - L \quad [2]$$

Where ERP = dB above 1 watt
dBw = translator power output in dB above 1 watt
G = transmitting antenna gain in dB
L = transmission line loss in dB

Knowing any of the above figures one can easily calculate the others.

A second method of estimating the true coverage of a given FM translator is to calculate the point-to-point signal, i.e., path losses. For this method one assumes at least 6/10 first Fresnel Zone radius clearance. The following general equation can be employed to calculate the signal available at the listener's receiving antenna.[1]

$$P_i = ERP - (36.6 + 20 \operatorname{Log} F + 20 \operatorname{Log} D) \quad [3]$$

Where P_i = Power at an isotropic receiving antenna in dB below 1 watt
ERP = is in dB above 1 watt
F = frequency in MHz
D = path length in miles

As an example let's assume from the previous problem the distance is 15 miles at a frequency of 100 MHz, and the ERP is 100 watts (+20 dBw).

$$P_1 = +20 - (36.6 + 20 \operatorname{Log} + 20 \operatorname{Log} 15)$$

According to this calculation the received power at 15 miles will be -80.1 dBw. This will exceed the desired level of 34 dBu by +2.9 dB.

The $F(50,50)$ curves are generally considered to be conservative. They allow for some nonideal propagation paths. In areas where outdoor receiving antennas are used with low-loss lead-in lines from the antenna to the receiver, more optimistic coverage will prevail.

Receiving Antenna Requirements

In order to determine the necessary receiving antenna gain, the following standard equation may be employed:

[1]At 100 MHz a signal level of 34 dBu is represented by -83.0 dB below 1.0 watt of power available from an isotropic receiving antenna.

$$G_R = \text{ERP}_M - (36.6 + 20 \text{ Log } F + 20 \text{ Log } D) - f - L_r \quad [4]$$

Where G_R = the receiving antenna gain
dBw_r = the translator power below 1 watt to yield a satisfactory signal to noise ratio
L_r = lead-in line loss in dB
ERP_M = ERP of originating station in dB above 1 watt
F = frequency in MHz
D = path length in miles
f = loss in dB due to inadequate path clearance.

An ideal signal to noise factor of 40 dB would require -92 dBw_r or 178 mv across 50 ohms, with a system noise factor of 6 dB.

The system noise factor is the ideal noise factor of a translator receiver, modified by the effective antenna temperature, galactic noise, and other extra-terrestrial noise.

The use of Eq. 4 is illustrated as follows. Assume an originating station operates at 100 MHz with an ERP of 100 kw and the distance from the FM translator site is 90 miles. Assume that the first Fresnel Zone clearance is calculated from Eq. 1, and that an additional "f" loss of 2 dB can be expected. Assume also a system noise factor of 6 dB and a lead-in line loss of 1 dB. If a 40 dB signal to noise ratio is required, the following calculation results:

$$G_R = 10 \text{ Log } (100{,}000) - (36.6 + 20 \text{ Log } 100 + 20 \text{ Log } 90) - 2 - 1 + 92$$

This yields a required receiving antenna gain of +23.3 dB.

Design Considerations for an FM Booster Station

Basically all that has been said which pertains to FM translators also applies equally to FM boosters. There is one major new consideration. The receiving antenna and transmitting antenna must be physically separated by at least 300 ft. The FM translator by contrast can utilize the same tower for both antennas.

The booster antennas should take advantage of natural features to aid signal isolation. For example antennas can be erected on opposite sides of a mountain peak or a large building. Other standard techniques include cross-polarization of the two antennas and "nulling" of the two antennas. One should achieve at least 60 dB of isolation between antennas.

Translator-Booster Antennas

General Characteristics

Antenna Gain. This is commonly defined as the gain over an isotropic antenna. Directional antennas exhibit gain by virtue of their ability to concentrate the available power in a particular direction.

Horizontal Beam Width. In all cases except those using a nondirectional antenna, this is a measure of the angle encompassed between the half-power points of the major lobe. These are defined as those points at which the radiated power is one-half of that at the bearing of the maximum signal. This is 70.7 percent of the field intensity, when expressed in voltage, in lieu of power.

Nondirectional antennas, while they are assumed to be perfectly circular, are not. The variation from a perfect circle is expressed as so many plus or minus dB of circularity.

Vertical Beam Width. This is expressed as the angle encompassed between the elevations at which one-half power is radiated. As with the horizontal beam width, this is 70.7 percent of the maximum field radiated. It is only important to know the angle below the horizon where the one-half power point occurs, for it is this angle which can affect satisfactory reception to nearby receiving sites. If a directional antenna has very high gain, or a nondirectional antenna has reasonable gain, this will result in improper coverage to nearby receiving sites. They will be overshadowed.

Input Impedance-VSWR. The output stage of a typical FM translator is designed to deliver power to a resistance load of 70-ohms, having negligible reactance.

Regardless of how long the transmission line may be, if it has the same characteristic impedance and is matched at the antenna end, it will

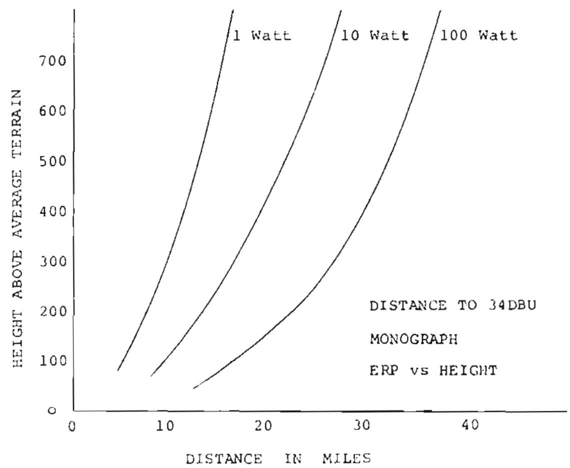


Fig. 24. Monograph of coverage.

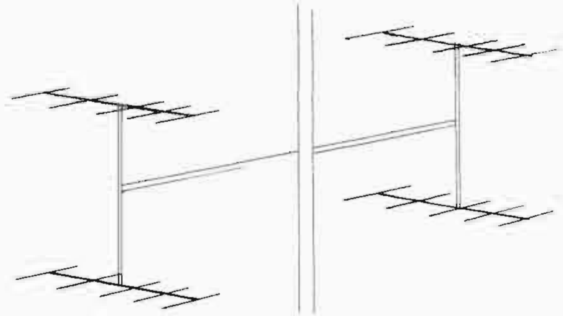


Fig. 25. Antenna stacking.

accept the full power. In the event the antenna does not perfectly match the impedance of the transmission line, standing waves will appear. These will not normally affect an FM signal unless it is stereo or SCA. For example, a line that has a VSWR of 2:1, or impedance, of either one-half or twice the correct impedance, with varying amounts of reactance, depending upon the line length. This will effect the linearity and efficiency of the final amplifier.

Power Capability. Professional grade FM translator antennas are designed to accept power levels up to 100 watts. Type N coaxial fittings are commonly used for connecting to transmission lines.

Antenna Types—Transmitting. FM translator and FM booster antennas tend to be of the type which use reflectors, driven elements, and directors commonly known as Yagi antenna beams. These are used both singly, in pairs stacked vertically or horizontally, or as quads. Nondirectional types consist of simple horizontal ring antennas which have from one to four bays stacked vertically. This type of antenna produces a nondirectional signal.

The Yagi antenna has the advantage of a narrow band width. This helps discriminate against unwanted signals. The Yagi generally can provide gains of 10 dB or more over an isotropic, depending upon the number of elements. By exciting two Yagis, in phase, the gain is increased by 3 dB. Every time the number of elements is doubled, the gain is increased by 3 dB, as shown in Table 1.

TABLE 1

Number of Yagis	dB Gain
Single yagi	10
Two yagis	13
Four yagis	16
Eight yagis	19
Sixteen yagis	22

The horizontal beam width of a single Yagi antenna is approximately 30° between the one-half power points. Increasing the number of Yagis decreases this beam width. In the event this beam width needs to be increased beyond 30°, this is accomplished by skewing two Yagi antennas. Care must be taken to be sure the proper phase is maintained. Otherwise holes may occur in the coverage pattern, due to signal cancellation.

The FCC has permitted dual polarity. This is accomplished by constructing a Yagi with elements in both planes on the same boom, or by coupling two Yagis, one oriented horizontally and the other vertically, in close proximity.

Antenna Types—Receiving. The foregoing discussion on transmitting type antennas applies equally to receiving antennas. The formation of multiple arrays is desirable, since high directivity is desired. This is to help discriminate against unwanted signals.

Vertical Stacking—the resulting horizontal directivity is unaffected, but the vertical beam width is decreased. For receiving sites close to the ground, as well as ones where the received signal is from beyond the horizon, some advantage will occur from "space diversity." If the incoming signal is exhibiting layering, one or more of the antennas may receive a relatively strong signal while the other may not. Thus they will tend to average out the received signal.

Horizontal Stacking—in this case the vertical directivity is unchanged while the horizontal beam width is decreased. By proper spacing cancellation of incoming signals along any one bearing can occur, with the gain reduced to almost zero. This phenomenon can be useful in minimizing unwanted interfering signals. Fig. 26 shows how a null is produced along a bearing A. The Equation is:

$$D = N \frac{\lambda}{2 \sin A} \qquad [5]$$

Where D = Distance in feet between Yagis
λ = Wavelength in feet
N = Any odd number.

For example, assume an interfering FM station operates at 100 MHz, bears 30° from the desired FM signal, and let "N" be three. This calculates to an antenna spacing of 29.5 ft. This is a practical spacing. Keep in mind that these offsets can be used to cancel adjacent channel signals or cochannel signals. To achieve the maximum null depth, vernier adjustments must be added. These are in the form of line stretchers to one of the feed lines, to allow phase adjustment, plus attenuators to each line to allow for amplitude adjustment.

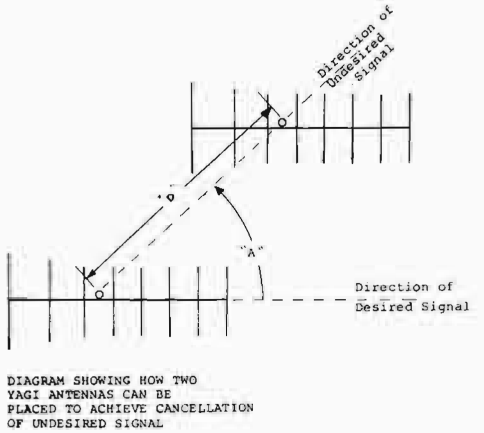


Fig. 26. Antenna offsets.

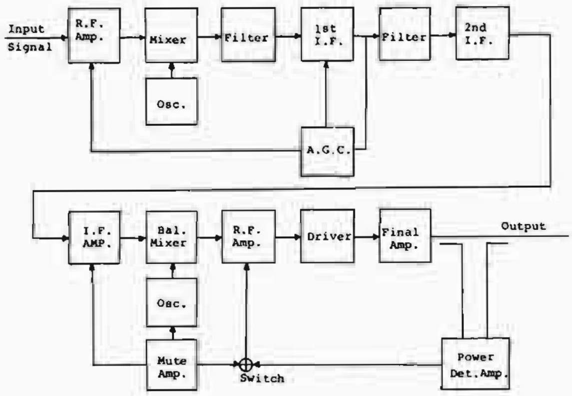


Fig. 27. Basic block diagram, translator.

Transmission Lines

It is best to reduce losses in both receiving and transmitting transmission lines as much as possible. This is normally done by employing flexible coaxial cables of RG-8 or RG-11 types. These are quite good up to 100 ft. or so. Beyond these lengths it is more efficient to use larger diameter coaxial cables with either foam or air dielectric. For any given diameter the air dielectric has the lowest loss. Air dielectric has the disadvantage of requiring pressurization with dry gas to avoid moisture and corrosion.

Losses in typical cables at 100 MHz are:

TABLE 2

Type	Loss/100 ft.
RG-8/μ(Foam)	1.80 dB
RG-11/μ(Foam)	1.50 dB
7/8 Foam	0.435 dB
7/8 Air	0.370 dB
1-5/8 Foam	0.305 dB
1-5/8 Air	0.207 dB

FM Translator Circuit Description

General

In FM translators there were no early beginnings or changes in the basic approach as with TV translators. All FM translators employ single conversion with intermediate frequencies of 10.7 MHz, and consist of three basic parts. These are the receiver-down converter, the transmitter-up converter, and the power supply.

Basic Circuit

Fig. 27 shows a block diagram of a 10 watt translator.

Receiver-Down Converter. The received signal is amplified, then mixed with the down converter oscillator and converted to an intermediate frequency of 10.7 MHz. The down oscillator operates below the incoming frequency by the difference of the IF frequency. It is then processed through a highly selective lumped constant filter, amplified, filtered again, and amplified again before being coupled to the up converter transmitter.

Up Converter-Transmitter. The IF signal passed through two IF stages, is then coupled to a balanced mixer, where it is mixed with the up oscillator output and heterodyned to the transmitting frequency. This sum frequency is then amplified through three stages before being applied to the final 10 watt amplifier. The signal then passes through the output coupling where the required band pass is achieved and spurious signals are eliminated. The directional coupler enables front panel measurement of forward power and reverse power.

Automatic Gain Control is achieved by virtue of a double loop. The AGC signal in the receiver is coupled from the AGC detector to both the RF and IF amplifiers to control variations in received signal levels. The second AGC amplifier is in the transmitter. Its output is coupled to the muting switch which in turn shuts off the drive to the output stage when a loss of incoming signal occurs.

An output from the reflectometer circuit is coupled through an IC amplifier to regulate the bias applied to the driver stage. This method is capable of regulating power output within ± 1 percent. The reflectower also couples a signal through an IC amplifier to provide protection against an open or short circuit in the load. This is accomplished by reducing the drive to the final which in turn alters the bias. This in effect turns down the power when a large mismatch load is present. The power supply provides a low dc voltage. It remains constantly energized, even though the FM translator may be in the "off" mode. The down-converter receiver, front end local oscillators and IF amplifier remain powered, while the up-converter transmitter, high level output circuits are deenergized until turned on by the muting circuit when an incoming signal appears. The voltage output of the power supply is regulated to maintain constant operation, at 18 v.

FM Booster Circuit Diagram

There are only two major differences between the circuit employed in a booster and that of a translator. One is the fact that there is only one oscillator. Since in a booster the incoming signal is at the same frequency as the output, there is no need for more than one oscillator. The crystal is mounted in the down-converter receiver module. The oscillator signal is coupled to the up-converter transmitter by a coax cable.

The second major difference is that the input and output modules are not mounted in the same chassis. Our experiments, with early designs, showed that to achieve the separation required between input and output one must physically locate these two modules 300 ft. apart. There is no other way to keep the output from "talking" back to the input unless one employs physical separation. The IF signal is coupled between the two modules by a 300 ft. plus length of coaxial cable.

The output circuit and tune-up procedure is the same as with the translator.

Test Equipment and Alignment

For on-site adjustments the following test equipment is necessary:

1. Test meter (V.O.M.), Simpson 260 or equivalent
2. Signal Generator, Boonton 210A or equivalent
3. Alignment tools and non-magnetic screw drivers

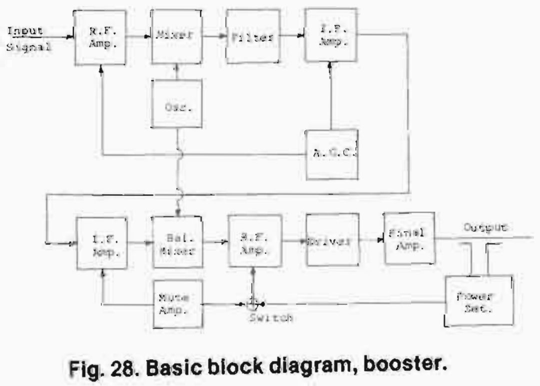


Fig. 28. Basic block diagram, booster.

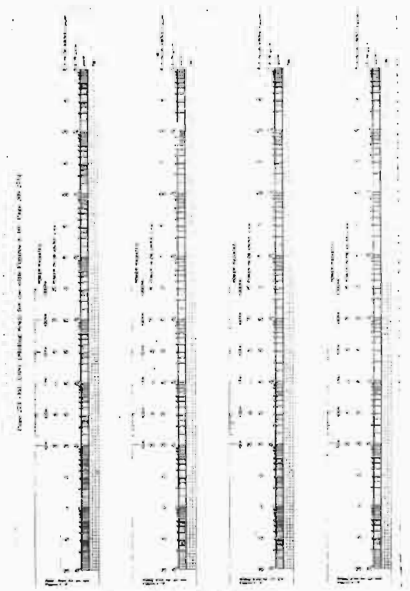


Fig. 29. FCC 74.1236 curve.

4. Low VSWR dummy load capable of dissipating 10 watts output power from the translator.

The FM translator is aligned by adjusting it into the dummy load. Final adjustments are made by connecting the translator to the antenna, with the final amplifier plate circuit retuned to match the load presented by the antenna.

Power Supply. The power supply is checked first. The input dc voltage can be read directly

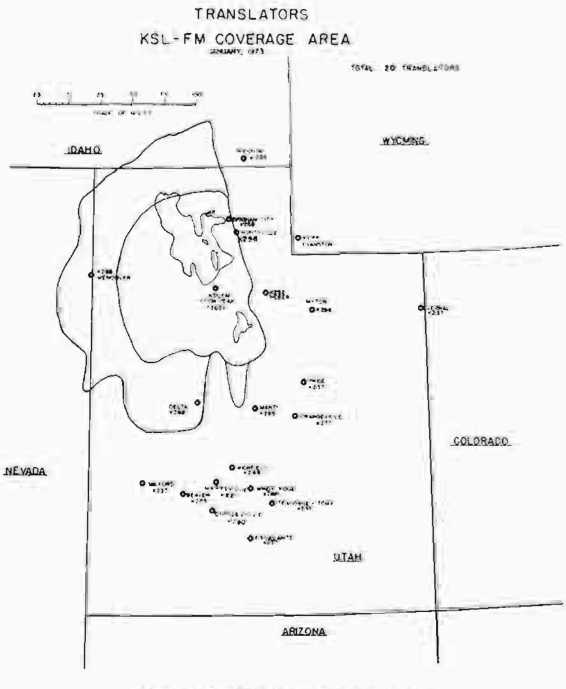


Fig. 30. KSL coverage map.

from the front panel multimeter. This should normally read +28 v. The multimeter should then be set to read regulated voltage. This should read +18 v. These voltages can be checked with the test meter. If the regulated voltage is not +18 v, it can be adjusted by R-11.

Down-Converter Receiver. The next step is to verify the operation of the local oscillator. The test meter is used to verify the oscillator output. The signal generator is then coupled to the FM translator input and set to the required input frequency.

The RF gain control is set to maximum gain, and the output of the signal generator reduced to a point of indicating two major divisions, as read on the front panel multimeter. The RF tuned circuits are then adjusted for maximum deflection as shown on the front panel meter. The signal generator is then removed and the FM antenna reconnected. The RF gain control is then adjusted for normal gain. In some cases this gain must be increased or decreased to afford best performance without interference from local stations.

Up-Converter Transmitter. As with the receiver, the first step is to verify the operation of the up-oscillator with the test meter. The front panel meter should be set to read drive No. 1 current. This stage is then adjusted for maximum indication. This is repeated by setting the front panel meter to read drive No. 2. Again the stage is tuned for maximum indication. The front panel meter is then set to read forward power. In this position this output power is adjusted by the front panel control to read precisely 10 watts. A portable FM radio can then be employed to verify clean operation.

34

Lightning Protection for Broadcast Stations

Roy B. Carpenter, Jr.
Director, Lightning Elimination Associates of Downey, California

Lightning strikes to broadcast transmitter facilities are of course created by atmospheric electricity, and have been responsible for significant losses of both equipment and revenue time. These losses have at times been extensive and resulted in the demise of the operating firm. Within the range of the writer's experience, equipment losses alone have ranged to over $40,000 in one strike.

Atmospheric electricity also creates other forms of hazard to radio stations. The strong electrostatic field, which can reach 5 kv per centimeter, charges the isolated guy wires and tower, much like a capacitor. A subsequent stroke to a nearby target, or a cloud-to-cloud discharge, changes this electrostatic field drastically. The antenna elements compensate by dumping the charge, across insulators and into the earth. The results of this phenomenon known as "guy snapping" are twofold: large reflected waves are sent over the transmission line into the transmitter and the insulators eventually breakdown due to the "tracking" effect. They also have been known to explode as the result of absorbed water vaporizing rapidly.

Damage from atmospheric electricity is also manifested by its influence on the primary power to the station. Most stations in high lightning incident areas suffer as much equipment damage and downtime from primary power surges induced by lightning, as they do from direct strikes to the incoming phase conductors, nearby or at some distance away from the station; or by induced transients resulting from large field changes in areas where these power lines pass through. Either form can be deleterious to solid state electronics in particular. Present day surge protection is designed to deal with this phenomenon; however, they often do not respond fast enough for some of these transients or they allow too high an overvoltage, and when used alone, may prove to be only partially effective.

Transients induced on the remote signal and/or control lines will also damage equipment. The causes are the same as the power line surges and transients. The treatment is usually much more difficult.

To understand the reason for these forms of lightning-induced damages, it may be well to review some of the more significant physical characteristics of atmospheric electricity. The following is a composite data taken from many sources:[1]

1. Stroke charge content is from 2 to 200 coulombs.
2. The peak currents achieve values between 2,000 and 400,000 amperes.
3. The stroke current flow durations vary from about 1 to 100 milliseconds.
4. The current rise times vary from less than one microsecond to over 10.
5. The relaxation or recharge time requires more than 40 sec., and can take many minutes.
6. The average field strength under a storm is between 10 and 30 kv per meter; it rises to between 3 and 5 kv per centimeter just before a strike.
7. The cloud-to-earth potential can exceed 10^8 volts within an active storm area.

One of the more significant of these factors is the shape and rise time characteristic of the impulsive type lightning stroke. While the non-impulsive or so-called "hot" stroke rises slowly to its peak, taking 100 milliseconds or more to abate its energy, it is not so with the impulsive stroke. It can rise to peaks averaging 20,000 amperes within *less than one* μ *sec.* This factor is the cause of most lightning damage to broadcast stations. This is particularly different when considered in conjunction with stations having high resistance grounds; or the AM station without any path to ground for these high frequency, high energy levels. As an example, consider a FM or TV station with a five-ohm ground; the average 20,000 ampere stroke will develop about 100,000

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[1] *Atmospheric Electricity*, J. Alan Chalmers, Pergamon Press, 2nd Edition, 1967.

volts between equipment ground and true ground. Equipment not prepared to accept these kinds of transients will be damaged.

Philosophically, protection as a subject can be based on either remedial principals or preventive principals. A remedial form of protection is based on the assumption that lightning must occur in the area of concern and the protective system must be designed to deal with all of its manifestations, within the systems. Of course, the effectiveness of such an approach depends on the engineers' ability to identify all manifestations and provide adequate means of protection. Conversely, the preventive scheme only deals with the source of the problem, the atmospheric electricity. Although the specific designs must of necessity be prepared by specifically trained engineering consultants, this chapter delineates typical configuration and application criteria.

PROTECTION AGAINST STRIKES TO TRANSMITTER FACILITIES

The protection of transmitter systems against direct lightning strikes involves dealing with the tower. Because of its height above earth, and its metallic nature, it makes an ideal lightning collector (or Lightning Rod). Conventional remedial forms of protection amounted to the use of lightning rods on the top of the tower with Ball or Horn Gaps at the base of the tower and good grounding to carry away the high currents. Design details may be found in Lightning Protection.[2] Over the years these concepts have proved to be useful in reducing the deleterious effects of the strikes but were never 100 percent effective. As an example, reference is made to the case history of Radio CKLW recorded in Lightning Prevention.[3]

To prevent damage with any degree of assurance, it is necessary to prevent strikes to the antenna towers and the feed lines. A recent development by a California company has made this possible through the development of a system called the Dissipation Array.[4] Since 1971, this system has proven successful in preventing lightning strikes for innumerable installations throughout the world.

The Dissipation Array System is applicable to AM or FM Broadcast Stations, as well as TV. It consists of three subsystems; the Dissipator, the Ground Current Collector, and Service Wiring. The installation must be designed specifically for each station to be protected by a competent consultant, with experience in the Dissipation Array System.

The system operational concept is based on the "Point Discharge" phenomenon; where a sharp point in a strong electrostatic field is found to leak off the charge by ionizing adjacent air molecules. Where a difference of potential in excess of 10 kv exists between the point and its surroundings, a current will continue to flow. Since the atmospheric electricity generated by charged clouds can exceed 10^8 volts prior to discharge and the ion current flow is proportioned to the square of the difference in potential, the charged clouds provide all the motivating force required. The overall concept is illustrated by Fig. 1, using one possible array design.

The Dissipators are the primary component of the Dissipation Array System. They must be designed to take advantage of the large gradient formed over the towers by the electrostatic field. There must be a sufficient number of points, properly oriented, located, and separated, to create the required ion current flow and an associated space charge to shield the area of concern. These Dissipators take various shapes and forms, usually mounted on top of each tower.

Several forms of the Array are illustrated by Fig. 2, 3, and 4. Their static weight varies from 60 to 250 pounds. The effective wind loading area varies from ¾ to 3½ sq. ft., acting at the top of each tower; variations in these parameters are the direct result of design tailoring to fit specific requirements and constraints.

Antenna loading effects are a prime consideration for the AM Broadcaster. The potential design variations for the Dissipators are such that the antenna top loading effect can be varied over a wide range, starting from less than 0.1 percent to over the equivalent of a 40-ft. tower

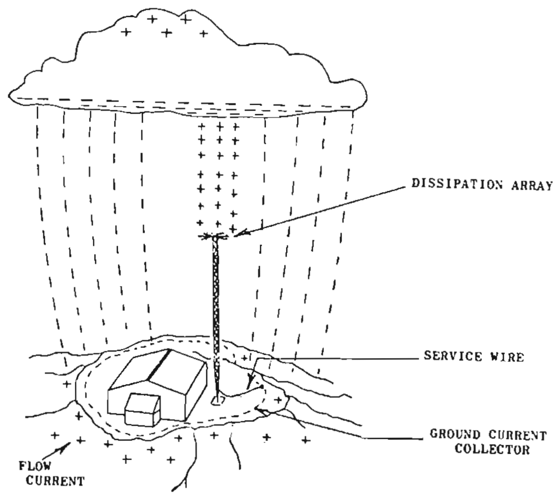

Fig. 1. Typical dissipation array installation, FM broadcast station.

[2]*Lightning Protection*, J.L. Marshall, Wiley, 1973.

[3]Lightning Prevention: A Year's Trial, Staff of CKLW, *Broadcast Management Engineering*, April 1974.

[4]A proprietary system produced by Lightning Elimination Associates, Inc., of Downey, California.

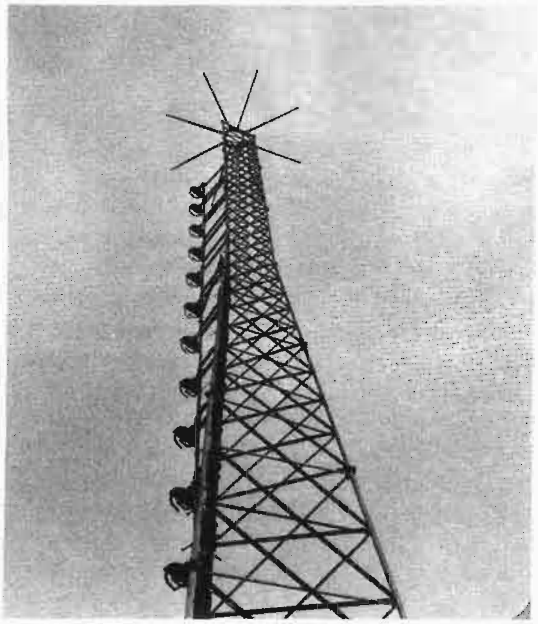

Fig. 2. Umbrella array, FM broadcast station.

section. The array/tower design can be integrated such that the cost of one or two tower section can be saved. As a result, the Dissipation Array System may actually cost less than the antenna alone. These kinds of data must be obtained from the supplier. (See Footnote 4.) Fig. 2 illustrates a typical Umbrella Array, used for the protection of FM stations; a form of this may be used for AM stations desiring some top loading. Fig. 3 illustrates another possible configuration used for the protection of AM where minimum top loading is required. Fig. 4 illustrates one possible configuration for the protection of TV stations and some FM stations where the tower top is not available for use. Note that a Dissipation Array System does not have to be the highest

Fig. 3. Panel array, AM broadcast station.

Fig. 4. Spreader array, TV station.

element on the tower. It can be several hundred feet below the top, if properly installed.

The Ground Current Collector is designed to collect the surface charge induced by the atmospheric electricity, and provide a preferred path from the earth to the dissipating medium. Since this charge is on the earth's surface, so also must the collector be deployed there. Applications for the different kinds of broadcast stations are somewhat different, more because of economics than the technical requirements.

For Broadcast Stations in the LF to 1,500 Hz range, the collector requirement can be satisfied by the usual ground mat or counterpoid radials, as long as they are spaced at no more than 5°. This may also be true of other stations using similar counterpoids.

For FM and TV stations, a Ground Current Collector must be installed, approximately as illustrated in Fig. 5. It may also serve as the station electrical ground. In contrast to the conventional lightning rod grounding system, this system need make only good ground contact. It is buried at about 12 in. in depth, surrounding the tower and buildings, and tied into tower and building with at least three radials. The wire may be a six or eight gauge copperweld, with short ground rods of about four ft., driven at about 50-ft. intervals. Proper operation of this subsystem is totally dependent on a well-integrated *system* design.

The Service Wiring is important in that it is the means whereby the charge is conducted from

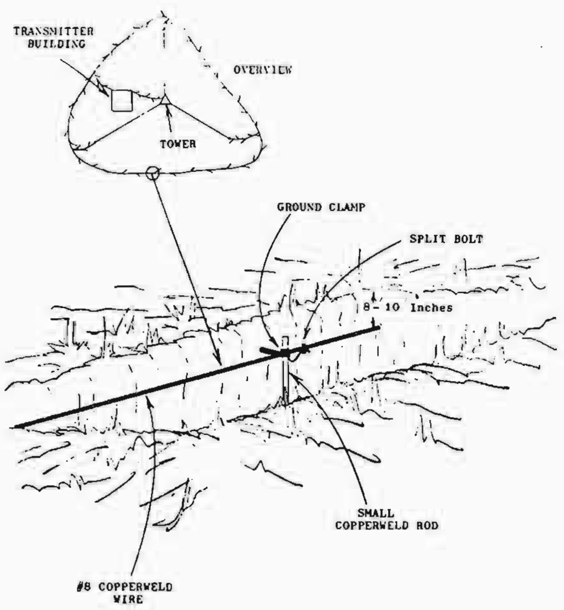

Fig. 5. Typical ground current collector installation.

the Ground Current Collector to the Dissipator. The design objective is to assure a low resistance, multiredundant path for the dissipation current. For FM and TV stations this presents very little difficulty since the tower itself is grounded and usually of low resistance. However, at least one single conductor is recommended to run the full length of the tower, to assure no loss of continuity.

For AM stations with base insulated towers, some form of dc path is required from the tower to earth. A Static Drain Choke or grounded ¼ wave stub will usually satisfy this requirement. If this does not exist, some form of choke feed must be devised. The remainder of the subsystem can be as for the FM station and illustrated by Fig. 1.

PROTECTION AGAINST GUY WIRE INSULATOR ARKING

Since the electrostatic fields under charged clouds can achieve a potential of 3 kv per centimeter of height above the earth, an insulated guy wire suspended at an average height of 100 meters can take on a potential of 30 million volts just prior to a local discharge. Even if a stroke does not hit the antenna system. the collapsing field around the tower and its guys will leave a bound charge on the guy wire. The results are so-called "Secondary Arking," where the charge jumps the insulator in a cascading effect, on a path toward earth. There are two ways of eliminating, or reducing this phenomenon to a tolerable level. This may be accomplished by providing some form of a leakage path for the bound charge, and/or by reducing the field in the antenna farm area.

One option involves the use of Dissipating Guy Wires, either with or without resistive type insulators. This concept provides a means for leaking the charge off slowly through a form of corona. This charge, being no longer bound to the wire by its "smooth" round surface, will leak off at an exponentially decaying rate, under the right conditions.

A second option involves the use of a larger Dissipation Array System for the transmitter area protection. With this concept, the Dissipators in particular are "oversized" to provide a much greater dissipation capability—the design objective being to minimize the field excursions within the antenna or antenna farm area. This can require up to a factor of ten greater dissipation capability than for lightning stroke prevention alone.

The use of resistive insulators alone has improved the situation; however, inherently slow response time limits their potential effectiveness. Whereas their usefulness was limited because of the destructive effects of a lightning strike; use in conjunction with a Dissipation Array System would eliminate that hazard.

Another option involves the use of tunned chokes in place of the insulators. To implement this concept, each insulator would be replaced with a specially designed broad band choke, which would exert maximum impedance to the operating frequency; and yet pass the slowly varying dissipation current and/or the induced charges created by atmospheric electricity. The drawback is related to the fact that it must be tuned to or near the operating frequency. (See Footnote 4.)

PROTECTION AGAINST TRANSIENTS INDUCED INTO THE ANTENNA FEED SYSTEM

Open wire Transmission Lines are particularly vulnerable to induced transients created by the rapid field changes associated with atmospheric electricity, even though there are no direct strikes to the transmitter area. Local cloud-to-cloud discharges can change the field strength by over 30 kv per meter. As a result, transmission lines set 3 meters above earth could easily experience transients of up to 90-kv peaks. Protection against this form of transients can take several forms. These may be classified as remedial or preventative.

Typical of the remedial forms is the Magniphase Solid State Line Protector sold by Continental Electronics,[5] or its counterparts, the Line Protection Unit sold by RCA,[6] separately or as part of their transmitter package. These subsystems are designed to protect the transmission lines, antennas, and antenna tuning units from damage due to line faults, arks and overloads, particularly those created by large variations in the atmospheric electricity. These units are designed to sense the Transmission Line impedance and temporarily interrupt the transmitter output when significant changes from the norm occur. Design data and/or installation instructions are available from the suppliers. (See Footnotes 5 and 6.) The major disadvantage with this form of protection has to do with its impact on station performance. Continuous interruptions and complete shutdown are not infrequent, particularly under heavy lightning conditions.

A preventative concept, based on a Dissipation Array derivative can also eliminate this hazard or reduce its influence to acceptable levels. This is accomplished by generating an ion screen that effectively shields the transmission line from the atmospheric electrical activity. A Dissipator of some form is required to protect the full length of the line, in this case, elevated well above it. The Ground Current Collector must run parallel with the line, just below the surface of the earth, and connected to the transmission line grounded wires at each support. One such installation is illustrated by Fig. 6.

A second option would involve use of many ground wires surrounding the center conductor, such that a Faraday Shield effect is achieved, spacings of not more than 10 cm. may be required to satisfy this requirement.

A Buried Coaxial Feed will normally eliminate the transients induced by changing fields created by atmospheric electricity. However, if the runs

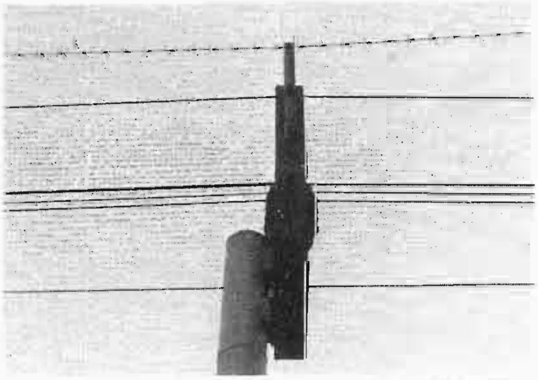

Fig. 6. Typical dissipator installation for an open-wire transmission line.

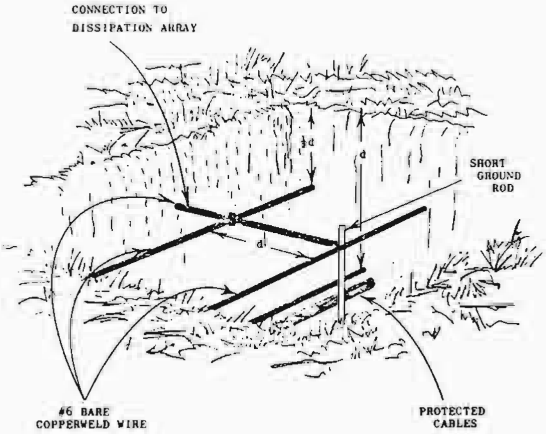

Fig. 7. Recommended coaxial feed installation.

are of significant length, and/or proceed through an area where lightning strikes to the towers are possible, several forms of induced transients are very probable. These forms come about as the result of movements of the charge induced in the earth due to the presence of a charged cloud. If the coax is in the presence of this charge and a local strike occurs to one of the towers, that charge will take the most conductive path to that tower, and very often the coax shield will provide that path. The resulting transient induced on the center conductor can be of greater magnitude than that induced on elevated/open transmission lines. These lines are also subject to direct strikes and in poor soil can "collect" strikes from as far as 100 ft. on either side of the line.

Protection against these phenomena can take two forms. In most cases, protection of the tower area with a Dissipation Array System will eliminate the direct strike and perhaps much of the induced transients as well.

A second option involves the use of two shield wires, buried in the same trench, at one-half the distance from the surface of the earth to the coax, on 45° angles from the centerline, as illustrated by Fig. 7. About a 6 gauge (5 or 6 mm) copper wire should be used, with short ground rods of about 1 meter length, spaced about 16-meter intervals. Where a Dissipation Array is used, these shield wires should be connected directly to the Dissipator.

PROTECTION AGAINST POWER LINE SURGES

With the advent of solid state electronics, broadcast facilities have become more susceptible to variations in the primary line voltage. Electrical storms create several forms of transients which appear on the primary power lines, as a significant variation in the voltage. These

[5]Continental Electronic Mfg. Co., Dallas, Texas.

[6]RCA, Broadcast Transmitter, Division, Camden, New Jersey.

variations or transients are created by two related but different phenomena; i.e., by direct strikes to the lines, close-in or at some distance, and induced transients. They are related in that they are created by atmospheric electricity; they are different in both magnitude and immediate cause.

A Direct Strike to a power line serving the station will dump between 2 and 200 coulombs of charge on the line, within 1,000 msec. If it is an impulsive stroke, it can reach a peak of 20,000 amperes in less than 1 μsec. If it strikes the line within one or two miles of the station, much of the high frequency energy will pass through the conventional surge protection. The result will be a loss of many solid components.

Induced Transients are created by the same mechanism that causes "guy snapping" or insulator ark-over; i.e., the large excursions in field strength under the storm system. However, the major difference is in the Q of the lines. Since they have a much greater storage capacity, much larger charges can be induced into the power lines. The results on the broadcast station are similar to the direct strike. Deleterious transients are coupled into the station.

Protection can be provided against both situations. One option involves protecting the sensitive portion of the incoming distribution lines with a Dissipation Array concept similar to that suggested for the Transmission Line. Since there may be many miles of line involved, this may not be economically feasible. A second option involves use of a specially designed low-pass filter, in conjunction with one of several forms of conventional surge protectors, that are commercially available. Because of the variation in primary voltages, phases and frequencies, each of these must be designed individually. For a specific requirement a variation of this concept is to design the station's electrical power feed such that the incoming lines are passed through about 50 ft. of well-grounded metal conduit before entering the transmitter building. At the point of entry a high speed surge protection such as those commercially available from several suppliers[7] can be reasonably effective. However, some of these surge protectors have to be changed periodically, in areas of high lightning activity.

In cases where the foregoing is not practical and/or where a higher degree of protection is required, the specially designed low-pass filter concept is more attractive. A proprietary system, based on this concept is available through Lightning Elimination Associates, Inc., of California. A more conventional but less effective form of protection can be obtained through use of any one of the commercially available surge protection devices by itself.[8] These devices are designed to divert the surplus charge to ground by ionizing a conducting gas when the voltage exceeds a preselected voltage. However, when used alone, they often do not ionize in time to prevent the passage of some high frequency energy resulting from nearby strikes. Further, their successful use depends on the availability of a "good" ground; where good ground may be defined as one ohm or less. Greater resistances will permit in excess of 20,000 volts to develop, for short instants, between equipment and/or equipment and true ground.

CONCLUSIONS AND RECOMMENDATIONS

Modern technology has tamed the rigors of atmospheric electricity. However, as in all scientific disciplines, the solution to this problem has been removed from the realm of the novices. Lightning strikes to broadcast stations can be prevented, damage from transients can be eliminated; however, a qualified consultant is required. To be sure of the results, check the guarantee. Guarantees against lightning strikes and lightning damage are available.

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[7]Typical of this kind of protection is surge Eliminator, Model LEA-SE-220 marketed by Lightning Eliminator Associate or the ACR-1000 marketed by Transector Systems.

[8]The Model 1235-01 Surgitron marketed by Joslyn Electronics Systems Division.

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Subsidiary Communications and Stereophonic Broadcasting

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SUBSIDIARY COMMUNICATIONS AUTHORIZATION (SCA) FOR FM BROADCAST STATIONS

Federal Communications Commission Rules and Regulations provide for the utilization by FM broadcast stations of subcarriers transmitted along with the main channel programming.

This mode of operation, licensed under FCC Subsidiary Communications Authorization (SCA), can accrue advantages of financial or special service nature to commercial and noncommercial FM broadcasters.

The grant of the SCA service is conditioned on the rendering of services satisfying the basic requirements that the program transmissions shall be of a broadcast nature of interest primarily to limited segments of the public wishing to subscribe thereto, or that the signals transmitted relate directly to the operation of FM broadcast stations.

The Commission specifically states that those programs of a broadcast nature may be background music, storecasting, detailed weather forecasting, special time signals, or other material of a broadcast nature expressly designed and intended for business, professional, educational, trade, labor, agricultural, or other groups engaged in any lawful activity. This is an extremely broad area of acceptability; however, in practice by far the greatest utilization of SCA has been in the background music and storecasting categories since revenue to the FM broadcaster results from these commercial operations. These revenues have in many instances represented a major part of the income to the FM broadcaster. Other programming in current use relates to the dissemination of agricultural market information and, recently, the broadcast of "radio talking book" material to the visually handicapped. A number of educational institutions use their subchannels for "in-home" teaching purposes. The Commission has recently expanded the permissible transmission to include slow-scan TV, teletype, facsimile, and other nonaural electronic services.

Typical examples of SCA use in the category of signal transmission directly related to the operation of FM broadcast stations include coded telemetry data for FM broadcast remote control operations and the relaying of sports and other specialized types of programming on a regional network basis.

The current FCC rules pertaining to SCA engineering standards define very few parameters. The standards state only that the subchannel shall be frequency modulated, define the carrier frequency ranges for mono or stereo operation, stipulate carrier injection levels for each main channel mode, and specify permissible crosstalk levels from the SCA channel into the main channel. No standards for the performance of the subchannel itself are established. Audio frequency response, total harmonic distortion, preemphasis characteristics, signal-to-noise ratios, or crosstalk from the main channel programming into the subchannel are not specified. Thus, the Commission standards provide no indication of actual performance to be anticipated from the subchannel. It is anticipated that the FCC proposed rule-making mentioned above will include specific parameters as minimum standards for SCA transmission performance.

In actuality, a subcarrier multiplex channel is capable of surprisingly high-quality, low-noise operation.

It is the objective of this material to define these capabilities with direction as to the proper use and adjustment of the system elements to provide optimum performance. Each of the system elements is discussed in detail.

The heart of the system is, of course, the basic subchannel carrier generating and modulation processing equipment. There are a number of SCA generators available on the market, and the Commission permits the use of SCA generators of any manufacture with any FM broadcast transmitter/exciter which has been type-accepted for SCA operation. In other words, type acceptance of SCA generators is not required.

Let us first consider the effect of adding a new channel, the 67-kHz frequency-modulated subcarrier to an existing stereophonic FM broadcast system. Assuming that the 67-kHz subcarrier will be deviated ±6 kHz (61 to 73 kHz), we have present in the complete modulation spectrum this energy plus the main channel mono audio portion, essentially 30-15,000 Hz; the stereo pilot carrier at 19,000 Hz; and the stereo suppressed-carrier double sideband AM information, which when fully modulated occupies the region from 23 to 53 kHz, centered around the 38 kHz suppressed carrier. This information spectrum is shown in Fig. 1.

Several points become apparent. First, the addition of the SCA fully modulated subcarrier indicates the need for flat frequency response of the transmission system to 73 kHz rather than to the 53 kHz limit for stereo operation.

If any nonlinearities exist in the transmission system, troubles develop rather rapidly. These can result from improper neutralization or loading of any of the RF stages in the transmitter itself, high VSWR on the transmission line or narrow bandwidth characteristics in the antenna system.

Acceptable bandwidths are attainable with present day FM transmitters, but it is essential that the transmission system be routinely checked for maintenance of optimum bandwidth conditions. A spectrum analyzer, where available, provides the best means of detecting overall performance; however, FCC rules for type approval of stereo and SCA modulation monitors include the capability of measuring response within 1 dB accuracy from 50 Hz to 75 kHz. As a preliminary check, the overall response of the transmission system should be measured, using a spectrum analyzer or a type approved modulation monitor in conjunction with a signal generator covering the 50 to 75,000 Hz range. If nonlinear response is detected at the transmitter output, the source of the defect can be isolated by temporarily connecting the monitor feed to preceding RF stages, or the exciter output itself. This procedure is also helpful in isolating crosstalk problems, particularly where neutralized tetrode IPA or PA stages follow the exciter. *Any* nonlinearities in the transmission system will seriously affect both main to SCA and SCA to main channel crosstalk characteristics. Transmission line VSWR must be maintained at as reasonably low values as practical (typically 1.1 to 1) to assure optimum performance. Present day transmitting antenna designs usually provide adequate bandwidths. If, however, antenna problems appear which result in increased VSWR readings, increased crosstalk between the stereo and SCA information will almost certainly occur.

Fig. 1. Complete FM Spectrum of a stereo and SCA transmission.

A great deal of comment is heard relative to "birdies" and "whistles" which suddenly appear when a subchannel is added to a stereophonic operation. This condition, although potentially created in certain receiver designs, details of which will be given later, may also be generated in the transmitter part of the system. When present in the transmitter, they may be detected by a type-approved modulation monitor as described above and *must* be corrected if a clean overall system is to result.

The addition of the 67-kHz subcarrier to an existing stereo system presents the possibility of generated beat frequencies of 9 kHz and/or 10 kHz; or of random "swishy" by-products, all of which are in the audible range. The source of the 10-kHz signal is from the third harmonic of the 19-kHz pilot-carrier signal which falls at 57 kHz, 10 kHz below the 67-kHz subcarrier. Some earlier stereo generator designs also produced second harmonic content from the 38 kHz suppressed carrier switching circuitry. This second harmonic falls at 76 kHz and produces a 9 kHz product when intermixed with the 67-kHz subcarrier. The 9- or 10-kHz products appear as relatively clean "whistles" when no modulation is present. When the subchannel is modulated (deviated ±6 kHz) the products appear as "swishes" as the 67 kHz modulation sidebands are generated and beat with the pilot carrier third harmonic and/or the 38 kHz second harmonic.

If either 57 kHz or 76 kHz signals or any other spurious signals appear in the transmitter output, they must be eliminated. Suggested steps for optimum operation include:

1. Insure that the 19-kHz pilot carrier is free of third-harmonic content and does not exceed 10 percent injection level.

2. 38-kHz carrier suppression must be at least 50 dB below a 100 percent modulation reference level.

3. SCA carrier injection should be maintained at a 9½-10 percent level.

4. A sharp 5-kHz low-pass filter (optional with some SCA generators) should be inserted in the SCA program output circuitry. This prevents the appearance of harmonics of nonsinusoidal SCA program material above 5 kHz in the SCA generator output which can produce excessive SCA sidebands which would extend below the lower bandwidth limit assigned to the subchannel

information and generate interference with the stereo information channel which has a 53-kHz upper limit.

5. The left- and right-channel audio inputs of the stereo generator should incorporate 15-kHz low-pass filters to insure that sideband signals of the stereo transmission do not extend beyond the 23 to 53 kHz (38, ±15, kHz) limits assigned to it.

6. The SCA generator should include a 67-kHz bandpass filter in its output to insure that (a) the lower sidebands do not interfere with the 53-kHz upper stereo information frequency limit and (b) the upper sideband does not extend beyond the 75-kHz upper limit established by FCC rules.

7. Although modern FM transmitter and stereo/SCA generator design is capable of accommodating ±6 kHz deviation of the subchannel carrier, it is recognized that many broadcast systems utilize equipments of various ages and manufacturing designs. In a number of instances, it is worthwhile, if satisfactory performance cannot be realized with ±6 kHz deviation of the subcarrier, to consider reduction in deviation. Reducing the deviation to ±4 kHz results in a signal-to-noise increase of 4 dB in the subchannel transmission.

If the above precautions are taken, at worst, minimal SCA interference will be transmitted. In most cases, a spectral display will prove that SCA interference is not being transmitted.

The station engaged in SCA and stereo transmission must, however, insure that it is transmitting a clean signal and this can be verified by a properly operating monitor or spectrum analyzer. This can be done by removing all stereo modulation and measuring the SCA interference (crosstalk) into the main (L + R) channel and the stereo sub (L-R) channel. Any crosstalk or interference must be down at least 60 dB from 100 percent modulation into the main and stereo subchannels. If these parameters are met, the station knows that at least it is not contributing intermodulation products or SCA interference.

Stations transmitting SCA have one additional problem, that of the stereo information getting into the SCA channel. This crosstalk interference is of great concern to the background-music operator and other users of the SCA channel. Clean SCA with stereo transmission requires optimum performance of the transmitter and associated equipment and in fact requires more demanding system and equipment linearity than for a stereo-only transmission.

In a stereo transmission, equal levels of signals are transmitted on the left and right channel. When SCA transmission is added, 90 percent of the total information is transmitted on the main and stereo channel with only 10 percent of the baseband modulation used for the SCA channel. Thus, the main and stereo channel is nine times greater in amplitude, requiring high transfer-characteristic linearity.

The 35-dB crosstalk (separation) between left and right audio channels of the stereo transmission is indeed excellent and hard to achieve at all frequencies, but this degree of crosstalk would be unusable for SCA programming. Poor separation between the main and stereo channels is more attributable to phase error, time delay or amplitude error than nonlinear transfer characteristics.

In an SCA transmission, crosstalk can originate due to nonlinearities in the FM exciter, transmitter, transmitting, and receiving antennas or multipath reception effects of the main channel section of the SCA receiver.

To preserve reasonably good phase linearity in an FM exciter, the actual cutoff frequency of the 53-kHz low-pass filter following the modulator in stereo generators may be 60 kHz or higher, and stereo sidebands can extend well into the SCA channel. Thus, linear crosstalk from the stereo subchannel (23-53 kHz) can be transmitted into the SCA channel. This is characterized as a "monkey-chatter." This is not due to nonlinearities but is created by upper stereo AM sidebands exceeding the 53-kHz design limit and appearing in the 67-kHz SCA channel. Nonsinusoidal stereo program material in the 8-15 kHz region with high harmonic content can also produce AM sidebands of the stereo information which extend into the SCA channel. These amplitude-modulated signals will ride up and down the response curve of the SCA band-pass filter, creating a form of phase modulation which will be detected as noise in the recovered SCA audio. This type of transmitted interference is easily corrected by inserting sharp 15-kHz low-pass filters in the left and right audio channels of the stereo generator, preventing any stereo upper sideband components from exceeding 53 kHz.

The absence or malfunction of 15-kHz low-pass filters may be detected by fluctuation of the pilot injection level reading on the stereo monitor. This fluctuation is produced by harmonics of the program audio frequencies falling into the pass band of a highly selective 19-kHz filter used in the pilot injection level measuring circuitry of the monitor.

The above sources of crosstalk relate to direct, or linear, operating conditions. The major, and most serious, cause of main or stereo crosstalk into the SCA channel is caused by nonlinear transfer characteristics (intermodulation distortion) which can originate in the exciter, power amplifier, transmitting and receiving antennas, or in the main channel portion of an SCA receiver.

An understanding of events occurring during the FM modulation process is necessary to better comprehend the crosstalk problem. The FM process is complex. An FM transmitter monaurally modulated 100 percent with a 600-Hz audio signal will create several hundred new carriers or sidebands above and below the center frequency. The strength of each of these carriers can be computed mathematically using Bessel functions. When a 67-kHz signal is added to the modulation process, two new carriers removed 67 kHz from the center frequency are produced. When these carriers are frequency modulated, additional new sidebands appear above and below these respective carriers. Any disturbance of these carriers or their sidebands will create intermodulation or crosstalk.

Most present-day FM exciters use the direct FM system operating at one-half the carrier frequency or at carrier frequency. The linearity of these modulated oscillators must be near perfect. The bandwidth of the RF amplifiers in the exciter following the modulated oscillator must be adequate to allow all of the upper and lower sidebands produced by the FM process to pass without deterioration. The correct phase relationship between the sidebands must be preserved. The shift in phase as the FM frequency changes must be a linear function. If the slightest regeneration is present, the phase shift will be more rapid above the center frequency than it is below, or vice versa, and intermodulation or crosstalk will occur. In effect, regeneration can be one of the most serious sources of crosstalk in the exciter. The pass band following the modulator must be at least 1 MHz wide for good linearity. The typical exciter illustrated in Fig. 2 is designed with all of these parameters in mind and with particular attention to proper filtering. The 15-kHz low-pass filters are used in the left and right audio input channels of the stereo generator. A 53-kHz low-pass filter is inserted in the stereo generator output. A 5-kHz low-pass audio input and a 67-kHz bandpass output filter are used in conjunction with the SCA generator.

Proper coupling must be maintained between the exciter and the subsequent RF amplifier stage. The stage being driven must present a non-reactive load to the exciter. Any reactance existing between the exciter and power amplifier will produce phase shift due to nonlinear response to signals appearing above and below the center frequency. Thus, the sidebands are altered from their original relationship to each other and crosstalk is produced. Improper neutralization of PA stages will cause regeneration and crosstalk.

A portion of the transmission system that is often overlooked is the transmitting antenna. Again, the transmitting antenna and transmission line must present to the transmitter a purely resistive load. A correctly tuned antenna system is capable of producing a VSWR close to unity, generally 1.1:1.

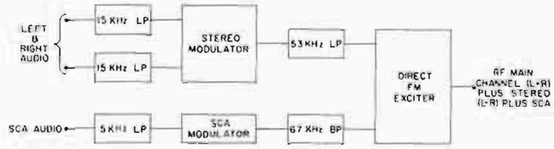

Fig. 2. Block diagram of a typical FM exciter.

A further test of good antenna performance is to sweep it out and measure the change in reactance over a minimum of 1 MHz from the center operating frequency. A curve, representing the change in reactance, should be symmetrical on either side of the operating frequency if satisfactory multiplex operation is to result.

It is often taken for granted that the antenna can cause no problem. The antenna should be measured and adjusted, especially if it has been in operation for a number of years and the SCA multiplex operation is now being initiated.

Some of the major causes of crosstalk in the transmitter end of SCA multiplexing have been outlined. Any station that follows good engineering procedures when converting to SCA operation will be rewarded with excellent results.

It was stated earlier that FCC engineering standards do not include performance characteristics for the SCA channel. As a guideline to what the anticipated performance of a subchannel might be, the following is typical of present-day SCA transmission with stereophonic main channel operation.

SCA subcarrier	67 kHz
SCA frequency response	30-5,000 Hz, ±1.5 dB
SCA total harmonic distortion	1.5%
Signal-to-noise (essentially crosstalk, main to SCA)	—55dB
Crosstalk, SCA to main	—60dB

The optimum performance attainable with SCA operation in conjunction with monophonic main channel programming is most impressive.

A series of field tests was conducted in the late 1960s utilizing the facilities of KFAB-FM, Omaha, Nebraska. A subchannel frequency of 58 kHz was used and a maximum deviation of ±12 kHz was employed. The modulation of the main carrier by the subcarrier (injection) was 20 percent. The main channel had a measured frequency response which was flat, within 1.2 dB, from 50 to 15,000 Hz. During all subchannel measurements, the monophonic main channel was programmed with high quality recorded music. The 75 μ sec. pre-emphasis was used in both the main channel and subcarrier channel. Measurements taken with type-approved monitoring equipment at the transmitter, were:

Crosstalk (subchannel into main)	Greater than —70 dB
Subchannel FM signal-to-noise (no main channel mod.)	—70 dB

SCA channel total harmonic distortion

Frequency in Hz	% Distortion
50	.55
100	.46
400	.45
1,000	.40
2,500	.80
5,000	.68
7,500	.65
10,000	.60
15,000	1.20

SCA frequency response (200 Hz ref.)

Frequency in Hz	Response (departure from 75-μsec. curve)
50	0.0 dB
100	0.0
200	0.0
1,000	+0.1
3,800	0.0
5,000	—0.6
10,000	—2.0
15,000	—0.7

Measurements were taken on a standard SCA receiver modified for ±12 kHz deviation, 15-kHz frequency response and 75 μ sec. de-emphasis. The receiver was located approximately 12 miles from the transmitter site, and used a simple indoor dipole antenna, oriented for maximum signal. The antenna input signal was approximately 1 mv. The results were as follows:

Crosstalk (subchannel into main)	greater than —70 dB
Crosstalk (main into SCA)	During a 15-minute test period, the highest crosstalk measured was -55 dB with total main channel modulation not exceeding 100%
SCA signal-to-noise, plus crosstalk	— 49 dB (using 400 Hz @ 100% modulation as reference)
SCA signal-to-noise (no main channel modulation)	—57 dB

While the applications for an SCA channel capable of this high degree of performance are extremely limited, the test data is of interest since it does demonstrate the subchannel capability, as well as the relative values of degradation contributed by the receiving equipment portion of the complete transmission system.

Generally, the introduction of SCA multiplex operation as an adjunct to an existing FM broadcast station operation suddenly involves the station engineering personnel with a "whole new ball game"—the SCA receiver. Frequently, the SCA operation involves the leasing of the facility by a third party interested primarily in the results produced at the receiving location, for which he assesses a fee. The SCA receivers used by the subchannel lessee are frequently selected, purchased, installed, and serviced by his own separate organization, completely unrelated to the FM station licensee.

Herein lies the potential for unbelievable misunderstandings! Are problems which may occur in the overall system produced by the transmitting end, or by the receiving end? Two points become of extreme importance to the station engineer. First, be certain the transmitting end is clean and technically sound; and second, and equally important, understand the technical aspects of the receiving process, particularly as it relates to the possibility of "crosstalk" problems, which are the most frequent complaint and which may be produced by effects in the receiving process with which previously you have not had to be concerned.

The receiving antenna, multipath effects, and the SCA receiver itself can generate nonlinear crosstalk. The SCA receiving antenna, even for line-of-sight situations, should be as highly-directional as possible and "cut-to-frequency." The antenna directivity characteristic is essential to insure maximum direct path signal intensity and to minimize reception of secondary signals reflected from structures in metropolitan areas or from terrain irregularities in mountainous environments. Reflected signals alter the phase relationship of the transmitted sidebands of a carrier produced by a transmitter with good linearity. Bear in mind that the programming to be recovered by the SCA receiver is carried on a subchannel with one-tenth of the signal strength of your transmitted signal.

The generally accepted standard SCA receiving antenna is of either 3- or 5-element, single-bay, Yagi configuration; occasionally supplemented by an additional bay for "fringe-area" installations. Coaxial transmission line, of 50- or 75-ohm surge impedance, is essential to minimize secondary feedline pick-up.

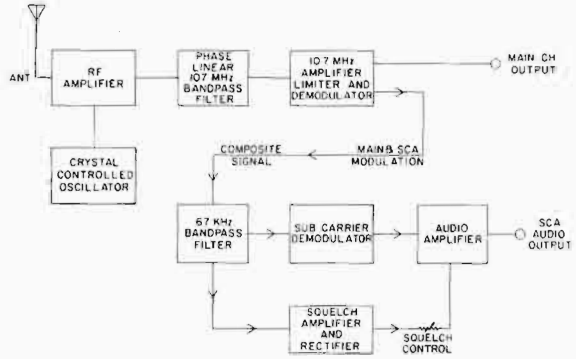

Fig. 3. Block diagram of a typical SCA receiver.

The block diagram of a typical SCA receiver is shown in Fig. 3.

The SCA receiver must amplify the RF carrier and detect it without seriously disturbing the original signal and its sideband information. To do this, most of the signal amplification and selectivity is achieved in the main IF amplifier section of the SCA receiver. Fortunately, present-day detectors are of sufficient bandwidth with good linearity and contribute very little to crosstalk. The problem has resolved itself to the band-pass IF filter or filters which must pass the modulated signal with sidebands undisturbed.

The requirement for an IF band-pass filter that will not create intermodulation products and will maintain good selectivity is costly and hard to achieve. The bandwidth must be adequate, and the phase linearity must be such that minimum disturbance of the upper and lower sidebands will occur. The bandwidth must be adequate to minimize the unwanted conversion of the FM signal to AM in the IF system which would produce a side product of intermodulation into the SCA carrier. Even though the signal is hard-limited, the intermodulation product will show up as phase shift, and will be detected by the FM detector and end up as crosstalk in the SCA audio.

SCA channel total harmonic distortion

Frequency in Hz	% Distortion
50	.50
100	.55
400	.60
1,000	.60
2,500	.60
5,000	.60
7,500	.90
10,000	.80
15,000	1.30

SCA channel frequency response (200 Hz ref.)

Frequency in Hz	Response (departure from 75-μsec. curve)
50	—0.2 dB
100	0.0
200	0.0
1,000	—0.4
3,800	—2.0
5,000	—2.6
10,000	—1.2
15,000	+0.4

The 67-kHz band-pass filter must have adequate selectivity to prevent linear crosstalk as previously described.

If intermodulation occurs anywhere in the transmission or receiver system, crosstalk results and there is no way to remove the main or stereo channel from the SCA channel.

A serious problem that occurred in early solid state receivers was front-end overload. Receivers using bipolar devices in the RF amplifier were very susceptible to this type of interference. This phenomenon was caused by strong RF signals, many channels removed from the desired signal, driving the base-emitter junction of the RF amplifier into conduction. Thus, the RF amplifier became an excellent mixer rather than an amplifier. This was evidenced by an apparent lack of receiver sensitivity and high noise. Removing the antenna, inserting pads, or short circuiting the antenna input restored the receiver to normal operation. The more sensitive the receiver, the greater the susceptibility to this type of overload. Forward AGC reduced the gain but this lowered the input impedance of the device drastically, which in turn reduced front-end selectivity, causing additional problems.

The advent of the JFET and especially the MOSFET transistor has greatly enhanced the overload characteristics of present-day receivers. MOSFETs, when used with good preselection, can operate with input signals up to 0.3 volts or greater with very low intermodulation products, thus fully utilizing the selectivity characteristics of the IF system.

Another source of intermodulation, or crosstalk, in receivers can occur in the IF amplifier limiters. Symmetrical limiters preserve the zero time axis crossing of the IF signal while providing hard amplitude limiting. This results in practically zero amplitude-to-phase modulation conversion and no intermodulation products.

The SCA receiver shown in Fig. 3 utilizes three direct coupled symmetrical limiters. Exceptionally good AM rejection results, and normally cannot be measured with commercial AM-FM signal generators because of the inherent incidental phase modulation of the AM-FM generator. The exceptionally wide bandwidth of the cascaded limiters also minimizes the effects of multipath distortion.

When initiating SCA transmission, another potential problem exists. A few of the regular listeners will complain of "birdies" or "whistles" in the stereo signal they receive. The station transmissions will be clean, the SCA program is satisfactory, and the reported "birdies" or "whistles" do not appear on the majority of stereo receivers in the station listening area.

This type of interference is generated by design deficiencies which exist in some FM stereo tuners/receivers, presently in use. It is created by generation of a 57-kHz signal (third harmonic of the 19-kHz pilot carrier) in a switching-type stereo demodulator, utilizing diode switches. In an identical manner to the previous caution relating to third harmonic generation in the station stereo generator, this 57-kHz signal produces a 10-kHz product when beat with the 67-kHz subcarrier which is included in the composite input signal to the stereo demodulator. When the subchannel is FM modulated, the reported "squishy" sound results. *This effect is generated in the listener's receiver!*

Square-wave switching demodulators, although capable of excellent stereo separation and stability, are the worst offenders.

A number of current stereo receivers utilize these demodulator designs but minimize SCA interference by use of a filter preceding the diode-switching demodulator. These filters ideally should provide a flat passband and linear phase response up to 53 kHz and infinite attenuation from 60 to 75 kHz. Filters providing these characteristics are relatively expensive and compromise designs vary from simple, low-cost to fairly exotic versions, at the sacrifice of stereo separation at the higher audio frequencies. Unfortunately, some receivers, even those in the higher price range, and of otherwise highest quality, have poor or no SCA filters!

An additional potential source of "receiver-generated" interference is in the 38-kHz regenerated stages where the 19-kHz pilot carrier is amplified, doubled in frequency and injected into the stereo demodulator. This regenerated 38-kHz signal must be absolutely free of any 19- or 76-kHz component. The presence of a second harmonic signal at 76 kHz will intermodulate with the 67-kHz subcarrier producing an audible 9 kHz "whistle" in the recovered stereo audio output.

Fortunately, integrated circuit chips incorporating phase lock loop stereo demodulator designs have been developed and are being used in more and more new consumer-electronics receiver designs. These inherently offer excellent SCA rejection and superior stereo separation at the higher audio frequencies.

A good deal of publicity has been generated on the subject of quadraphonic (four-channel) FM broadcasting as a supplemental service to existing stereophonic transmission. This has caused concern as to the effect on SCA channels.

First, the present FCC rules pertaining to stereo broadcasting permit the use of matrix-type four channel encoder/decoder systems which are fully compatible with present stereo systems. The use of matrix four-channel systems presents no conflict with the SCA channel since the channel interrelationships are identical to those for current stereo/SCA transmission.

Under the auspices of the Electronic Industries Association (EIA), a National Quadraphonic Radio Committee (NQRC) was established for the purpose of evaluating discrete quadraphonic systems developed by five proponents. The five systems were tested in "on-air" tests late in 1974, using the facilities of K-101 in San Francisco. *The EIA/NQRC tests included measurements to insure compatibility with SCA transmission.* All proposed systems met this criterion. Some of the proposed systems retain the present 67-kHz SCA carrier frequency, while others contemplate the use of an SCA channel at 95 kHz. While a 95-kHz SCA carrier would require a 4 to 5 dB greater signal level in fringe areas, the quality of reproduction and signal-to-noise ratios are equivalent to those obtained with a 67-kHz subcarrier frequency.

All of the proposed systems require bandwidths in excess of the present FCC, ±75 kHz limitation, hence, adoption of any of the proposed systems involves a change in the present rules. The substantial technical data compiled during the K-101 tests will be the basis on which the Commission will consider the establishment of engineering standards and rules pertaining to an FM broadcast quadraphonic system. Since all of the proposed systems under consideration do accommodate an SCA channel, there is no danger that this mode of transmission will become extinct. At worst, the subchannel frequency *may* be changed to other than its present 67-kHz location.

The material discussed to this point has been limited to the broadcasting of aural SCA material. The Commission has recently changed its rules to permit nonaural uses of SCA. Some of these new transmission modes include slow-scan TV, facsimile, teletype, etc. Most of the above referenced modes are regularly transmitted over low-grade telephone circuits. The response, distortion, and signal-to-noise capabilities of an SCA channel substantially exceed those of wire circuits, thus, a revision of Commission rules to permit transmission of nonaural services opens a new dimension of the SCA field.

Licenses have now been granted by the Commission permitting SCA transmissions of slow-scan TV, multichannel teletype, visual display systems, and an aural/visual electronic blackboard system. The technology exists for these new and interesting modes of broadcasting. The adoption of rules permitting these nonaural services on SCA subchannels is a milestone in FM broadcast technology.

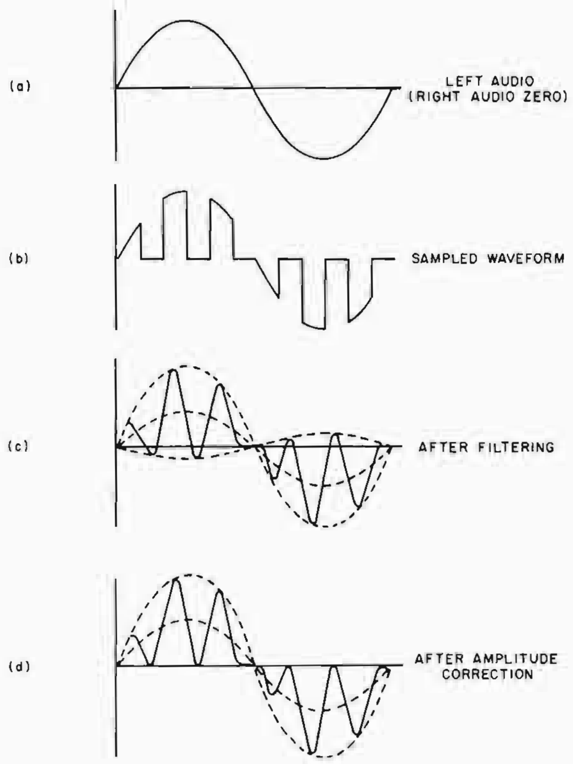

Fig. 4. Time division signal for left = 1, right = 0, L + R = 1, L · R = 1.

STEREOPHONIC BROADCASTING

Stereophonic broadcasting has given both added pleasure to the listener and increased responsibility to the broadcaster. Although stereophonic broadcasting has been permitted by the Federal Communications Commission for over 15 years, there is still a continuing need for the proper understanding of the system's operation and what safeguards must be developed to ensure the transmission of optimum stereophonic signals.

System Operation

A good part of the mystery of stereo is related to the way the theory of the system is explained and "(L + R) and (L - R)" tends to confuse the casual observer. Stereo is a time division system and should be explained from that viewpoint. The composite stereo signal, before it modulates the transmitter, is a chopped audio wave with specific time slots labeled Left or Right. The amplitude of the signal within these time slots represents the amplitude of the signal **in that channel at that time.**

Consider some examples of the resulting time signal as it exists at a discriminator after demodulation. (For clarity, the pilot carrier will be neglected for the moment.) In Fig. 4a, a Left audio signal is applied to the transmitter. After being chopped in a 4-diode time modulator, it looks similar to Fig. 4b. This waveform is cluttered with undesirable harmonics of the chopping rate (38 kHz) and is filtered, as in Fig. 4c. Filtering, however, creates an overshoot on the base line of the audio signal. This is an undesirable condition, because overshoot or undershoot represents poor channel separation.

Receivers decode the baseline as an opposite, or Right channel signal, and good separation depends on the baseline being as close to zero as possible. In Fig. 4c, therefore, the baseline signal is corrected with a cancel circuit, and the resultant waveform in Fig. 4d appears at the receiver discriminator. Since it is a chopped signal, the listener hears the average of the signal rather than the peaks, and by comparison it will appear to be 6 dB down from a conventional signal in the normal monaural receiver if no Right channel signal is present. Increasing the amplitude of this signal can cause distortion if its peak amplitude is at full modulation, for the peaks will clip and the average level will be affected.

For an example, put two similar signals on the Left and Right channels as reflected in Fig. 5. (Filtering, though present, is not necessary to explain the resultant waveform in Fig. 5c.) The alternate slots are added and fall into a neat dovetail arrangement, producing a conventional sine-wave signal with some switching imperfections that are disregarded in the receiver. The (L + R) signal, after chopping and reconstruction, closely resembles a conventional monaural audio signal and contributes to the compatibility of the system. Conventional or stereo receivers get the same information if it is applied in equal amplitude to *both* channels; that is, announcements or mono-program material must be applied to both L and R channels to appear distortion-free and be

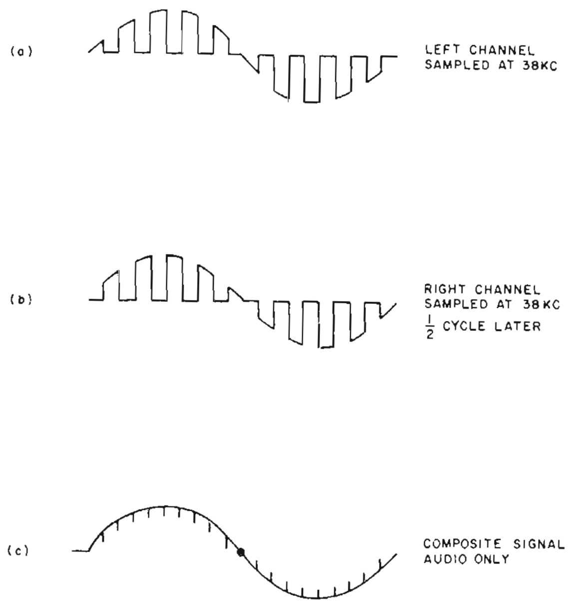

Fig. 5. Time division signal for L = R, L + R = 2, L - R = 0.

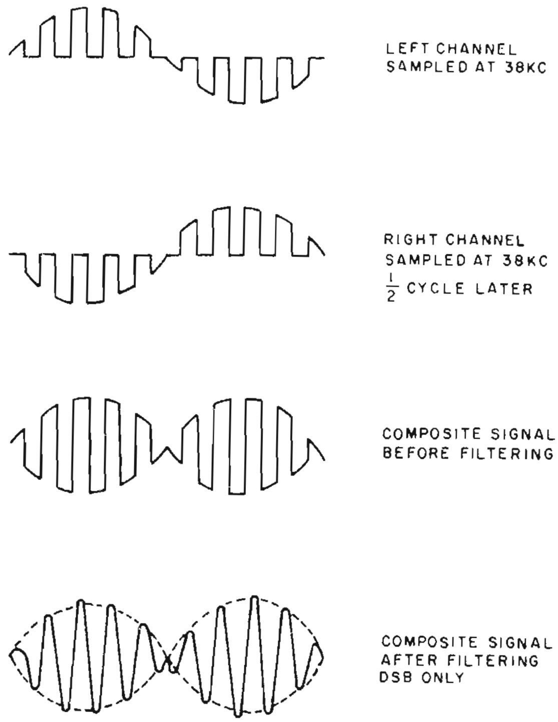

Fig. 6. Time division signal for left = minus right L + R = 0 L - R = 2.

of correct amplitude in all types of receivers. This sometimes creates a problem for stations engaging in AM and FM simulcast programing. Telephone line levels for remote transmitter situations prohibit the forming of a noise-free (L + R) signal to be used for the AM transmitter. In many instances, it proves best to form the AM audio at the console and use a third line for AM programing.

Phasing

Reversing the polarity of the Right channel results in a (L - R) signal, as shown in Fig. 6. Note that the average audio seen by a conventional receiver is zero. This characteristic of the signal furnishes a convenient method of checking the phasing through a system. Using a monaural record on a stereo turntable, the audio lines should be reversed until the loudest audio signal is heard in a monaural receiver. The system is then phased correctly. In a stereo system, the sound should appear to come from a source directly forward of the listener if the record is monaural. If phased incorrectly, the sound will appear to come more from the side, due to some audio cancellation occurring at the ear of the listener. Phasing presents a continuous console problem in day-to-day operation of stereo. It is a requirement that the console operator generally overlooks until the listener complains. It should be stated, however, that many modified stereo consoles present such a complexity to the operator as to require considerable time to master.

Transmitter

There are some basic principles regarding the tighter requirements made on the transmitter. The chopped signal drawn in Fig. 4 consists of two components. One, referred to as the average signal, is an audio component similar to the modulating signal but 6 dB below the peaks of the chopped signal. The second is a double-sideband signal very similar to the (L - R) signal in Fig. 6, with peak excursions of the same amplitude as the audio signal just mentioned. In fact, these signals must maintain peak amplitudes that are equal within 0.3 dB to meet FCC specifications on channel separation. An inequality will show up as an overshoot or undershoot (as in Fig. 4c) on the baseline. Disregarding pilot carrier phase requirements, *the channel separation of any system can be determined by examining this baseline overshoot at the discriminator of a wide band receiver.* Such an overshoot will occur if the amplitudes are not equal and also if the phase of the two components is not precisely correct. The stability of the stereo signal places a tight requirement on phase and amplitude of the audio circuits used to create the signal. It is almost mandatory, for instance, that dc coupling be used between the stereo generator and the modulator.

The synchronizing signal at 19 kHz, the pilot carrier, furnishes the "kick" for the switch in the transmitter and aids the receiver in decoding the L and R channels. Fig. 7 is a picture of an actual

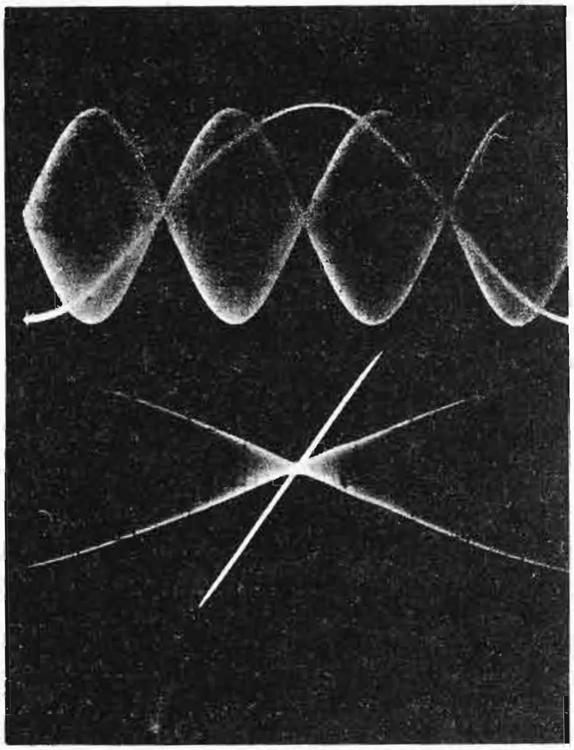

Fig. 7. (A) DSB signal and pilot carrier. (B) DSB signal and pilot carrier expand around the zero crossing.

(L - R) signal (similar to Fig. 6) which was taken in such a way that the audio modulation "fills in" the time slots. Superimposed on this signal is the

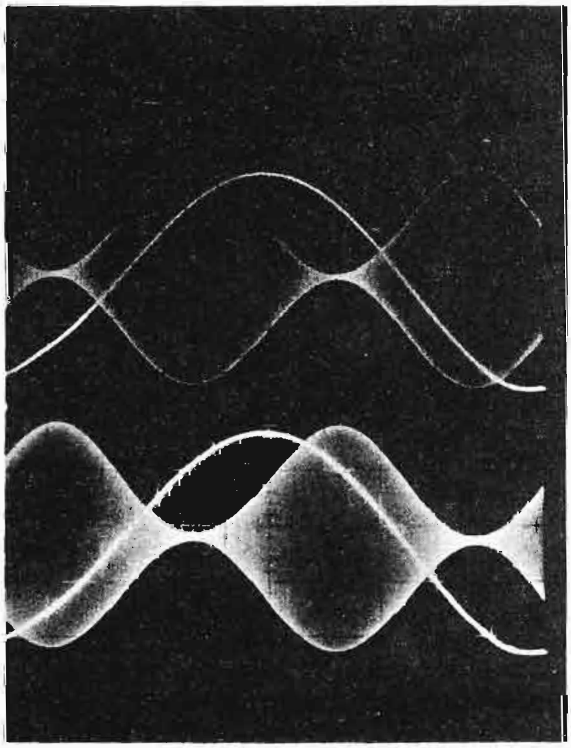

Fig. 8. (A) Left-only signal and pilot carrier. (B) Right-only signal and pilot carrier.

19-kHz pilot carrier. Fig. 7b shows, in expanded sweep, how closely the pilot must be in phase with the zero crossings of the 38-kHz oscillator. The pilot must be within $\pm 3°$ or 1 division on the lower scale to satisfy FCC requirements.

Fig. 8 demonstrates how pilot carrier phase determines that a channel is Left or Right. As stated in the FCC rules, the Left channel is defined as the channel where the 38-kHz zero crossings are positive-going with a positive-going pilot carrier. Fig. 8 represents an expanded version of Fig. 4. Again, modulation fills in the picture, but the signal shown is different from the (L - R) type in that there are no sharp criss-crosses on the baselines. The positive-going zero crossings of the 38-kHz sideband signal can be identified as occurring midway between the valley and the peak of the signal on the left side of the picture. Note that the pilot carrier crosses the zero axis positively at this point. In contrast, the pilot signal is out-of-phase with a positive-going right signal. Since there are two time slots for each cycle of the pilot, only the positive-going portion of the pilot carrier should be studied to avoid confusion. From the theory, it becomes apparent that the method used to generate the stereo signal determines reliability. A four-diode switching circuit accomplishes this in short order (see Fig. 9). Twelve passive, precision components are used to create a stereo audio signal for a wideband modulator. Stability of this signal is dependent only on these components if the exciter is sufficiently stable.

To answer the need for stereo, a wide-band modulator was designed for this time division signal. The principles involved in this modulator-exciter require some detail to explain, but it is sufficient to state that the following objectives are met:

1. The modulator accepts any audio signal from 30 Hz to 75,000 Hz on a single input.
2. The inherent distortion is kept below 0.3 percent at these frequencies.
3. The frequency response is within ± 0.1 dB between 50 Hz and 53 Hz.

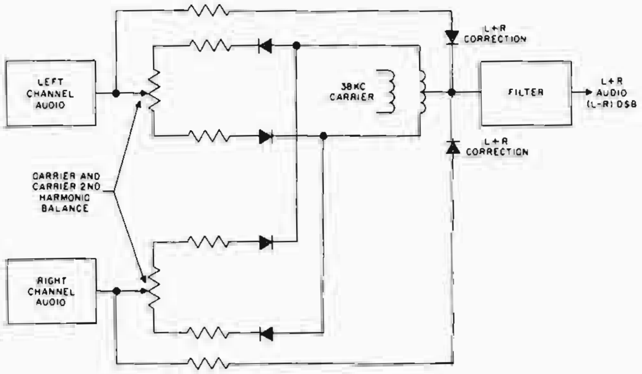

Fig. 9. Stereo generator switching circuit.

4. Frequency stability, including aging, will hold within ±500 Hz of assigned carrier under normal conditions; ±1,000 Hz under the worst conditions of age and environment.

Audio

A proper studio console for stereo considerably reduces production problems in all types of programing. A vital need in the console is to keep the important controls to a minimum to avoid shifting standards of balance and separation during the normal program day. In remote operation, telephone line levels must be matched at the transmitter by adjusting console levels with test tones and left untouched except for periodic checks. Every source must be checked for balance, that is, tape recorders, turntables, microphones. Modulation during programing should be watched by monitoring the outgoing telephone lines with VU meters. Additional remote control features should be added (stereo-mono switch). To achieve close balance, part of the audio circuits should be continuously variable instead of the step-type attenuation frequently used.

Limiters should be installed on each stereo channel. Limiting should be *used sparingly* because program material varies. Stereo performance can be affected by excessive limiting, but a good peak limiter can control modulation where broadcast monitors fail to report true modulation. If possible, the pre-emphasis should be ahead of the limiter to compress high frequencies equally with the lows. There are a number of stereo audio processors which incorporate pre-emphasis as an integral part of their circuit design.

Noticeable also has been the effect of excessive limiting on the mono version of the stereo signal. If the sound is full in one channel and bare in the other, a hiss is introduced by the unused limiter introducing full gain to the system under a maximum limiting condition. The mono listener also may notice a variation of volume level as the monaural version of the stereo signal goes in and out of limiting. The limiters, while providing constant volume in one channel, will be switching between channels as the virtual image of the sound goes from one channel to the other. Elements of the stereo signal under a maximum limiting condition will vary in level and will prove annoying to the mono listener.

Coverage

Stereo coverage of a station, unfortunately, is less than its monaural counterpart. Part of this is involved in the increased use of bandwidth without a corresponding increase in modulation. Because of this and the type of system chosen, background noise increases by 20 dB in the stereo channels over the corresponding noise in the mono (L + R) channel. Such a noise increase is noticeable in receivers with poor limiting characteristics in weak signal areas. As a general rule, reliable reception in stereo occurs out to the 1-mv contour. Beyond that, reception is a function of receiver and antenna characteristics, and listeners should be asked to use good outside antennas in these areas. High quality receivers can produce acceptable stereo at much lower field strengths than 1 mv/m.

The Stereo Record

Stereophonic recordings involve two separate channels of information. In order to achieve the acoustical perspective, depth, spaciousness, and other benefits that are possible, great care must be observed to maintain the proper phase relationship between the two channels of information, both in recording and reproduction. The same care must be observed in FM stereo broadcasting. This is particularly true because the transmission may be reproduced either stereophonically or monophonically, and it is essential that the quality of reproduction be the best possible in either case.

The 45°-45° stereophonic system chosen by the Record Industry Association of America (RIAA) as a standard was selected after careful consideration of the available systems. It was selected, for one reason, because of the compatibility that can be achieved with respect to monophonic reproduction. To achieve this, the RIAA standard states:

> In 45°-45° stereophonic disc phonograph records, equal and in-phase signals in the two channels shall result in lateral modulation of the groove.

As illustrated in Fig. 10 for the 45°-45° system, the two channels of information are recorded in a single groove with the modulation axis of the two systems at right angles with respect to each other, and 45° with respect to the surface of the record. The diagrams at the left and right, A and B, show the type of groove obtained when an identical signal is applied to the left and right coils separately and then together. It is important to note that in Fig. 10c vertical modulation results if the signals are equal in amplitude but out of phase. Likewise, Fig. 10d shows that lateral

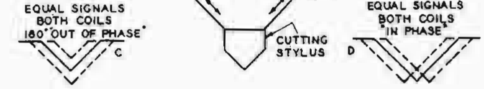

Fig. 10. 45°-45° stereo disc recorder.

modulation results if the two signals are equal and inphase.

In terms of record reproduction, if in the case of 10d the recording is reproduced with a suitable lateral pickup, information from both channels will be present. The sound quality will be like that of a monophonic record that had been cut with a lateral recorder where the signals had been obtained by combining the output of the two channels electrically. If the phase is reversed, as is the case shown in Fig. 10c, the modulation of the groove will be vertical and the results will be poor due to cancellation of the lateral components.

The problem of correct phasing is similar to that which must be observed in stereophonic broadcasting where monophonic reproduction is the sum of the left and right (L and R) channels. The phase relationship is of importance since an incorrect phasing will result in considerable cancellations, particularly at low frequencies. Only if the proper phasing has been observed will the sound quality be satisfactory.

Evaluating Stereophonic Records

A simple method of judging the monophonic quality of a stereophonic record is to reproduce it monophonically. This may be achieved by using a suitable lateral pickup and reproducing the record over a single channel amplifier and speaker system. By suitable is meant a pickup designed for monophonic record reproduction,one that has sufficient vertical compliance to properly track the vertical undulations of a stereophonic record without undue distortion or damage to the groove. A stereophonic pickup with the output leads tied together for monophonic reproduction provides a ready means of providing such a pickup.

Another method and one that might offer greater appeal to the broadcaster is to combine the outputs of the two pickup channels at the outputs of some of the amplifiers along the chain. When doing this, there may be some question about the channel gains and the phase relationship. These may be easily checked by playing a lateral frequency record. The VU meter readings for each channel should be equal. If the phase relationships are incorrect, the single VU meter that reads the combined outputs will show a drop in output as the channels are connected together.

The cancellation of signals due to improper phase relationship when reproducing music records results in a loss in the low frequencies and undesirable high frequency characteristics. When the phase and gain relationships are correct, a properly recorded stereo record will show nearly undetectable tonal balance differences between monophonic and stereophonic reproduction. The stereo reproduction will, of course, exhibit acoustical perspective, depth and spaciousness due to the additional information since it is derived from two channels instead of one.

Phase Checking Methods

Realizing the importance of observing and maintaining the proper phase between the stereo channels, a logical question that arises is: How can one check the phase relationship? Ideally, the two channels should be exact duplicates throughout their operating range. Frequency and phase response should match closely. In general, the phase relationship is the most difficult one to measure. However, with the aid of an audio oscillator and an oscilloscope, simple observations can be made that will determine whether or not the connections are inphase.

If an audio oscillator is connected to an oscilloscope, as illustrated in Fig. 11, with the high side of the oscillator connected to both high side terminals of the oscilloscope, a straight line inclined at a 45° angle to the right should be observed. Since this is a common signal equal in amplitude that is being applied to the oscilloscope, it is obviously the inphase condition. If two signals of the same frequency and amplitude were applied 180° out of phase, a 45° line would be observed which would slope towards the left. A 90° phase shift would result in a circle.

The oscillator and oscilloscope provide a simple set of tools for determining the "in" or "out" of phase conditions. They may be used for microphones and loudspeakers as well as amplifiers. The arrangements for such measurements are shown in Figs. 12, 13, and 14. When acoustic

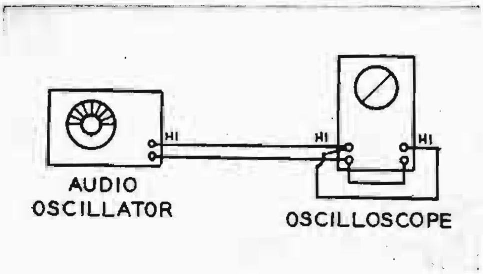

Fig. 11. Phase indicator.

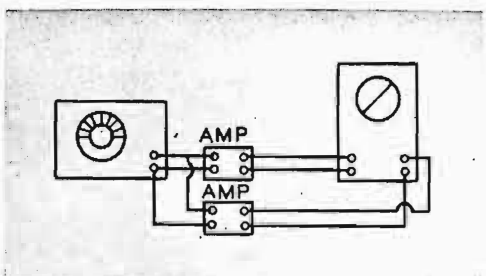

Fig. 12. Checking amplifiers.

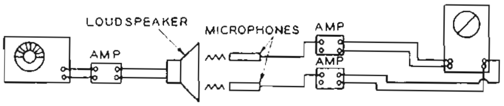

Fig. 13. Checking microphones.

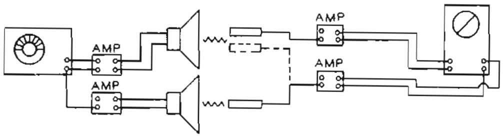

Fig. 14. Checking loudspeakers.

transmission is involved, a low frequency such as 200 Hz should be used to minimize phase differences due to the transmission of the signal through air. When checking loudspeakers as illustrated in Fig. 14, a quick check of the system can be made by first placing both microphones in front of one loudspeaker and noting the trace on the oscilloscope. The same trace should result when the microphone is shifted back to its original position. For checking the phase relationship of high frequency speakers, EIA recommends that direct current be used and the direction of motion of the diaphragm be observed, or a sensitive dc meter be connected across the terminals and the polarity of the voltage noted when the diaphragm is moved manually.

36

Remote Control of Broadcast Stations

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One of the modern operating techniques associated with broadcast stations is the remote control of transmitters. In 1953, the Federal Communications Commission first authorized nondirectional stations up to and including 10 kw to operate by remote control. During 1957, the Commission, at the request of the National Association of Broadcasters (NAB), amended its rules and extended remote control privileges to all types of standard and FM broadcast stations regardless of power or mode of operation. In May of 1963, the Commission, on its own motion, amended Part 73 of the rules to permit the remote control of UHF television transmitting facilities. On May 17, 1971, again at the request of the NAB, the rules were once again amended to permit the remote control of all television transmitting facilities regardless of frequency or type of operation. This final enactment by the FCC now permits the remote control of all types of broadcast transmitters irrespective of the service.

It is the purpose of this chapter to outline the necessary documents that must be submitted to the Federal Communications Commission when applying for remote control authorization and to discuss in general the various applications of remote control systems. To help the reader understand the proper procedure in applying for and utilizing remote control systems, the FCC rules and FCC Form No. 301-A is included in this chapter.

FCC RULES GOVERNING REMOTE CONTROL

AM Broadcasting

73.66 Remote Control Authorization

(a) An application to operate a station by remote control, to add a remote control point, or to change the location of a remote control point shall be made on FCC Form 301-A, except that:

(1) A request to operate a new station with nondirectional antenna by remote control may be included in the application (FCC Form 301) for construction permit or modification of construction permit.

(2) A request to change a remote control point to a new main studio location beyond the corporate limits of the community to which the station is assigned and at a point other than the authorized transmitter site may be included in the application (FCC Form 301) for authority to change the main studio location.

(3) No application need be filed to change a remote control point to an authorized main studio location within the corporate limits of the community to which the station is assigned or to its authorized transmitter site, or to delete a remote control point. However, any such change shall be reported promptly to the Commission, and to the Engineer-in-Charge of the radio district in which the station is located.

(b) An authorization for remote control will be issued only after a satisfactory showing has been made which includes the following:

(1) The location of remote control point(s).

(2) That the directional antenna system, if such is authorized, is in proper adjustment and is stable.

(c) Stations employing directional antennas and operated by remote control shall make a skeleton proof of performance each year. This skeleton proof shall consist of at least three field strength measurements on each of the radials established in the latest complete adjustment of the directional antenna system. These measurements shall be made at measurement locations utilized in such adjustment, and if the radial includes a monitoring point, as designated in the station authorization, one of the measurements shall be made at that point. The results of these measurements must be submitted with the station's license renewal application.

73.67 Remote Control Operation

(a) Operation by remote control shall be subject to the following conditions:

(1) The equipment at the operating and transmitting positions shall be so installed and

protected that it is not accessible to or capable of operation by persons other than those duly authorized by the licensee.

(2) The control circuits from the operating positions to the transmitter shall provide positive on and off control and shall be such that open circuits, short circuits, grounds or other line faults will not actuate the transmitter and any fault causing loss of such control will automatically place the transmitter in an inoperative position.

(3) A malfunction of any part of the remote control system resulting in improper control shall be cause for the immediate cessation of operation by remote control. A malfunction of any part of the remote control system resulting in inaccurate meter readings, shall be cause for terminating operation by remote control no longer than 1 hour after the malfunction is detected.

(4) Control and monitoring equipment shall be installed so as to allow the licensed operator at the remote control point to perform all the functions in a manner required by the Commission's rules.

(5) Calibration of required indicating instruments at each remote control point shall be made against the corresponding instruments at the transmitter site at least once each calendar week. Results of calibrations shall be entered in the maintenance log. Remote control point meters shall be calibrated to provide an indication within 2 percent of the corresponding instrument reading at the transmitter site. In no event shall a remote control meter be calibrated against another remote meter.

(6) All remote control meters shall conform with specifications prescribed for regular transmitter, antenna, and monitor meters.

(7) Meters with arbitrary scale divisions may be used provided that calibration charts or curves are provided at the transmitter remote control point showing the relationship between the arbitrary scales and the reading of the main meters.

(b) All stations, whether operating by remote control or direct control, shall be equipped so as to be able to follow the Emergency Action Notification procedures described in Sec. 73.911.

(c) The broadcast transmitter carrier may be amplitude modulated with a tone for the purpose of transmitting to the remote control point essential meter indications and other data on the operational condition of the broadcast transmitter and associated devices, subject to the following conditions:

(1) The tone shall have a frequency no higher than 30 Hz.

(2) The amplitude of modulation of the carrier by the tone shall not be higher than necessary to effect reliable and accurate data transmission, and shall not, in any case, exceed 6 percent.

(3) The tone shall be transmitted only at such times and during such intervals that the transmitted information is actually being observed or logged.

(4) Measures shall be employed to insure that during the periods the tone is being transmitted the total modulation of the carrier does not exceed 100 percent on negative peaks.

(5) Such tone transmissions shall not significantly degrade the quality of program transmission or produce audible effects resulting in public annoyance.

(6) Such tone transmissions shall not result in emissions of such a nature as to result in greater interference to other stations than is produced by normal program modulation.

FM Broadcasting

73.274 Remote Control Authorization

(a) An application to operate a station by remote control, to add a remote control point, or to change the location of a remote control point shall be made on FCC Form 301-A, except that:

(1) A request to operate a new station by remote control may be included in the application (FCC Form 301) for construction permit or modification of construction permit.

(2) A request to change a remote control point to a new studio location beyond the corporate limits of the community to which the station is assigned and at a point other than the authorized transmitter site may be included in the application (FCC Form 301) for authority to change the main studio location.

(3) No application need be filed to change a remote control point to an authorized main studio location within the corporate limits of the community to which the station is assigned or to its authorized transmitter site, or to delete a remote control point. However, any such change shall be reported to the Commission and to the Engineer-in-Charge of the radio district in which the station is located.

(b) An authorization for remote control will be issued only after a satisfactory showing has been made, including, among other things, the location of the remote control point(s).

73.275 Remote Control Operation

(a) Operation by remote control shall be subject to the following conditions:

(1) The equipment at the operating and transmitting positions shall be so installed and protected that it is not accessible to or capable of operation by persons other than those duly authorized by the licensee.

(2) The control circuits from the operating position to the transmitter shall provide positive

on and off control and shall be such that open circuits, short circuits, grounds or other line faults will not actuate the transmitter and any fault causing loss of such control will automatically place the transmitter in an inoperative position.

(3) A malfunction of any part of the remote control system resulting in improper control shall be cause for the immediate cessation of operation by remote control. A malfunction of any part of the remote control system, resulting in inaccurate meter readings, shall be cause for terminating operating by remote control no longer than 1 hour after the malfunction is detected.

(4) Control and monitoring equipment shall be installed so as to allow the licensed operator at the remote control point to perform all the functions in a manner required by the provisions of this part.

(5) Calibration of required indicating instruments at each remote control point shall be made against the corresponding instruments at the transmitter site at least once each calendar week. Results of calibration shall be entered in the maintenance log. Remote control point meters shall be calibrated to provide an indication within 2 percent of the corresponding instrument reading at the transmitter site. In no event shall a remote control meter be calibrated against another remote meter.

(6) All remote control meters shall conform with specifications required for the regular transmitter, antenna, and monitor meters.

(7) Meters with arbitrary scale divisions may be used provided that calibration charts or curves are provided at the transmitter remote control point showing the relationship between the arbitrary scales and the reading of the main meters.

(b) All stations, whether operating by remote control or direct control, shall be equipped so as to be able to follow the Emergency Action Notification procedures described in Sec. 73.911.

Television Broadcasting

73.676 Remote Control Operation

(a) Television broadcast stations authorized to operate by remote control shall provide, as a minimum, the following telemetry, control, and test functions at the control point:

(1) Means for turning the transmitter on and off at will.

(2) Suitable instruments for indicating the operating parameters which are required by Section 73.671 to be entered in the operating log. The indicating instruments shall show the actual values of such parameters, or decimal multiples of those parameters with no less accuracy than that specified in Section 73.688 for the indicating instruments employed at the transmitter. Any decimal multipliers applicable must be set forth in a tabulation posted at the operating position if manual logging is employed; on an automatically printed log the tabulation must be imprinted at least once for each calendar day. These requirements do not apply to instruments which show the values of operating parameters (e.g., grid drive, plate current and voltage of intermediate stages) which the rules do not require be logged, and instruments that indicate the condition of obstruction lighting.

(3) A sufficient number of control circuits to perform all transmitter adjustments are normally required on a daily basis to insure strict compliance with the technical requirements of the rules.

(4) Apparatus designed to use the signal radiated from the antenna, or fed from the antenna circuit by a coaxial link, and suitable for continuously and accurately monitoring the waveform and other characteristics of the transmitted visual signal including the percentage of modulation of the signal (a vectorscope or other instrument designed to depict the instantaneous phase and amplitude relationships of color components shall be provided, if any portion of the transmissions are in color). The apparatus shall be capable of providing both full field displays, and displays of test signals inserted on selected lines in the vertical blanking interval (see Section 73.682 (a) (22)); appropriate switching shall be provided so that either mode of presentation can be selected by the operator.

(5) A type approved aural modulation monitor, equipped, where necessary, with a properly designed signal frequency amplifier, which utilizes the signal radiated from the antenna, or obtained from the antenna circuit by a coaxial link, and is capable of continuously and accurately indicating the peak and quasi-peak percentages of modulation of the aural signal.

(6) Suitable instruments for generating special signals for the testing and adjustment of the entire transmission system from studio to antenna and the calibration of monitoring equipment, in accordance with paragraphs (f) and (g) of this section.

(7) Means for determining that any required obstruction lighting of the antenna and supporting tower is functioning properly.

(8) All stations, whether operating by remote control or direct control, shall be so equipped as to be able to follow the Emergency Action Notification procedures described in Section 73.911.

(b) The control point shall be under the immediate supervision and control of one or more operators meeting the requirements of Section 73.661 at all times when the station is operating by remote control. Such operators may perform other tasks which do not require absence from the remote control position, and do not otherwise impair necessary supervision of the TV transmitter.

(c) The control circuits from the control point to the transmitter and the return telemetry circuit shall be so designed and installed that open circuits, short circuits, accidental grounding or other line faults, where wire lines are used, or equipment failures, casual signals or random noise impulses, if other means are used, will not activate the transmitter. Any fault or failure which results in loss of control must cause the transmitter to cease operation. The loss of any telemetry function which provides information necessary to comply with the logging requirements of Section 73.671 shall result in the actuation of automatic circuitry which, not more than 1 hour from the time of telemetry failure, will terminate operation of the transmitter.

(d) The equipment at the control point and at the transmitter shall be so installed and protected as not to be accessible to or capable of being operated by persons other than those duly authorized to do so by the licensee.

(e) The waveform monitor at the remote control point shall be calibrated against a waveform monitor maintained at the transmitter during each inspection required by paragraph (g) of this section. Any calibration data found necessary to permit accurate interpretation of the indications of the remote monitor shall be posted at the remote control point in a position adjacent to the monitor.

(f) Test signals shall be generated and inserted in the vertical interval of the visual signal at the remote control point, and shall be observed at the remote control point after extraction from the radio frequency signal at the output of the transmitter. Normally, the radiated signal is utilized after off-the-air reception, but the signal may be obtained by coupling to the output circuit of the transmitter at the point where the radio frequency signal enters the antenna transmission line.

(1) The required test signals, and the place of insertion in the vertical interval shall be as follows:

(i) Multiburst, on field 1, line 18 (see Fig. 13 of 73.699).

(ii) Color bars, on field 2, line 18 (see Fig. 14 of 73.699). During monochrome transmission chrominance information shall not be included in this test signal.

(iii) Composite signal, on field 1, line 19 (see Fig. 15 of 73.699).

(iv) Generally, a composite signal of characteristics identical to those prescribed in subdivision (iii) of this subparagraph, shall be inserted on field 2, line 19, at the remote control point. However, to permit a separate determination to be made of the effects of the transmitter and the studio transmitter link on system performance, the composite signal on field 2, line 19 may be inserted at the transmitter input. Alternatively, in lieu of the composite signal, a licensee may insert any suitable test signal on field 2 of line 19, either at the remote control point or at the transmitter. When such signals are transmitted at the same time as program material and/or the required test signals, the characteristics of the licensee-selected signals shall be such as to minimize the possibility that their transmission will result in interference with the required test signals, or in degradation of the picture or sound signals.

Figs. 6 and 7 of 73.699 identify the numbered lines and fields referred to in this subparagraph.

(2) The required test signals shall be transmitted continuously during all periods of regular station operation.

(3) The required test signals shall be observed immediately after commencement of operation, and thereafter at intervals not exceeding 3 hours. More frequent observations shall be made as necessary to insure proper performance of the transmitter and associated equipment.

(4) The date and time of each observation of the test signals shall be entered in the operating log, together with notations as to the results of these observations.

(5) Any signals or noise already existing on lines 18 and 19 (e.g., network test signals), shall be erased prior to the insertion in the vertical interval of locally generated test signals.

(g) The remote control and monitoring equipment shall be calibrated and tested and the television broadcast transmitter shall be inspected as often as is necessary to insure operation in accordance with the rules in this Subpart E; in any event at least 5 days each week, with an interval of not less than 12 hours elapsing between successive inspections, provided, however, that the required calibration, testing and inspection may be made at successive times no longer than 1 week apart if the station is equipped with such additional transmitting and/or switching facilities as may be necessary to insure that malfunctioning of the main visual or aural transmitters shall not preclude continued operation at a transmitter power output level of not less than 20 percent of the authorized output power of the malfunctioning transmitter. The facilities required for such continued operation shall be activated automatically by the malfunctioning of the main transmitter, or manually from the remote control point.

Note: Until April 30, 1974, noncommercial educational television broadcast stations on channels 14-70 operating by remote control may calibrate, test, and inspect their equipment at successive times not longer than 1 week apart, without having installed those additional transmitting and/or switching facilities whose availability is required in paragraph (g) as a condition precedent to the adoption of such a schedule.

(h) Upon completion of the calibration, testing, and inspection required by paragraphs (e) and (g) of this section, the inspecting operator shall enter a signed statement in the maintenance log that the required tests and inspection have been made, noting in detail the tests, adjustments, and repairs which were made to insure proper operation, and shall specify the amount of time, exclusive of travel time to and from the transmitter, which was devoted to this task. If complete repair could not be effected, the statement shall set forth in detail the items of equipment concerned, the nature of the defect and the reasons for failure to make the needed repairs.

Note: Subject to the specific exception set forth in the note appended to paragraph (g), all television broadcast stations on Channels 14-70 authorized to operate by remote control prior to April 30, 1971, and not meeting all of the requirements of this section, are afforded a period of 1 year in which to achieve full compliance. On or before April 30, 1972, all such stations shall file new remote control applications, FCC Form 301-A, supplying all information required by Section 73.677, and upon a grant thereof, operate in accordance with this section.

73.677 Remote Control Authorization

(a) An application to operate a television broadcasting station by remote control, to add a remote control point, or to change the location of a remote control point shall be made on FCC Form 301-A. The application shall include the following information:

(1) The location of the control point, the reason for its choice if at other than the main studio, and the approximate airline distance from the control point to the television broadcast transmitter site.

(2) The number and purpose of the control and telemetry functions that will be provided at the control point.

(3) The method by which control functions will be transmitted to the television transmitter.

(4) The method by which telemetry data required by the rules will be transmitted from the television transmitter to the control point.

(5) A description of the fail-safe features of the remote control system which will insure that loss of either required control or telemetry will place the television transmitter in a nonradiating condition, pursuant to Section 73.676(c).

(6) Measures taken to prevent tampering with or activation of transmitting and remote control equipment by unauthorized persons.

(7) A desciption of all apparatus maintained for off-the-air monitoring, with particular attention to features intended to insure that the demodulated visual signal is free from noise, interference, or from distortion introduced at the receiving point.

(8) A description of apparatus which will be maintained at the control point for the generation and reception of test signals, and of the apparatus employed for their insertion in and extraction from the vertical blanking interval.

(9) A description of any features of the transmitting plant intended to insure continuity of operation in the event of malfunctioning or failure of the main transmitter, and of the automatic or remote control switching arrangements to be utilized in connection therewith.

(10) A description of means employed or procedures which will be followed to make the daily frequency check required by Section 73.690(c).

(11) The method of determining, at the control point, that tower obstruction lighting is functioning properly.

(12) A description of the facilities maintained at the control point to permit compliance with Section 73.911.

PREPARING FCC FORM 301-A

Nondirectional AM and FM

The remote control application for stations in this category is relatively simple. The application should be filed on FCC Form No. 301-A. Note that for this type of station, only Items 1 through 5 on page 1 and all of page 2 need be completed. The remaining items and pages of the form pertain to either directional or television stations. The information required is not complicated and can, in most cases, be completed by the stations technical personnel. They should of course be familiar with the pertinent provisions of the Commission's rules as set forth previosuly in this chapter. Installation of the equipment may be accomplished by station personnel or by the manufacturer and no FCC Certification or Type Approval is required. The equipment must of course be installed in a manner that complies with the general safety and fire underwriters code, and must be in compliance with Section 73.93 of the rules which states as follows:

The transmitter and required monitors and metering equipment, or the required extension meters and monitoring equipment and other required metering equipments or the controls and required monitoring and metering equipment in an authorized remote control operation, shall be readily accessible to the licensed operator and located sufficiently close to the normal operating locations that deviations from normal indications of required instruments can be observed from that location.

FCC FORM 301-A
JULY 1971

FORM APPROVED
BUDGET BUREAU NO. 52.R0145

(THIS SPACE FOR COMMISSION USE ONLY)

SECTION I

UNITED STATES OF AMERICA
FEDERAL COMMUNICATIONS COMMISSION

APPLICATION FOR AUTHORITY TO OPERATE A BROADCAST STATION BY REMOTE CONTROL OR TO MAKE CHANGES IN A REMOTE CONTROL AUTHORIZATION

INSTRUCTIONS

A. This form is to be used only by the licensees or permittees of Standard, FM (commercial and non-commercial) and Television (commercial and non-commercial) Broadcast Stations. This form consists of this Section I and the following sections: Section II, Standard Broadcast Station Directional Antenna Information; Section III, Television Broadcast Station Information.

B. Use *separate* application form for *each type* of broadcast station.

C. Prepare three copies of this form and all exhibits, and forward all copies to the Federal Communications Commission, Washington, D. C. 20554.

D. Number exhibits serially in the space provided in the body of the form and list each exhibit in the space provided on page 2.

E. This application must be executed by applicant, if an individual; by a partner of applicant, if a partnership; by an officer of applicant, if a corporation or association; or by attorney of applicant only under conditions shown in Section 1.303, Practice and Procedure, in which event satisfactory evidence of disability of applicant or his absence from the Continental United States and authority of attorney to act must be submitted with application.

F. Before filling out this application, the applicant should familiarize himself with the provisions of Part 73 of the Commission's Rules and Regulations dealing with remote control of the particular type of broadcast station for which this application is being filed.

G. BE SURE ALL NECESSARY INFORMATION IS FURNISHED AND ALL PARAGRAPHS ARE FULLY ANSWERED. IF ANY PORTIONS OF THE APPLICATION ARE NOT APPLICABLE, SPECIFICALLY SO STATE. DEFECTIVE OR INCOMPLETE APPLICATIONS MAY BE RETURNED WITHOUT CONSIDERATION.

1. Name of licensee or permittee:

2. Mailing address:

Street

City	State	ZIP Code

3. Identification of existing station:

Call Sign (If unassigned, state file number)

Station location (community of license)

City	State

4. Facilities proposed to be operated by remote control:

NOTE: Only facilities for which station holds an outstanding authorization or for which an application is pending may be specified. (Check all appropriate boxes)

(a) ☐ STANDARD BROADCAST TRANSMITTER(S):

☐ Main Non-DA ☐ Auxiliary Non-DA
☐ Main DA-D ☐ Auxiliary DA-D
☐ Main DA-N ☐ Auxiliary DA-N
☐ Main DA-CH ☐ Auxiliary DA-CH
☐ Alternate Main ☐ Other (Specify): ____________

(b) ☐ FM BROADCAST TRANSMITTER(S):

☐ Main ☐ Alternate Main ☐ Auxiliary

Other (Specify): ____________

(c) ☐ TELEVISION BROADCAST TRANSMITTER(S):

☐ Main ☐ Alternate Main ☐ Auxiliary
☐ Auxiliary Transmitter and Auxiliary Antenna (Check this box only where auxiliary facilities are authorized for location at other than main transmitter site.)

☐ Other (Specify): ____________

5. Request is hereby made for authority to establish a remote control point as follows (this is the point from which the transmitter is controlled):

a. ____
(Street address (or other identification)) *(City)* *(State)* *(ZIP Code)*

b. Airline distance between transmitter and remote control point: miles.

c. Is proposed remote control point located at the main studio? YES ☐ NO ☐

If answered "No" submit as Exhibit No. giving reasons for its separate location.

FCC Form 301-A Section I, Page 2

THE APPLICANT certifies that remote control operation will be in accordance with the Commission's Rules and Regulations.

THE APPLICANT hereby waives any claim to the use of any particular frequency or of the ether as against the regulatory power of the United States because of the previous use of the same, whether by license or otherwise, and requests an authorization in accordance with this application. (See Section 304 of the Communications Act of 1934.)

THE APPLICANT represents that this application is not filed for the purpose of impeding, obstructing, or delaying determination on any other application with which it may be in conflict.

THE APPLICANT acknowledges that all the statements made in this application and attached exhibits are considered material representations and that all the exhibits are a material part hereof and are incorporated herein as if set out in full in the application.

CERTIFICATION

I certify that the statements in this application are true, complete, and correct to the best of my knowledge and belief, and are made in good faith.

Signed and dated this ____ day of ____________, 19 ____

INCLUDE FILING FEE WITH THIS APPLICATION.
SEE PART 1 OF FCC RULES FOR AMOUNT OF FEE.

____
(Name of Applicant)

WILLFUL FALSE STATEMENTS MADE ON THIS FORM ARE PUNISHABLE BY FINE AND IMPRISONMENT. U. S. CODE, TITLE 18, SECTION 1001.

By ______________________________
(Signature)

Title ______________________________

If applicant is represented by legal counsel, state name and post office address:

EXHIBITS furnished as required by this form:

EXHIBIT NO.	SECTION AND PARA. NO. OF FORM	NAME OF OFFICER OR EMPLOYEE (1) BY WHOM OR (2) UNDER WHOSE DIRECTION EXHIBIT WAS PREPARED (SHOW WHICH)	OFFICIAL TITLE

I certify that I represent the applicant in the capacity indicated below and that I have examined the statement of technical information and that it is true to the best of my knowledge and belief.

Date ____________ Signature ______________________ Telephone ____________
(check appropriate box below) *(include Area Code)*

☐ Technical Director ☐ Consulting Engineer
☐ Registered Professional Engineer ☐ Chief Operator

FCC Form 301-A STANDARD BROADCAST STATION DIRECTIONAL ANTENNA INFORMATION Section II

1. Submit as Exhibit No. a statement describing the stability of the directional antenna system during the one-year period preceding this application. This statement shall include, but shall not be limited to, such information as the nature and degree of any adjustment required, the maintenance procedures followed and the adequacy of the present monitoring system to indicate changes in the operation of the array.

2. Antenna resistance and reactance measurement:

Antenna resistance and reactance are to be determined in accordance with the procedure described in Section 73.54(a)(b)(c) and (d) of the Rules.

Attach as Exhibit No. the information required to be supplied by Section 73.54(e) of the Rules.

3. Operating constants based on data in paragraph 2:

RF common point current without modulation for night power in amperes	RF common point current without modulation for day power in amperes
Actual measured common point resistance (in ohms) at operating frequency Night Day	Actual measured common point reactance (in ohms) at operating frequency Night Day

Currents and phases for directional operation:

TOWER	PHASE READING IN DEGREES		ANTENNA BASE CURRENT		Remote Indication of Antenna Current	
	NIGHT	DAY	NIGHT	DAY	NIGHT	DAY

4. Submit as Exhibit No. the weekly readings of field intensity at each monitoring point specified in the station license for the one-year period preceding this application. (Monthly readings will be acceptable where such readings are authorized.)

5. Submit as Exhibit No. the values for each of the following: (a) common point current; (b) base currents and their calculated ratios, expressed to at least three significant figures; (c) phase monitor sample currents or remote base currents and their calculated ratios; (d) phase indications; (e) final amplifier plate voltage; and (f) plate current. These values shall be those observed during the thirty-day period preceding this application, and the values shall be obtained from readings taken at approximately the same time.

6. Submit as Exhibit No. a partial proof of performance consisting of at least 10 measurements, including the point designated as a monitoring point, taken at a distance of from 2 to 10 miles from the antenna on each radial measured in connection with the last complete adjustment of the directional antenna system. These measurements shall be analyzed in accordance with Section 73.186 of the Rules.

7. REMARKS:

FCC Form 301-A — TELEVISION BROADCAST STATION INFORMATION — SECTION III

1. Purpose of Application (Check appropriate box):

- [ ] Initial remote control authorization
- [ ] Add additional remote control point(s)
- [ ] Change remote control point(s)
- [ ] Modify remote control system
- [ ] Add additional transmitter(s)
- [ ] Other (Specify): ________________

2. Furnish as Exhibit No. ______ responses and/or exhibits, as appropriate, for each of the items listed below, together with such block or schematic diagrams as may be necessary or desirable to fully disclose all aspects of proposed remote control system.

(a) State the number and purpose of the *control* and *telemetry* functions that will be provided at the control point.

(b) Describe the method by which *control* functions will be transmitted to the television transmitter(s).

(c) Describe the method by which *telemetry* data required by the Rules will be transmitted to the control point.

NOTE: If transmission of telemetry and alerting signals via a subcarrier on the aural carrier is proposed, state subcarrier frequency and make and type of subcarrier generating equipment. Also describe the means to be employed by which the level of subcarrier injection will be controlled and monitored (See Section 73.682(a)(23) of the Rules.)

(d) Describe the fail-safe features of the remote control system which will insure that loss of either the required *control* or *telemetry* functions will place the transmitter in a non-radiating condition.

(e) Describe measures proposed to prevent tampering or activation of transmitting and control equipment by unauthorized persons.

(f) Furnish a description, including make and type, of all major components of monitoring equipment proposed to be employed for off-the-air monitoring at the remote control point, such as visual and aural radio frequency amplifiers, visual demodulator, aural modulation monitor, vertical interval test signal encoder and decoder, and apparatus for observing the transmitted visual waveform. For any composite component whose performance is critical to the accurate functioning of the monitoring system, test data shall be furnished to demonstrate its adequacy.

(g) Describe the method by which the daily frequency checks required by Section 73.690(c) of the Rules will be made.

(h) Describe the method for determining at the remote control point that tower obstruction lighting, if required, is functioning properly.

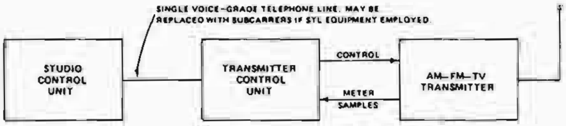
(i) Describe the facilities maintained at the remote control point to permit compliance with the Emergency Action Notification Procedures of Section 73.932 of the Rules.

3. Is it proposed to operate under the exceptional provisions of Section 73.676(g) of the Rules, which permits a minimum of one transmitter inspection per week? YES [ ] NO [ ]

If answered "Yes," fully describe the proposed emergency operating provisions, including the automatic or remote control switching arrangements, by which at least 20 percent of the authorized visual and aural transmitter operating output powers can be maintained in the event of failure of the main transmitters. See Section 73.676(g) of the Rules.

NOTE: Any alternate or auxiliary transmitting equipment proposed for this purpose must be either specified in an outstanding instrument of authorization or proposed in a pending application for construction permit for the station.

4. RFMARKS:



BLOCK DIAGRAM OF BASIC REMITE CONTROLLED INSTALLATION

Reference to Form No. 301-A will reveal the general nature and simplicity of the information required in the application.

Directional Stations

In addition to completing the necessary information required by nondirectional stations on pages one and two of Form No. 301-A applicants requesting the remote control of directional facilities must supply additional information pertaining to the operation and stability of the directional antenna system, which are as follows:

1. An exhibit describing the stability of the directional antenna system during the one-year period preceding the application.
2. A determination of antenna resistance and reactance measurement.
3. Directional antenna operating constants.
4. Weekly readings of field intensity at the monitoring points for a one-year period.
5. A 30-day review of antenna and transmitter operating parameters.
6. A partial proof-of-performance of the directional antenna system.

Television Stations

The completion of the television portion of FCC Form 301-A, as it pertains to authority to operate television facilities by remote control, is somewhat more detailed than the provisions pertaining to AM or FM. In addition to providing information concerning the remote control location, and other administrative details, the Commission requires complete and detailed information which graphically explains the proposed installation and method of control and the metering and fail-safe features of the remote control system. Set out below are examples for completing Section III of FCC Form 301-A as it pertains to the remote control of television transmitters. The examples shown are based upon the use of an RCA analog Model BTR-30A1 and the Moseley digital Model DRS-1A Digital Remote System with appropriate changes.

ANALOG REMOTE CONTROL

2. Furnish as Exhibit No. 1 responses and/or exhibits, as appropriate, for each of the items listed below, together with such block or schematic diagrams as may be necessary or desirable to fully disclose all apsects of proposed remote control system.

(a) *State the number and purpose of the control and telemetry functions that will be provided at the control point.*

Note: Although specific assignments of control and telemetry functions will depend on the specific transmitter equipment, the following is furnished as a guide. Part A is a list of suggested functions for a *single transmitter*, and Part B for a *dual transmitter*.

A. Single transmitter control and telemetry functions.

Function	*Control*	*Telemetry*
1.	Transmitter on/off	Visual PA Filament
2.	Plate on/off	Visual PA Plate Voltage
3.	Overload Reset	Visual PA Plate Current
4.	—	Aural PA Plate Current
5.	—	Aural PA Plate Voltage
6.	Visual Excitation Raise/Lower	Visual Output Power
7.	Video Level Raise/Lower	Visual Output Power
8.	Sync Gain Raise/Lower	Visual Output Power
9.	Aural Excitation Raise/Lower	Aural Power Output
10.	EBS on/off	Aural Power Output
11.	—	Visual VSWR
12.	—	Aural VSWR
13.	Tower Lights on/off	Tower Lights
14.-30.	Spare	Spare

B. Dual transmitter control and telemetry functions.

Function	*Control*	*Telemetry*
1.	Transmitter A on	A Visual PA Fil. Voltage
2.	Transmitter B on	B Visual PA Fil. Voltage
3.	Plate Voltage A on	A Visual PA Plate Voltage
4.	Plate Voltage B on	B Visual PA Plate Voltage
5.	Plate Voltage A off	A Aural PA Plate Voltage
6.	Plate Voltage B off	B Aural PA Plate Voltage
7.	Transmitter A off	A Visual PA Plate Current
8.	Transmitter B off	B Visual PA Plate Current
9.	Overload Reset A	A Aural PA Plate Current
10.	Overload Reset B	B Aural PA Plate Current
11.	Aural Excitation Raise/Lower	Total Aural Power
12.	—	A Aural Power
13.	—	B Aural Power
14.	Aural Power Balance Raise/Lower	Aural Reject Power
15.	—	Aural VSWR
16.	Visual Excitation Raise/Lower	Total Visual Power
17.	A Video Level Raise/Lower	Visual Reject Power
18.	—	A Visual Power
19.	B Video Level Raise/Lower	Visual Reject Power
20.	—	B Visual Power
21.	Combined Video Level Raise/Lower	Total Visual Power
22.	A Sync Level Raise/Lower	Visual Reject Power
23.	B Sync Level Raise/Lower	Visual Reject Power
24.	Combined Sync Gain Raise/Lower	Total Visual Power
25.	—	Visual VSWR
26.	Mode: A/B Parallel/EBS	Total Aural Power
27.	Mode: A Air - B Test B Air - A Test	 Total Aural Power
28.	Exciter Switchover Manual/Auto	—
29.	Exciter A/B	—
30.	Tower Lights on/off	Tower Lights

(b) *Describe the method by which control functions will be transmitted to the television transmitter(s).*

See Fig. 1a or 1b.

Control is accomplished with three audio tones, with frequencies of 920 Hz, 790 Hz, and 670 Hz. The 920 Hz tone is sent from the Studio Unit to the Transmitter Unit continuously, and is keyed off briefly to advance the stepping switch in the transmitter to select the dc sample voltage which is to be returned to the studio unit for metering or telemetry. It also selects the control channel. The number of positions the stepping switch advances is equal to the number of these brief interruptions. The control commands are actuated by depressing the raise or lower button on the Studio Unit. Depressing one of these buttons adds a second tone, 670 Hz for lower, 790 for raise, to the 920 Hz tone.

Note 1: For *wire line interconnection,* add the following:

A two-way, communications grade leased telephone line will be used to interconnect the Studio Control Unit, located at the studio control point, and the Transmitter Control Unit, located at the transmitter site. The leased line will have a maximum loss of 20 dB at frequencies from 650 Hz to 1,350 Hz.

Note 2: For transmission of control tones by STL microwave audio subcarrier, add the following:

These control tones will be transmitted from the Studio Control Unit, located at the studio control point, to the Transmitter Control Unit, located at the transmitter site, by means of an audio channel diplexed on the STL Microwave System. This diplexing will be achieved by frequency modulating an RF subcarrier at 6.8 MHz with the audio tones, and superimposing this modulated subcarrier upon the video signal for simultaneous transmission. The subcarrier will be demodulated at the transmitter site, and routed to the Transmitter Control Unit.

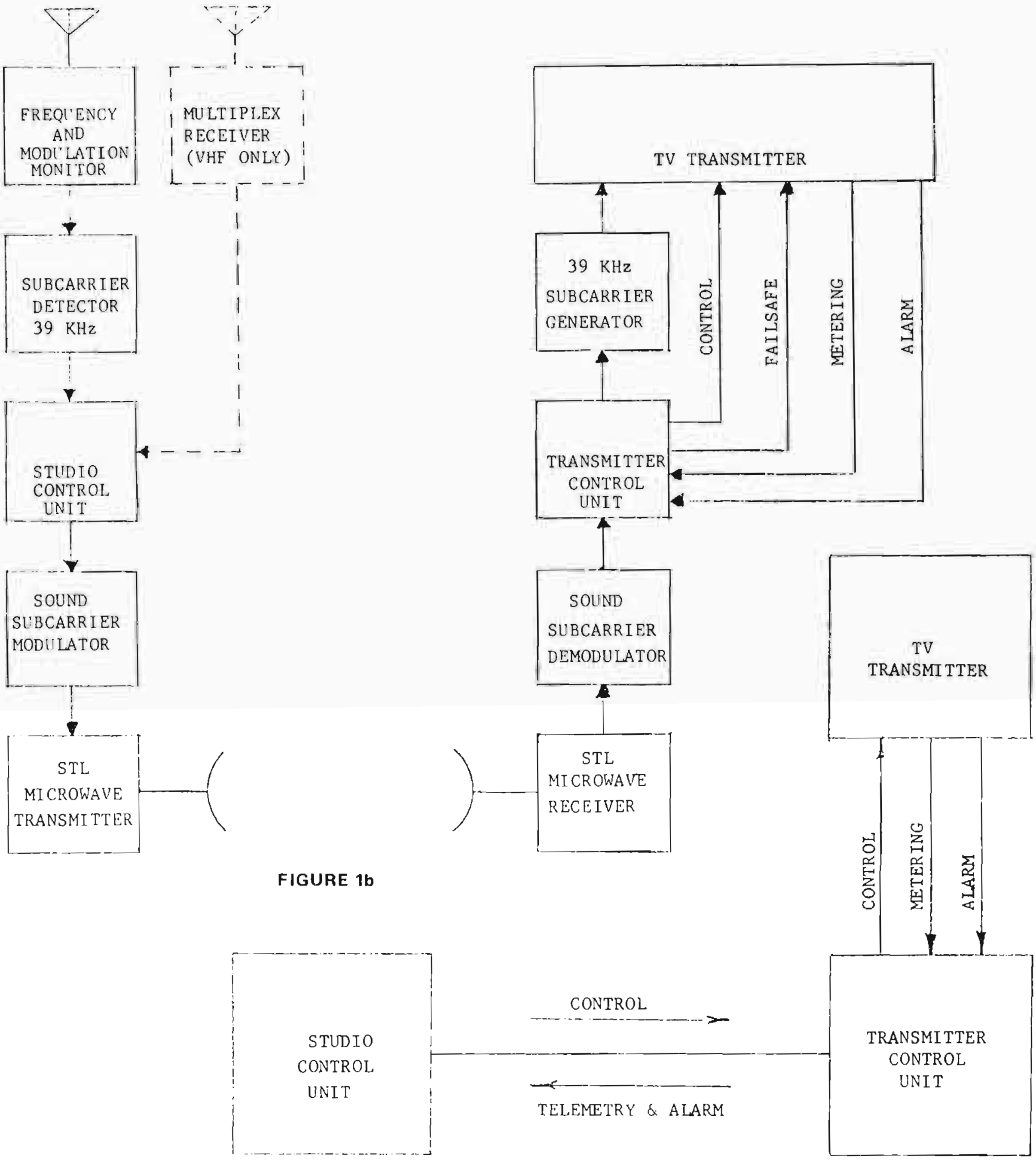


FIGURE 1b

FIGURE 1a

Fig. 1a. Remote control via voice quality wire line. Fig. 1b Remote control via STL microwave audio channel telemetry via TV aural subcarrier.

(c) *Describe the method by which telemetry data required by the Rules will be transmitted to the control point.*

See Figure 1a or 1b.

Metering or telemetry return is accomplished by presenting to the remote control system a dc sample voltage representative of the parameter to be monitored, which is selected as described in 2b above. This dc sample voltage is converted to an audio tone. Individual calibration potentiometers enable correct calibration of each parameter. Conversion is accomplished by means of a voltage-controlled oscillator which has a basic frequency range of 80 Hz to 120 Hz. The 80 Hz is representative of a zero input and 140 Hz of a full scale or maximum input. The output of this voltage-controlled oscillator is divided down to a range of 20 Hz to 30 Hz. The 20 Hz to 30 Hz tone is utilized to amplitude modulate a 1,280 Hz carrier.

Note 3: For *wire line* interconnection, add the following:

The 1,280 Hz carrier will be transmitted to the studio control point by means of a two-way communications grade leased telephone line, interconnecting the Transmitter Control Unit, located at the transmitter site, and the Studio Control Unit, located at the studio control point. In the Studio Control Unit, the 1,280 Hz carrier is demodulated and the 20 Hz to 30 Hz tone is recovered. The 20 Hz to 30 Hz tone is applied to a pulse counting demodulator enabling recovery of a current proportional to the original dc sample voltage. This current is utilized for deflection of the appropriate meter for parameter display.

Note 4: For telemetry by means of a subcarrier on the Aural Transmitter, add the following:

The 1,280 Hz carrier is applied to the input of a subcarrier generator unit, where it is frequency modulated on a 39 kHz subcarrier. This 39 kHz subcarrier is applied to the audio input of the aural transmitter along with the TV aural program material. The 39 kHz subcarrier will be adjusted to a level to produce a deviation of the TV aural carrier not exceeding 10 percent (±2.5 kHz).

Note 5: It is necessary to add a statement regarding the subcarrier frequency, the make and type of subcarrier generator, and the method of controlling and monitoring the subcarrier injection level. The make and type of subcarrier generator is either (a), a plug-in module which is a part of the RCA BTR-30A1 Transmitter Control Unit, for a basic remote control system, or (b), a Moseley Associates Type SCG-8 Subcarrier Generator, for a remote control system which includes status indication, tolerance alarms, and/or automatic logging. The subcarrier frequency is 39 kHz.

The subcarrier injection level will be adjusted, by means of an output level control incorporated in the subcarrier generator, to a value which will produce a deviation of the aural carrier of 10 percent ±2.5 kHz). This deviation will be monitored by means of a calibrated voltage output from the aural modulation monitor, (TFT-701, TFT-702) located at the studio control point.

Note 6: Recovery of the telemetry information at the studio control point may be accomplished by the use of a type TMR-2 Multiplex Receiver (VHF only), or a type SCD-8 Subcarrier Detector in conjunction with a VHF or UHF Aural Modulation Monitor with an SCA output. In either case, the 39 kHz subcarrier is demodulated to the 1,280 Hz carrier, which is in turn fed to the BTR-30A1 Studio Control Unit. The applicable equipment should be identified, and shown in block diagram form. (See Fig. 1b)

In the Studio Control Unit, the 1,280 Hz carrier is demodulated and the 20 Hz to 30 Hz tone is recovered. The 20 Hz to 30 Hz tone is applied to a pulse counting demodulator enabling recovery of a current proportional to the original dc sample voltage. This current is utilized for deflection of the appropriate meter for parameter display.

(d) *Describe the fail-safe features of the remote control system which will insure that loss of either the required control or telemetry functions will place the transmitter in a non-radiating condition.*

Control Fail-Safe: Control fail-safe is accomplished by continuous monitoring of the 920 Hz control as described in 2b. A Fail-safe detector energizes a fail-safe relay in the Transmitter Control Unit as long as the 920 Hz tone is being received. If this tone is interrupted by a failure of equipment or the transmission medium, the fail-safe relay is deenergized after a delay of approximately 20 seconds. Contacts of the fail-safe relay are in series with the controlled transmitter interlock circuits, causing the transmitter to be placed in a non-radiating condition.

Telemetry Fail-Safe: Circuitry is incorporated in the Studio Control Unit to detect the presence of the telemetry signal. Should the telemetry signal be interrupted, a 577 Hz tone is relayed to the transmitter site with the other control information. At the transmitter site, this tone is detected to signify the failure of the telemetry system. This information is relayed to a BRF-1 Fail-Safe Unit. The BRF-1 incorporates a one-hour integrated circuit timer which is started upon failure of telemetry. When this timer is fully cycled, a telemetry fail-safe relay is deenergized opening contacts to an interface panel containing a latching circuit that opens the transmitter interlock circuit. This circuit can only be reset by actuating a reset button at the transmitter site. In addition, the BRF-1 Fail-Safe Unit monitors dc sample voltages representing the parameters required by Section 73.671(a) of the rules. Should one or more of these sample voltages fail, the one hour timer is also started, resulting in automatic transmitter shut-down as above.

(e) *Describe measures proposed to prevent tampering or activation of transmitting and control equipment by unauthorized persons.*

The security measures and devices employed at the transmitter site and the studio should be described, including security fences, locks, and alarm systems. If illegal entry alarms are to be included, together with other alarms of off-normal conditions, such as over temperature, tower light alarms, emergency power, and others, are to be transmitted to the studio control point, an SCS-2 Status Indicator System may be utilized.

The operation of the SCS-2 Status Indicator System may be described as follows:

The SCS-2 Status Indicator consists of a transmitter unit located at the transmitter site, and a receiver unit, located at the studio control point. It will report 14 status or alarm functions by means of indicator lights and relay contacts to actuate an external warning device. The alarm is initiated by an external contact closure to actuate the assigned status channel. The SCS-2 uses a three level, frequency shift, keyed signal for transmitting the status of each channel. A 2,700 Hz carrier is shifted to either 2,500 Hz or 2,300 Hz. This signal consists of a sync pulse followed by 14 pulses to indicate the status of each channel. The pulse train is transmitted every 400 milliseconds, and the response time for indication of an alarm is less than 0.5 second. The frequency shift signal is transmitted to the studio control point along with the telemetry signals by the method described in 2c.

(f) *Furnish a description, including make and type, of all major components of monitoring equipment proposed to be employed for off-the-air monitoring at the remote control point, such as visual and aural radio frequency amplifiers, visual demodulator, aural modulation monitor, vertical interval test signal encoder and decoder, and apparatus for observing the transmitted visual waveform. For any composite component whose performance is critical to the accurate functioning of the monitoring system, test data shall be furnished to demonstrate its adequacy.*

Refer to Exhibit 1, Fig. 2.

(g) *Describe the method by which the daily frequency checks required by Section 73.690(c) of the Rules will be made.*

A Time and Frequency Technology Type TFT-701 visual and aural frequency and Aural Modulation Monitor will be in operation at the studio control point.

Refer to Exhibit, Fig. 2.

(h) *Describe the method for determining at the remote control point that tower obstruction lighting, if required, is functioning properly.*

The tower lighting system may be monitored by an automatic device which will sample ac current to detect a tower light failure and report via the BTR-30A1 alarm system to the studio control point. Alternatively, the ac current may be monitored on each leg of the tower lighting circuits by means of the TLK-2 Tower Light Monitor Kit, and sample voltages proportional to these currents connected to telemetry inputs at the BTR-30A1. Transmitter Control Unit, provides control point meter indication of individual lighting level circuit current.

(i) *Describe the facilities maintained at the remote control point to permit compliance with the Emergency Action Notification Procedures of Section 73.932 of the Rules.*

Describe the equipment to be installed which is capable of receiving the Emergency Action Notifications and Terminations transmitted by Primary EBS station for the local area.

Questions 3 and 4 are self-explanatory and pertain to transmitter redundancy and the inspection of transmitting facilities. Those stations utilizing 20 percent power redundancy are required to inspect the transmitter facility but once during each 7-day period.

DIGITAL REMOTE CONTROL

2. Furnish as Exhibit No. 1 responses and/or exhibits, as appropriate, for each of the items listed below, together with such block or schematic diagrams as may be necessary or desirable to fully disclose all aspects of proposed remote control system.

(a) *State the number and purpose of the control and telemetry functions that will be provided at the control point.*

Note: Although specific assignments of control and telemetry functions will depend on the specific transmitter equipment, the following is furnished as a guide. Part A is a list of suggested functions for a *single transmitter,* and Part B for a *dual transmitter.*

A. Single transmitter control and telemetry functions.

Function	*Control*	*Telemetry*
1.	Transmitter on/off	Visual PA Filament
2.	Plate on/off	Visual PA Plate Voltage
3.	Overload Reset	Visual PA Plate Current
4.	—	Aural PA Plate Current
5.	—	Aural PA Plate Voltage
6.	Visual Excitation Raise/Lower	Visual Output Power
7.	Video Level Riase/Lower	Visual Output Power
8.	Sync Gain Raise/Lower	Visual Output Power

Function	*Control*	*Telemetry*
9.	Aural Excitation Raise/Lower	Aural Power Output
10.	EBS on/off	Aural Power Output
11.	—	Visual VSWR
12.	—	Aural VSWR
13.	Tower Lights on/off	Tower Lights
14.-30	Spare	Spare

B. Dual transmitter control and telemetry functions.

Function	*Control*	*Telemetry*
1.	Transmitteer A on	A Visual PA Fil. Voltage
2.	Transmitter B on	B Visual PA Fil. Voltage
3.	Plate Voltage A on	A Visual PA Plate Voltage
4.	Plate Voltage B on	B Visual PA Plate Voltage
5.	Plate Voltage A off	A Aural PA Plate Voltage
6.	Plate Voltage B off	B Aural PA Plate Voltage
7.	Transmitter A off	A Visual PA Plate Current
8.	Transmitter B off	B Visual PA Plate Current
9.	Overload Reset A	A Aural PA Plate Current
10.	Overload Reset B	B Aural PA Plate Current
11.	Aural Excitation Raise/Lower	Total Aural Power
12.	—	A Aural Power
13.	—	B Aural Power
14.	Aural Power Balance Raise/Lower	Aural Reject Power
15.	—	Aural VSWR
16.	Visual Excitation Raise/Lower	Total Visual Power
17.	A Video Level Raise/Lower	Visual Reject Power
18.	—	A Visual Power
19.	B Video Level Raise/Lower	Visual Reject Power
20.	—	B Visual Power
21.	Combined Video Level Raise/Lower	Total Visual Power
22.	A Sync Level Raise/Lower	Visual Reject Power
23.	B Sync Level Raise/Lower	Visual Reject Power
24.	Combined Sync Gain Raise/Lower	Total Visual Power
25.	—	Visual VSWR
26.	Mode: A/B Parallel/EBS	Total Aural Power
27.	Mode: A Air - B Test B Air - A Test	Total Aural Power
28.	Exciter Switchover Manual/Auro	—
29.	Exciter A/B	—
30.	Tower Lights on/off	Tower Lights

(b) *Describe the method by which control functions will be transmitted to the television transmitter(s).*

See Fig. 1c or 1d.

Control is accomplished via commands manually initiated by the operator through activation of the Control Terminal situated at the studio or remote control point. Each channel of the system has the capability of performing two command functions, Raise and Lower. Channel selection, Raise and Lower, and fail-safe information (control and telemetry) is generated in the Control Terminal in the form of a digital word. The digital word is transmitted in a serial form by a two-level fsk system. This fsk signal is detected at the transmitter site and the reconstructed digital word is fed to the Remote Terminal of the system for decoding and actual activation of the selected command. For assurance of activation of the selected command, a parity check is incorporated. After satisfying the parity requirements, the selected relay is energized. A signal derived from the selected relay is used to generate a digital word to give positive indication to the operator that the desired control command has taken place.

Note 1: For *wire line interconnection,* add the following:

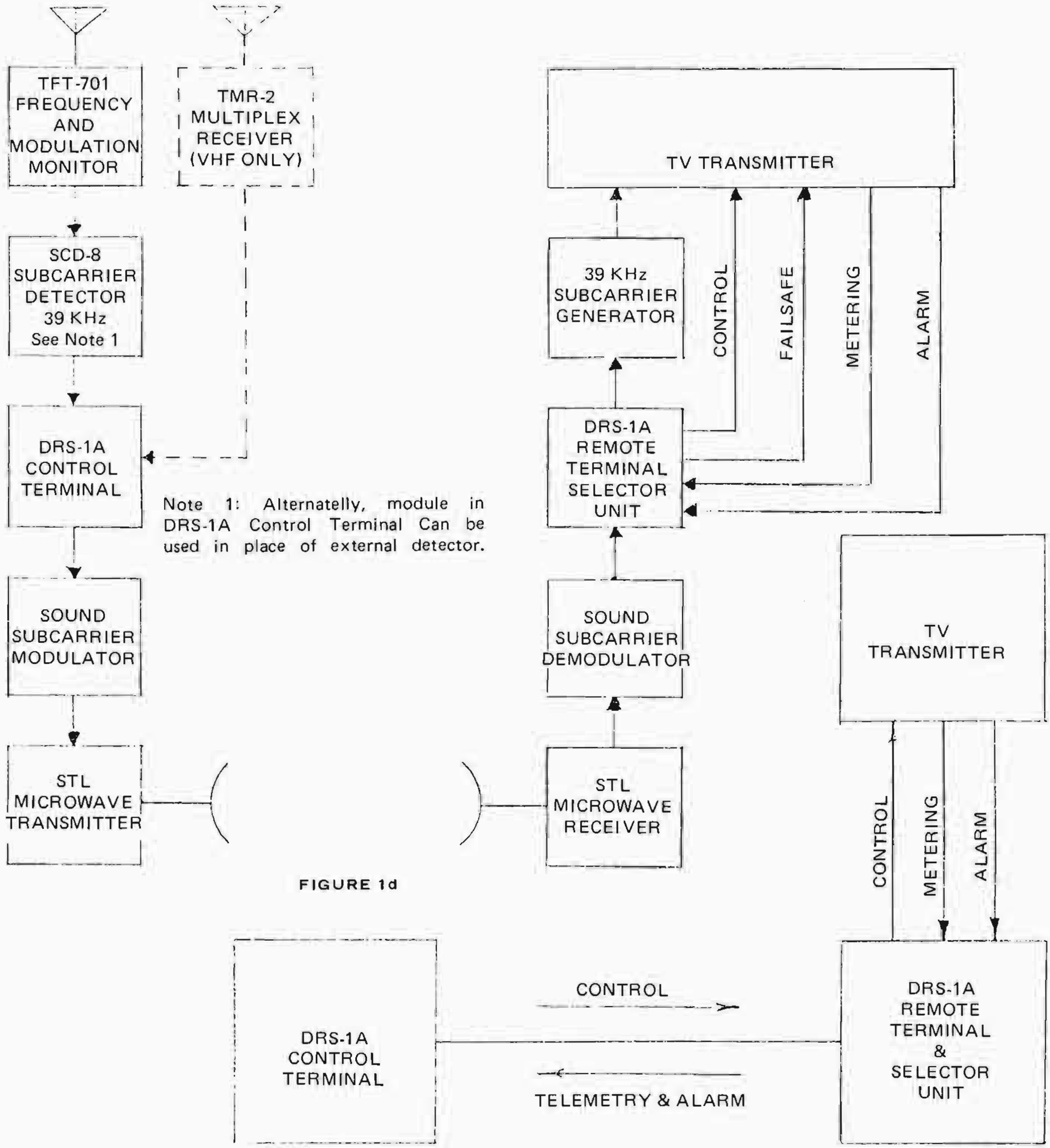


FIGURE 1d

FIGURE 1c

Fig. 1c. Remote control via voice quality wire line. Fig. 1d Remote control via STL microwave audio channel telemetry via TV aural subcarrier.

A two-way, communications-grade, leased telephone line will be used to interconnect the Control Terminal, located at the studio control point, and the Remote Terminal, located at the transmitter site. The leased line will have a maximum loss of 30 dB at frequencies from 300 Hz to 2,700 Hz. (An ATT Interstate Series 3002, unconditioned circuit is typical of this requirement.)

Note 2: For transmission of control tones by STL microwave audio subcarrier, add the following:

These control tones will be transmitted from the Control Terminal, located at the studio control point, to the Remote Terminal, located at the transmitter site, by means of an audio channel diplexed on the STL microwave system. This diplexing will be achieved by frequency modulating an RF subcarrier at 6.8 MHz, typically, with the audio tones and superimposing this modulated subcarrier upon the video signal for simultaneous transmission. The subcarrier will be demodulated at the transmitter site, and routed to the Transmitter Control Unit.

(c) *Describe the method by which telemetry data required by the Rules will be transmitted to the control point.*

See Fig. 1c or 1d.

Metering or telemetry return is accomplished by presenting to the remote control system a dc sample voltage representative of the parameter to be monitored. This dc sample voltage is converted to a "digital word." Telemetry information is returned from the transmitter site to the remote control point in a manner identical to that used for command information. (See 2b for description of channel selection procedure.) This digital word is properly conditioned for transmission over the interconnecting circuit by the modem. The parameter is displayed on a 3½-digit readout in the Control Terminal at the studio or remote control point. Individual calibration potentiometers enable correct calibration of each parameter.

Note 3: For *wire line* interconnection, add the following:

The two-level fsk signal is transmitted to the remote control point by means of a two-way communications-grade leased telephone line, interconnecting the Remote Terminal located at the transmitter site with the Control Terminal located at the studio control point.

Note 4: For telemetry by means of a subcarrier on the Aural Transmitter, add the following:

The two-level fsk telemetry signal is applied to the input of a subcarrier generator unit, whose carrier frequency is 39 kHz. This 39 kHz subcarrier is applied to the Aural Transmitter along with the TV aural program material. The subcarrier will then be adjusted to a level to produce a deviation of the TV aural carrier not exceeding 10 percent (± 2.5 kHz).

Note 5: It is necessary to add a statement regarding the subcarrier frequency, the make and type of subcarrier generator, and the method of controlling and monitoring the subcarrier injection level. The make and type of subcarrier generator is a module which is a part of the DRS-1A Remote Terminal.

Note 6: Recovery of the telemetry information at the studio control point may be accomplished by the use of a Type TMR-2 Multiplex Receiver (VHF only), or a Type SCD-8 Subcarrier Detector in conjunction with a VHF or UHF Aural Modulation Monitor with an SCA output. In either case, the 39 kHz subcarrier is demodulated ot the two-level fsk telemetry signal, which in turn is fed to the Control Terminal. The applicable equipment should be identified and shown in block diagram form (see Fig. 1d).

(d) *Describe the fail-safe features of the remote control system which will insure that loss of either the required control or telemetry functions will place the transmitter in a nonradiating condition.*

Control Fail-Safe: Transmitted with every command "digital word" generated in the Control Terminal is a fail-safe code. The Remote Terminal situated at the TV transmitter site continuously monitors the "digital word" for the fail-safe code. The absence of this code establishes a fail-safe condition. In the case of the "control link," a fail-safe condition for more than 20 seconds opens a relay which places the transmitter in a nonradiating mode.

Telemetry Fail-Safe: Telemetry fail-safe is accomplished through the use of the Model FSU-1 Fail-Safe Unit. The purpose of this fail-safe unit is twofold. The first is to observe the presence of the dc sample voltages. These dc sample voltages, four in number, represent the parameters required to be logged by Paragraph 73.671(a). Should any of the dc sample voltages fail (have no output), the FSU-1 Fail-Safe Unit is initiated. The second purpose of telemetry fail-safe involves vertification that the telemetry information is present at the remote control point. Presence of the metering signal is determined by a telemetry fail-safe detector in the Control Terminal of the DRS-1 Digital Remote System. Should telemetry information not be present, an additional telemetry fail-safe code is relayed to the transmitter site with the other control information. Should either the dc sample voltages fail, or the telemetry information not arrive at the remote control point, the Model FSU-1 Fail-Safe Unit is activated to start a one-hour integrated circuit timer. At the end of this one-hour time period, the fail-safe output from the FSU-1 automatically operates a relay whose contacts are used to place the TV transmitter in a nonradiating mode.

(e) *Describe measures proposed to prevent tampering or activation of transmitting and control equipment by unauthorized persons.*

The security measures and devices employed at the transmitter site and the studio should be described, including security fences, locks, and alarm systems. If illegal entry alarms are to be included, together with other alarms of off-normal conditions, such as over temperature, tower light alarms, emergency power, and others, are to be transmitted to the studio control point, a Status Subsystem of the DRS-1A digital Remote System may be utilized.

The operation of the Status Subsystem for the DRS-1A can be described as follows:

Telemetry is returned in a digital form or word by means of the two-level fsk signal described above. A segment of each digital word is reserved for the Status Subsystem. Twenty-four status or alarm functions are reported in this manner. The Status Subsystem consists of a Remote Terminal at the transmitter site and a Control Terminal at the studio control point.

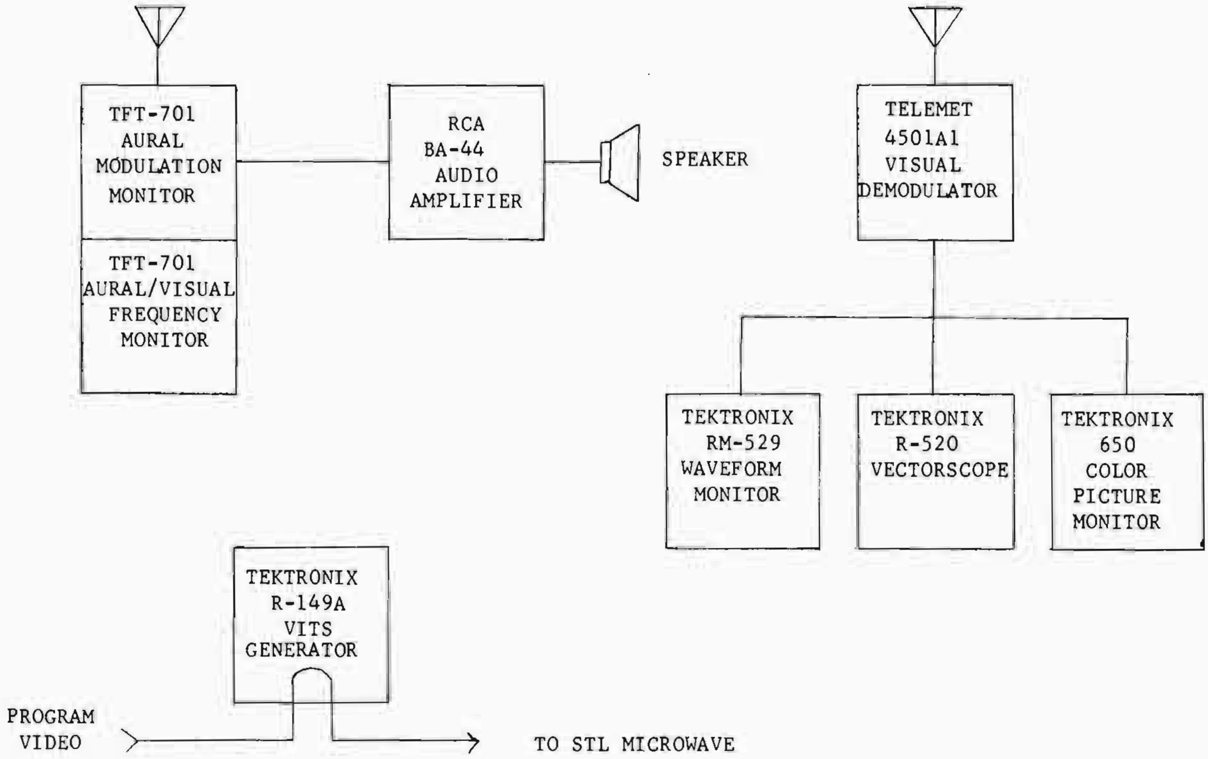


Fig. 2. Studio control point monitoring and VITS generation.

(f) *Furnish a description, including make and type, of all major components of monitoring equipment proposed to be employed for off-the-air monitoring at the remote control point, such as visual and aural radio frequency amplifiers, visual demodulator, aural modulation monitor, vertical interval test signal encoder and decoder, and apparatus for observing the transmitted visual waveform. For any composite component whose performance is critical to the accurate functioning of the monitoring system, test data shall be furnished to demonstrate its adequacy.*

Refer to Exhibit 1, Fig. 2.

(g) *Describe the method by which the daily frequency checks required by Section 73.690(c) of the Rules will be made.*

A Time and Frequency Technology Type TFT-701 visual and aural frequency and Aural Modulation Monitor will be in operation at the studio control point.

Refer to Exhibit, Fig. 2.

(h) *Describe the method for determining at the remote control point that tower obstruction lighting, if required, is functioning properly.*

The tower lighting system may be monitored by an automatic device which will sample ac current to detect a tower light failure and report via the DRS-1A Status Subsystem to the studio control point. Alternatively, the ac current may be monitored on each leg of the tower lighting circuits by means of the TLK-2 Tower Light Monitor Kit, and sample voltages proportional to these currents connected to telemetry inputs of the DRS-1A to provide control point telemetry indication of the individual lighting level circuit current.

(i) *Describe the facilities maintained at the remote control point to permit compliance with the Emergency Action Notification Procedures of Section 73.932 of the Rules.*

Describe the equipment to be installed which is capable of receiving the Emergency Action Notifications and Terminations transmitted by Primary EBS station for the local area.

Questions 3 and 4 are self-explanatory and pertain to transmitter redundancy and the inspection of transmitting facilities. Those stations utilizing 20 percent power redundancy are required to inspect the transmitter facility but once during each seven-day period.

GENERAL

Remote control of a transmitter is in many instances accomplished over interconnecting telephone circuitry. It is also possible to remotely control a transmitter over STL or radio circuits with return metering information being fed back either by radio circuits or multiplex. The choice of system used, either wireline or radio, depends upon the user and will be dictated by the facilities at hand, including the availability and dependability of common carrier telephone lines.

Telephone line tariffs may play an important part in determining the method of studio/transmitter remote control interconnection. In many instances, remote-control lines are quite short and the cost reasonable. In the case of longer runs, the broadcaster should consider the use of interconnecting radio circuits (STL).

Once one is familiar with the rules governing remote control, a decision must be made as to the type of equipment to be used to remotely control the transmitter. Excellent commercial equipment is made by a number of manufacturers and is available in a wide price range. A number of manufacturers have systems which are somewhat tailor made for certain types of installations. They should, of course, be consulted as to equipment availability to satisfy specific requirements. Two important ingredients are required by the Federal Communications Commission in any remote control system. The rules require that remote control equipment allow an operator to turn the transmitter on and off and to raise and lower the output power of the transmitter. Also a "fail-safe" circuit must be incorporated into the system to ensure that the transmitter will automatically shut down to prevent "free running."

Communication is essential between the transmitter and the remote control point. This may be accomplished by a regular city telephone, a separate order wire, a telephone system built into the remote control unit, or an existing program line which is not in use. An off-air monitor is highly desirable and an Emergency Broadcast System (EBS) receiver is required at the control point.

Television stations operating by remote control, must of course, have at the remote control location in addition to the normal transmitter monitoring equipment, the necessary waveform monitors, and vectorscopes to measure the video parameters, color content and the Vertical Interval Test Signal (VITS).

THE REMOTE CONTROL SYSTEM

The system described herein is the Moseley Model PBR-30A and/or the RCA Model BTR-30A1 Remote Control Units. Any comparable system could be used in a similar manner. This system provides for 30 metering channels, and 60 control functions. It meets all requirements for AM/FM/TV remote control, incorporates fail-safe design, and has computer-type logic circuitry.

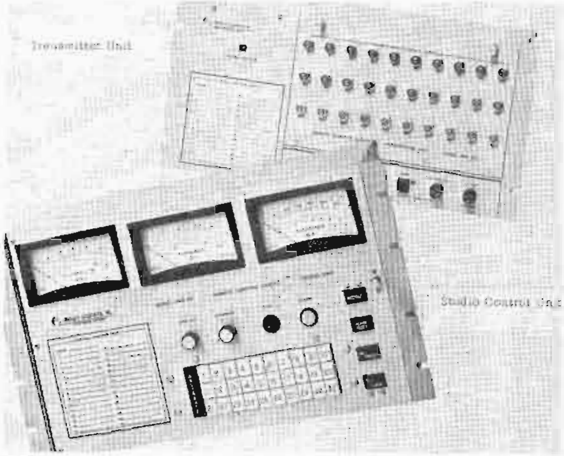


Fig. 3. Typical 30 metering, 60 function remote control system. (Courtesy Mosely Associates, Inc.)

The basic remote control installation includes a "studio control unit" and a "transmitter control unit," as shown in Fig. 3, and the block diagram depicted in Fig. 4. The system will operate on a single voice-grade telephone circuit or studio-transmitter link (STL). A comparable digital system is the Moseley DRS-1A. This is shown in Figs. 5 and 6.

The FCC rules now provide for a complete AM radio remote control system using an STL for the control of the transmitter and a return metering circuit using subaudible audio tones impressed upon the AM carrier between 20 and 30 Hz. The information presented below describes the basic concept of this type of remote control system and the block diagram appearing in Fig. 7 will be helpful in understanding the design of the AM (wireless) remote control system.

A two-way wireless path must be established between the studio or control point and the transmitter site. These paths provide for the flow of (a) program and control information to the transmitter and (b) the return of metering or telemetry information to the studio.

The basis for the control path is an Aural Studio-Transmitter Link (STL) operating in the current 947 MHz to 952 MHz band. The primary purpose of the STL is to provide a program link from the studio to the transmitter site and thus replace a leased telephone circuit. An FM subcarrier is multiplexed on the STL to convey actual remote control command information.

From the attached block diagram, note that the subcarrier has an operating frequency of 26 kHz. The subcarrier generator and detector are printed

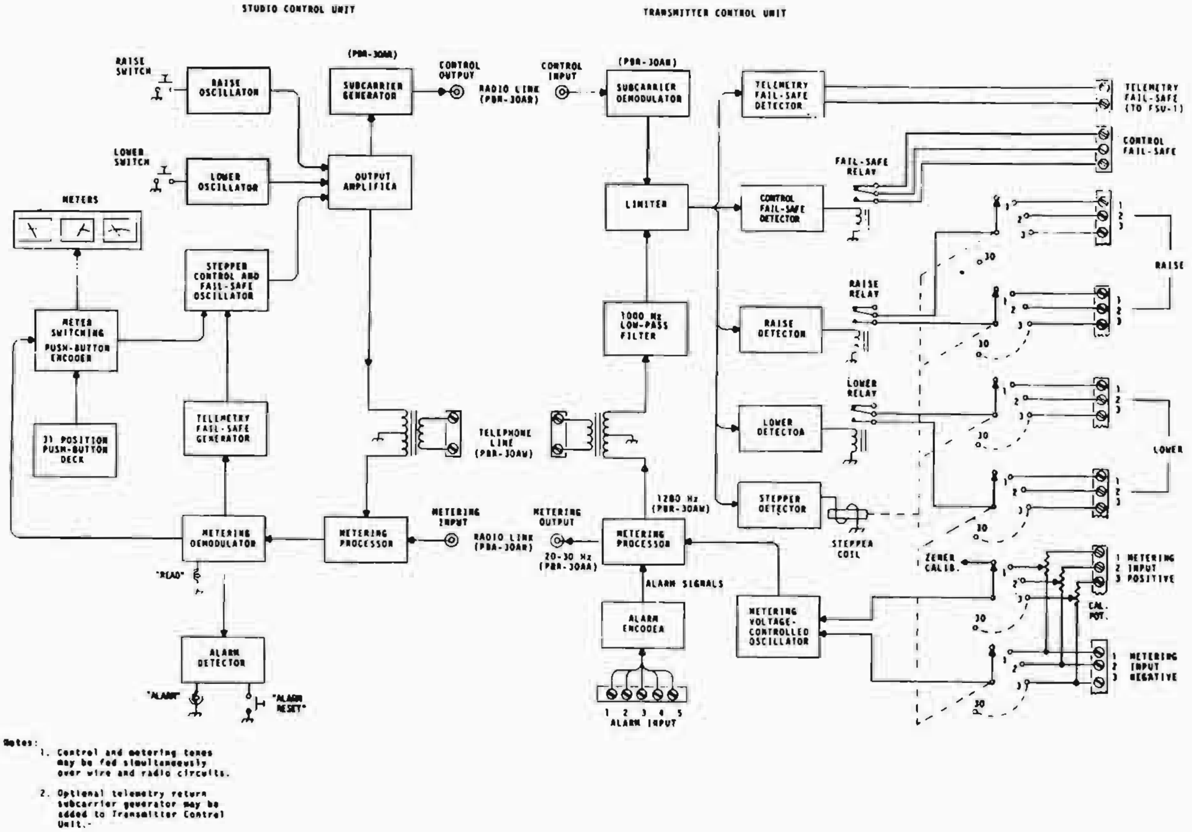


Fig. 4. Block diagram of typical 30 metering 60 control function remote control system. (Courtesy of Moseley Associates, Inc.)

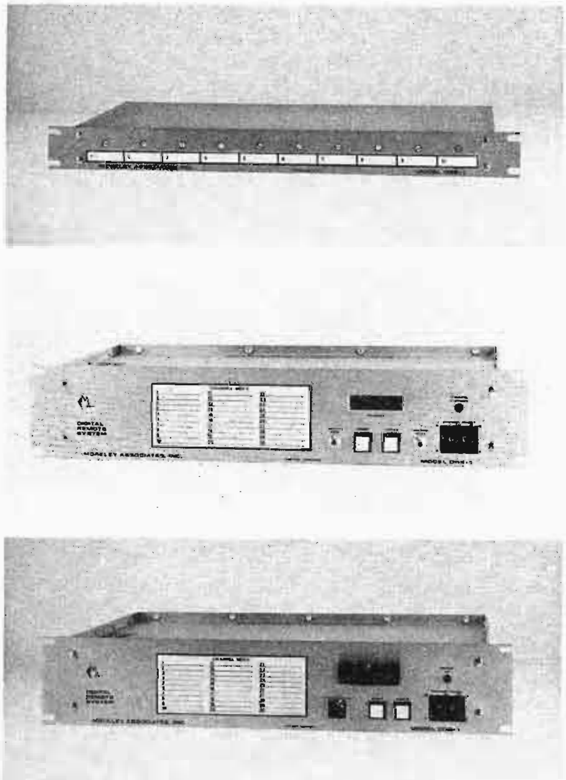


Fig. 5. Typical digital remote control system. (Courtesy of Moseley Associates, Inc.)

circuit modules housed within the Studio and Transmitter Unit, respectively. The subcarrier is referred to as the control subcarrier. The audio tones generated by the remote control system for control purposes are conveyed by the subcarrier.

Metering signals are derived from dc sampling points within the transmitter and associated equipment. The dc voltage is converted within the Transmitter Unit of the remote control system to a subaudible tone in the 20 Hz to 30 Hz spectrum. The subaudible metering signal is combined with the program audio and then applied to the audio input of the AM transmitter for return to the studio.

As shown on the block diagram, the Metering Insertion Unit mixes the subaudible metering signal and program audio before application to the AM transmitter. But, the Metering Insertion Unit serves three other very important functions. First, filtering is provided to remove any component from the program audio in the region occupied by the subaudible metering signal. Secondly, switching is provided so that the subaudible metering signal may be switched on and off. The filter mentioned previously is also switched in and out of the circuit simultaneously with the subaudible metering signal. Finally, in conjunction with this switching function, an adjustable audio pad is provided so that total

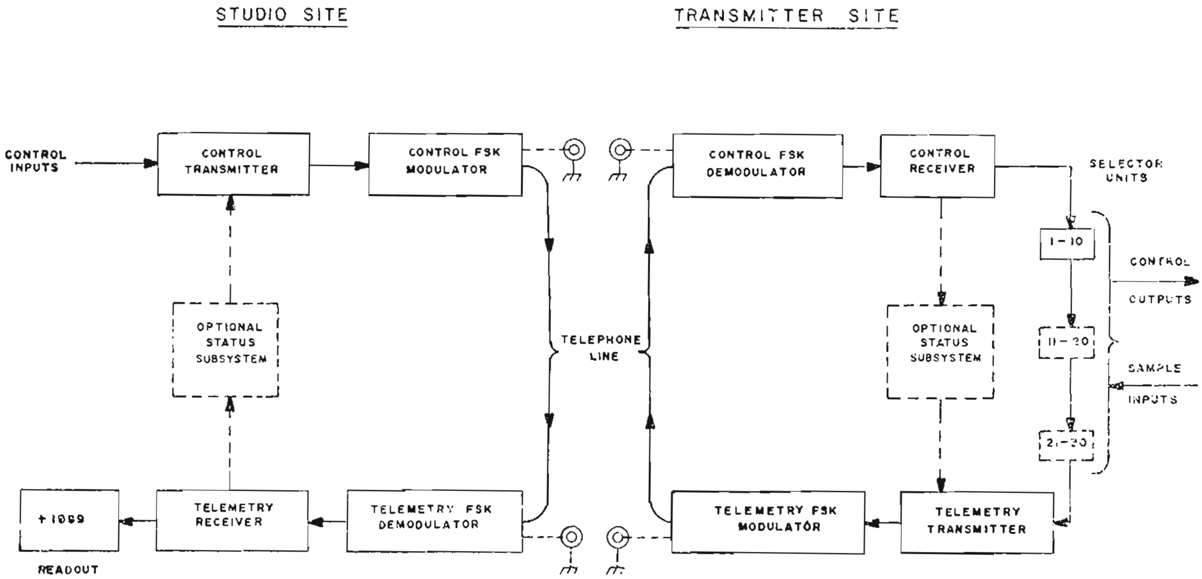


Fig. 6a. DRS-1AW remote control system with telephone line interconnection.

modulation will remain at 100 percent with or without the subaudible metering signal. It should be noted that the Metering Insertion Unit exhibits a 5 dB insertion loss in the program line. Thus, in some installations, it may be necessary to install a limiting amplifier to compensate for the filter attenuation.

At the studio, it is necessary to recover the subaudible metering signal from the AM carrier for display on an appropriate meter or monitor. For stations operating monitors from an RF amplifier, these monitors may be used for telemetry recovery.

It should be remembered that the Commission has set an upper limit of 30 Hz on this type of metering and 20 Hz becomes a realistic lower limit. With the spectrum of 20 Hz to 30 Hz, it is difficult to accurately meter modulation through the remote control system because of bandwidth

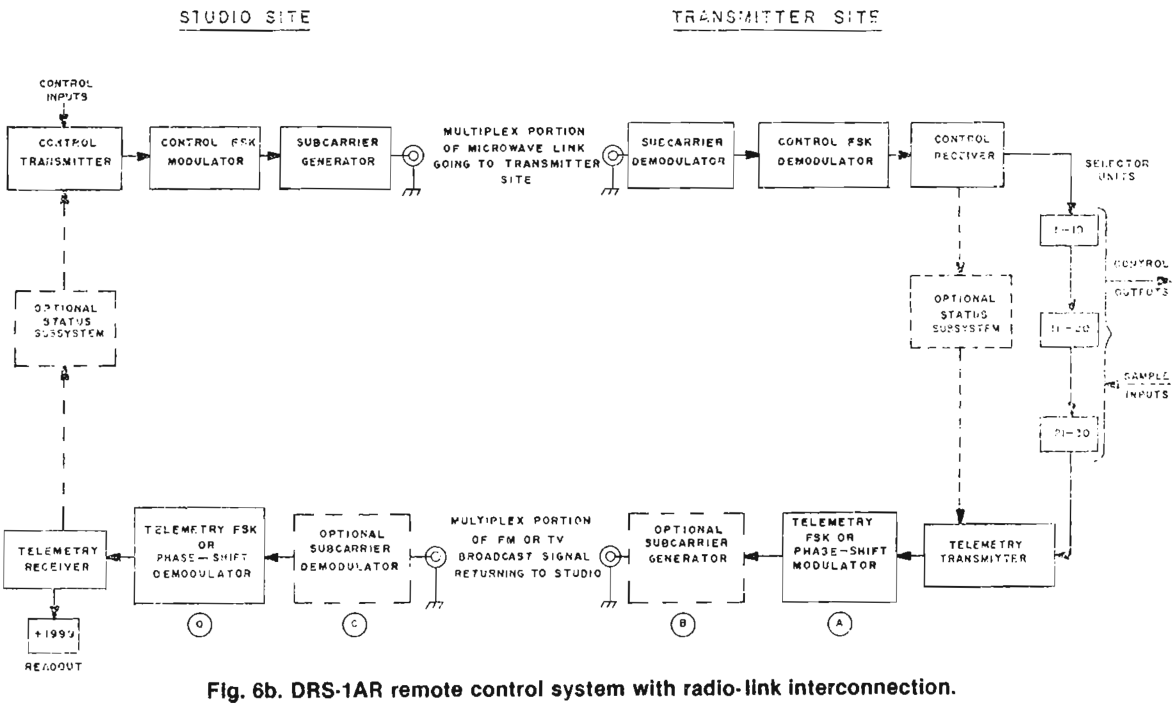


Fig. 6b. DRS-1AR remote control system with radio-link interconnection.

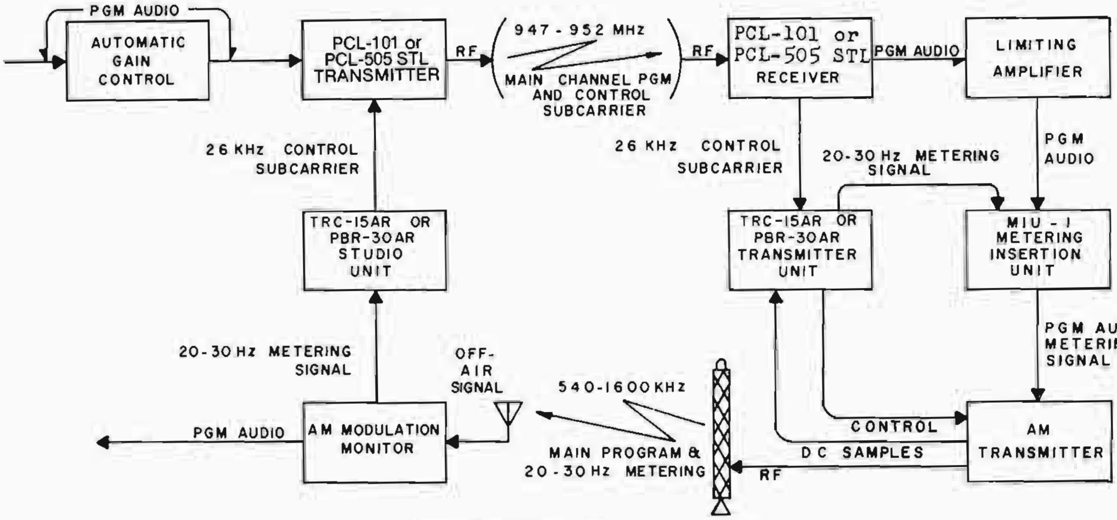
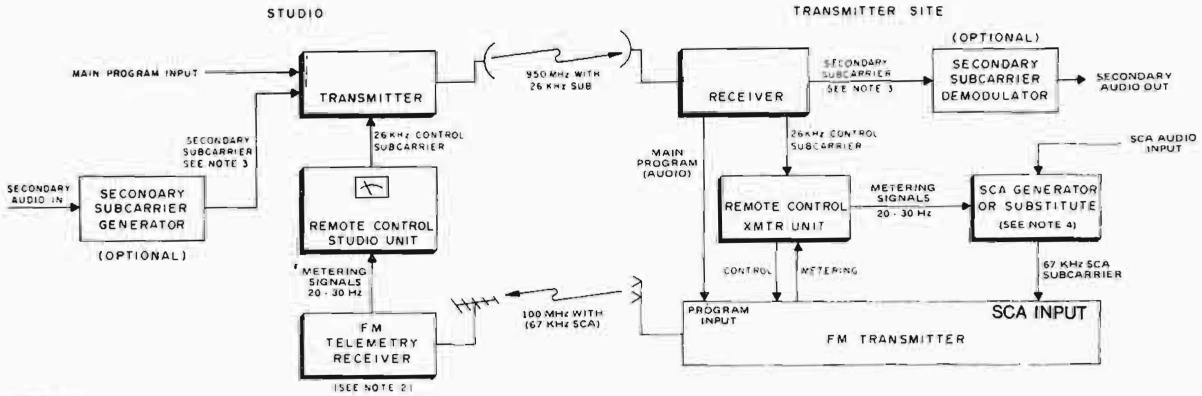


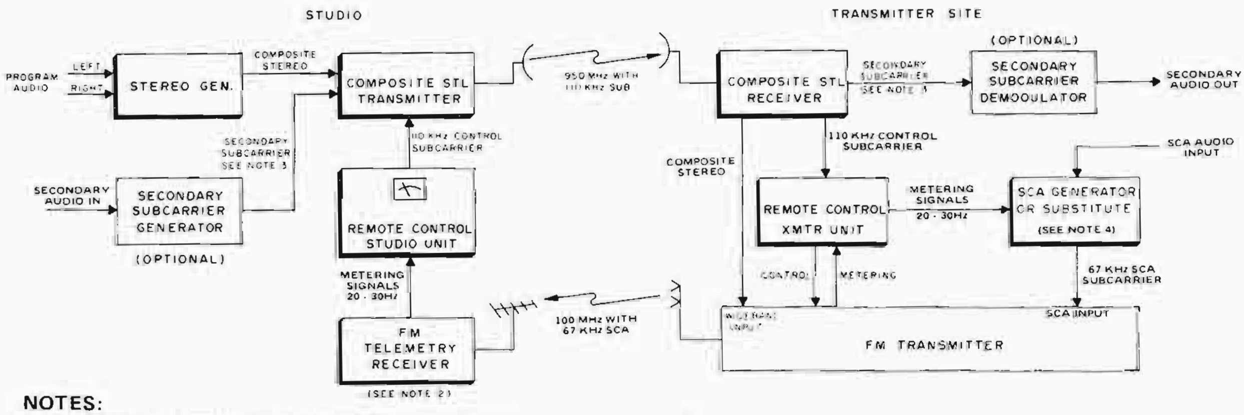
Fig. 7a. Block diagram of AM (wireless) remote control system. (Courtesy of Moseley Associates, Inc.)



NOTES:

1. Secondary subcarrier may be used to relay SCA program audio, engineering order wire, or other desired limited audio response requirements.
2. In some applications, this can be replaced with FCC Type Approved SCA Monitor.
3. Typical frequency is 67 kHz.
4. If SCA programming is not used, replace with Telemetry SCA Generator module.

Fig. 7b. Block diagram of FM (wireless) remote control system using monaural STL system.



NOTES:

1. Secondary subcarrier may be used to relay SCA program audio, engineering order wire, or other desired limited audio response requirements.
2. In some applications, this can be replaced with FCC Type Approved SCA Monitor.
3. Typical frequency is 185 kHz.
4. If SCA programming is not used, replace with Telemetry SCA Generator module.

Fig. 7c. Block diagram of FM (wireless) remote control system using composite STL system.

limitations. For this reason, an off-air modulation monitor becomes a requirement for AM radio (STL) remote control.

In summary, the major requirements stipulated by the Commission are that the upper limit on the subaudible metering signal be 30 Hz, and that the subaudible metering signal shall not modulate the AM transmitter more than 6 percent. Remote control systems have been designed with this in mind. The filter mentioned previously as part of the Metering Insertion Unit will also comply with Section 73.40(a) as required for this type of operation while rejecting signals in the 20 Hz to 30 Hz spectrum by more than 50 dB.

For FM applications, techniques similar to those described for AM are used for relaying command and metering information. An FM subcarrier is multiplexed on the STL for command information transmission to the transmitter site. As two types of STL systems are used for FM stations, two typical control subcarrier frequencies are normally encountered. For the monaural STL (used either for monaural programming or two systems operating in a dual configuration), the subcarrier frequency is 26 kHz; the composite STL (single link for stereo) uses a command subcarrier frequency of 110 kHz. Unlike AM, metering information for FM cannot be returned directly on the carrier of the FM station. This information must be returned via an SCA channel multiplexed on the FM carrier. The subaudible tone (20-30 Hz) can be applied to an SCA channel that is programmed without affecting this programming. Either STL configuration allows for the addition of a second subcarrier for relaying SCA programming to the transmitter site. Figs. 7b and 7c exemplify typical configurations for FM wireless remote control systems.

Further comment concerning digital remote control systems is in order. As mentioned above, Figs. 5 and 6 represent a medium-sized digital remote control system. Larger capacity digital remote control systems are currently available, and are typically used for larger AM and FM facilities and many TV applications. Digital systems of this type may even be computer-assisted. Computer-assisted operation can greatly enhance operator convenience as well as overall plant operation. Such operation simplifies the establishment of tolerance limits for metering or telemetry information, increases the capability for alarming and operator notification, allows for presentation of a large number of telemetry or status channels via a CRT display, greatly enhances automatic logging capabilities, and can even look forward to the possibility of Automatic Transmitter Systems (ATS). At the time of preparation of this material, Automatic Transmitter Systems are under consideration by the FCC.

PLANNING FOR TV TRANSMITTER REMOTE CONTROL

Planning of remote control facilities for a television transmitter should be based on a careful review of applicable FCC regulations as well as the specific needs of the individual station. Exact equipment requirements will vary with the type of television transmitter to be controlled. The following information is intended to provide an introduction to TV transmitter remote control systems rather than a specific equipment list for any one type transmitter or station.

Equipment required for television transmitter remote control includes not only the remote control units but also equipment for remote monitoring of the visual and aural signals and for generation of vertical interval test signals in accordance with applicable regulations.

A brief description of the requirements of each family of equipment is provided in the following paragraphs.

Remote Control System

This is the equipment which handles the basic command functions for operation of the transmitter and the means of returning the necessary metering and alarm signals. The regulations require a sufficient number of remote control functions to perform all transmitter adjustments normally required on a daily basis to insure strict compliance with the technical requirements of the FCC rules. Remote metering is required for all parameters which must be entered in the TV transmitter operating log. Means are required for determining that any required obstruction lighting of the antenna and supporting tower is operating normally.

Fail-safe protection is required to assure that any fault or failure which results in loss of control will cause the transmitter to cease operation. Loss of metering of any of the parameters which are required for transmitter logging must activate an automatic device which will terminate operation of the transmitter not more than one hour after the loss.

Individual stations may wish to provide more control and metering functions than the minimum required. For this reason, and to allow for added functions that may be desired in the future, it is recommended that provision be made for spare control and metering functions.

Interconnection between the transmitter and remote control point is available by a choice of methods. Fig. 8 is a simplified block diagram showing a 30-function remote control system with interconnection between the studio and transmitter by means of a voice quality telephone circuit. A maximum of 20 dB of line attenuation is allowable between the transmitter and remote control location.

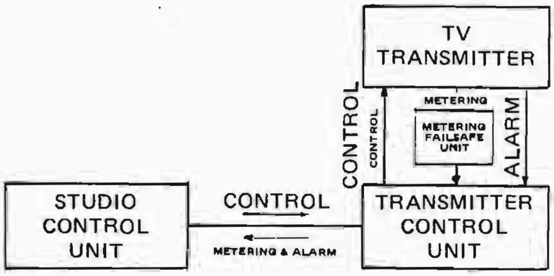


Fig. 8. Remote control via voice quality wire line.

Fig. 9 is a block diagram showing interconnection by means of a TV microwave STL link from the remote control point to the transmitter. A separate audio subcarrier modulator and demodulator are required in the TV microwave system to carry the audio control tones to the transmitter site. Metering and alarm signals are returned to the remote control point by means of a subcarrier on the aural channel of the TV transmitter. The audio tones containing the metering information are modulated on a 39 kHz subcarrier generated within the transmitter control unit and introduced into the TV transmitter aural channel. At the remote control point, the subcarrier is recovered from the transmitted aural signal at the output of an off-air multiplex receiver containing a subcarrier demodulator. The recovered metering tones are then introduced to the studio control unit.

The wireless interconnection system has the obvious disadvantage that metering and status information will be lost in the event of failure of the TV aural transmitter. On the other hand, in some transmitter locations it may be difficult to obtain a telephone circuit with sufficient reliability for transmitter remote control purposes, and in this case wireless interconnection will be preferred.

For parallel TV transmitters, consideration should be given to the use of duplicate remote control units and telephone lines for 100 percent redundance of the control system as well as the transmitter. An alternate method of achieving system redundancy would be to have one control system interconnected by wire line and another by TV relay and aural channel subcarrier.

Automatic Logging System (Optional)

Automatic logging equipment increases the benefits of remote control of the television transmitter by relieving the studio operating personnel of the manual logging task except for observation of the VIT signals and logging of the observations. In the event that automatic logging is provided, the functions which must be logged are the same as those which must be logged in a manually operated transmitter.

Automatic tolerance alarms must be provided for those parameters which are subject to tolerance limitations in accordance with FCC regulations, i.e., visual output power and aural final amplifier plate voltage and current. Transmitter visual and aural carrier frequency need only be checked once daily to assure operation within frequency tolerance and need not be alarmed if logged manually. If logged automatically these parameters must be alarmed.

Fig. 10 shows an Automatic Logging System and Tolerance Alarm Unit used in conjunction with a remote control system. Also included is a Status Indicator System to provide 14 status or alarm channels in addition to the 5 alarm channels provided in the basic control equipment. The Automatic Logging equipment uses a separate series of audio tones to transmit metering and alarm information to the remote control location where the logged digital information is printed by

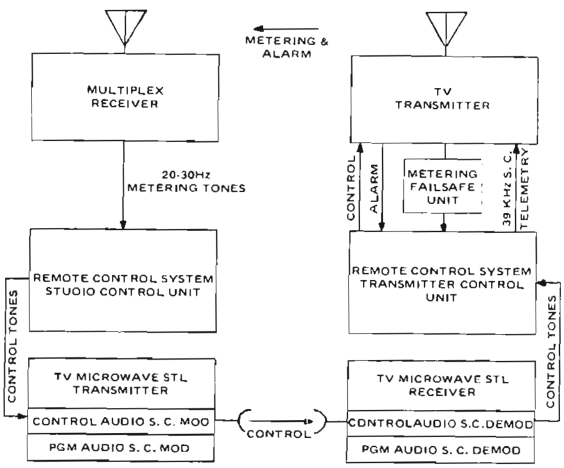


Fig. 9. Control via microwave and metering via aural subcarrier.

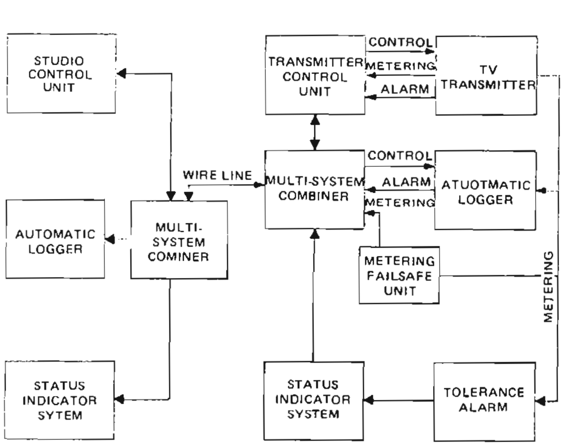


Fig. 10. Remote control and automatic logging via voice quality wire line.

an electric typewriter. Logging is initiated automatically by a clock at half hour intervals.

The remote control and logging tones may be transmitted over separate voice quality telephone circuits. With the use of a Combiner, the remote control and automatic logging tones as well as the Status Indicator tones may be transmitted simultaneously over a single telephone circuit. If preferred, this unit may be used to combine the remote control reporting, automatic logging and status indicating data on a 39 kHz subcarrier on the aural channel of the TV transmitter.

Remote Monitoring Equipment

A block diagram indicating the monitoring equipment items required at the remote control location is shown in Fig. 11. A type-approved aural modulation monitor is required with continuous indication of peak and quasi-peak percentage of modulation of the aural signal. Equipment for measuring aural and visual frequency is required and may be located at either the remote location or at the transmitter site. If located at the transmitter, provision must be made for remote metering of the frequency readings. Aural modulation monitors and frequency monitors are available with sufficient sensitivity for off-air monitoring of the transmitted signal. Older monitors intended for use at the transmitter location may not have sufficient RF gain for off-air monitoring service. An audio amplifier and loudspeaker are needed for aural monitoring of the received audio signal.

An off-air visual demodulator is required at the remote control location to permit continuous monitoring of the waveform and other characteristics of the transmitted visual signal. As a practical requirement, a separate visual demodulator is needed at the transmitter site for use in making measurements of transmitter performance and for making transmitter setup adjustments.

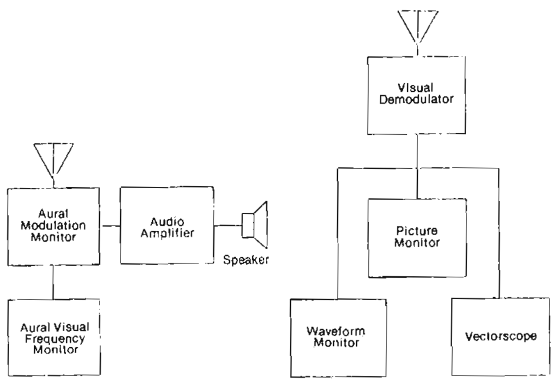


Fig. 11. Monitoring at remote location.

A video waveform monitor is required for continuous monitoring of the transmitted visual signal. This monitor must be capable of both full field displays and displays of test signals inserted on selected lines in the vertical blanking interval. In addition a vectorscope is required if any portion of the transmission is in color. A picture monitor is recommended for a visual display of the received signal. A color monitor should be provided if color program material is transmitted. It is suggested that both a monochrome and a color picture monitor be provided if space permits.

Vertical Interval Test Generating Equipment

The FCC rules governing remote control require that a series of test signals be generated and inserted in the vertical interval of the visual signal at the remote control point in the feed to the transmitter. The signal must be observed at the remote control point after extraction from the received RF signal. This signal is normally obtained at the output of the off-air visual demodulator and viewed on a video waveform monitor and vectorscope (see *Monitoring Equipment*).

The required test signals consist of multiburst on Field 1, Line 17, color bars on Field 2, Line 17 and a composite signal on Field 1, Line 18. The composite signal contains a stair step with superimposed color subcarrier frequency, a 2T sine squared pulse, a 12.5T sine squared pulse and white bar. Normally the composite signal is also fed to Field 2, Line 18 at the remote control point. However, FCC regulations permit insertion of the composite test signal of field 2 to be inserted at the transmitter to provide a comparison of the degradation of the signal caused by the microwave up-link against that contributed by the transmitter. Alternatively, a licensee may insert any suitable test signal on Field 2, Line 18 either at the transmitter or at the remote control point. The alternate test signal should have approximately the same APL as the composite test signal.

A block diagram of a representative vertical interval test signal generating system is shown in Fig. 12. The composite video output signal from Studio Master Control is fed to a television signal generator. This unit genlocks to the incoming signal and is capable of deleting an incoming VITS signal. It inserts all of the required test signals with the exception of color bars which are provided by the Generator. In the event that the composite test signal of Field 2 is inserted at the transmitter input, a second signal generator is needed at the transmitter location. The monitoring equipment required for observation of the vertical interval test signal at the remote control point is described above under Remote Monitoring Equipment.

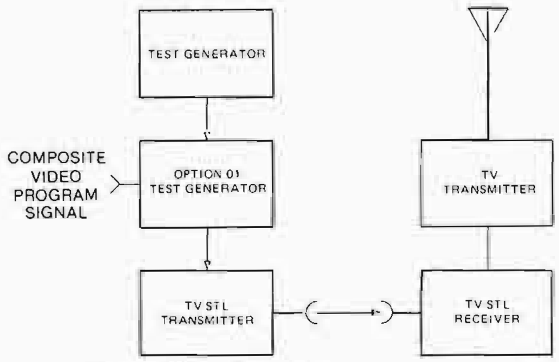


Fig. 12. Vertical interval test signal generating system.

Interface

One additional area deserves consideration in relation to broadcast transmitter remote control equipment. This is the interface of the remote control equipment to the transmitter proper. Two basic types of connections are required to the transmitter-control or command and metering or telemetry. Control provides for the actual functions to be accomplished such as Filament On/Off, Plate On/Off, etc. Metering is the sampling of the desired parameters, the result being a dc voltage of a low value that is proportional to the sampled parameter.

Control/Command

Actual control can be one of two types—the opening or closing of relay contacts or rotating devices. Relay contacts are generally used for all on/off control functions. Individual transmitter control ladders will be the determining factor for actual contact selection. In some transmitters, it is necessary to apply a control voltage to the control ladder. In this instance, and for most general installations, it is advisable to use repeating or slave relays. Repeating or slave relays are additional relays that are utilized between the remote control system and the transmitter(s). They afford protection to the remote control system should an abnormal condition occur in the control ladder of the transmitter if excessive voltage or current is present.

Rotating devices can be used in conjunction with a potentiometer, variable capacitor, or other transmitter control of this type which may require adjustment from the control point. Many transmitter manufacturers either provide, as a part of the transmitter, or as an accessory motor or motors, rheostat assemblies for controlling plate voltage or drive to the final RF amplifier stage. These controls are used to maintain RF output within prescribed limits with variations in line voltage or other changes that may affect RF output level. With TV transmitters, motors are used for setting certain video controls. A motor with reversible capability is used for actual control. In most instances, slippable clutches or microswitches are used to limit rotation.

Metering/Telemetry

Various techniques can be and are employed for the metering of operating parameters at the remote control point. Certain essential parameters must be read and logged in the operating log at the remote control point. These parameters are defined in the FCC Rules and Regulations relating to the particular type of service. Typically, however, these can be restricted to a few general types of parameters. These are plate voltage and current at the final RF stage of the transmitter, power output or line current, and other operating parameters. Most modern broadcast transmitters have incorporated provisions for remote control. In many cases, all control and metering samples are terminated in a single strip simplifying installation. We will briefly discuss some of the most commonly used parameters below.

Plate Voltage

Plate voltage is probably one of the easiest parameters to meter. A simple resistive network will suffice. All that is necessary is that plate voltage be reduced to a potential, usually on the order of 1 to 5 v dc, sufficient to drive the remote control system. Fig. 13 is representative of this

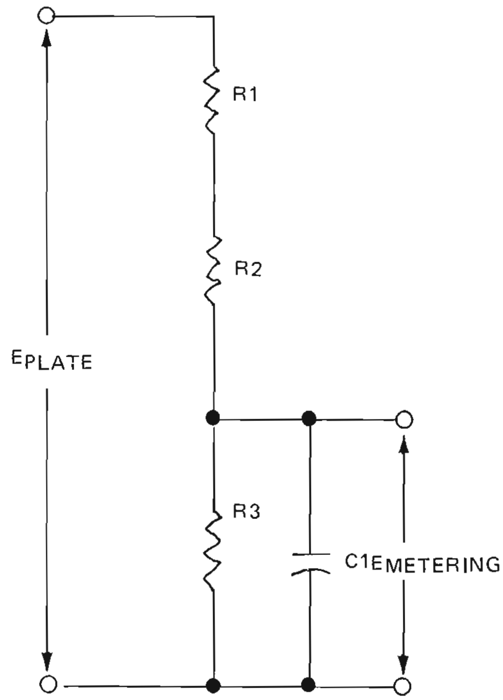


Fig. 13. Plate voltage sampling unit.

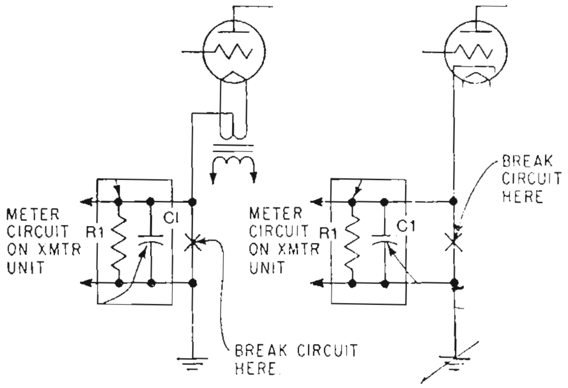


Fig. 14. Diagram of plate current sampling unit.

type of resistive network. In this configuration, R1 is attached to the output of the B+ supply at some convenient point. With some transmitters, such as UHF-TV transmitters utilizing klystrons, the plate or beam voltage is at a high potential. In these cases, it is advisable to raise slightly the value of the resistor between the beam voltage meter and ground or chassis. In most cases, by increasing this resistor to 4.7 K, a sufficient dc sample can be obtained at the negative side of the meter.

Plate Current

Several methods can be used for sampling plate current. A commonly used method is the sampling of cathode current. Fig. 14 shows the insertion of a low-value resistor between ground or chassis and the cathode. The other approach shown in this figure is the insertion of a low-value resistor between the filament transformer center-tap and ground or chassis. These points will provide a dc sample representative of total cathode current and introduces an error due to grid and, if used, screen currents.

Fig. 15 shows a universal plate circuit sampling kit. This kit can be used for sampling either plate voltage or plate current. It can also be used for the conversion of negative plate voltages, such as that described above for UHF-TV transmitters, to positive samples sometimes required. As this device can be directly inserted in series with the plate circuit, grid and screen currents are not measured.

Tower Lights

Tower light operation can be observed at the control point through the use of the remote control system. Standard practice is to sample the

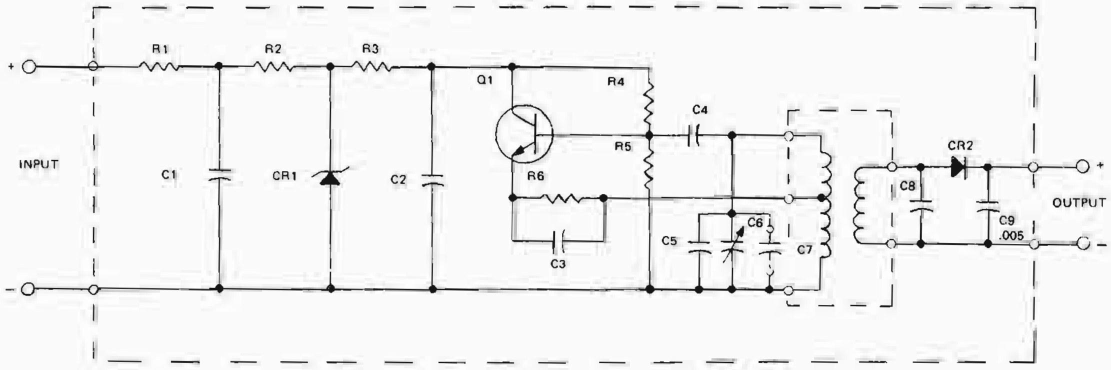


Fig. 15a. Typical universal plate current sampling unit.

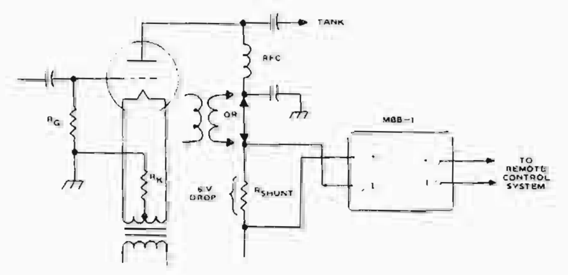


Fig. 15b. Typical installation to telemeter actual plate current.

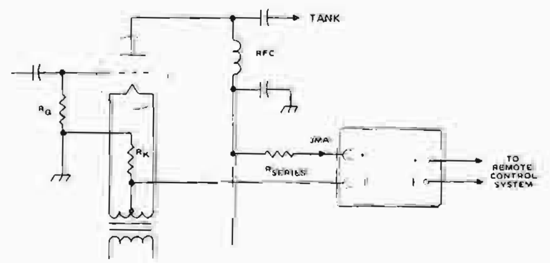


Fig. 15c. Typical installation to telemeter actual plate voltage.

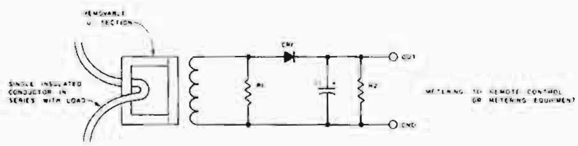


Fig. 16. Typical tower light current sampling unit.

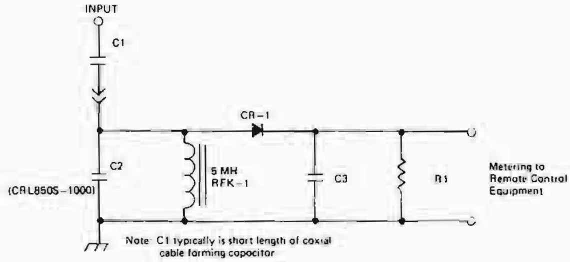


Fig. 18. RF voltage sampling unit.

current being shown in power circuits feeding the obstruction lighting system. With this measurement, it is possible to determine if both side lights and beacons are in operation. Various sampling methods can be used for tower lights (see Fig. 16).

AM Base Currents

Standard broadcast stations must have a remote indication of antenna base current. For those stations using directional arrays, all-active towers and common point would have to be included. The antenna monitor associated with this type of operation will be discussed below.

In most instances, a diode assembly will be used for obtaining this sample voltage. Fig. 17 shows an inductively coupled diode assembly. The pickup coil should be placed near the transmission line at a point just preceding the regular base current or common point current meter. Another approach, Fig. 18, uses voltage for obtaining the sample. This device must be connected to a "live" point.

Another common practice is the use of phase sampling loops. Fig. 19 exemplifies a common circuit. The relays must be used for switching between antenna monitor inputs and diodes to prevent loading by the diodes and the possible resulting erroneous indications by the phase monitor. Type-approved antenna monitors may also be used if they have outputs available for measuring antenna current. In any event, one method used should be specified when filing FCC Form 301-A.

FM/TV Output

Output of FM and TV transmitters can be sampled in a variety of ways. If the transmitter is

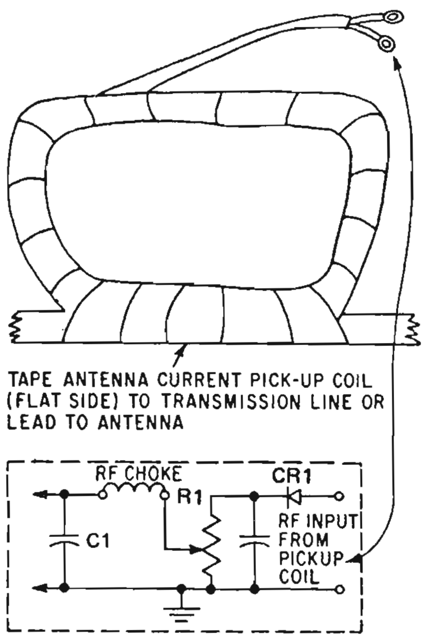


Fig. 17. Connections to antenna-current pickup coal for rectifying and filtering RF.

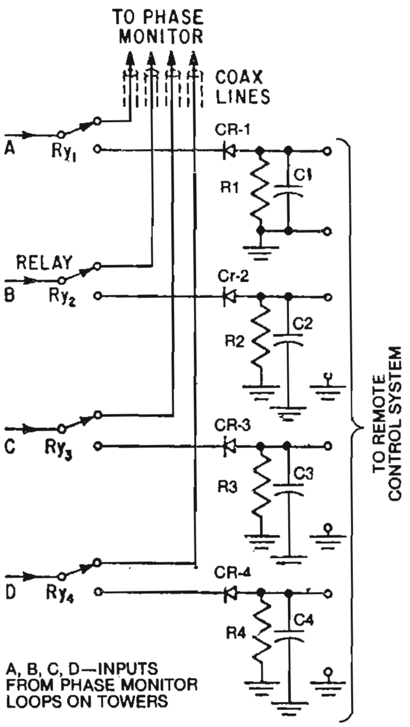


Fig. 19. Switching center connection of coax from loops on towers to remote-control system.

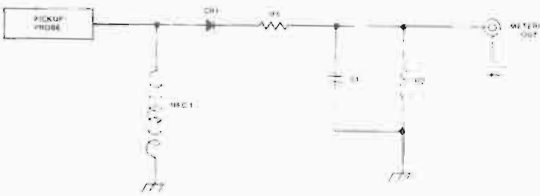


Fig. 20. FM/TV output sampling unit.

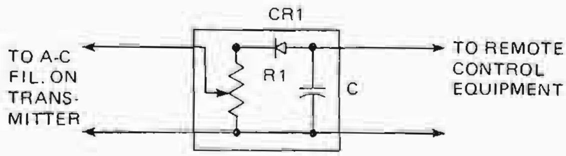


Fig. 22. Filament voltage sampling unit.

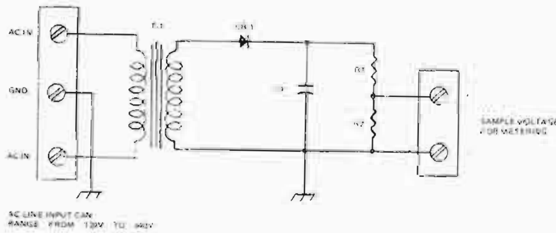


Fig. 21. Typical AC line voltage sampling unit.

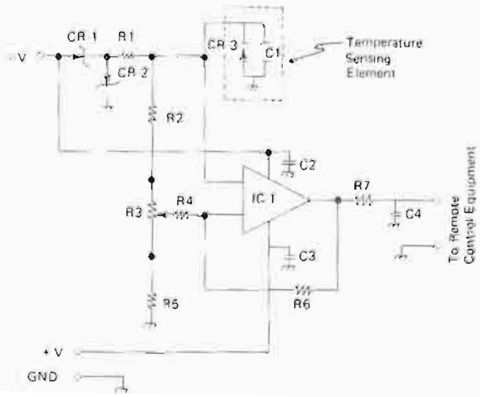


Fig. 23. Typical air temperature sampling unit.

not equipped with a sampling device, a sampling device such as that shown in Fig. 20 can be used. This device must be mounted on an unpressured section of transmission line. A small opening is made in the line and the probe inserted. This probe is used for sensing voltage present in the transmission line. The sample voltage is rectified before being applied to the remote control system. Such a device is sensitive to transmission line VSWR and, hence, is not recommended if critical measurement of transmitter power is desired.

Another common method for obtaining a forward power sample for FM and TV transmitters is to insert a dc amplifier in series with a built-in reflectometer, if used. In those systems using digital techniques, the logarithmic voltage developed in a reflectometer must be linearized for ease in calibration and display. Several manufacturers offer devices for the "linearizing" of the logarithmic forward power sample.

Line Voltage

In some remote controlled installations, it is desirable to monitor ac power mains for fluctuations in potential. Fig. 21 shows methods of obtaining this sample. It is for single phase circuits. If it is desired to monitor a three-phase circuit, simply monitor each of the three phases individually.

Should current want to be monitored in the ac power mains, some of the aforementioned methods for tower lights could be employed.

Filament Voltage

For ac filament voltages, it is necessary to sample the filament voltage and rectify to obtain the necessary dc sample for feeding the remote control system. Fig. 22 exemplifies circuitry for metering AC filament voltages. Alternatively, it is common practice to meter the line voltage applied to the filament transformer.

Temperature

In some installations, it may be desirable to monitor temperatures associated with transmitters or their environmental surroundings. Fig. 23 shows circuits which can be used for this purpose. In both circuits, temperature is measured through the use of thermistors, and the resulting variations in voltage because of temperature changes. The circuit shown in Fig. 23 is more refined and provides a linear relationship between output voltage and temperature.

37

The Emergency Broadcast System (EBS)

The role of communications in defending the Nation and protecting the life and property of its citizens has been recognized since the Federal Communications Commission was established in 1934. Over the intervening years, as the international situation has changed and as the Nation's communications systems have vastly expanded and improved, the role of communications in promoting the national defense and protecting life and property has likewise undergone farreaching changes.

Today when the United States has the capability of responding to a national emergency in a matter of minutes, it is imperative that the President be able to communicate with the entire Nation on a few moments' notice. Similarly, other federal officials, as well as state and local authorities, must be able to quickly transmit vital information to the public in times of emergency.

The Emergency Broadcast System (EBS) has been devised to provide the President and the federal government, as well as heads of state and local governments, or their designated representatives, with a means of communicating with the general public during emergency situations. Every home, business and institution will be able, when the EBS is activated, to receive Presidential messages and other pertinent announcements and news by tuning to an emergency broadcast station serving their local area.

The responsibility of the broadcast industry for providing emergency communications capability had its origins a number of years ago with the birth of CONELRAD, an acronym for *CO*ntrol of *EL*ectromagnetic *RAD*iation utilizing specially authorized standard broadcast stations. It was developed by the Federal Communications Commission during the period 1951-1953 at the joint request of the USAF Air Defense Command and the Federal Civil Defense Administration and remained in effect until early 1964. It was designed to satisfy the following two requirements:

1. Warn the general public and transmit emergency information during periods of declared national emergency (i.e., imminent threat of war, attack warning).

2. Minimize any radio navigational aid that the signals of the participating stations might furnish to attacking enemy aircraft.

Navigational aid denial was accomplished by restricting all authorized stations to operation on only two channels in the standard broadcast band (640 kHz and 1240 kHz). All nonparticipating stations were required to cease operations during such emergencies, and no transmissions were permitted on the remainder of the standard broadcast channels. In addition, the authorized stations transmitted intermittently. The combination of intermittent operation from any given station, plus the high concentration of signals originating from many different directions rendered radio direction-finding techniques practically useless. However, the high degree of cochannel interference that resulted from this operational mode severely limited the service areas of the participating stations. Initially, there were approximately 200 broadcast stations participating operationally in CONELRAD. This figure increased to approximately 1300 by late 1953 and stayed constant for the remainder of the program. In 1961, as a result of the development of ballistic missiles and the consequent diminishing importance of the tactical role of manned bombers, the Air Defense Command dropped the stringent technical restrictions they had imposed upon CONELRAD operation, and agreed that the authorized stations could operate with their regularly licensed facilities (power, frequency, etc.). The resulting increased service areas produced an improved emergency communication facility.

In 1964, a new improved system designated as the *Emergency Broadcast System* (EBS) was implemented. This name change was accomplished in order to differentiate the former (CONELRAD) two-channel 640 and 1240 kHz restricted communication system from station operation with regularly assigned facilities. It was during this change-over period that provision was made for FM broadcast stations to participate in the establishment of State Defense (relay) Networks.

Prior to 1972, in the event of a national emergency, participants in CONELRAD and the later EBS operation were required to possess a special emergency operating authorization called a National Defense Emergency Authorization (NDEA). Stations desiring to participate had to submit an informal application for a NDEA to the Commission, accompanied by documentary assurance that the station would comply with certain qualifying criteria set forth in the Basic EBS Plan.

In early 1972, all outstanding NDEAs were cancelled and replaced by new emergency operating authorizations called Emergency Broadcast System Authorizations, and the former qualifying criteria were abolished. All existing broadcast stations (unlike during the CONELRAD and early EBS periods which did not include television and all FM Stations) were furnished with new EBS Authorizations, accompanied by a memorandum advising them if they elected not to actively participate in the EBS they were instructed to return their authorizations, accompanied by a written request that they be cancelled. Similarly, all new broadcast stations licensed subsequent to the initial authorization period have been tendered EBS Authorizations, again accompanied by a letter advising that the authorizations should be returned with a written request for cancellation, in event the licensee does not want to actively participate. The abolishment of stringent EBS authorization qualifying criteria plus the expedited authorization distribution procedures have resulted in an increase in active station participation in the EBS from approximately 40 percent to over 94 percent of the total broadcast stations in the United States.

The term "key station" has no official status, and is not formally defined in the Commission's EBS Rules. However, the Number 1 Common Program Control Station (CPCS-1) in an EBS Operational Area is a key station in the system.

Current State Emergency Broadcast System (EBS) Operational Plans have been completed for the 50 states, the District of Columbia, and the three territories (Guam, Puerto Rico and Virgin Islands). These plans are subdivided into 506 Operational Areas, each area containing at least one Common Program Control Station (CPCS). There are other CPCSs in an Operational area but they are considered backups. Therefore, there are 506 CPCS-1 stations in the Emergency Broadcast System that may be considered key stations.

In addition, there are a total of 597 broadcast stations participating in the EBS Protected Station Program that also may be considered key stations. They maintain government loaned auxiliary power generating and other equipment in a fallout protected environment. There are 196 of these stations which are not the CPCS-1. Thus, it may be said that there is a total of 702 key stations in the Emergency Broadcast System; i.e., 506 CPCS-1s and 196 other stations in the EBS Protected Station Program.

SYSTEM ORGANIZATION

The Emergency Broadcast System (EBS) uses the facilities and personnel of the entire communications industry—broadcast stations, telephone companies and national press services—on a voluntary, organized basis to establish an emergency broadcasting network. This network is operated by the industry under government regulations and procedures and in a manner consistent with national security requirements. Broadcast station licensees participating in the EBS have been issued Emergency Broadcast System (EBS) Authorizations by the Federal Communications Commission. Under peacetime conditions, Presidential broadcasts are handled by existing nongovernment radio and television facilities. Under conditions that would call for the activation of the EBS the normal flow of communications could be disrupted, altered, or destroyed.

National-level EAN will be released only upon Presidential authority, and the White House will direct release of the Emergency Action Notification (EAN) which constitutes the notice to all broadcast stations and participating radio and television networks of an emergency situation. Both the Emergency Action Notification and Termination are transmitted only over the Emergency Broadcast System. Upon activation of the National-Level EBS, the White House Communication Agency (WHCA), which is responsible for providing all communications for the President under all conditions, will deliver the Presidential messages to selected origination points. From these points the Presidential messages or broadcast will be distributed to participating EBS stations via the nationwide Radio and Television Broadcast Network program distribution facilities.

The Federal Communications Commission has been assigned the overall responsibility for the development of the Emergency Broadcast System. The FCC ensures effective coordination between that agency, Office of Telecommunications Policy, other required government agencies and nongovernment entities concerned. The National Industry Advisory Committee (NIAC) has been organized to advise and assist the FCC and other appropriate authorities. Membership in NIAC and its subcommittees is restricted to officers and employees of nongovernment Federal Communications Commission licensees (communications industry). It is to study and submit recommendations for emergency communications policies, plans, systems, and procedures for all licensed and regulated communications in order to provide continued emergency communications service during emergency situations.

Key in development of the EBS is the National-Level Broadcast Services Subcommittee. This subcommittee, with the assistance of Special Working Groups, provides the NIAC and the FCC with continuing advice and recommendations to ensure a workable EBS. Members are responsible for providing advice and assistance in programming guidance, production, and other operations of the National-Level interconnecting facilities and systems voluntarily participating in the EBS.

A State Emergency Communications Committee (SECC) has been organized in each of the 50 States, Guam, Puerto Rico, Virgin Islands, and the District of Columbia. The function of the SECC is to prepare coordinated operational emergency communications plans, systems, and procedures for their areas. A Broadcast Services Subcommittee is responsible for a state EBS Plan. State plans must be consistent with the approved National-Level plans.

An Operational Area Emergency Communications Committee, which functions as a subcommittee of the SECC, has been organized within geographical Operational (Local) Areas designated in coordination between SECC and State authorities. An Operational (Local) Area may include one or more communities; portion of two or more states may be included in borderline situations. The function of a Broadcast Services Subcommittee of the Operational Area Emergency Communication Committee is to develop operational emergency communications systems, plans, and procedures for inclusion in the state EBS Plans for use during local level day-to-day emergency situations.

Again, participation in the EBS by FCC licensees is on a voluntary basis. The FCC sends new licensees an EBS authorization and a letter requesting their voluntary participation in the EBS. Licensees subsequently receive an appropriate EBS checklist, a portion of the state plan essential to their operation in the EBS, a special instruction card to be posted at AP/UPI teletypewriter machines and the EBS Rules and Regulations.

Participating stations that remain on the air during a National-Level emergency situation must carry Presidential messages "live" at the time of transmission. Activities of the National-Level EBS will preempt operation of the state or operational (Local) area EBS.

National programming and news which is not broadcast at the time of original transmission will be recorded locally by the Common Program Control Station (CPCS) for broadcast at the earliest opportunity consistent with operational (Local) area requirements.

SYSTEM OPERATION

National Level Activation and Termination.

(See Fig. 1.)

Implementation

The Emergency Action Notification (EAN) will be released at the National level upon request of the White House. When the White House directs activation of the National-Level EBS, the White House Communications Agency (WHCA), after a series of interim steps, issues instructions to implement the EBS. The Emergency Action Notification (EAN) message is then released which is eventually received by the Nation's broadcast stations. A dedicated teletypewriter net connecting the radio and television broadcasting networks and wire services transmits these messages. Following the EAN, there is a one-min. pause to allow time for the broadcasting networks to transmit a message over their internal alerting facilities, alerting stations that normal programming will be preempted by the EBS. Simultaneously, the EAN is transmitted over the respective Radio Wire Teletype Networks to alert those stations equipped to receive this service. Broadcast stations not equipped to receive either network alerting information or Radio Wire Teletype Network transmissions must rely on receipt of the EAN via off-the-air monitoring from other stations. Receipt of the EAN by any one of the methods discussed above is sufficient for the broadcast stations to commence emergency actions.

Station Responsibility

Upon receipt of the EAN certain actions are taken by all stations. These actions are:

a. Authenticate the EAN.

b. Discontinue normal programming and broadcast a special announcement alerting the public to the fact that important instructions are forthcoming.

c. Transmit the Attention Signal.

d. Broadcast the message which informs the public of the fact that an emergency situation exists, that some stations will remain on the air, and that additional news and information will follow. Those stations required to cease transmitting will so inform their listeners.

The actions taken by the broadcast stations following transmission of the attention signal depend on the station designation. Stations fall into the categories of:

a. Primary Station (Primary)

b. Primary Relay Station (PRI Relay)

c. Common Program Control Station (CPCS)

d. Originating Primary Relay Station (Orig. PRI Relay)

e. Nonparticipating Station (Non-EBS)

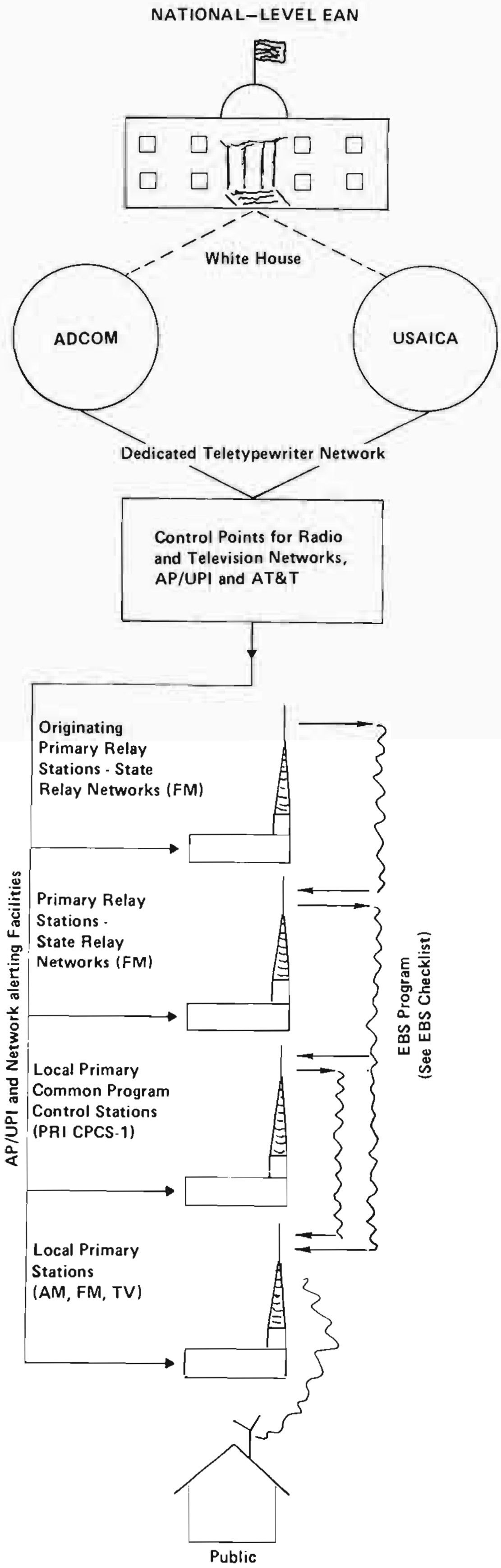


Fig. 1. Off-the-air monitoring.

Participating stations monitor the CPCS or PRI Relay station in their area or radio and television broadcasting networks for further instructions and broadcast emergency programming when it becomes available. Nonparticipating stations remove their carriers from the air and standby for the termination of the emergency. Should it become apparent the CPCS or PRI Relay stations may not be able to provide appropriate emergency program feed, other participating stations may elect to assume the duties by providing program feed.

When the National-level EBS is no longer needed, the Emergency Action Termination Message is transmitted. Broadcast stations receive the notification in the same manner as activation. The Common-Carriers then return the networks to normal configuration, and broadcast stations resume normal programming in accordance with their regular station authorization.

System Tests

Periodic Teletype Test Transmissions. The wire services will separately conduct test transmission to AM, FM, and TV broadcast stations on their Radio Wire Teletype Networks, a maximum of twice a month on a random basis at times of their choice. The subscribing broadcast stations enter the date and time of receipt of these test transmission operating consistently in the (broadcast) station program or operating log.

Closed Circuit Tests. These tests of the EBS will be conducted on a random or scheduled basis not more than once a month and not less than once every three months but only after FCC approval. Scheduled Closed Circuit Tests will be conducted at a time selected by the White House, the National Industry Advisory Committee (NIAC) representatives, and the FCC Defense Commissioner. The Closed Circuit Test Activation Message is disseminated to the various radio stations by:

1. The internal alerting facilities of the radio networks.
2. The Radio Wire Teletype Networks to all subscribers.

The common-carriers do not add participating independent stations to any of the Radio Networks during a Closed Circuit Test, unless ordered by the FCC.

During a Closed Circuit Test, broadcast stations do not interrupt programming and do not broadcast the message. The radio stations are required to:

a. Monitor the Radio Network for the Test Program.
b. Check the wire services teletype;
c. Authenticate the message and;

d. Record the time of the test consistently in the operating or program log.

Because of the limited time available for the Closed Circuit Test, the **Termination** of the test will occur on the following Closing Cue as it appears in the text of the program:

"This concludes the Closed Circuit Test of the Emergency Broadcast System."

Weekly Transmission Tests. All radio and TV stations are required to conduct a weekly test of the Attention Signal. This must be done once a week at a random day and time between 8:30 am and local sunset.

State Level EBS Operation (See Fig. 2)

Implementation

Upon receipt of a State-Level EAN all broadcast stations, including stations operating under equipment or program test authority, may, at the discretion of management, conduct operations in accordance with the provisions of the state-level EBS Plan. Day-to-day emergencies posing a threat to the safety of life and property which could cause activation of the State-Level EBS include tornadoes, hurricanes, floods, tidal waves, earthquakes, icing conditions, heavy snows, widespread fires, discharge of toxic gases, widespread power failures, industrial explosions, and civil disorders. In most instances the State-Level EAN will be released from the State Emergency Operations Center (EOC). Common-Carrier or Remote Pickup Units (RPU) are used to provide communications from the EOC. An FCC EBS authorization is not required for a broadcast station to participate in the operation of the State-Level EBS. Receipt of the State-Level EAN will be through the means of Off-the-Air Monitoring or as otherwise stipulated in the State EBS Plan.

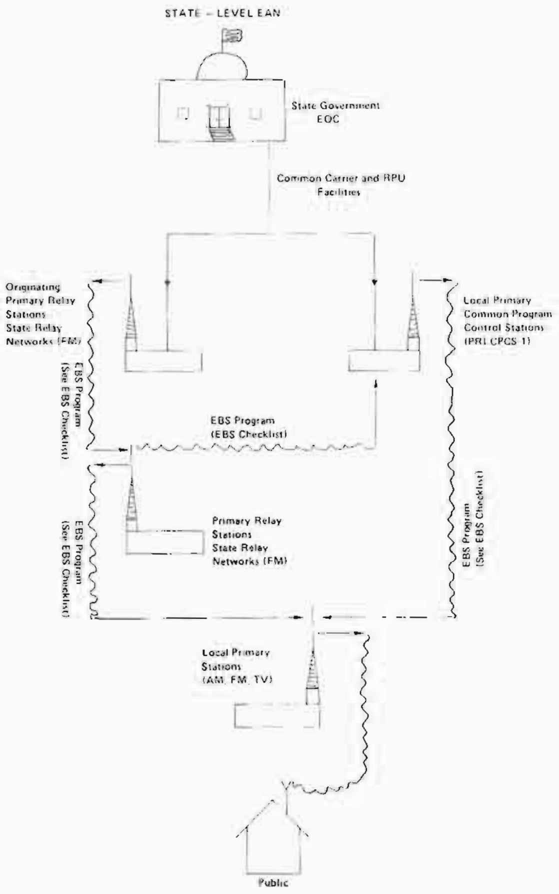


Fig. 2. Off-the-air monitoring.

Station Responsibility

Actions to be taken by the broadcast stations after receipt of the EAN are as follows:

a. Monitor the State Relay Network (PRI Relay Stations) for receipt of any further instructions from the original PRI Relay Station.

b. Monitor the Primary Station designated as the CPCS-1 for your Operational (Local) Area for receipt of any further instructions.

c. Discontinue normal program operation and broadcast the alert message.

d. Transmit the Attention Signal.

e. Broadcast the State-Level EBS EAN Message.

f. Upon completion of the above transmission resume normal programming until receipt of the cue from the CPCS for the Operational (Local) Area, or Primary Relay Station for the State EBS Network. Then begin broadcasting the common state-level program.

Upon receipt of notification of the termination of the State-Level EBS, participating broadcast stations will resume regular operations in accordance with the station authorization.

Operational (Local) Area EBS (See Fig. 3)

Implementation

Upon receipt of an Operational (Local) Area EAN, all broadcast stations, including stations operating under equipment or program test authority, which are voluntarily participating, may, at the discretion of management, conduct operations in accordance with the provisions of the State EBS Plan. Day-to-day emergencies posing a threat to the safety of life and property which could cause activation of the Operational (Local) Area EBS include tornadoes, hurricanes, floods, tidal waves, earthquakes, icing condi-

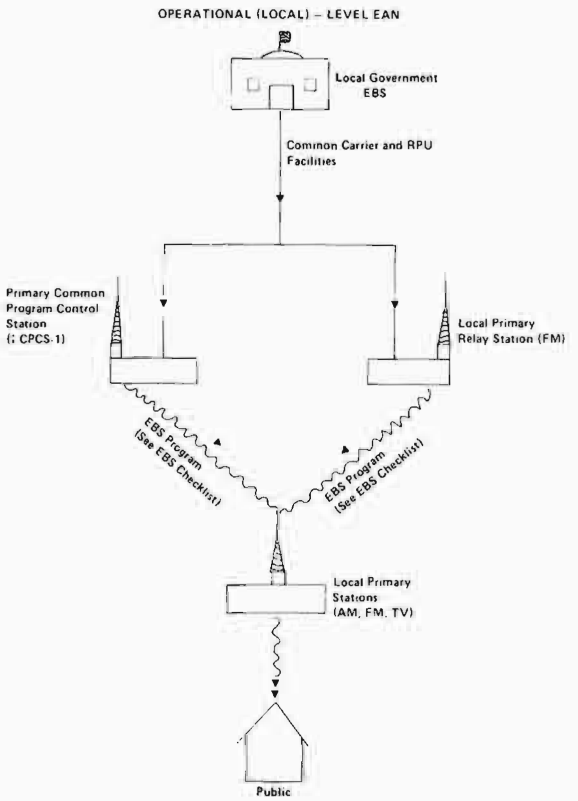


Fig. 3. Off-the-air monitoring.

tions, heavy snows, widespread fires, discharge of toxic gases, widespread power failures, industrial explosions, and civil disorders. In most instances the Operational (Local) Area EAN will be released from the local government Emergency Operations Center (EOC). Common-Carrier or Remote Pickup Units (RPU) are used to provide communications from the EOC. An FCC EBS Authorization is not required for a broadcast station to participate in the operation of the Operational (Local) Area EBS. Receipt of the Operation (Local) Area EAN will be through the means of Off-the-Air Monitoring or as otherwise stipulated in the State EBS Plan.

Station Responsibility

Actions to be taken by the broadcast stations after receipt of the EAN are as follows:

a. Monitor the Primary Station designated as the CPSC-1 for the Operational (Local) Area for the receipt of instructions.

b. Monitor the Primary Relay Station for the Operational (Local) Area for receipt of any further instructions.

c. Discontinue normal program operation and broadcast the alert message contained in the EBS Checklists.

d. Transmit the Attention Signal.

e. Broadcast the Operational (Local) Area EBS EAN Message.

f. Upon completion of the above transmission, resume normal programming until receipt of the cue from the CPCS-1 for the Operational (Local) Area. Then begin broadcasting the common program.

Upon receipt of the termination of the Operational (Local) Area-Level EBS, participating broadcast stations will resume regular operations in accordance with the station authorization.

State and Local Tests

Test of implementing procedures developed at the state and local level may be conducted on a day-to-day basis as indicated in the State EBS Operational Plans. Coordinated tests of EBS operational procedures for an entire State or Operational Area may be conducted in lieu of the weekly transmission tests.

ORGANIZATION, FUNCTIONS AND RESPONSIBILITIES OF THE NATIONAL INDUSTRY ADVISORY COMMITTEE

Introduction

Under normal conditions, the President of the United States and other Federal, National, State, and Operational (Local) area authorities and organizations, and the US population enjoy the benefits of a vast domestic and international communications complex. This vast complex of wire, cable, and radio communications is readily available in aural, visual, and functional forms to provide communications services in the public interest, convenience, and necessity. These non-government services rendered may be broadly categorized into Radio Broadcast Services, Safety and Special Radio Services, and Common Carrier Communications Services. (See Fig. 4.)

The Nation's broadcast facilities provide a mass communications medium for the daily dissemination of local, state, national, and international news and programming in the public interest by both aural and visual means.

The Safety and Special Radio Services provide essential communications for a variety of activities ranging from the safety of life and property (public safety, aviation, and marine), to heavy and light industry (industrial and land transportation), to the pleasure and general public use of radio (amateur and citizens).

The Nation's common carrier facilities, wire, cable, CATV, and radio (including satellite) facilities, provide an efficient nationwide and worldwide communications complex rendering

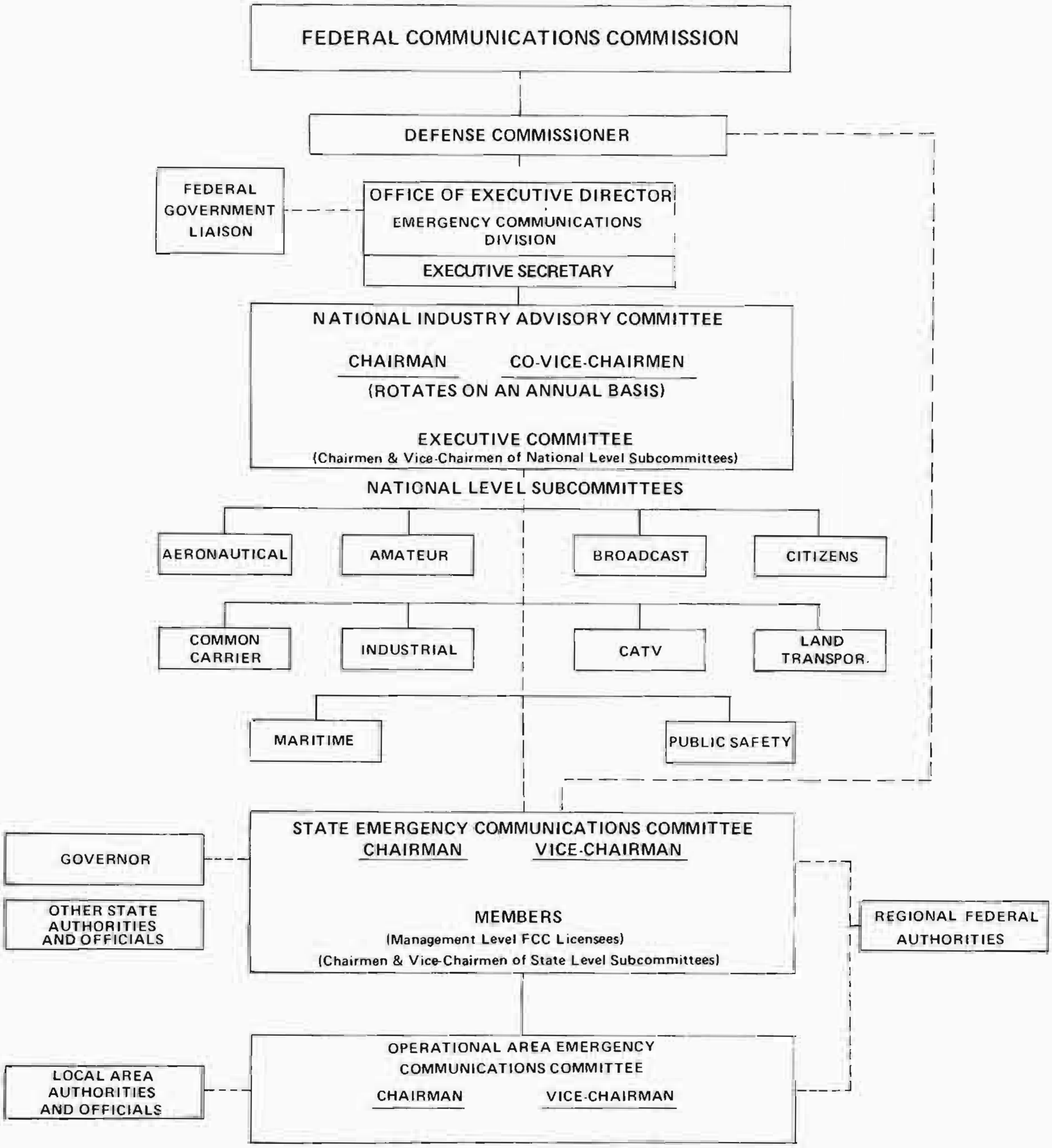


Fig. 4. National Industry Advisory Committee organization chart.

an extensive base of communications services available for hire. These services include telephone, telegraph, radio and television program services, CATV, and a multitude of leased communications services.

Communications in all forms are deeply integrated into emergency activities. During conditions of a national crisis or war, it is essential that the President and other appropriate authorities be able to communicate directly with the US population. The dissemination of Operational (Local) Area, State, and National Programming and news is also essential during such periods. If the President of the United States needs to issue an Emergency Action Notification, then specific operational emergency plans for all FCC licensed and regulated communications services are required to provide continued vital and essential communications capability. Both interstate and intrastate nongovernment communications facilities are utilized in fulfilling operational emergency communications requirements and supporting communications interconnections and planned arrangements for a continuity of service.

SCOPE OF PROBLEM

A broad range of emergency contingencies and requirements dictates the necessity for the orderly development, approval and implementation of operational emergency communications policies, plans, systems, and procedures capable of expeditious emergency activation, and utilizing, on a voluntary, organized basis, nongovernment personnel and Federal Communications Commission licensed and regulated facilities, covering:

1. *Common-carrier services.* (a) Extension, discontinuance, or reduction of common carrier facilities or services, and issuance of appropriate authorizations for such facilities, services, and personnel in an emergency; and control of all rates, charges, practices, classifications, and regulations for service to government and nongovernment users during an emergency, in consonance with overall national economic stabilization policies.

(b) Development and administration of priority systems for public correspondence and for the use and resumption of leased intercity private line service in an emergency.

(c) Use of common-carrier facilities and services to overseas point to meet vital needs in an emergency.

2. *Broadcasting services.* The construction, activation, or deactivation of AM, FM, TV, and auxiliary broadcast facilities and services; the continuation or suspension of broadcasting services and facilities; and the issuance of appropriate authorizations for such facilities, services, and personnel in emergency situations.

3. *Safety and special radio services.* Authorization, operation, and use of safety and special radio services, facilities, and personnel in the national interest in an emergency.

4. *Radio frequency assignment.* Assignment of radio frequencies to, and their use by Commission licensees in an emergency.

5. *Electromagnetic radiation.* Closing of any radio station or any device capable of emitting electromagnetic radiation or suspension or amending any rules or regulations applicable thereto, in any emergency, except for those belonging to, or operated by, any department or agency of the United States Government.

6. *Investigation and enforcement.* Investigation of violations of pertinent law and regulations in an emergency, and the development of procedures designated to initiate, recommend, or otherwise bring about appropriate enforcement actions required in the interest of national security.

7. *Priorities and allocations.* Systems for the emergency application of priorities and allocations to the production, distribution, and use of resources for which FCC has been assigned responsibility.

8. *Requirements.* Assembly, development as appropriate, and evaluation of requirements for assigned resources, taking into account estimated needs for military, atomic energy, civilian, and foreign purposes. Such evaluation shall take into consideration geographical distribution of requirements under emergency conditions.

9. *Evaluation.* Assessment of assigned resources in order to estimate availability from all sources under an emergency situation, analysis of resource availabilities in relation to estimated requirements, and development of appropriate recommendations and programs, including those necessary for the maintenance of an adequate mobilization base. Provision of data and assistance before and after attack for national resource analysis purposes.

10. *Claimancy.* Plans to claim from the appropriate agency supporting materials, manpower, equipment, supplies, and services which would be needed to carry out assigned responsibilities and other essential functions of FCC, and cooperation with other agencies in developing programs to insure availability of such resources in an emergency.

11. *Facilities Protection.* Facilities protection guidance material adapted to the needs of the facilities and services concerned and promotion of a national program to stimulate disaster preparedness and control in order to minimize the effects of overt or covert attack on facilities or other resources for which FCC has management responsibility, including, but not limited to, organization and training of facility employees, personnel shelter, evacuation plans, records protection, continuity of management, emergency repair, dispersal of facilities, and mutual aid associations for an emergency.

12. *Warfare effects monitoring and reporting.* A capability, both at national and field levels, to estimate the effects of attack on assigned resources and to collaborate with and provide data to the Office of Preparedness, the Department of Defense, and other agencies, as appropriate, in verifying and updating estimates of resource status through exchanges of data and mutual assistance, and providing for the detection, identification, monitoring and reporting of such warfare effects at selected facilities.

13. *Salvage and rehabilitation.* Plans for salvage, decontamination, and rehabilitation of facilities involving resources under FCC jurisdiction.

14. *Research.* Research in areas directly concerned with carrying out emergency preparedness responsibilities, designating representatives

for necessary ad hoc or task force groups and providing advice and assistance to other agencies through FCC in research in emergency communications.

15. *Stockpiles.* Assistance in formulating and carrying out plans for stockpiling of strategic and critical communications materials and survival items.

16. *Direct economic controls.* Cooperation with federal financial agencies in the development of emergency preparedness measures involving emergency financial and credit measures, as well as price, rent, wage and salary stabilization, and consumer rationing programs.

17. *Financial aid.* Plans and procedures in cooperation with the federal financial agencies for financial and credit assistance to those segments of the private sector for which FCC is responsible in the event such assistance is needed under emergency conditions.

18. *Emergency public information.* (a) Obtaining and providing information regarding the emergency functions or assignments of the individual departments or agencies for dissemination to the American people via the Emergency Broadcast System during an emergency.

(b) Determination of requirements and making arrangements for prerecordings to provide continuity of program service over the Emergency Broadcast System.

National Industry Advisory Committee

Introduction

A National Industry Advisory Committee (NIAC) has been organized to advise and assist the Federal Communications Commission, and other appropriate authorities. NIAC's function is to study and submit recommendations for emergency communications policies, plans, systems, and procedures, for all FCC licensed and regulated communications in order to provide continued emergency communications services under conditions of crisis or war. In addition, NIAC considers the adaptation and use of the systems, arrangements, and interconnecting facilities set forth in approved Operational Plans on a voluntary, organized basis during national, state, and operational (local) situations posing a threat to the safety of life and property. Included also are those conditions constituting a state of public peril or disaster. Such use of these capabilities during emergency situations is in accordance with the Commission's emergency and preparedness responsibilities, as defined in sections 1, 4(o), 301, 308(a) and 606 of the Communications Act of 1934, as amended, and Executive Order 11490.

Organization

The National Industry Advisory Committee:

A Chairman
A Vice Chairman
Executive Secretary
An Executive Committee composed of the Chairman and Vice Chairmen of National Level Subcommittees

National Level Subcommittees:

Aeronautical Communications Services Subcommittee
Amateur Radio Service Subcommittee
Broadcast Services Subcommittee
CATV Communications Services Subcommittee
Citizens Radio Service Subcommittee
Domestic and International Common Carrier Communications Services Subcommittee
Industrial Communications Services Subcommittee
Land Transportation Communications Services Subcommittee
Maritime Communications Services Subcommittee
Public Safety Communications Services Subcommittee

Members of the NIAC are appointed for a term not exceeding two years by the Federal Communications Commission, subject to appropriate security clearance when warranted. Membership in the NIAC and its subcommittees is restricted to officers and employees of nongovernment Federal Communications Commission licensees (communications industry), subject to formal waiver when it is deemed in the public interest, convenience, and necessity. ("Nongovernment," as used herein, excludes federal government but includes state and local government Federal Communications Commission licensees. Communications facilities of federal government agencies are not licensed by the Federal Communications Commission.) Since all appointees serve at the pleasure of the Commission, any appointment may be terminated without cause. Such termination will be effective upon receipt of written notification from the Commission.

The Executive Secretary serves as the official correspondent for the National Industry Advisory Committee.

Functions and Responsibilities

The NIAC is concerned with operational emergency communications policies, plans, systems and procedures to fulfill stated requirements under a broad range of emergency contingencies posing a threat to the safety of life and property. The principal functions and responsibilities include but are not limited to:

a. Studying and submitting recommendations to the Federal Communications Commission concerning operational emergency communications.

b. Providing advice and recommendations through the Federal Communications Commission to appropriate federal, national, state and local authorities and organizations to enhance emergency communications operations.

c. Maintaining liaison with the nongovernment communications industry.

d. Maintaining liaison with all subcommittees, Special National Industry Advisory Committee Working Groups, and ad hoc committees to coordinate and assist in the planning for the utilization of nongovernment communications facilities during emergencies.

e. Coordinating with the Federal Communications Commission in the establishment of authentication procedures for use during emergencies.

f. Advising the Federal Communications Commission concerning industry opinion relative to any proposed test or exercise of emergency communications systems, plans, and procedures. Also assisting, observing and evaluating the effectiveness of such activities.

g. Evaluating proposals for the development and use of operational emergency communications systems, plans, and procedures.

h. Encouraging studies and research directed towards the improvement of existing and development of new systems, plans, and policies which will improve the overall effectiveness of emergency communications.

i. Maintaining liaison with State Emergency Communications Committees.

Procedures

Detailed procedures with respect to operation, management, and functioning of the National Industry Advisory Committee, Subcommittees and Working Groups are published in separate documents and are available from the Executive Secretary, National Industry Advisory Committee, Federal Communications Commission, Washington, D.C. 20554.

Over-the-air EBS Station Monitoring

In order to insure the effectiveness of the Emergency Broadcast System, all licensees must have installed and in operating condition, equipment capable of transmitting and receiving the Attention Signal. The receiving equipment must be maintained in operating condition, including arrangements for human listening or automatic alarm devices and shall be installed at the designated transmitter control point and/or studio location in such a way that it enables the broadcast station staff, at normal duty locations, to be alerted instantaneously upon the receipt of the Attention Signal and to immediately monitor the emergency programming.

The Attention signal consists of the simultaneous transmission of two audio tones for not less than 20 sec. nor more than 25 sec. The characteristics of the two-ton signaling system are as follows:

Encoder

Function. To give an alert by demuting a monitoring receiver at the station receiving the signal. The monitor is continuously tuned to the sending station for EBS information.

Signal. Two simultaneous audio frequencies, 853 Hz and 960 Hz, each ± 0.5 Hz.

Harmonic distortion. Not to exceed 5 percent of each tone at encoder output.

Minimum level of modulation. Each tone must be capable of modulating the transmitter to not less than 40%, with all equipment ordinarily used in the audio line between the encoder and transmitter. To assure this, the specification further says that the output at each audio tone shall be at least + 8 dBm into a 600-ohm load. The unit shall allow calibration of each tone separately.

Time period. On activation, the two tones shall be generated for not less than 20 sec. nor more than 25 sec.

Operating temperature. All foregoing specs maintained in ambient temperature 0° to 50°C.

Humidity. All specs must be maintained up to 95 percent relative humidity.

Supply voltage variation. Operation must be within tolerances with supply voltage from 85 percent to 115 percent of the rated value.

Testing conditions. Must maintain the frequency, distortion, and time period specs in a minimum RF field of 10 v/M at a frequency in the AM broadcast band, and with a minimum RF field of 0.5 v/M in either the FM or TV frequency band.

Indicator device. A visual and/or aural indicator must show clearly that the device has been activated.

Switch guard. The activation switch must have protection which will prevent accidental operation; this must include remote-control switches.

Decoder

The decoder must be activated only on *simultaneous detection* of the two audio tones, 853 Hz and 960 Hz. This simultaneous reception must demute the monitoring receiver. The additional capability of activiting an external alarm is not *required*, but has obvious value.

To prevent falsing, the decoder must have: a time delay not less than 8 seconds, and not more than 16 seconds; must have bandwidth such that there is no response to tones that vary more than ± 5 Hz from each of the frequencies, 853 Hz and 960 Hz.

The decoder must have a reset switch, for returning the receiver to a muted state after activation.

The decoder must maintain all the foregoing specifications in ambient temperature from 0° to 50°C.

For the convenience of operating personnel, the EBS decoder is in most cases muted for normal periods of operation. Such devices are, of course, activated upon receipt of the alert signal.

Special Reception Techniques

In certain instances either where stations are at a critical distance from another station or where receiving conditions are generally difficult by reason of directional operation, atmospherics, etc., extraordinary means are sometimes necessary to ensure the reception of the alert signal from another station. The Federal Communications Commission has provided information concerning the use of special receiving antennas which are applicable for such purposes. The application of this information, in many situations, will enable satisfactory reception of stations which ordinarily are completely unintelligible.

Shielding and Filtering

In cases where applicable, it is advisable to locate the antenna as far from a source of interference (or radio transmitter antenna) as possible and use coaxial or shielded transmission line to the receiver input terminals. Appropriate filtering and bypassing of power leads in order to eliminate the possible effect of high RF fields on the reception of the desired signal may be required. The antenna transmission line to the receiver may have to incorporate trap circuits to filter out the local transmitter radiation. For low-impedance receiver input, the circuit may be a parallel-resonant trap connected in series with the inner conductor of the coax. For high-impedance receiver input, the trap will perform most satisfactorily if connected directly across the input terminals, tuned to the frequency of the local station. Sometimes, both traps are required when the local RF field is high and/or when the cross-modulation products produced in a superheterodyne receiver cause adverse reception effects or when the undesired radiation is on a different frequency from the desired.

Loop Antenna

When the desired and undesired stations are on the same or very nearly the same frequencies, a directional antenna is often necessary. Such an antenna is also necessary in areas of weak signal strength from the desired station. A simple type of such antenna is the loop antenna, which is of maximum effectiveness only when the signals under consideration are within the ground-wave area. When this antenna is used, the null (obtained broadside to the plane of the loop) is oriented toward the undesired station. Maximum voltage is induced in the loop when the plane of the loop points toward the desired station. Since the antenna is bidirectional, a station on the back side may produce sufficient signal to cause interference, in which case a more elaborate directional receiving antenna may be required (see Fig. 5).

Beverage, or "Wave," Antenna

A very effective receiving directional antenna is the Beverage type. The theory of this antenna has been well covered in texts for many years and is not included here. Among the desirable properties of the Beverage, or the "wave," antenna for reception are:

1. It delivers a stronger signal over the entire standard broadcast band than a good simple antenna of the single-wire variety.
2. When terminated, it is unidirectional but can be used as a bidirectional antenna either by switching the termination or by being unterminated.
3. Atmospherics and industrial interference are considerably reduced, especially when the source is in a direction other than that of the main lobe of the antenna.

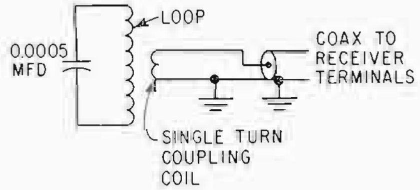


Fig. 5. Simplified schematic of a loop antenna with construction details. ***Loop dimensions:*** **13 turns of No. 20 wire wound on a 12-in. square form, with 1/8 in. spacing between turns. The coupling coil is a single turn wound inside the loop and spaced approximately 1 in. from the loop. The mechanical mounting is optional, but for best results the loop should be mounted in the clear and away from metallic objects. Experiments with various turns in the coupling coil and using a coaxial cable from the loop to the receiver might prove beneficial. Shielding the loop is important in direction-finding work but is not important for ordinary reception.**

4. The antenna is low in cost, has long life, and is usually easy and simple to erect provided the space is available.

Emergency Broadcast System (EBS)
Checklist for Participating Stations

The following checklist is a condensation of the Basic Emergency Broadcast System Plan, and contains simplified instructions for each type of situation. The checklist contains step-by-step procedures for stations to follow when receiving a National-Level Emergency Action Notification. Also the termination procedures to be followed by all licensees at the conclusion of the National-Level Emergency. The checklist provides detailed procedural information as to what action must be taken when in receipt of National-Level Closed Circuit Tests, the periodic Teletype Tests and the Weekly Transmission Tests. Lastly, step-by-step instructions are included for state and local level procedures and tests. More detailed information may be found, concerning these simplified instructions, by referring to Part 73 of the Commission's Rules and Regulations.

NATIONAL LEVEL INSTRUCTIONS

When EBS is activated by the White House, all broadcast stations must take the following actions. Stations should record all emergency broadcast (including notification) and log all significant events in the event these records are required at a later date.

Activation Procedures—All Stations

1. Receive Emergency Action Notification—EAN

(This is the notice which activates EBS—Presidential messages may be received as soon as 5 mins.)

Notification by one of the following methods is sufficient to commence action:

- AP and UPI TELETYPE — Preceded and followed by a line of "X's" and 10 bell alarm
- RADIO-TV NETWORKS — Affiliates only—preceded by network alerting signal—Continue to monitor for further instructions
- EBS MONITOR RECEIVER — Preceded by Two-Tone Attention Signal—See Step 5 for message format—Continue to monitor for further instructions—Your EBS Monitoring assignment is specified in the State EBS Operational Plan.

EMERGENCY ACTION NOTIFICATION MESSAGE—AP AND UPI SUBSCRIBERS/NETWORK AFFILIATES ONLY

"This is an Emergency Action Notifi*cation requested by the White House. The AUTHENTICATOR WORD for this notification is (—). All stations follow procedures in the EBS Checklist for national level emergency. The President of the United States or his designated representative will shortly deliver a message over the EMERGENCY BROADCAST SYSTEM. The Authenticator Word is (—).*"

2. Authenticate Notification AP and UPI Subscribers/Network Affiliates Only

Compare authenticator words in notification with words on current EBS authenticator list. Take no further action if words do not match.

Different activation and termination words are provided for each date. Words are effective 12:01 a.m. Washington, D.C. time

3. Discontinue Normal Programming And Broadcast Announcement

(TV Stations shall display an appropriate EBS slide and transmit all following announcements visually and aurally in the manner required by Section 73.675(b) of the FCC Rules. Foreign language stations report all announcements in foreign language.

"We interrupt this program; this is a national emergency. Important instructions will follow.' '

4. Transmit Attention Signal

Broadcast the Two-Tone Attention Signal (see section 73.906 of the rules) for from 20 to 25 secs.

Note. Noncommercial educational FM broadcast stations of 10 watts or less which are exempt from having the capability to transmit the Two-Tone Attention Signal.

Primary Stations Only
(Including PRI CPCS Stations)

5. Broadcast Announcement

"This is an Emergency Action Notification. All stations shall broadcast this Emergency Action

Notification Message. This station has interrupted its regular program at the request of the White House to participate in the Emergency Broadcast System. During this emergency, some stations will remain on the air broadcasting news and official information to the public in assigned areas. This is station (call letters). **We will remain on the air to serve the** (operational area name) **area. If you are not in this area, you should tune to other stations until you hear one broadcasting news and information for your area. You are listening to the Emergency Broadcast System serving the** (operational area name) **area. Do not use your telephone. The telephone lines should be kept open for emergency use. The Emergency Broadcast System has been activated to keep you informed. I repeat . . ."** (Repeat Announcement)

6. Monitor Following Sources For Further Instructions And Broadcast Emergency Programming As Soon As Available:

Sources

- **Common Program Control Station For Operational Area**
- **Radio-TV Network Lines**
  Affiliates & Non-affiliates serviced by participating communications common-carriers
- **Primary Relay (FM) Station of State Relay Network**
- **Any other source that may be available**

Priorities

Record lower priority programming for rebroadcast at earliest opportunity.

First—Presidential messages—Must be carried "live"

Second—Operation Area (LOCAL) Programming

Third—State Programming

Fourth—National Programming and News

7. Use This Standby Script Until Emergency Programming Available—Later As Filler

"We interrupt our program at the request of the White House. This is the Emergency Broadcast System. All normal broadcasting has been discontinued during this emergency. This is station (call letters). **This station will continue to broadcast, furnishing news, official information and instructions, as soon as possible, for the** (operational area name) **area. If you are not in the** (operational area name) **area, tune to a station furnishing information for your area. I repeat—We interrupt our program at the request of the White House. This is the Emergency Broadcast System. All normal broadcasting has been discontinued during this emergency. This station will continue to broadcast, furnishing news, official information and instructions, as soon as possible, for the** (operational area name) **area. If you are not in the** (operational area name) **area, turn to a station furnishing information for your area. Do not use your telephone. The telephone lines should be kept open for official use. The Emergency Broadcast System has been activated to keep you informed. To repeat—This is station** *(call letters).* **This station will broadcast news, official information and instruction for the** *(operational area name)* **area. If you are in the** *(operational area name)* **area, keep tuned to this station for further emergency information. It is important that you listen carefully to announcements only on the station broadcasting information for your area." (Repeat as needed.)**

8. Monitor For Emergency Action Termination

Same methods as for notification—Upon receipt, proceed to termination procedures.

Primary Relay Stations Only
(Including Originating Primary Relay Stations)

5. Broadcast Announcement

"This is an Emergency Action Notification. All stations shall broadcast this Emergency Action Notification Message. This station has interrupted its regular program at the request of the White House to participate in the Emergency Broadcast System. During this emergency, some stations will remain on the air broadcasting news and official information to the public in assigned areas. This is station (call letters). **We will be serving as a program distribution and relay channel to other stations. We will remain on the air to serve the** (operational area name) **area. If you are not in this area, you should tune to other stations until you hear one broadcasting news and information for your area. Do not use your telephone. The telephone lines should be kept open for official use. The Emergency Broadcast System has been activated to keep you informed. I repeat . . ."** (Repeat Announcement.)

6. Monitor Following Sources For Further Instructions And Broadcast Emergency Programming As Soon As Available

Sources

- **Common Program Control Station For Operational Area**

- **Radio-TV Network Lines**
  Affiliates and Non-Affiliates serviced by participating communications common-carriers.
- **Another Primary Relay Station of the State Relay Network**
- **Any other source that may be available.**

Priorities

Record lower priority programming for rebroadcast at earliest opportunity.

First—Presidential Messages—Must be carried "live"
Second—Operational Area (LOCAL) Programming
Third—State Programming
Fourth—National Programming and News

7. Use This Standby Script Until Emergency Programming Available—Later As Filler

"We interrupt our program at the request of the White House. This is the Emergency Broadcast System. All normal broadcasting has been discontinued during this emergency. This is station (call letters). **This station will continue to broadcast, furnishing news, official information and instructions, as soon as possible, for the** (operation area name) **area. If you are not in the** (operational area name) **area, tune to a station furnishing information for your area. I repeat—We interrupt our program at the request of the White House. This is the Emergency Broadcast System. All normal broadcasting has been discontinued during this emergency. This station will continue to broadcast, furnishing news, official information and instructions, as soon as possible, for the** (operational area name) **area. If you are not in the** (operational area name) **area, tune to a station furnishing information for your area.**
Do not use your telephone. The telephone lines should be kept open for official use. The Emergency Broadcast System has been activated to keep you informed. To repeat—This is station (call letters). **This station will broadcast news, official information and instruction for the** (operational area name) **area. If you are in the** (operational area name) **area, keep tuned to this station for further emergency information. It is important that you listen carefully to announcements only on the station broadcasting information for your area.' '** (Repeat as needed)

8. Monitor For Emergency Action Termination

Same methods as for notification—Upon receipt, proceed to termination procedures.

Termination Procedures—All Stations

1. Receive Emergency Action Termination

(Same methods as for notification)

EMERGENCY ACTION TERMINATION MESSAGE—AP/UPI SUBSCRIBERS/ NETWORK AFFILIATES ONLY

"This is an Emergency Action Termination. The AUTHENTICATOR WORD for this termination is (—). All stations follow the EBS Checklist for termination procedures. The Authenticator Word is (—)."

2. Authenticate Termination

Compare authenticator words in termination with words on current authenticator list. Do not initiate termination of words do not match.
(Red envelope contained in pocket on inside front cover.)

3. Broadcast Announcement:

"This concludes operations under the Emergency Broadcast System. All broadcast stations may now resume normal broadcast operations." (Repeat announcement.)

4. Resume Normal Programming

(In accordance with regular station authorization)

NATIONAL LEVEL TESTS

National interconnecting arrangements and facilities (Networks, Key Stations, AP/UPI, AT&T) will be tested periodically. See Basic EBS Plan for detailed instructions. Procedures for tests which affect all stations are described below.

Closed Circuit Tests

(Radio Network Affiliates and AP/UPI Subscribers)

DO NOT INTERRUPT PROGRAM—DO NOT BROADCAST TEST MESSAGE

Notification Methods

• RADIO NETWORKS	Affiliates only—Preceded by network alerting signal
• AP and UPI TELETYPE	Preceded and followed by a line of "X's" and 10 bell alarm

CLOSED CIRCUIT TEST ACTIVATION

MESSAGE—AP/UPI SUBSCRIBERS/ RADIO NETWORK AFFILIATES ONLY

"This is notification of a closed circuit test of the EMERGENCY BROAD-

CAST SYSTEM. The test program will begin at ____________, Washington, D.C. time. Radio stations do not broadcast this message and do not broadcast the audio program. The test Authenticator Word is _______. This message authorizes a closed circuit test of the Emergency Broadcast System. Broadcast stations monitor radio network lines for closed circuit test program. All stations follow procedures in the EBS Checklist for closed circuit test. The test Authenticator Word is ____________."

Action By Station:

1. **Monitor Radio Network For Test Program**
2. **Check AP and UPI Teletype**
3. **Authenticate Test Message**

Compare Authenticator Words with test words printed on outside of EBS AUTHENTICATOR LIST ENVELOPE *(Red envelope).* If words do not match take no further action.

4. **Record Time Test Received in Station Operating or Program Log**

Termination Methods:

• RADIO NETWORKS	Affiliates only—receive following aural Closing Cue: "This concludes the Closed Circuit Test of the Emergency Broadcast System."
• AP and UPI TELETYPE	Preceded and followed by a line of "X's" and 10 bell alarm.

Closed Circuit Test Termination Message
(AP and UPI Subscribers Only)

"This is an EBS Closed Circuit Test Termination. The Authenticator Word for this termination is (—). The Closed Circuit Test was terminated at (Date and Time), Washington, D.C. Time. The Authenticator Words is (—)."

Action By Station:

1. **Radio Network Affiliates Monitor Network For Closing Cue**

2. **AP and UPI Subscribers Check Teletype For Closed Circuit Test Termination Message**

3. **Authenticate Test Termination Message**

Compare Authenticator Word with test words printed on outside of EBS Authenticator List Envelope *(Red Envelope).* If words do not match take no further action.

4. **Record Time Test Termination Message Received in Station Operating or Program Log**

Periodic AP and UPI Test Transmissions
(AP and UPI Subscribers Only)

DO NOT INTERRUPT PROGRAM—DO NOT BROADCAST TEST MESSAGE

Notification Method

• AP and UPI TELETYPE	Preceded and followed by a line of "X's" and 10 bell alarm

Periodic Teletype Test Message

"This is a test of the Emergency Action Notification Procedures. If this were not a test, you would receive an Emergency Action Notification Message containing Authenticator Words. This is a test of the Emergency Action Notification Procedures. All stations follow procedures in EBS Checklist for periodic teletype tests."

Action By Station

1. **Record Time Test Received In Station Operating or Program Log**

(No authentication provided)

WEEKLY TRANSMISSION TESTS OF THE ATTENTION SIGNAL AND TEST SCRIPT

(All Radio and TV Stations)

TRANSMIT ATTENTION SIGNAL TEST A MINIMUM OF ONCE A WEEK AT RANDOM DAYS AND TIMES BETWEEN 8:30 AM AND LOCAL SUNSET

Action By Station

1. **Discontinue Normal Programming**
2. **Broadcast Announcement:**

(TV stations shall display an appropriate EBS slide and transmit all following announcements visually and aurally in the manner described by Section 73.675(b) of the FCC Rules. Foreign language stations repeat all announcements in foreign language.

"This is a test. This station is conducting a test of the Emergency Broadcast System. This is only a test.' '

3. Transmit Attention Signal

BROADCAST THE TWO-TONE ATTENTION SIGNAL (SEE SECTION 73.906 OF THE RULES)

4. Broadcast Announcement:

"This is a test of the Emergency Broadcast System. The broadcasters of your area in voluntary cooperation with the FCC and other authorities have developed this system to keep you informed in the event of an emergency. If this had been an actual emergency, you would have been instructed where to tune in your area for news and official information. This concludes this test of the Emergency Broadcast System.

5. Resume Regular Programming

6. Record Time Test Conducted in Station Operating or Program Log

STATE AND LOCAL LEVEL INSTRUCTIONS

These procedures may be amended or altered as set forth in procedural guides, SOP's, and other implementing instructions which are considered an appendix to the State EBS Operational Plan.

1. ACTIVATION

- STATE LEVEL — A request for activation may be directed to the Originating Primary Relay Station by the Governor, his designated representative, the National Weather Service, the State Civil Defence or State Office of Emergency Services.
- LOCAL LEVEL: — A request for activation may be directed to the Common Program Control Station (CPCS-1) by the Weather Service, local Civil Defence, and local government or public safety officials.

2. AUTHENTICATION

The Originating Primary Relay Station and/or Common Program Control Station will authenticate request for activation according to the State EBS Operational Plan and associated implementing instructions.

3. IMPLEMENTATION

(a) Record emergency program material. (Optional).

(b) Broadcast the Following announcement:

> *"We interrupt this program because of a* (state/local) *emergency. Important information will follow."*

(c) *Transmit the EBS Attention Signal for from 20 to 25 seconds.*

(d) Broadcast the following announcement:

> *"We interrupt this program to activate the* (name of State or Operational Area) *Emergency Broadcast System at the request of* (activating Official) *at* (time)."

(e) Broadcast emergency program material (from (a) above).

NOTE: TV stations participating in the State or local level EBS shall display an appropriate EBS slide and transmit all announcement visually and aurally in the manner required by Section 73.675 (b) of the FCC Rules. Foreign language stations repeat all.

4. TERMINATION

(a) Upon receipt of the termination notice from activating official, make the following announcement:

> *"This concludes operations under the* (name of State or Operational Area) *Emergency Broadcast System. All broadcast stations may now resume normal broadcast operations."*

(b) Record emergency operation in station operating or program log. Send brief summary to FCC (Optional).

STATE AND LOCAL TESTS

Tests of implementing procedures developed at the State and local levels may be conducted on a day-to-day basis as indicated in State EBS Operational Plans. Coordinated tests of EBS operational procedures for an entire State or Operational Area may be conducted in lieu of the Weekly Transmission Tests of the Attention Signal and Test Script required by Section 73.961 (c) of the Rules.

Station Notes

NATIONAL LEVEL INSTRUCTIONS

Emergency Broadcast System (EBS) Checklist (Nonparticipating Stations)

When EBS is activated by the White House, all broadcast stations must take the following actions. Stations should record all emergency broadcast (including notification) and log all significant events in the event these records are required at a later date.

Activation Procedures-All Stations

1. Receive Emergency Action Notification-EAN

(This is the notice which activates EBS—Presidential messages may be received as soon as 5 mins.)

Notification by one of the following methods is sufficient to commence action:

• AP and UPI TELETYPE	Preceded and followed by a line of "X's" and 10 bell alarm
• RADIO-TV NETWORKS	Affiliates only—preceded by network alerting signal—Continue to monitor for further instructions
• OFF-THE-AIR MONITOR	Preceded by Two-Tone attention signal—See Step 5for message format—Continue to monitor for further instructions

Your EBS Monitoring assignment is specified in the State EBS Operational Plan.

EMERGENCY ACTION NOTIFICATION MESSAGE—AP/UPI SUBSCRIBERS/ NETWORK AFFILIATES ONLY

"This is an Emergency Action Notification requested by the White House. The AUTHENTICATOR WORD for this notification is (—). All stations follow procedures in the EBS Checklist for national level emergency. The President of the United States or his designated representative will shortly deliver a message over the EMERGENCY BROADCAST SYSTEM. The Authentitor Word is (—)."

2. Authenticate Notification AP and UPI Subscribers/Network Affiliates Only

Compare authenticator words in notification with words on current EBS authenticator list. Take no further action if words do not match.

Different activation and termination words are provided for each date. Words are effective 12:01 a.m. Washington, D.C. time.

3. Discontinue Normal Programming And Broadcast Announcement

(TV Stations display appropriate EBS slide and transmit all following announcements visually and aurally in the manner required by Section 73.675(b) of the FCC Rules. Foreign language stations repeat announcements in foreign language.)

"We interrupt this program; this is a national emergency. Important instructions will follow."

4. Transmit Attention Signal

Broadcast the Two-Tone Attention Signal (see section 73.906 of the rules)

Note. Noncommercial educational FM broadcast stations of 10 watts or less which are exempt from having the capability to transmit the Two-Tone Attention Signal shall remain quiet for 25 secs.

5. Broadcast Announcement

"This is an Emergency Action Notification. All stations shall broadcast this Emergency Action Notification Message. This station has interrupted its regular program at the request of the White House to participate in the Emergency Broadcast System. During this emergency, some stations will remain on the air broadcasting news and official information to the public in assigned areas. This is station (call letters). **We will be leaving the air. You should now tune to other stations until you hear one broadcasting emergency news and information for your area. This station will not be broadcasting news and information for your area. You should now tune until you hear a station broadcasting news and information for your area. Do not use your telephone. The telephone lines should be kept open for official use. The Emergency Broadcast System has been activated to keep you informed. I repeat . . ."** (Repeat Announcement)

6. Remove Carrier From Air.

7. Monitor For Emergency Action Termination

Same method as for notification—Upon receipt, proceed to termination procedures.

Termination Procedures—All Stations

1. Receive Emergency Action Termination

(Same methods as for notification)

EMERGENCY ACTION TERMINATION MESSAGE—AP/UPI SUBSCRIBERS/ NETWORK AFFILIATES ONLY

"This is an Emergency Action Termination. The AUTHENTICATOR WORD for this termination is (—). All stations follow the EBS Checklist for termination procedures. The Authenticator Word is (—)."

2. Authenticate Termination

Compare authenticator words in termination with words on current authenticator list. Do not initiate termination if words do not match.

(Red envelope contained in pocket on inside front cover.)

3. Broadcast Announcement

"This concludes operations under the Emergency Broadcast System. All broadcast stations may now resume normal broadcast operations." (Repeat Announcement)

4. Resume Normal Programming

(In accordance with regular station authorization)

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Maintenance of Broadcast Equipment

PREVENTIVE VERSUS CASUAL MAINTENANCE

The broadcaster may wonder at first why a regular preventive maintenance schedule should be necessary when he has been getting along very well with casual maintenance. The answer lies partly in the far more complex equipment needed for today's broadcast system and partly in the highly competitive aspects of the market place.

In all fairness to those broadcasters who firmly believe casual maintenance is sufficient, it must be pointed out that some highly successful operations have no maintenance engineers as such. An examination of their methods will reveal, however, that transmitter and studio technicians spend a certain amount of their time checking equipment not in use while the station is on the network or in other ways fitting some maintenance into their daily working schedules. Furthermore, these technicians will be found to be highly experienced men who are familiar with the circuitry of the equipment and are excellent "troubleshooters." It will thus be seen that while no formal preventive maintenance schedule is in force in the station, a larger percentage of the working day is being spent in maintenance. It remains a problem requiring a decision to be made by each broadcaster as to whether he will hire maintenance men who can keep the equipment in good operating condition and be able to use less experienced men at the transmitter and studio or he will hire technicians who have the experience, knowledge, and "feel" for maintenance and who can get the station back on the air quickly in the event of equipment failure.

In this part, a suggested preventive maintenance schedule is shown and a few suggestions of a general nature are listed in the hope it may provide the broadcaster with a beginning to which he can add such procedures as are pertinent to his particular type of equipment. Each piece of equipment will have its own individual characteristics, and specific operating procedures for each equipment item are furnished by the manufacturer. It is suggested that a collection of the instruction books for the equipment in the new station be gathered together, and from this collection, specific details can be drawn to supplement the general material which follows.

The object of any maintenance program, whether it be preventive or casual, is to keep the equipment operating at optimum—to satisfy the regulations set forth by the FCC—and to keep operating costs down. Although the most careful and thoughtful maintenance program cannot always prevent occasional equipment failures, the symptoms of impending failure can often be observed during the day's operation, and a well-defined system of reporting should be developed. At the transmitter, the log is the logical place. If it is a chart-recorded log, so much the better. The studio should have a regular place to put notices of equipment troubles. After the maintenance man checks the item noted as being faulty, he makes such adjustments or repairs as are necessary and initials the notice with the notation "adjusted," "tube changed," or whatever work was done. The sheets or logs are kept on file after completion of the work, and over a period of time they provide a good source of study for the idiosyncrasies of each equipment item. From a collection of this nature, conclusions can be drawn as to what type of trouble to expect from each piece of equipment, and in many cases equipment failures can be foreseen and corrected in advance of failure.

In the following pages, a general outline of preventive maintenance is given. Complete details applicable to all kinds and makes of equipment naturally cannot be given, nor is it the purpose of this part to replace the specific instructions given by the manufacturer for the care and maintenance of each equipment item. The purpose of the discussion is rather to supplement these specific instructions by a few notes and suggestions made by station operators as a means of gathering together in one place the beginning of a maintenance manual. The value of such a manual to each station depends entirely on supplementation by recommendations drawn from (1) the manufacturers' instruction manuals and (2) the experience of the chief engineer and his staff as the station develops.

TELEVISION STUDIO PREVENTIVE MAINTENANCE SCHEDULE

Daily

Dust.

Check for signs of overheating on all equipment.

Check pickup equipment for abnormal conditions such as position of control knobs and poor picture quality which may not have been reported.

Check cameras for geometric distortion, alignment, and resolution.

The scanning system of the film photographic sound track must be checked. The alignment of the exciter lamp filament with the optical assembly should be checked. Optical assemblies and any apertures in the light path should be cleaned. Photocells should be examined for oil on the glass.

Projection lenses should be wiped with lens tissue. Coated lenses should be cleaned very carefully in accordance with the manufacturer's instructions.

Check the need for unusual control-knob settings.

Clean film projectors in accordance with manufacturers' instructions, checking especially for accumulations of dust, lint, and emulsion on gate, pressure shoe rollers, teeth, picture aperture, etc.

Visually check the microphone and cables for serious abrasions from pinching, kinks, etc.

Weekly

Thorough internal and external cleaning of cameras, camera controls, monitors, and power supplies. Check insulation on wires.

Check and record equipment voltages.

Run test checks on cameras and projectors using test charts, slides, or films such as those recommended by EIA or SMPTE.

Check the amplitude and pulse widths of the synchronizing generator.

Oil film projectors.

Check and clean fader controls on both audio and video equipment.

Check microphones.

Check the air filter on the power supply.

Lubricate the wheels and moving parts of camera dollies and booms, microphone booms, pulleys for studio lights, and mechanical parts of studio cameras (pan and tilt and optical focusing mechanisms, etc.).

Monthly

Record and compare voltages on all equipment.

Check adjustment of all control knobs, and readjust where necessary.

Check tubes on all equipment.

Check and clean relays and switch contacts in all equipment. Some relays in more recent systems are protected sufficiently from dust and dirt and may not need such frequent inspection.

Low-level audio amplifiers with "plug-in" chassis should be moved in and out a few times to renew the contact between fins and sockets.

FIELD PICKUP (REMOTE) PREVENTIVE MAINTENANCE SCHEDULE (This is also applicable to STL)

Note: These daily, weekly, and monthly schedules will naturally be revised in accordance with usage given equipment.

Daily

Check the switching system for abnormal conditions.

Check cameras for geometric distortion, alignment, and resolution.

Check pickup equipment for abnormal conditions.

Check all equipment for overheating.

Dust.

Weekly

Clean cameras and power supplies internally and externally.

Check and readjust controls.

Inspect and tighten cable connectors and clamps.

Check amplitude and pulse widths of synchronizing generator.

Lubricate moving parts of cameras.

Check and clean fader controls on both audio and video equipment.

Visually check weatherproofing of cables, connectors, and other parts of equipment subjected to weather.

Check batteries if applicable.

Monthly

Check tubes on all equipment (see Studio Preventive-maintenance Schedule).

Record and compare cable voltages.

Check air filters.

Check and clean relays and switch contacts in all equipment.

Transistors

No specific maintenance procedures are included in this Part for translators or solid state devices.

TRANSMITTER PREVENTIVE MAINTENANCE SCHEDULE

Daily

Check the filament line voltages every hour, and adjust if required. FCC Rules governing transmitter logs require that the operating constants of the last radio stage of the aural transmitter (total plate current and plate voltage), transmission-line meter readings for both transmitters, be observed and recorded at three-hour intervals.

Check visual and aural monitoring circuits, observing both voltage and current meters. Changing current or voltage indicates either deteriorating tubes or equipment. If the operator observes any rapid changes, a sufficient note should be left with the log as instructions for the maintenance crew.

Dust and generally inspect for overheating or other signs of abnormal operation.

Weekly

Check all tubes which are not metered in the transmitter.

Clean the internal parts of the transmitter (insulators, etc.). Check of noise, distortion, and frequency characteristics of aural transmitter generally. Check the visual frequency and broadband characteristics of the visual transmitter generally.

(On the last two mentioned checks, spot checks will ordinarily suffice on a weekly basis. However, in this case, a more thorough check should be made monthly.)

Inspect blowers and flow meters. Clean and/or lubricate if required.

Test door interlocks and disconnect switches, being certain that they result in interruption of high voltage when access doors and windows are opened.

Check and operate all relay contacts. Observe closely for hearing.

Check transmission lines for tightness by observing gas or air pressure.

Add distilled water to cooler unit if required.

Correct all meter needles to normal nonenergized readings.

Monthly

Inspect and lubricate small blower motors.

Test spare tubes.

Clean socket contacts if necessary.

Service relay contacts if necessary.

Check air filters, and clean or replace as necessary.

Visually check the condition of the water in the cooling system.

Quarterly

Inspect every unit in transmitter in detail, using tests recommended by the manufacturer.

Service all power contactors if necessary after inspection.

Make a visual inspection of the physical condition of the antenna tower and transmission line.

Inspect and test tower-lighting equipment according to Part 17 of FCC Rules.

Semiannually

Tighten all connections, both electrical and mechanical, in the transmitter and associated equipment.

Lubricate exhaust fans.

Lubricate high-pressure blowers, and check the operation of the air interlocks.

Lubricate the water-cooling system.

Check the outdoor protection to the water-cooler intake before cold weather and for free circulation before summer.

SAFETY

Every possible means of affording maximum protection to personnel working in the station should be considered. Equipment has been designed to operate safely as long as reasonable care and judgment are exercised, but it cannot be too strongly impressed on every person coming into contact with the equipment that the safety rules for handling each item must be observed, since the high voltage of certain components is sufficient to endanger life. Some general safety precautions are given below, and more will probably suggest themselves to the station operator and can be added.

1. Inspect safety interlocks regularly for proper functioning. Check leads and connections to grounding hooks.
2. Check ground connections for tightness.
3. Check insulation on all leads regularly. Never use leads with broken insulation.
4. All high-voltage capacitors should be discharged before they are touched. Although "bleeder" resistors do discharge capacitors after a reasonable time, in consideration of the voltages used, it will still be safer to discharge the capacitor with a shorting bar. Due precaution must be observed in the removal of the shorting bar.
5. Rubber gloves should be worn when working on high-voltage equipment, and a rubber sheet should be placed over the sill of the transmitter compartment or over any place where it is possible to come into contact with live equipment.
6. Before repairs are made on high-voltage equipment, instruction books and schematics should be closely studied. It may also be pointed out here that *high voltage somtimes appears at unexpected points in defective equipment.*

7. Ground leads of test equipment should not be connected to a high-voltage point, since the ground lead of most instruments is connected internally to the case.

8. When high voltages are measured, consideration should be given to both ac and dc voltages present, and peak voltages should be taken into account when selecting voltmeters and multipliers.

9. Rubber gloves and blankets will not afford protection against high radio-frequency voltages. When work is done on circuits carrying high RF voltages, the circuit should be inoperative before work is begun.

10. Extreme care must be used when touching tubes that have been in operation for a considerable length of time, since serious burns can result.

11. Pressure developed on the envelope of large vacuum tubes is extremely high, and when the tube envelope is broken, it must be remembered that the tube will implode—not explode. This means that there is a possibility of the tube base being projected through another portion of the tube. For this reason, tubes should be kept in cartons until time for their actual use. Safety goggles and gloves should be worn when handling large vacuum tubes. Spectators should be kept at a safe distance whenever a tube is outside its carton.

A means of disposition of these tubes must be found, bearing the above hazards in mind, to prevent the scattering of shattered glass and the possibility of the tube elements and base flying free. One suggestion is that the tube should be placed in a shipping container, the container sealed, and a crowbar or similar instrument driven through its top. Another suggestion is that the tube should be placed in a shipping container, leaving the neck or gun end of the tube exposed. A tarpaulin or burlap bag is thrown over the neck to deflect any glass, and the neck is struck sharply with a hammer.

12. It is not generally known that carbon tetrachloride is a strong toxic chemical and that continued breathing of the fumes is cumulative and can become injurious to health. Its use as an open cleaning agent is not recommended. The Navy has discontinued its use for projector cleaning and recommends that alcohol be used wherever possible.

It must be remembered, however, that alcohol and naphtha are both inflammable, and proper precautions must be taken in using either.

GENERAL

In the following pages, some amplification of the preventive-maintenance schedules will be found. In some cases, it may seem that the emphasis has been shifted from "preventive" to "casual" maintenance or from maintenance to operation principles. These are the areas where experience of presently operating stations has indicated a need for calling special attention of the technical staff of the new station.

Certain principles of maintenance are common to all types of equipment. For example, throughout this article, frequent mention is made of the removal of dust from equipment. This is extremely important because, among other things, excessive dust may lead to current leakage or arc-over between high-voltage points. Obviously, dust will do more damage to open equipment than to completely enclosed equipment, but daily efforts must be made to keep the collection of dust at a minimum on all equipment. The problem of dusting requires tools ranging from soft, lint-free cloths and absorbent pads to vacuum cleaners. A small hand-type vacuum which can be reversed and used as a blower may be a wise investment for the station. Various sizes of paint brushes will be helpful in removal of dust and lint from small equipment items. When cloths and brushes are used, they should be absolutely dry or moistened with a volatile liquid such as carbon tet, alcohol, naphtha, etc.—never with oil.

All equipment tests should be made as soon as possible after the close of the day's programming or after the last use of the equipment item during the day. After tests or checks are completed, the equipment should be placed in operating condition to be sure that it is functioning properly. Before any tests are begun, instruction books and schematics should be closely studied and safety precautions observed. Inspection can be made by feel (for overheating), by smell (this often locates an overheated part such as a transformer or reactor), and visual inspection for loose, broken, warping, or cracked connections and broken parts, insulations, or wires.

Before dismantling any part of the equipment, be certain the correct input signals and voltages are being applied. (In other words, there is no use dismantling the engine of a car if it's just out of gas.) The correct input signals and voltages are supplied by the manufacturer as part of the operating instructions.

Be logical—check the obvious first. Also, as mentioned above, instruction books, schematic drawings, and other technical data on the equipment should be readily available to all technical personnel.

TESTS AND TEST EQUIPMENT

Many stations initially going on the air have underestimated the need for appropriate test equipment only to find themselves later on faced with the need for purchasing more such equipment. In addition to the more common test equipment, additional test devices may be required depending upon the complexity of the installation.

Tubes

A record of test readings and hours in use on all critical tubes is considered desirable. In addition to revealing tubes which are likely to fail in the near future, such a record may also reveal types of tubes which are not giving satisfactory service and which should be studied closely to determine the cause of failures. Either a card file or a loose-leaf notebook will be suitable for tube records.

Spare tubes, particularly of the transmitting type, should be operated regularly to prevent them from becoming "gassy."

When transmitter tubes are first received at the station, they should be tested at a time outside the regular hours of operation or into a dummy antenna if this is available. The "tube biography" is then begun with the date of test and condition in which the tube was received being the first entries. Transmitter tubes are guaranteed for a minimum number of hours, and a prorated rebate is made by the manufacturer if failure occurs before the completion of the guarantee. Therefore, a record of the number of hours in operation and other pertinent data is essential for each tube until it is eliminated from service, since hundreds of dollars are involved.

Water-cooled Tubes

The proper care and maintenance of water-cooled tubes is of primary importance in ensuring good service. These suggestions are made as a general outline. They should be checked against the instructions given for different types of water-cooled tubes by the manufacturer, since such instructions will vary.

1. Installation of the water-cooling system and of each new tube placed in service should be in strict accordance with the manufacturer's instructions. Improper operation for only a few minutes can ruin a tube.
2. Always use distilled or water of equal purity in the system. Tap water or even the spring water used for office water coolers often contains impurities which become electrostatically precipitated and form scale, which interferes with the proper operation of the system.
3. Remove the filter strainer regularly, and clean out any sludge that has formed. This should be done quite frequently during the run-in period and periodically thereafter.
4. After the system is cleaned, water should be circulated for a short time and then the entire system refilled with fresh distilled or equally pure water. Never allow chlorinated water to enter the system, as it greatly increases the corrosion rate of the pipes and ducts in the tubes.
5. Regular oiling and greasing of the system motor should be a part of the maintenance routine.
6. Avoid operating the water-cooling system at too high a pressure, since this will cause excessive water turbulence in the tube passages with the possibility of an increase in microphonics.
7. It is highly important to protect the outside intake of the water-cooling system before cold weather begins. (In one station, the intake system was installed in the basement of the transmitter house with no further protection. The first night the temperature dropped below freezing, the intake system froze, causing a great deal of damage and expense before the situation could be corrected.)

Air-cooled Tubes

In general, the maintenance of air-cooling systems is relatively simple. Air filters should be regularly inspected and cleaned or replaced when necessary. Small strips of cloth tied to the blower will give an instant visual check on whether or not the system is working. A suggestion has been made that when the system is first placed in operation, the temperature of the intake and outgo air should be noted and the differential established as an operating standard for the system. (Each system will be found to have its own differential.) The same temperature measurements can be made monthly, and as soon as a wide departure from the standard appears, a check on the system can be made to determine the cause. In making such a check, try the filters first. The cause will usually be found in a clogged filter. Periodically, jackets should be removed from the tubes and fins cleaned with a soft, lint-free cloth. Fins, of course, should be perfectly clean on initial installation. Fan and motor bearings must not be overlooked. Lubrication will depend on whether the bearings are sealed or open. Sealed bearings require attention only every few years.

High-power Radio Tubes

Manufacturing techniques over the past years have greatly increased the reliability and life of high-power transmitting tubes. Experience over the years has indicated that one of the sources of tube failure is the mechanical stress resulting from repeated heating and cooling whenever the tubes are shut down. In certain installations, it is the accepted practice never to turn off the filaments of the tubes completely. Tubes are operated either continuously at rated filament voltage or at reduced voltage during the periods when no plate voltage is applied. During such periods care must be taken that adequate cooling of the seals is accomplished according to the manufacturer's specifications.

Capacitors

Dust must be removed regularly from high-voltage capacitors, since its accumulation tends to cause arc-overs and increases chances of equipment failure. If the method of cleaning with lint-free cloths is used instead of a bellows, extreme caution must be exercised to see that the capacitor is inoperative and *discharged* before handling. Leads and terminal connections must be regularly checked for loose or broken connections, and the insulators checked for cracks.

An excessive rise in the temperature of a high-voltage capacitor can be detected by placing the palm of the hand against it after a long period of operation. Be certain that the capacitor is inoperative and *discharged* and that the case is grounded before touching these capacitors. High-resistance paths to ground have been known to develop, and a normally "grounded" case conductor can become very "hot" electrically. This may be an indication of impending failure from dielectric leakage or improper ventilation. Prompt replacement will avoid loss of air time from overheated capacitors.

Low-voltage capacitors do not require so much care as those of the high-voltage type but should be kept free of dust, oil deposits, and other foreign matter. Since the leads used here are not so rugged as those in the high-voltage type, greater care is necessary in inspection for loose or poorly soldered connections.

Different organizations have found widely differing lengths of service for electrolytic units. Twelve to thirty months seems to be the minimum and maximum periods of service. Dried-out capacitors are one cause of hum bars in the television image. Excessive temperature rises often result in nonlinear scanning, since the capacitance is known to vary with temperature changes.

Resistors

Check load resistors and terminating resistors at least once each year, and replace if there is a critical deviation. Dust should not be permitted to collect on any resistor, especially in high-voltage circuits. Snap-in resistors should have firm, clean contacts to prevent heating at the terminals. If a resistor is removed for cleaning, be certain to follow through, making sure that it is properly replaced; otherwise damage may result to the equipment when it is energized.

Patch Panels and Cables

In both video and audio systems, jacks and plugs should, of course, be maintained in perfectly clean condition. If a faulty cable develops, it should be removed from service and sent to the repair shop immediately. Plugs in audio equipment should be polished regularly. Visual inspection of the connections is very important.

AM AND FM

Preventive maintenance schedule for AM nondirectional and FM stations.

Recommended Maintenance Equipment

The following is a list of items which should be available for handling the regular maintenance procedures.

1. An instruction manual for every piece of technical equipment in the station.
2. A log book set up to indicate the title of each instruction book, its location, and the number of copies available.
3. A file drawer at the transmitter and at the studio where all technical information pertaining to that portion of the plant may be kept.
4. A separate log book for the transmitter and studio, set up with the following headings: Inspection Date; Equipment; Maintenance Performed; Special Remarks.
5. A copy of the NAB Engineering Handbook.
6. A copy of the FCC Rules.
7. The following tools and test equipment:
   a. Small hand tools, consisting of screw drivers, pliers, soldering iron, piece of fine crocus cloth, socket wrenches, pipe cleaners, and contact solvent, etc.
   b. A multimeter having a minimum sensitivity of 20,000 ohms per volt.
   c. A vacuum tube voltmeter.
   d. A mutual conductance tube checker.
   e. A 5 in. cathode ray oscilloscope.
   f. A complete set of audio noise and distortion equipment.
8. Spare parts for each piece of station equipment in accordance with manufacturer's recommendations.
9. An inventory of all station equipment broken down into two categories: "Inside Studio and Transmitter Plant" and "Outside Transmitter Plant."
10. A transmitter tube log, set up to show hours in operation.

Weekly

Check all metered circuits for normal indications in accordance with manufacturer's instruction book.

Inspect all cables and wires and test for loose connections.
Check all pots for noise by rotating with circuit on.
Check all switches for proper operation.
Check all pilot bulbs for proper operation.
Check all turntables in all speeds for correct mechanical and electrical operation.
Check all tape recorders in all speeds for correct mechanical/electrical operation and head alignment.
Check audio console with pots wide open for hum.
Check remote control equipment in accordance with procedure set forth.
Check any miscellaneous equipment in accordance with above.
Check logs for last 7 days for completeness and unusual readings.
Calibrate all remote meters.

Monthly Procedure

Inside Transmitter and Studio Plant

Complete regular weekly preventive maintenance procedure.
Inspect all equipment and parts for charring, heating discoloration, or loose connections.
Clean all equipment during above inspection and remove dust, dirt and foreign particles that may have accumulated.
Inspect all the tube sockets for cracks and dirt. Remove any dirt with contact solvent or crocus cloth.
Test all tubes.
Check voltages with voltmeter against voltage chart.
Check tube log against hours run for transmitter final and modulator tubes.
Check transmitter into dummy load and determine efficiency.
Inspect all switches for normal operation.
Check dehydrator for proper operation.

Outside Transmitter Plant

Inspect antenna coupler for any obvious parts which show charring, heating, discoloration, or loose connections.
Clean entire unit during above inspection to remove all dust, dirt, and foreign particles that may have accumulated.
Inspect remote diode tube socket for cracks and dirt. Remove any dirt with contact solvent or crocus cloth.
Clean antenna meter switch with solvent or crocus cloth.
Check coaxial cable visually for any wear, loose supports, etc.
Visually inspect ground system.
Check tower lights, light control, and flasher.
Check tower visually for any loose guys, broken insulators, etc.
Check and oil lock on tower fence gate.

Quarterly Procedure

Inside Transmitter and Studio Plant

Complete regular monthly preventive maintenance procedure.
Lubricate all motors in transmitter and studio plant for which lubrication is provided.
Check line meter at transmitter and antenna coupling unit for normal readings.
Clean all air filters and if necessary replace.
Make a complete set of noise and distortion measurements on transmitter-studio plant in accordance with FCC Rules. Plot and tabulate data for engineering file.

Outside Transmitter Plant

Complete regular monthly preventive maintenance procedure.
Check tower guys for proper tension by vibration method.
Use field glasses and inspect guy insulators for any breaks or chips.
Check paint on tower for peeling.
Check transmission line support for mechanical rigidity.
Check fence and gate for rigidity.
Check transmitter building on inside and out for any needed repairs.
Check tower lighting system in accordance with Section 17.38 of the rules.

AM DIRECTIONAL ANTENNA PREVENTIVE MAINTENANCE SCHEDULE

Monday

Check all condensers and other equipment in antenna phasing unit immediately after sign-off for overheating.
Clean and check all transmission line end seals.
Clean interior of all sections of antenna phasing units.
Clean contacts and check alignment of antenna transfer relay.
Check and tighten all connections in antenna phasing unit.
Check gas filled condensed pressures.

Tuesday

With array set for directional operation, check drive-point impedance with radio-frequency bridge at operating frequency (first and third Tuesdays in month).

With array set for nondirectional operation, check drive point impedance with radio frequency bridge at operating frequency (first and third Tuesdays in month).

Set up array for normal full-power directional operation. Compare readings of all antenna and remote antenna meters. (Calibrate if necessary.)

Make complete set of field-strength readings at indicated monitor points (second and fourth Tuesdays in month).

Check and record all transmission line gas pressures.

Wednesday-Saturday Antenna Coupling Units

Check all condensers and equipment in coupling house for overheating immediately after sign-off.

Check spacing and clean antenna and transmission-line horn gaps.

Check and clean all antenna lead-in insulators.

Check and clean all transmission-line end-seals.

Clean contacts and check alignment of antenna relay.

Clean contacts and check alignment of antenna ammeter switch.

Check and tighten all connections of inductance coils and condensers.

Clean all meters.

In transmission building, read and record all transmission-line gas pressures.

First Aid and Resuscitation Policy

It should be required that each and every man in technical operations be thoroughly familiar with first aid procedures in the event of an emergency so that his life or the life of one of his coworkers can be saved. *He should be ready to act immediately in any emergency.*

Heads of the technical divisions should *be held responsible* for the carrying out of the program which includes the proper setting up of training classes at regular intervals (preferably every three months), the insistence that each man under his direction duly attends and qualifies, and the maintenance of safety bulletin boards and distribution of pertinent safety information.

The training should include a thorough instruction in resuscitation by a competent instructor, also training in *first aid* with particular emphasis on the type of injuries likely in our operations such as control of bleeding and treatment of burns and general injuries.

General Foreword

Experience, particularly in use of electrical equipment, has shown that all engineers, at times, expose themselves to danger: new engineers because of inexperience, older ones because of overconfidence and habits of work which they have formed. In an endeavor to reduce such exposures, these suggestions have been included.

Although these suggestions cover most of the common accidents, it would be practically impossible to make them cover all, especially those of changing conditions and methods. The purpose is to create the tendency always to *think and act in terms of safety.* In case of electrical shock, it is always important when attempting to free the victim to

1. *Protect yourself* with dry insulating material.
2. *Break the circuit* by opening the power switch or by pulling the victim free of the live conductor. *Be careful and move fast—seconds count. Don't touch the victim with your bare hands until the circuit is broken.*

Procedure to Follow for Prone Pressure Method of Resuscitation

As soon as possible, feel with your fingers in the patient's mouth and throat and remove any foreign body (tobacco, false teeth, etc.). If the mouth is shut tight, pay no more attention to it until later. Do not stop to loosen patient's clothing, but immediately begin actual resuscitation. Every moment of delay is serious. Proceed as follows:

1. Lay the patient on his belly, one arm extending directly overhead, the other arm bent at the elbow and with the face turned outward and resting on hand or forearm so that the nose and mouth are free for breathing.
2. Kneel, straddling the patient's thighs. Place the palms of the hands on the small of the back with fingers resting on the ribs, the little finger just touching the lowest rib, with the thumb and fingers in a natural position, and the tips of the fingers just out of sight (see Fig. 1a).

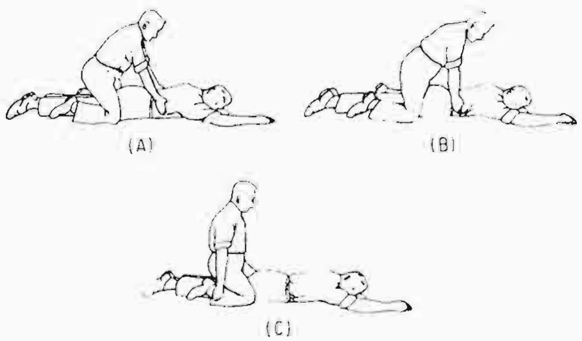

Fig. 1. Prone pressure method of resuscitation.

MOUTH-TO-MOUTH AND MOUTH-TO-NOSE RESPIRATION

1. Place the patient on his back. Wipe any foreign matter out of his mouth with your fingers. Lift his neck. Tilt his head back so that his chin points straight upward.

2. You may also position the patient by grasping his lower jaw, as shown here, and lifting upward. But be careful not to press your fingers into soft throat tissue.

3. If his mouth is open, insert your thumb between his teeth to raise his jaw. These steps should open a passage for air, by freeing the tongue from the throat.

4. Pinch his nostrils shut. Open your mouth as wide as possible, place it tightly over his mouth, and blow into him. Remove mouth; wait for rush of exhaled air.

5. Or, especially if his teeth are clenched, you may place your mouth over his nose and breathe into it. For a small child, place your mouth over his mouth *and* his nostrils.

6. If foreign matter blocks patient's throat, roll him onto side and slap him beween the shoulders. Quickly resume blowing—12 times a minute for an adult, 20 for a child.

3. With arms held straight, swing forward slowly so that the weight of your body is gradually brought to bear upon the patient. The shoulder should be directly over the heel of the hand at the end of the forward swing. *Do not bend your elbows!* This operation should take about 2 seconds (see Fig. 1b).

4. Now immediately swing backward so as to remove the pressure completely (see Fig. 1c).

5. After 2 seconds swing forward again. Thus repeat deliberately 12 to 15 times a minute the double movement of compression and release, a complete respiration in 4 or 5 seconds.

6. Continue artificial respiration without interruption until natural breathing is restored, if necessary 4 hours or longer, or until a physician declares that the patient is dead.

7. As soon as artificial respiration has been started and while it is being continued, an assistant should loosen any tight clothing about the patient's neck, chest, or waist. *Keep the patient warm. Send for a doctor.* Do not give any liquids whatever by mouth until the patient is fully conscious.

8. To avoid strain on the heart, when the patient revives, he should be kept lying down and should not be allowed to stand or sit up. If the doctor has not arrived by the time the patient has revived, he should be given some stimulant, such as one teaspoonful of aromatic spirits of ammonia in a small glass of water or a hot drink of tea or coffee. Keep him warm!

9. Resuscitation should be carried on at the nearest possible point to where the patient received his injuries. He should not be moved from this point until he is breathing normally of his own volition and then moved only in a lying position.

10. A brief return of natural respiration is not a certain indication for stopping the resuscitation. Not infrequently the patient, after a temporary recovery of respiration, stops breathing again. Watch, and if breathing stops, resume artificial respiration.

11. In carrying out resuscitation it may be necessary to change the operator. This change must be made without losing the rhythm of respiration. By this procedure no confusion results at the time of change of operator and a regular rhythm is kept up.

It is important that resuscitation effort continue when a patient does not revive. *Sometimes a period of* 4 *hours may be required.*

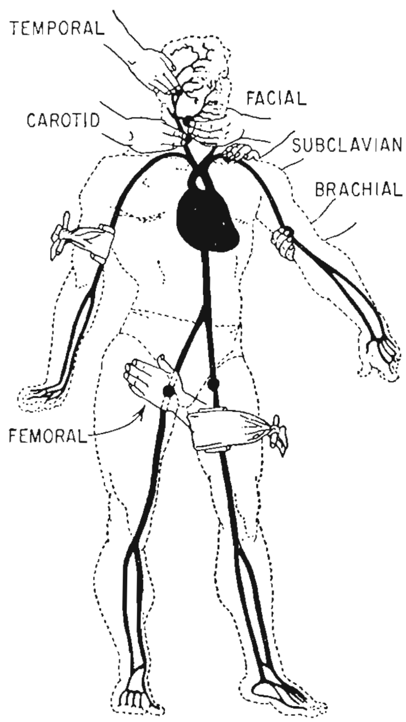

Fig. 2. Pressure points for control of severe bleeding.

Control of Severe Bleeding in the Event of an Emergency

Severe bleeding requires immediate and prompt action, and its control may save a life. All stations should be provided with suitable tourniquets, and all personnel should be ready to act in any emergency. A second person should send immediately for a doctor.

1. *Venous bleeding:* When a vein has been cut, the blood is *dark red* and flows steadily. Pressure, if required, should be applied *below* the wound, or *away* from the heart, to stop bleeding.
2. *Arterial bleeding:* When an artery has been cut, the blood is *bright red* and flows in *spurts.* Pressure should be applied *above* the wound, or *between* the wound and the heart, to stop bleeding. Pressure is best applied by a *tourniquet,* although the fingers and hand can be used temporarily (see Fig. 2).
3. *A tourniquet* is a strip of cloth, bandage, or other material tied above the wound. Place a thick pad, such as a folded handkerchief, on the inside of the arm or leg and under the tourniquet. Loosely tie a simple double knot in the cloth, place a stick or other rigid member between the knots, and tighten the outer knot by pulling the outer ends of cloth. Twist the stick or rigid member until bleeding stops. *Do not* maintain such pressure longer than 15 minutes at a time.
4. *If bleeding continues* after the tourniquet is loosened, allow blood to flow for 30 to 60 seconds and then reapply pressure. Continue this procedure until bleeding has stopped.
5. *Obtain medical services as soon as possible.*

Treatment and Avoidance of Electrical Injuries

Electric shock may be induced either by currents of high voltage or by comparatively low voltage. More people are killed on 110 volts a-c than any other voltage. We are all well aware of cases of shock and burns which result from high voltages, yet the vast majority of serious electrical injuries come from currents of low voltage. The severity of an electrical burn depends upon whether the current is alternating or direct, the voltage and amperage of the current, the character of the ground connection (remember, a concrete floor is *not* an insulator), duration of contact, and the extent of surface involved.

Electrical injuries can be classified as follows:

1. Shock, animation suspended and arrested respirations.
2. Electrical flashes or glare injuries to the eyes.
3. First-degree burns, with red dry skin as in sunburn followed early by blister formation and pain.
4. Second-degree burns, where skin continuity is destroyed.
5. Third-degree burns, where there is destruction en masse of the tissue, perhaps including muscle, nerve, and bone.

In shock due to low voltage, such as used for our domestic household appliances, using 110 to 120 volts, the usual cause of accident is neglect to dry hands or other portions of the body properly.

An accident was reported where a woman answered the telephone and neglected to dry her hands. As she reached up to turn on a light, she received a severe shock and had intense pains in her right shoulder. As she was unable to move her arm, her doctor ordered an X ray. There was no history of a fall or other injury. The picture revealed a dislocation of the shoulder joint and complete avulsion of the greater tubercle. Attempts to reduce the dislocation resulted in fracture of the neck of the humerus. Open reduction through surgery was resorted to, and it was found that the electric current had completely changed the character of the bone, which now was filled with thousands of tiny fissures. Similar effects have been noted in inorganic substances such as glass, porcelain, and metal.

Both *high-* and *low*-tension currents have the same lethal effect, and death is produced, not by amperage or voltage, but by a combination of several physiochemical and physiological phe-

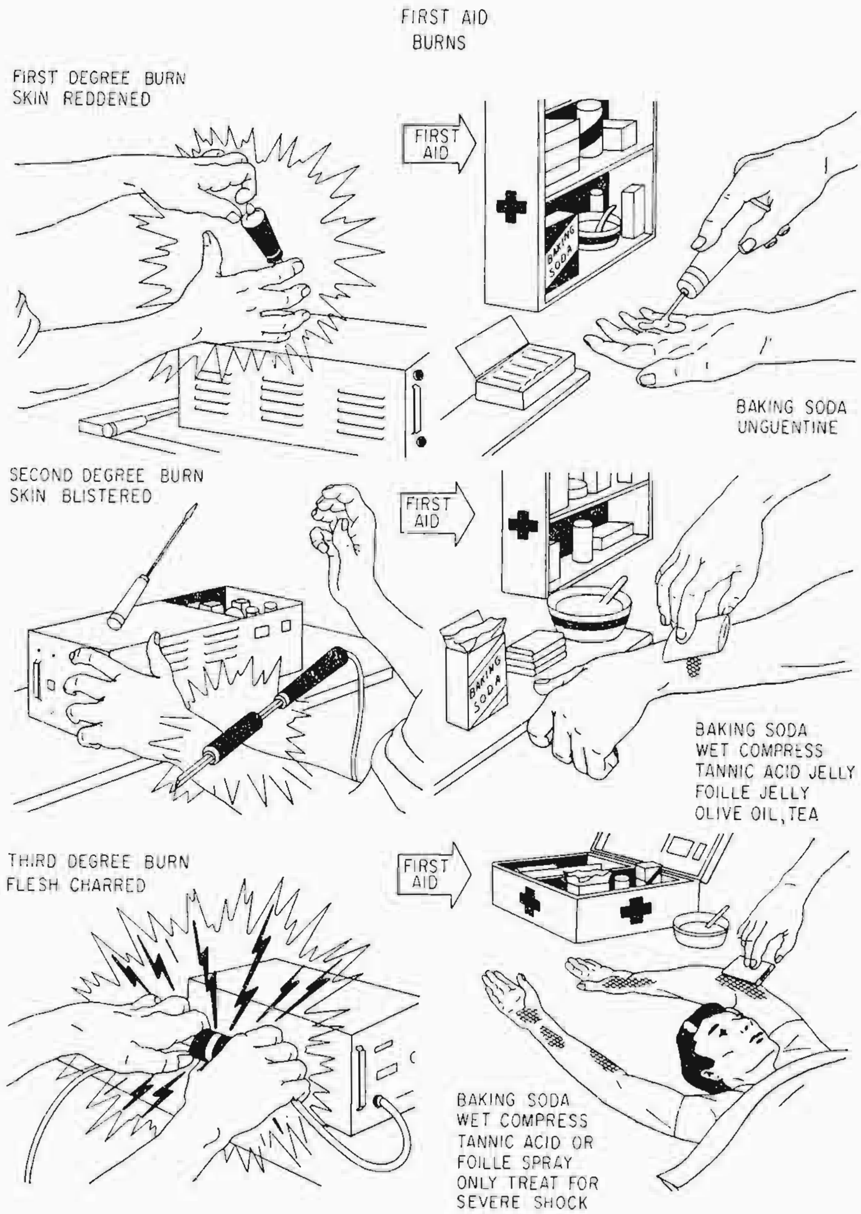

Fig. 3. Treatment for burns.

nomena. *Alternating currents are more dangerous than direct. A good rule to follow when working on or servicing "live" equipment is to keep one hand in your pocket, thus reducing the possibility of a ground return through the upper portion of the body.*

One point which cannot be stressed too often is the importance of dry skin when working around any electrical apparatus. Never touch any electrical fixture when your hands or other parts of your body are wet, especially when there are cuts or abrasions of the skin and particularly where there is a ground current.

These higher voltages usually cause an immediate violent contraction of the muscles, and if the hand has grasped the wire, it cannot be released. Such unfortunates are said to be "frozen" as long as the current continues. Under no circumstances attempt to pull such a victim free or you may share his fate. Rush for the main switch if it is at hand, or otherwise disconnect all current first. Dry wood, dry rope, or a dry coat may help in pulling a victim free, but the location of the switch should be known to everyone in the laboratory. Such an electric shock may and usually does produce severe burns and, if the current is not shut off in time may even char the bones.

In severe cases of electric shock, leaving out burns and their treatment for the moment, we find that the patient has become unconscious. Respiration has stopped completely, but the heart continues to beat until asphyxia intervenes. A certain number of cases develop a ventricular fibrillation; that is, the electrical impulses which regulate the heartbeat are thrown out of order so that the pacemaker is no longer in control, and instead of a normal of 70 to 80 beats per minute, we have 200 to 400. These cases, as a rule, end fatally.

Fortunately, in most cases, there is merely a prolonged apnea—stoppage of breathing. *Artificial respiration by the prone or Schaefer method must be started at once and continued if necessary for 8 to 10 hours. Cases pronounced dead by all medical tests have suddenly been revived as late as 8 hours after the accident.* Injections of cardiac or respiratory stimulants are worthless and a waste of time in electrical shock.

After electric-shock treatment has been started, there is time to treat any burns. However, severe bleeding must be stopped before proceeding with resuscitation.

Treatment for Shock (Not Electrical)

Cots and blankets should be provided for caring for the patient until the doctor arrives. Shock cases require the use of blankets as stated below.

1. Any person severely injured is potentially a patient in shock and should be regarded and treated as such. It is important to conserve body heat, particularly in cold weather; prevent added injury or danger; and get medical services as soon as possible.
2. *Keep the patient lying down* in a comfortable position. Never permit him to stand or walk.
3. *Keep the patient warm.* In many cases the only first aid measure necessary and possible is to wrap the patient underneath, as well as on top, to prevent further loss of heat. Blankets, robes, coats, or any other available woolen material can be used.

General Rules

1. Unconscious persons take cold very easily. Pneumonia is a very frequent complication. Keep the patient warm by use of hot pads or hot-water bottles, but remember that an unconscious man cannot tell you when he is being burned.
2. If necessary to move the patient, keep him lying down and do not permit him to help himself.
3. Never try to give an unconscious person a drink. It will choke him.
4. Never stop artificial respiration in less than 4 hours if the patient has not fully recovered, and if there has been any sign of recovery, continue at least 8 hours.
5. Start artificial respiration at once, and have someone telephone for the emergency squad.

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Audio-Frequency Proof-of-Performance Measurements

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The Commission's rules require each licensee to make audio performance measurements of both the main and alternate main transmitters at least once each calendar year. The dates between successive sets of measurements must not be more than 14 months. One set of measurements must be made during the four month period preceding the filing date of the application for renewal of the station license. Equipment performance measurements for auxiliary transmitters are not required and any qualified individual may make the required measurements. The data, together with a description of the instruments and procedure utilized in making the measurements, must be signed and dated by the person making the measurements. The data may be kept on file at either the transmitter or remote control point and must be retained for a period of two years. The measurements must be made available for inspection to any duly authorized representative of the Federal Communications Commission.

WHAT MEASUREMENTS ARE REQUIRED

For AM Stations

1. Overall audio-frequency response from 50 to 7,500 Hz for approximately 25, 50, 85, and 100 (if obtainable) percent modulation.
2. Audio-frequency harmonic content for 25, 50, 85, and 100 percent modulation for fundamental frequencies of 50, 100, 400, 1,000, 5,000, and 7,500 Hz (either arithmetical or root-sum-square values up to tenth harmonic or root-sum-square values up to tenth harmonic or 16,000 Hz).
3. Percentage carrier shift for 25, 50, 85, and 100 percent modulation with 400 Hz tone.
4. Carrier hum and extraneous noise generated within the equipment.
5. Spurious radiations including radio-frequency harmonics.

For FM Stations (Monophonic)

1. Audio-frequency response from 50 to 15,000 Hz for approximately 25, 50, and 100 percent modulation. Measurements must be made for at least 50, 100, 400, 1,000, 5,000, 10,000, and 15,000 Hz. (Frequency swing of plus and minus 75 kHz is considered 100 percent modulation.)
2. Audio-frequency harmonic distortion for 25, 50, and 100 percent modulation for the fundamental frequencies of 50, 100, 400, 1,000, and 5,000 Hz and audio-frequency harmonic distortion for 100 percent modulation for the fundamental frequencies of 10,000 and 15,000 Hz. Measurements shall include harmonics to 30,000 Hz.
3. Output noise level (frequency modulation) in the band 50 to 15,000 Hz in decibels below the audio-frequency level representing a frequency swing of 75 kHz.
4. Output noise level (amplitude modulation) in the band 50 to 15,000 Hz in decibels below the audio-frequency level representing 100 percent amplitude modulation.
5. Each of the above measurements shall be made employing 75 microsecond de-emphasis.

WHAT EQUIPMENT IS REQUIRED

The Commission does not attempt to set up the procedures or to recommend the equipment to be employed. There are a number of methods of making the required measurements, and numerous makes and models of equipment which are suitable for this purpose are available. In general, however, means must be provided for an audio input signal of known frequency and level and means for measuring the output in the terms desired. The specifications for such equipment must necessarily be considered in connection with the performance standards established by the Commission. It is obvious that the equipment must have such accuracy as to be well within the limits of the operation specifications for the station.

The following equipment is suggested:

1. *Audio oscillator.* This instrument should preferably have a fundamental range of 30 to 17,000 Hz or more. The audio-frequency harmonic content over the entire range should not exceed 1 percent. (Instruments are available

where the distortion does not exceed 0.1 to 0.25 percent.) Accuracy of calibration should be within 3.0 percent, although much greater accuracy will be found in the higher grade instruments. Both high- and low-impedance outputs are desirable.

2. *Attenuator or pad.* To control the signal fed to the microphone terminals from the audio oscillator an accurate attenuator or pad is required. It must be capable of attenuating the signal from at least 50 to 80 dB. (Some audio oscillators have a suitable attenuator built into the unit.)

3. *Level indicator.* The purpose of this item is to measure the input level and/or output level. It is usually available at the station in the form of a VU meter or vacuum-tube voltmeter. It is also included in some audio signal generators.

4. *Isolation and matching transformer.* This is used to isolate the test equipment from the station circuits and to match the impedances of the two. The requirements for this unit depend on the input impedance (normally 600-ohms) and the output impedance of the attenuator.

5. *Distortion and noise meter.* This instrument should have a scale permitting distortion readings as low as 0.5 and as high as 20 to 30 percent. For carrier noise and hum measurements the meter reading should extend to at least 60 dB (preferably lower) below an audio-frequency signal of 0 dbm (the term dbm means the power level expressed in decibels referred to 1 mw). High and low input impedance must be available, and the low impedance is preferably of the bridging type.

6. *Modulation monitor.* This item is required by the FCC in each broadcast station and is, therefore, assumed available.

7. *Field-strength meter or communications-type receiver.* With regard to the observations required on the radio-frequency transmissions of the standard stations, the Commission's Rules state that field-strength measurements are preferred but that observations made with a communications-type receiver will be accepted. To conduct such observations considerable care must be exercised in the selection of the receiver as well as in its actual use. As a general rule this receiver should have at least one stage of RF ahead of the first detector. It should be well shielded, and the frequency range should permit observations to at least the tenth or fifteenth harmonic of the fundamental frequency of the station. A means of making comparative signal-strength checks such as an "S meter" is very desirable and almost essential if suitable and meaningful observations are to be made. Amateur communications receivers will often meet these requirements. Although such observations are not required with respect to FM stations, it is a wise precaution to check spurious and harmonic radiations. Particular attention should be given to the second harmonic to avoid causing interference to television stations.

8. *Oscilloscope.* Although an oscilloscope is not essential, it is often very useful in analyzing and correcting difficulties which prevent compliance with the requirements.

HOW TO MAKE MEASUREMENTS

Detailed instructions for the operation of the particular piece of equipment are normally supplied by the manufacturer and should be followed. Some manufacturers include procedures for making the measurements required by the FCC, but this practice is far from universal. To assist in overcoming this lack and for the benefit of stations assembling the equipment from units purchased from different manufacturers, a step-by-step procedure for making the required measurements is set forth below, together with precautions that should be taken in setting up the equipment and making the measurements.

PRECAUTIONS

1. All measurements shall be made with the equipment adjusted for normal program operation and shall include all circuits between the main studio microphone terminals and the antenna output, including telephone lines, pre-emphasis circuits, and any equalizers employed except for microphones, and without compression if a compression amplifier is installed unless otherwise noted.

Where an AM station operates DA-2 or DA-N, it is not required to make measurements under both conditions of antenna operation unless there is reason to believe some unusual condition exists. The practice of making two sets of measurements, however, is considered advisable. If the antenna systems are adjusted so that the transmitter is feeding in exactly the same impedances under both conditions, there should be no difference. (Some difficulty may be experienced at the higher audio frequencies when the common-point impedance(s) for sidebands is greatly different from that at the carrier frequency.)

2. Audio systems of most broadcast stations use balanced 600-ohm ungrounded circuits. This, however, is not universal, and before attempting to make measurements, the facts in this regard must be determined. Otherwise, the measurements obviously will be in error and serious damage may result to the station equipment, the measuring equipment, or both.

3. It is very important to guard against stray fields affecting the accuracy of the measurements. This is particularly true with respect to use of the distortion and noise meter and of the VTVM when used in the presence of the transmitter.

Difficulties of this nature are usually evidenced by residual readings. It is suggested that:

a. Use short power cord and bypass it; also reverse plug for lowest residual reading.

b. The chassis of the instrument must be firmly grounded with as short a lead as possible to the station ground bus.

c. Use short voltmeter leads with RF chokes, and bypass. It may also be necessary to shield the terminals and the instrument itself. In some cases shielding the front will be adequate.

d. In some cases, particularly where a high power transmitter is involved, it will be found impossible to reduce the residual reading (R_R) to zero. In such cases a reasonable accurate corrected reading (R_c) may be found by applying the root-mean-square (RMS) principle to the final reading (R_F) i.e., $R_c) = R_F^2 - R_R^2$. Example: If the minimal resident reading is 0.50 and the final reading is 2.50, the corrected value or reading would equal $\sqrt{2.50^2 - 0.50^2} = 2.45$.

PROCEDURE FOR AM STATIONS

Audio-frequency Response

1. Adjust all equipment from microphone preamplifier input terminals to the antenna for normal program operation.
2. Bypass any limiting amplifiers.
3. Connect the audio-signal-generator equipment as shown in Fig. 1. Details of this will depend on the type and impedances of the oscillator, attenuator, and the station audio circuits. (*Do not connect to input terminals yet.*)
4. Adjust the oscillator to1,000 Hz.
5. Adjust the oscillator amplitude control until the VTVM reads zero.
6. Adjust the attenuator to approximately 40 or 50 dB.
7. Connect the signal generator to the microphone preamplifier input circuit.
8. Adjust the amplitude control until the VTVM reads approximately 15 dBm.
9. Adjust the attenuator until the station modulation monitor indicates 25 percent modulation, at the same time making certain that the VTVM still reads the same as Step 8. If it does not, readjust the amplitude control and attenuator until the modulation monitor shows 25 percent at the same time that the VTVM shows the same as in Step 8.
10. Record the attenuator setting in all the upper spaces of the form shown on Form AFP-1 for 25 percent modulation and also in the second space under 1,000 Hz.
11. Adjust the oscillator to 50 Hz.
12. Adjust the amplitude control and attenuator until the modulation monitor reads 25 percent at the same time the VTVM reads the same as in Step 8.
13. Record the attenuator setting in the second space down under 50 Hz in Form AFP-1.
14. Subtract the entry in the second space down from that in the first space, and enter the difference in the third or lower space.
15. Repeat steps 11 to 14 for 100, 400, 5,000, and 7,500 Hz. There should not be more than approximately 0.2 dB difference between any two successive readings. If there is, readings should be taken at intermediate frequencies.
16. Repeat Steps 9 through 15 for 50, 85, and 100 percent modulation. (If 100 percent modulation is not obtainable, use the highest percentage that is obtainable.)
17. Plot all readings in the lower spaces for each percentage of modulation on the graph sheets on Form AFP-2.
18. If the decibel variation between 100 and 5,000 Hz is greater than 2 dB from that at 1,000 Hz, operation is in violation of the Commission's Rules. Appropriate corrective steps should be taken, and the measurements repeated.

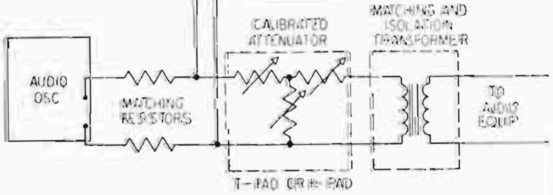


Fig. 1. Basic method of connecting audio-signal-generator equipment.

Audio-frequency Harmonic Distortion

1. Repeat Steps 1 through 9 above.
2. Connect the distortion and noise meter to the output of the transmitter. This connection depends on the instrument employed, and the instructions of the manufacturer should be followed. In general, there are two principal types: one in which the detector circuit is built into the meter and the other where a separate detector must be provided. In the latter case it is normal to use the detector in the modulation monitor.
3. Following the instructions of the manufacturer of the distortion and noise meter determine the harmonic content for 1,000 Hz and record in the space provided on Form AFP-3.
4. Repeat Steps 9 through 12 under Procedure for AM Stations and Step 3 above for 50, 100, 400, 5,000, and 7,500 Hz.
5. Repeat Steps 4 through 12 under Audio-frequency Response and Steps 3 and 4 above for 50, 85, and 100 percent modulation.

6. Plot the data on graphs on Form AFP-3.
7. If the harmonic content is greater than 5 percent from 0 to 84 percent modulation or 7.5 from 85 to 95 percent modulation, operation is in violation of the Commission's rules. Appropriate corrective steps should be taken and the measurements repeated.

Percentage Carrier (Current) Shift

1. Adjust all equipment from the microphone preamplifier input terminals to the antenna for normal program operation.
2. Bypass any limiting amplifiers.
3. Connect the audio signal generator equipment as shown in Fig. 1. Details of this will depend on the type and impedances of the various units and of the station audio circuits. (*Do not connect to the input terminals yet.*)
4. Adjust the oscillator to 400 Hz.
5. Adjust the oscillator amplitude for minimum output.
6. Adjust the attenuator to 40 or 50 dB.
7. Connect to the microphone preamplifier input.
8. Connect a dc voltmeter having a very high input impedance so as to read the dc potential in the detector circuit used in the output of the transmitter as described under Audio Harmonic Distortion.
9. If the detector in the distortion and noise meter is used, adjust the control until maximum dc voltage is obtained.
10. Read and record in the spaces provided on Form AFP-4. (This is the "no-modulation" reading.)
11. Increase the input by adjusting the oscillator amplitude control and the attenuator until the modulation monitor reads 25 percent.
12. Read the dc voltage and record it in the space provided on Form AFP-4. (This is the reading with 25 percent modulation.)
13. Enter the difference between the reading without modulation and the reading with modulation in the space provided.
14. Calculate and enter in the space provided in the percent carrier shift for 25 percent modulation. Percentage of carrier shift is the difference between the readings with and without modulation divided by the reading without modulation and multiplied by 100.
15. Repeat for 50, 85, and 100 percent modulation.
16. If the carrier shift is greater than 5 percent at any percentage of modulation, operation is in violation of the Commission's rules. Appropriate corrective steps should be taken and the measurements repeated.

Carrier Hum and Extraneous Noise

1. Adjust all equipment from the microphone amplifier input terminals to the antenna for normal program operation.
2. Bypass any limiting amplifiers.
3. Connect the audio-signal-generator equipment as shown in Fig. 1. Details of this will depend on the type and impedances of the various units and of the station audio circuits. (*Do not connect to the input terminals yet.*)
4. Adjust the oscillator to 400 Hz.
5. Adjust the amplitude control to 15 dB.
6. Adjust the attenuator to approximately 40 dB.
7. Connect to the input of the microphone preamplifier.
8. Adjust the attenuator until the modulation monitor indicates 100 percent modulation.
9. Connect the distortion and noise meter to the output of the transmitter. This connection depends on the instrument employed, and the instructions of the manufacturer should be followed. In the event the instrument does not have a detector circuit built into it, the detector of the modulation monitor can be employed provided it has a low hum and noise level, as this will be added to that of the transmitter in the readings.
10. Follow the instructions of the manufacturer, which will be, in general, to adjust the sensitivity so as to obtain a full-scale reading with the output meter set for maximum reading.
11. Disconnect the radio signal generator, and connect a 600-ohm (wire-wound) resistor across the input terminals of the main studio amplifier. If the input impedance is other than 600 ohms, use the corresponding value of resistor. (The signal generator can be turned off and 20 to 30 dB inserted by the attenuator, but the resistor connected across the input is the preferred method.)
12. Increase the sensitivity of the output meter until a reading is obtained. Read and record.
13. Calculate the combined hum and noise. In percent this is the reading obtained in Step 12 divided by the reading in Step 10 and multiplied by 100. The hum and noise ratio to the 100 percent value can be converted to decibels in the usual manner. Both should be recorded on Form AFP-4.
14. If the hum and noise is less than 50 dB below 100 percent modulation between 150 and 5,000 Hz or less than 40 dB below 100 percent modulation outside that range operation, it is in violation of the Commission's rules. Appropriate corrective steps should be taken and the measurements repeated.

Spurious Radiations

1. All equipment, including any limiting amplifiers, should be in normal adjustment with a program or test tone at as high a percentage of modulation as is ever used.

2. With the communications receiver, make observations at a distance of approximately ½ mile from the antenna or closer if possible for spurious emissions including harmonics. With the gain control turned to a maximum, tune around the frequency of the station and on up to the tenth or fifteenth harmonic of the assigned frequency. By means of the S meter determine and record the approximate signal strength of the spurious emissions that are found.

3. In the event any of consequence are found, steps should be taken to eliminate or reduce them as far as possible. In the event that any disagreement arises with the Commission, it may be necessary to take actual field measurements. It is not acceptable for the radiations on other than the assigned frequency to exceed 60 dB below the fundamental, and they should be 70 or 80 dB down.

PROCEDURE FOR FM STATIONS (MONOPHONIC)

Audio-frequency Response

1. Repeat the procedure outlined under Procedure for AM Stations *except:* Use audio frequencies of 50, 100, 400, 1,000, 5,000, 10,000, and 15,000 Hz at 25, 50, and 100 percent modulation.

(These measurements should be made without deemphasis; however, standard 75-μsec deemphasis can be employed in the measuring circuit or in the system provided the accuracy of the deemphasis circuit is sufficient to ensure that the measured response is within the prescribed limits.)

2. Record in the space provided on Form AFP-5.

3. Plot the data on Form AFP-6.

Audio-frequency Harmonic Distortion

1. Repeat the procedure outlined under Procedure for AM Stations, Audio-frequency Harmonic Distortion, for AM stations *except:* Use audio frequencies of 50, 100, 400, 1,000, and 5,000 Hz for 25 and 50 percent modulation and audio frequencies of 50, 100, 400, 1,000, 5,000, 10,000, and 15,000 Hz for 100 percent modulation. (These measurements should be made with standard 75-μsec deemphasis in the measuring circuit or system and should include harmonics to 30,000 Hz.)

2. Plot the data on Form AFP-7.

3. If this distortion exceeds the following values, operation is in violation of the Commission's rules and the equipment should be readjusted and the measurements repeated: 50 to 100 Hz, 3.5 percent; 100 to 1,500 Hz, 2.5 percent; 7,500 to 15,000 Hz, 3.0 percent.

Output Noise (FM)

1. Repeat the procedure outlined under Carrier Hum and Extraneous Noise for AM stations using FM detection and standard 75-μsec deemphasis and VU meter.

2. Record in spaces provided on Form AFP-8.

3. If the noise is in excess of 60 dB down from the audio level representing a frequency swing of ± 75 kHz, operation is in violation of the Commission's rules and appropriate corrective steps should be taken and the measurements repeated.

Output Noise (AM)

1. Shunt the 600-ohm wire wound resistor across microphone preamplifier input.

2. Determine the audio voltage equivalent to 100 percent modulation. This may be considered as equal to the dc voltage across the meter determining the power level in the monitor.

3. By use of the distortion and noise meter with standard 75-μsec deemphasis and VU meter, determine the audio voltage at the same point for the same carrier level.

4. Compute the percent AM modulation by dividing the audio voltage by the carrier level voltage and multiply by 100. Convert to decibels down from 100 percent modulation. Record in spaces provided on Form AFP-8.

5. If the noise is in excess of 50 dB below the audio level representing 100 percent modulation, operation is in violation of the Commission's rules. Appropriate corrective steps should be taken and the measurements repeated.

HOW TO USE THE MEASUREMENTS

Compliance with the Commission's rules in regard to filing the measurements was covered earlier. However, the measurements were required in the first place to determine whether the emissions of the station are satisfactory and in accordance with the rules and good engineering practice. Obviously, if the distortion, hum, noise, RF harmonics, or other spurious emissions are not within the rules, appropriate corrective steps must be taken and new measurements made. Even if the measurements are within the requirements, there are very likely adjustments or changes that can be made with little or no expense which would materially improve the operation or correct a weakness or border-line operation which may otherwise cause off-the-air time later.

In other words, these measurements should not be considered just a necessary nuisance to comply with the Commission's requirements but should be used for station improvement. If the station purchases the equipment, a procedure should be established for making the measurements at regular intervals and the measurements kept on file, together with a record of the adjustments that have been made from time to time to maintain proper operation. This will often indicate potential sources of complete failure at inopportune times, particularly in bad weather, when lines and equipment are more prone to fail and more difficult to repair.

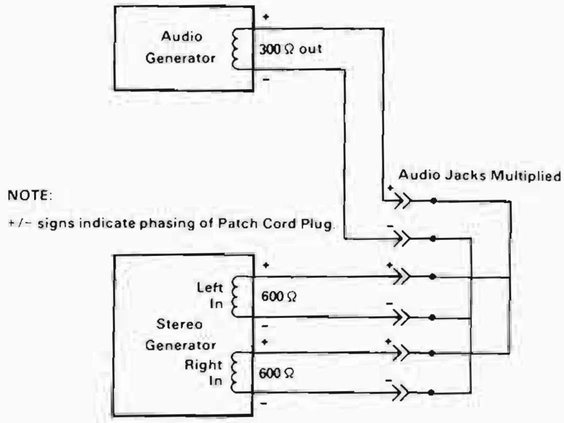


Fig. 2. Simple setup to feed to Left and Right audio channels with monaural signal generator.

As shown, the Stereo Generator is being fed an in-phase (L=+R) signal.

To feed out of phase (L≠−R), reverse the polarity of plug into Right channel.

Since the two 600 ohm input impedances are effectively strapped in parallel, the generator will not see 600 ohms. Therefore, its output should be set as near to 300 ohms as possible, according to the impedances available on the generator.

PROCEDURE FOR FM STATIONS (STEREO)

An FM Station that operates in a Stereo manner, whether on a full time or part time basis, must perform an annual Stereo Proof of Performance. This Stereo Proof is in *addition* to the required annual monaural proof required of all FM Stations. Both modes of operation must meet the requirements of Section 73.254, 73.313, 73.322 of the FCC rules.

Measurements Required

1. Audio frequency response measurements on the left and right audio channels separately at 90 + 10 percent pilot, 40 + 10 percent pilot, 15 + 10 percent pilot percent main channel modulation. As a minimum, these measurements should be made at the fundamental audio frequencies of 50, 100, 400, 1,000, 5,000, 10,000, 15,000 Hz. 1,000 Hz is used as a reference. No deemphasis used during measurements.

More measurements may be made, particularly above 1,000 Hz, which will help in drawing the graph of the response curve and give a more realistic view of the system.

Limits: The system audio response must fit within the FCC Standard Preemphasis curve.

2. Audio Frequency Distortion Measurements on the Left and Right audio channels at 100 percent, 50 percent, 25 percent (includes 10 percent pilot) modulation of the main channel for fundamental audio frequencies of 50, 100, 400, 1,000, 5,000 Hz. At 100 percent modulation, fundamental frequencies of 10,000 and 15,000 Hz. 75 μsec deemphasis used in measurements.

Limits: 50 to 100 Hz, 3.5 percent; 100 to 7,500 Hz, 2.5 percent; 7,500 to 15,000 Hz, 3 percent.

3. Output Noise level (FM) in the band 50 to 15,000 Hz in decibels below the level representing 100 percent main carrier modulation. 75 μsec deemphasis used.

Limits: −60 dB. Each channel.

4. Output Noise level (AM) in the band 50 to 15,000 Hz in decibels below the level representing 100 percent amplitude modulation of the carrier. 75μ sec deemphasis used.

Limits: −60 dB. Each channel.

5. Separation Measurements of the Left and Right audio channels in the band 50 to 15,000 Hz in decibels at a level representing 90 percent (+ 10 percent pilot) main carrier modulation.

Limits: −29.7 dB for each channel.

6. Cross-talk measurements of Main channel into subchannel when main channel is modulated 90 percent (+ 10 percent pilot) with 400 Hz, while subchannel is unmodulated.

Cross-talk measurement of subchannel into the main channel while the subchannel is modulated 100 percent with 400 Hz, modulating the main channel to 90 percent (+ 10 percent pilot) and no audio modulation on main channel.

Limit: −45 dB for both the main and the subchannel.

7. Subcarrier suppression measurements with no audio modulation on the main channel, subchannel modulated by 5,000, 7,500, 10,000, 15,000 Hz, subchannel modulating the main channel to 90 percent (+ 10 percent pilot).

Subcarrier suppression measurement without modulation on the main channel, subchannel or pilot.

Limit: 1 percent main channel modulation (— 40 dB).

Equipment Needed

1. The same basic equipment required for the monaural Proof.
2. A Stereo Modulation Monitor. This is required as an operational instrument by the FCC rules. All modern monitors incorporate the required circuits, switches, pads, and metering to make the specialized Stereo measurements.
3. An oscilloscope, although not entirely necessary, is a useful instrument for determining if the system phasing is correct.
4. Some device for feeding the monaural audio signal generator into the left and right audio channels, maintaining correct phasing and impedance matching. This may be built up of various resisters and switches. If the input to the stereo system is on an audio patch panel, a simpler method can be used, provided there are three sets of jacks that are multiplied together. The audio generator is fed to one of the multiple jacks, while two identical length patch cords feed the left and right channels. Each plug should be adequately marked for phasing and which channel.

Precautions

Before making the measurements, certain checks should be made and precautions taken.

1. *Identical* circuit paths and levels are most important. The matrix in the Stereo Generator algebraically adds and subtracts the Left and Right audio channels to provide the main channel modulation and the subchannel modulation. The matrix in the receiver reverses the process to restore the Left and Right audio channels. Should the Left and Right audio channels not be identical in both amplitude response and phase of all passing audio-frequencies, complete addition and subtraction cannot take place. What remains will appear in the opposite channel as reduced separation.
2. System should be checked for 180° phasing. Whenever equipment has been removed for repairs, it is possible that the leads were inadvertently reversed when the equipment was replaced. Such a shift in phase will reverse the Left and Right audio channels.
3. System should be checked for lesser degrees of phase error. Smaller amounts of phase error will cause reduced separation.
4. The demodulator switching action of the monitor should be the same as that used in the Stereo Generator. The monitor should be adjusted or modified as directed in its instruction manual to make the monitor correspond with the generator. Should one unit be square wave switching while the other is sine wave switching, reduced separation measurements will result.
5. Impedance matching of the inputs is most important, as a mismatch will effect both amplitudes and frequency response.
6. Proper terminations are important. This is especially true when only one channel is measured. During such times, the input to the other channel should be terminated with a resister of a value equal to the input impedance. If the channel is left open and unterminated, open circuit hum may be introduced that will affect the measurements taken.

Techniques

There are several types of modulation monitors available. Although none are identical, each performs the required functions in its own way. It is beyond the scope of this section to discuss individual monitors. It is assumed that the engineer making the proof is familiar with operation of the monitor in use. Methods for performing the measurements differ from one type monitor to another.

A check for the correctness of phasing should be done as the first step. Unless the phasing is correct, all the measurements will be in error.

Set up the equipment as shown in Fig. 3. Composite signal from the output of the stereo generator is coupled to the vertical amplifier input of the oscilliscope. At the same time, 19 kHz pilot is fed to horizontal trigger input of the oscilloscope. Using the 19 kHz as a trigger will help stabilize the CRO display. Next, adjust the horizontal sweep controls so that only one cycle is displayed on the CRO.

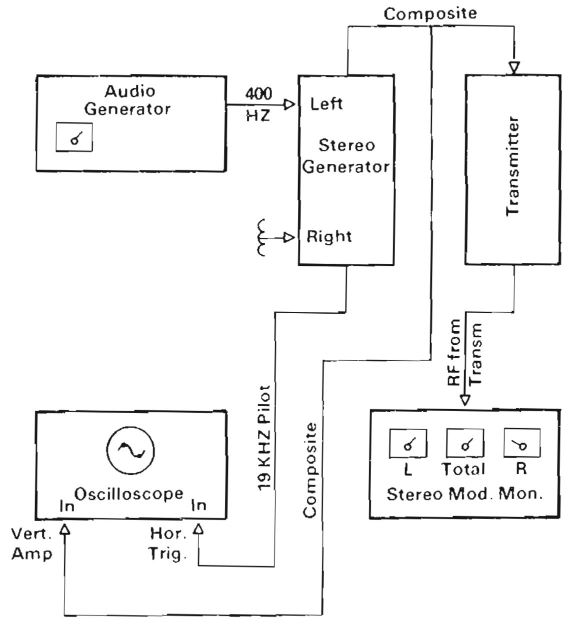
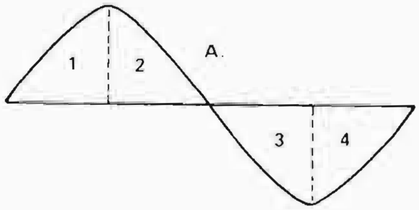
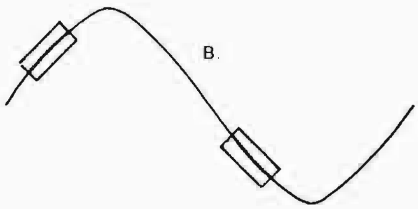


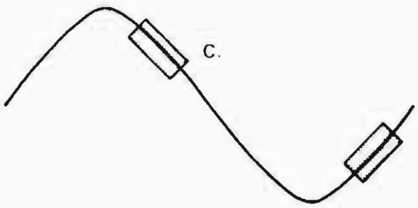
Fig. 3. Equipment set up for checking system phasing. As shown, system is being checked for 180° phasing using Left channel.



A. One full cycle divided in 4 quadrants, a zero base line drawn in.



B. Small amount of 400 Hz fed to Left channel only. Modulation appears in 1st and 3rd quadrants of the cycle.



C. Small amount of 400 Hz fed to Right channel only. Modulation appears in 2nd and 4th quadrants of the cycle.

Fig. 4. One cycle of 19 kHz display on CRO and modulation and correct 180° phasing.

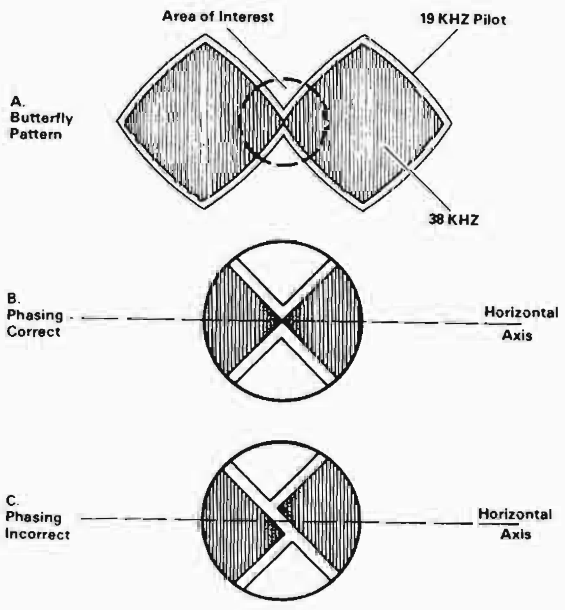


Fig. 5. Butterfly pattern of oscilloscope, used for checking smaller amounts of phase error.

Feed a small amount of 400 Hz audio into the left channel only, the right channel input terminated in 600-ohms. If the phasing is correct, the 400 Hz modulation will appear in the 1st and 3rd quadrants of the cycle displayed on the CRO. At the same time, the left audio meter on the Stereo Monitor will be indicating modulation. This test verifies that both the Stereo Generator and Monitor are correctly phased.

The right channel may now be checked. Simply feed the 400 Hz audio to the right channel, terminate the left channel. The 400 Hz modulation should now appear in the 2nd and 4th quadrants of the cycle displayed on the CRO, and the right meter on the monitor should be indicating. The 180° phasing is now verified.

Lesser degrees of phase error may now be checked. Leave the equipment set up as for the previous test, but with this exception. Feed 400 Hz out of phase (L = − R) to both left and right audio channels. Modulate for 90 + 10 percent pilot total modulation. Adjust the horizontal sweeps on the oscilloscope for the butterfly pattern.

Careful observation of the CRO pattern will show that both wings are filled with fine vertical lines (38 kHz), a dual outer envelope (19 kHz pilot). The central crossover point where the wings join together is the main point of interest. The CRO display should now be expanded so the central area can be observed better. Phasing is correct when the two points of the wings are on the same horizontal axis. Incorrect phasing will be indicated when the two points are on opposite sides of the horizontal axis. How far apart and which side of the line the points are located will depend upon the direction and amount of phase error. If incorrect phasing is indicated, adjust the phasing control on the Stereo Generator so the points are on the same axis.

The audio response, distortion and noise measurements are basically the same as those taken during the monaural proof, with the exception of the dual channels and the stereo section of the monitor.

The stereo proof will require a considerable number of measurements to be taken. Motion economy will make the work proceed faster and require less switching actions. One can combine the response, distortion, and separation measurements on one channel and at the three main carrier modulation percentages. For example, with the audio signal set to feed 1,000 Hz to the left audio channel, the distortion analyzer will be attached to the Left output. Adjust the input to modulate the main channel 100 percent (includes 10 percent pilot). Enter this level onto the appropriate sheet, then measure distortion and enter that reading on the distortion sheet. Next, measure the separation of the Right channel

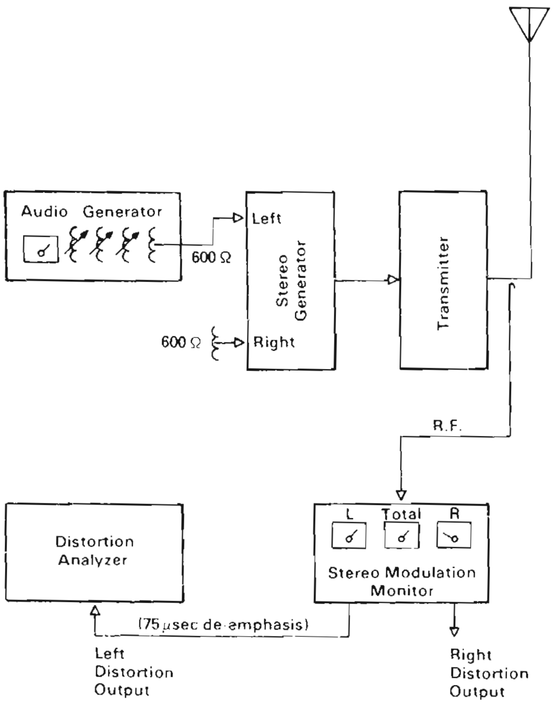


Fig. 6. Equipment setup for measuring audio response and distortion in the system. As shown, equipment is ready to measure the Left channel. To measure the Right channel, the feed is to the Right channel and the distortion meter is moved to the right distortion output of monitor.

(according to monitor in use) and enter that reading on the separation sheet. Next, drop the input level so total modulation is 50 percent, again check distortion and enter on appropriate sheets. Do the same with 25 percent modulation. Separation measurements are made at 100 percent modulation only.

When combining measurements in this way, the work will go faster, but there are possibilities for entering the results in the wrong columns or on the wrong sheets. But if done with care, the work will be performed in a shorter period of time.

Preparing the Results

Whether one uses the charts as given in this manual or those of his own design, here are a few suggestions:

Graphs should be prepared of the audio response and distortion so as to give a quick overall view of the system. The left and right channels should be plotted on the same graph and on the same reference points. Such an overlay will quickly show where the two channels differ. As a further suggestion, each channel can be drawn in with a color different than the opposite channel, or one channel may be drawn in a solid curve while the other is drawn in a dashed curve. In either case, and differences in channels will be very evident.

A graph should also be drawn for the distortion measurements, again plotting both curves on the same sheet and reference points. As a quick aid in viewing the overall system distortion performance, draw in the limits of distortion permitted.

Since a monaural proof must also be made, both the stereo and monaural proofs should be combined in the same folder or other packaging. This will provide a single volume showing the total results of the station overall technical performance. File in the usual manner as done with proofs.

Station KC , City State

OVERALL AUDIO FREQUENCY RESPONSE DATA

25% MODULATION

CPS	30	50	100	400	1000	5000	7500
(1)							
(2)							
(3)							

50% MODULATION

CPS	30	50	100	400	1000	5000	7500
(1)							
(2)							
(3)							

85% MODULATION

CPS	30	50	100	400	1000	5000	7500
(1)							
(2)							
(3)							

100%(or %) MODULATION

CPS	30	50	100	400	1000	5000	7500
(1)							
(2)							
(3)							

(1) RECORD THE ATTENUATOR READING FOR THE 1000 CPS REFERENCE SIGNAL IN EACH SPACE IN THIS ROW.

(2) RECORD THE ATTENUATOR READINGS FOR THE SPECIFIED FREQUENCIES IN THIS ROW.

(3) RECORD THE AUDIO FREQUENCY RESPONSE VARIATION IN THIS ROW WHICH IS OBTAINED BY SUBTRACTING ROW (2) FROM ROW (1) THESE FINAL FIGURES ARE TO BE USED IN PLOTTING THE GRAPHS.

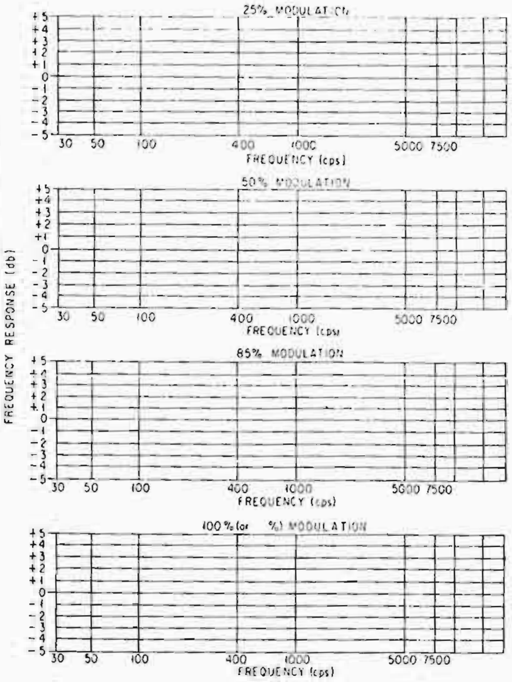
__________ Engineer _____ 19___

Form No. AFP-1

Form AFP-1.

Station KC, City State

OVERALL AUDIO FREQUENCY RESPONSE CURVES



ENGINEER 19

Form No AFP-2

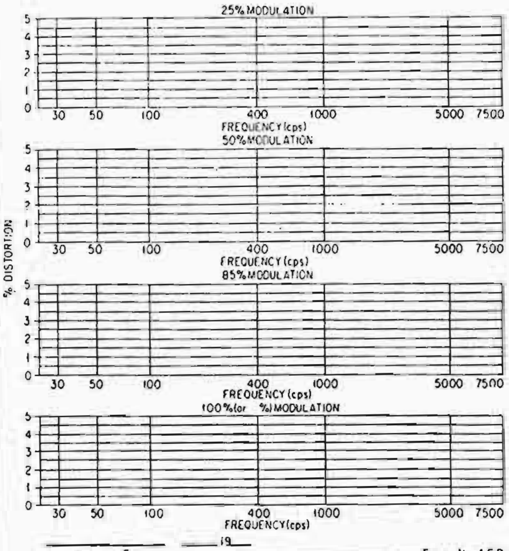
Form AFP-2.

Station KC, City State

AUDIO FREQUENCY HARMONIC CONTENT DATA AND CURVES

HARMONIC DISTORTION

% MOD. CPS	30	50	100	400	1000	5000	7500
25							
50							
85							
100							



Engineer 19

Form No AFP-3

Form AFP-3.

Station KC, City State

CARRIER SHIFT AND COMBINED NOISE AND HUM DATA

CARRIER SHIFT DATA (at 400 cps)

% MOD	25	50	85	100
(1)				
(2)				
(3)				
(4)				

(1) RECORD DC VOLTMETER READING WITHOUT MODULATION IN EACH SPACE IN THIS ROW.

(2) RECORD DC VOLTMETER READINGS WITH MODULATION IN THIS ROW.

(3) SUBTRACT ROW (2) FROM ROW (1) AND RECORD DIFFERENCE IN THIS ROW.

(4) COMPUTE CARRIER SHIFT BY EQUATION $\frac{\text{ROW (3)}}{\text{ROW (1)}} \times 100$, AND RECORD RESULTS IN THIS ROW.

COMBINED NOISE AND HUM READING

DB	%

Engineer 19

Form No. AFP-4

Form AFP-4.

Station Ch. City State

OVERALL AUDIO FREQUENCY RESPONSE DATA

25% MODULATION

CPS	50	100	400	1000	5000	10000	15000
(1)							
(2)							
(3)							

50% MODULATION

CPS	50	100	400	1000	5000	10000	15000
(1)							
(2)							
(3)							

100% MODULATION

CPS	50	100	400	1000	5000	10000	15000
(1)							
(2)							
(3)							

—— % MODULATION

CPS	50	100	400	1000	5000	10000	15000
(1)							
(2)							
(3)							

(1) RECORD THE ATTENUATOR READING FOR THE 1000 CPS REFERENCE SIGNAL IN EACH SPACE IN THIS ROW.

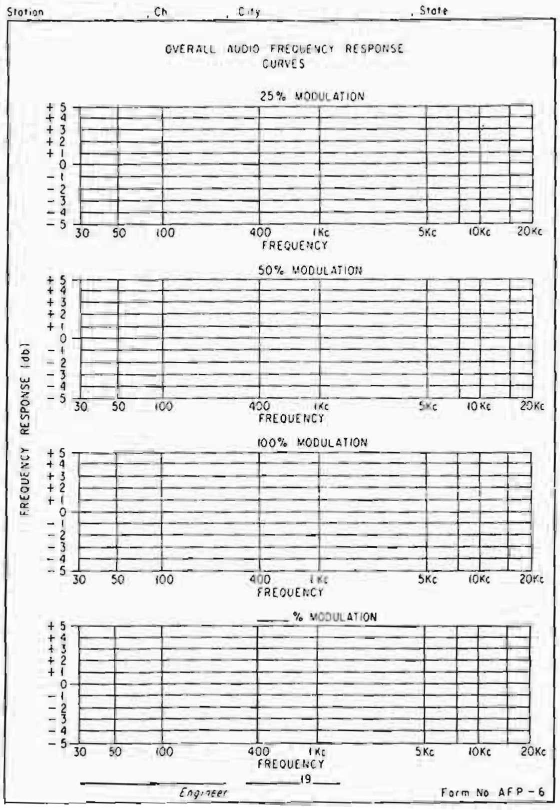
(2) RECORD THE ATTENUATOR READINGS FOR THE SPECIFIED FREQUENCIES IN THIS ROW.

(3) RECORD THE AUDIO FREQUENCY RESPONSE VARIATION IN THIS ROW WHICH IS OBTAINED BY SUBTRACTING ROW (2) FROM ROW (1). THESE FINAL FIGURES ARE TO BE USED IN PLOTTING THE GRAPHS.

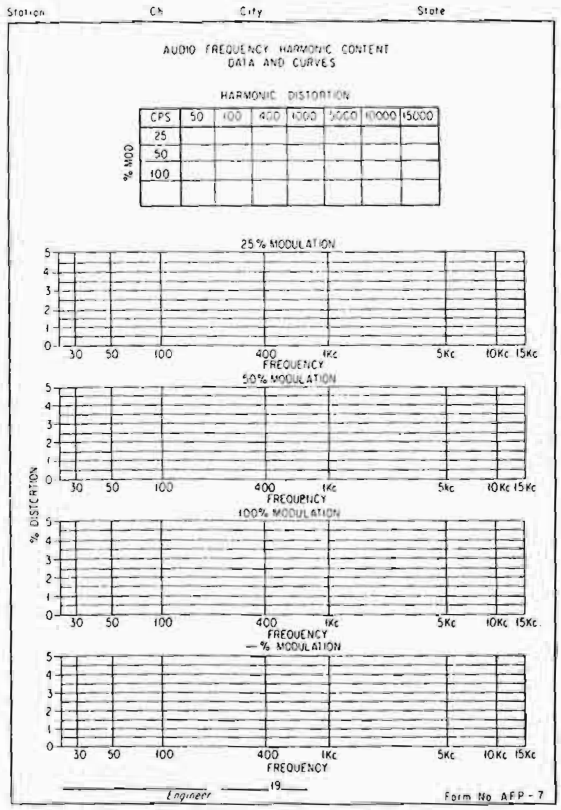
Engineer 19

Form No. AFP-5

Form AFP-5.



Form AFP-6.



Form AFP-7.

Station ____ Ch. ____ City ____ State ____

OUTPUT NOISE LEVEL DATA

OUTPUT NOISE LEVEL (Frequency modulation)

VM READING AT 100% MODULATION	NOISE VOLTAGE	% NOISE $\frac{\text{COLUMN 2}}{\text{COLUMN 1}}$ ×100	DB DOWN

OUTPUT NOISE LEVEL (Amplitude modulation)

VM READING AT 100% MODULATION	NOISE VOLTAGE	% NOISE $\frac{\text{COLUMN 2}}{\text{COLUMN 1}}$ ×100	DB DOWN

____ Engineer ____ 19____

Form No AFP − 8

Form AFP-8.

40

Proof-of-Performance for A Television Station

Joseph L. Stern

WHY A PROOF-OF-PERFORMANCE

Proof-of-performance is required by the FCC when an application is filed for a license for a television broadcast station. It assures both the licensee and the Federal Communications Commission that construction and operation have been in accordance with the formal authorizing instruments of the Commission. When modifications are made after the initial licensing, submission of a "proof" is once again required as evidence of continued compliance with the regulations. In addition, and quite importantly, the proof provides an opportunity for the licensee to assess the performance of his plant for his own and his viewers' benefit.

After a "proof" has been accepted by the Commission and the Program Test Authority granted, it is incumbent on the licensee to make periodic proof measurements (1) to have the information available as proof to an FCC inspector that the station is operating within the rules and regulations, (2) to have available as a reference in license renewal applications, and (3) to indicate to the operator that his equipment is operating at peak performance, transmitting pictures and sound of the highest possible quality at all times.

The transmission of a "standard television signal" is a requirement of the rules and the "proof" attests to compliance.

The equipment manufacturer submits Type Acceptance data to the FCC to prove that the transmitter is designed and built to meet the requirements of the Commission's rules and regulations. The TV station submits proof-of-performance data to prove that, as installed, the equipment still meets the rules and regulations.

In making a "proof," the operator establishes a method of operational maintenance which will guide him in a continuous quality assessment. A properly executed "proof," carried out with the full understanding of the operating staff, is a very valuable tool for the station. The measurements carried out for the "proof" can be established as required periodic maintenance measurements within the plant. The formal submission of these data or their inspection by the FCC can be equated to an audit of a carefully kept set of accounting records, confirming the soundness of the operation.

For many operators a "proof" has the onus of something very special and difficult. It is often thought that unusual and obscure measurement techniques are required just to satisfy a special governmental regulation. The following explanation of the performance of a "proof" will show that the measurements are simple to undertake. These measurements not only satisfy the requirements of the FCC, but in addition, assure the licensee that he is getting the maximum return from his equipment and manpower investment.

THE PERFORMANCE OF A PROOF

As an absolute minimum, the "proof" is a series of exhibits detailing information requested in Section II-C of FCC Form 302, License Application Engineering Data Television Broadcast as amended (Fig. 1a and 1b). As a practical minimum, the "proof" is what the name implies, proof (1) that the facility for which license application has been made is, in fact, constructed in accordance with the construction permit and (2) that the facility is capable of operating in conformance with the Commission's Rules and Regulations—that it has transmitted a "standard television signal."

To measure the performance of the television plant, all the normal segments of the system must be included. The main studio, as well as the transmitting plant, should be included in the measurement, for this is the source of the original signals. While program content is not a part of the reported measurements, the handling of program material, both audio and video, is the object of the measurements.

Broadcast Application — FEDERAL COMMUNICATIONS COMMISSION — Section II-C

LICENSE APPLICATION ENGINEERING DATA TELEVISION BROADCAST	Name of applicant	

1. Facilities authorized in construction permit

Call letters	Channel No.	File No. of construction permit

Frequency	Carrier frequency
____ ____ MHz	Visual .... MHz Aural .... MHz

Effective Radiated Power (visual)	Effective Radiated Power (aural)	Antenna height above average terrain
In dbk: In kw:	In dbk: In kw:	feet

2. Station location (principal community)

State	City or town

3. Transmitter location

State	County
City or town	Street Address (or other identification)

4. Main studio location

State	County
City or town	Street address

5. Transmitters Installed

Visual

Make	Type No.	Rated power
		In dbk: In kw:

Aural

Make	Type No.	Rated power
		In dbk: In kw:

Operating constants

Visual transmitter (while transmitting black)

D. C. plate current in last radio stage, in amperes	Applied D. C. plate voltage of last radio stage, in volts

Transmitter power output (after vestigial sideband filter, if used, and after multiplexer, if combined)	Multiplexer loss in db, if separate:	Input to transmission line in dbk:
In dbk: In kw:		

Transmission line power loss in db:	Antenna input power in dbk:	Antenna power gain in db:	Effective radiated power
			In dbk: In kw:

Attach as Exhibit No. complete information concerning the method of power output determination. If power is measured at output of multiplexer, so state.

Reading of power output meter (transmission line voltage, current or power; indicate which) while operating at authorized power:

Aural transmitter

D. C. plate current in last radio stage, in amperes	Applied D. C. plate voltage of last radio stage, in volts
Plate input power to last radio stage in kilowatts	Efficiency factor F of transmitter at operating power, in percent
Transmitter power output In dbk: In kw:	RF transmission line meter reading

6. Antenna and transmission line

Antenna make and Type No.	Number of sections	Power gain in db

Antenna supporting structure

Overall height of antenna system above ground in feet

Geographical coordinates of antenna (to nearest second)
North latitude ° ' " West longitude ° ' "

If directional antenna is used, give full details including horizontal and vertical plane radiation patterns, as Exhibit No.

Is electrical or mechanical beam tilting employed? Yes ☐ No ☐
If so, describe fully in Exhibit No. , including horizontal and pertinent vertical radiation patterns.

Has antenna been altered to provide null fill-in? Yes ☐ No ☐
If so, describe fully in Exhibit No.

Transmission line

Make	Type No.	Coaxial or waveguide
Size (nominal inside transverse dimensions) in inches	Length in feet	Power loss in db for this length

Multiplexer

Make	Type No.

If emergency antenna or transmission line measures are provided, describe in Exhibit No.

7. Modulation monitors

(a) Visual monitor or monitoring equipment

Make	Type No. (or describe in Exhibit No.)

(b) Aural monitor

Make	Type No.

8. Frequency monitors

(a) Visual monitor

Make	Normal limits of deviation of carrier frequency shown by monitor
Type No.	cps. high/low to cps. high/low

Fig. 1a.

Broadcast Application — TELEVISION BROADCAST ENGINEERING DATA — Section II-C, Page 2

8. (Continued)

(b) Aural monitor

Make	Normal limits of deviation of carrier frequency shown by monitor
Type No.	high cps. to cps. high low low

If either frequency monitor indicates any carrier deviation in excess of the permissible tolerance, describe in Exhibit No. and state the corrective measures taken.

If the carrier frequencies have been measured by other means, describe in Exhibit No. , giving the date, method used or frequency measuring service employed, the results obtained and the monitor readings (high or low) at the time.

9. **Performance data - Visual transmitter**

a. Attach as Exhibit No. data showing the following:

1. Overall attenuation versus frequency of the visual transmitter;
2. Field strength or voltage of the lower side-band for a modulating frequency of 1.25 MH_z or greater, and of the upper side-band for a modulating frequency of 4.75 MH_z or greater;
3. A description of the equipment and technique used in making these measurements.

b. Attach as Exhibit No. data demonstrating that the waveform of the transmitted signal conforms to that specified by the standards. Until the form of these measurements may be specified by the Commission, the character of this data is left to the discretion of the applicant.

c. Attach as Exhibit No. a photograph of a test pattern taken from a receiver or monitor connected to the transmitter output.

10. **Performance data - Aural transmitter**

Attach as Exhibit No. data, diagrams, and appropriate graphs together with description of measurement procedures and instruments with regard to the following: (All measurements shall be made with the equipment adjusted for normal program operation and shall include all circuits between the main studio microphone terminals and the antenna output, including telephone lines, preemphasis circuits and any equalizers employed except for microphones, and without compression if a compression amplifier is installed.)

a. Audio frequency response from 50 to 15,000 Hertz for approximately 25, 50 and 100 percent modulation. Measurements shall be made on at least the following audio frequencies: 50, 100, 400, 1000, 5000, 10,000 and 15,000 Hertz. The frequency response measurements should normally be made without deemphasis; however, standard 75 microsecond deemphasis may be employed in the measuring equipment or system provided the accuracy of the deemphasis circuit is sufficient to insure that the measured response is within the prescribed limits.

b. Audio frequency harmonic distortion for 25, 50 and 100 percent modulation for the fundamental frequencies of 50, 100, 400, 1000 and 5,000 $Hert_z$. Audio frequency harmonics for 100 percent modulation for fundamental frequencies of 10,000 and 15,000 $Hert_z$. Measurements shall normally include harmonics to 30,000 $Hert_z$. The distortion measurements shall be made employing 75 microsecond deemphasis in the measuring equipment or system.

c. Output noise level (frequency modulation) in the band of 50 to 15,000 Hertz in decibels below the audio frequency level representing a frequency swing of 25 kilohertz. The noise measurements shall be made employing 75 microsecond deemphasis in the measuring equipment or system.

d. Output noise level (amplitude modulation) in the band of 50 to 15,000 Hertz in decibels below the level representing 100 percent amplitude modulation. The noise measurements shall be made employing 75 microsecond deemphasis in the measuring equipment or system.

11. In what respect, if any, does the apparatus constructed differ from that described in the application for construction permit or in the permit?

I certify that I represent the applicant in the capacity indicated below and that I have examined the foregoing statement of technical information and that it is true to the best of my knowledge and belief.

Date ____________________ Signature ____________________

(check appropriate box below)

☐ Technical Director ☐ Chief Operator ☐ Registered Professional Engineer ☐ Consulting Engineer

Fig. 1b.

Most of the visual transmitter characteristics described in the rules specify the transmitter as the item being measured but, at the same time, define the transmission standards as applying to the radiated signal. Thus, it is incumbent on the operator to prove the performance of the transmitter where it is specifically requested and also to prove that the entire system can meet the transmission standards. If it is impossible to measure the complete system at one time, an attempt should be made to provide the transmitting plant with operating tolerances more stringent than those in the rules, allowing for some degradation in the studio plant and studio-to-transmitter circuits.

The aural transmitter is defined in two ways: as a transmitter for some measurements and as a transmitting system for others. Transmission measurements for the aural system must be made through this entire system starting with the microphone preamplifier, while the operating characteristics of the aural transmitter alone can naturally be measured on the aural transmitter itself. In all cases, however, for both the aural and visual transmitters, it must be remembered that the "transmitter" input terminals are the *input terminals of the "plant"* and not those physically on the transmitter cabinet. Here the intent of the regulations is quite clear: Those normally used preemphasis and auxiliary components required for proper operation of the transmitter, within the transmitting plant, *are all considered as being a part of the transmitter.*

Examination of FCC Form 302, Section II-C (Fig. 1a and 1b) will aid in demonstrating the performance of a "proof." All information that can be definitively listed is requested in the blank form while information that requires detailing is requested in exhibit form.

Determination of Transmitter Power Output

The first exhibit requested complete information concerning the method of power-output determination (II-C-5). Section 73.689(a)(1) of the rules stipulates that the peak output power of the visual transmitter shall be measured at the output following the vestigial-sideband filter and harmonic filter (if one is used) while operating into a dummy load of substantially zero reactance and a resistance equal to the transmission-line surge impedance while transmitting a standard black picture. The object is simply to provide a means for measuring the output power of the transmitter while operating into a load substantially equal to the load normally seen by the transmitter (which includes the various system filters, traps, transmission line switches, transmission line and antenna system). To accomplish this end, it is necessary to know the impedance characteristics both of the antenna system and of the dummy load being used.[1] This can be ascertained by standard impedance-measuring techniques utilizing bridges, admittance meters, or sweep frequency techniques. Once the similarity of the antenna system and the dummy load wattmeter have been established, a simple power reading can be made. It should be recognized during this measurement, that there are many components between the transmitter output and the antenna system input that can have small losses. The use of lower sideband notch filters, diplexers, and triplexers must be taken into consideration, and their losses attributed to the antenna or transmitter system (as was originally outlined in the equipment description included in the application for construction permit).

When the power measurement is made on the visual transmitter, the peak output power of the transmitter, operating with black picture and standard sync (Fig. 2a and 2b), is determined by reading the average power directly from the dummy load wattmeter and multiplying this value by 1.68.[2] It is advisable to make this measurement at three or more power levels so that it will be possible to plot a graph of peak power output versus the reading of the power-output monitor device of the transmitter. This graph will allow the operating staff to determine readily that they are always operating within the plus 10 minus 20 percent output power variation permitted by Section 73.689(b)(1) of the rules and regulations.

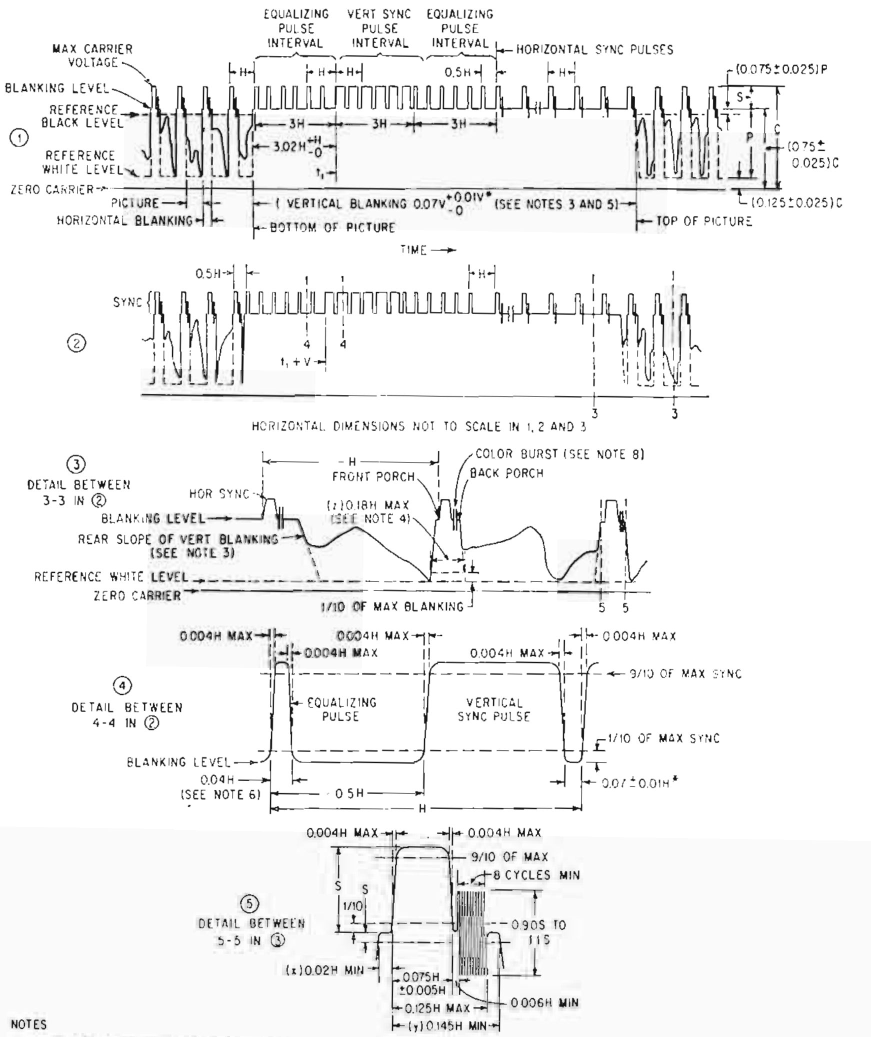
Paragraph II-C-5 of Form 302 requests information to allow determinations of the output power of the aural transmitter by the indirect method as noted in Section 73.689(a)(2). Unfortunately, this method does not take into account possible tube-efficiency variations due to the varying loading conditions possible for the final stage of the transmitter. For the condition of operation for which the transmitter is tuned, the correct stage efficiency can be determined from a power measurement with a dummy load watt-

[1]Section 73.689(a)(1) does suggest, however, that the direct plate voltage and current of the last radio stage and the transmission line meter can be read while making a power measurement into the dummy load and compared with similar readings taken with the dummy load replaced by the antenna system. Substantial argument between these readings should indicate the substantial equality of loads.

[2]The duration of all horizontal, vertical sync and equalizing pulses adds up to 8.9 percent of a TV frame. The average-to-peak power ratio indicated on the meter can be calculated from the value and the relative amplitudes of the black signal (75 percent) and the sync (100 percent). Thus

$$\frac{P_{av}}{P_{pk}} \frac{(0.75 + 0.25 \times 8.9\%)^2}{1}, \quad \frac{P_{av}}{P_{pk}} = 0.596.$$

To determine peak power the meter reading must then be multiplied by 1/0.596 or 1.68. Note that this factor holds only for standard sync height and width.



NOTES

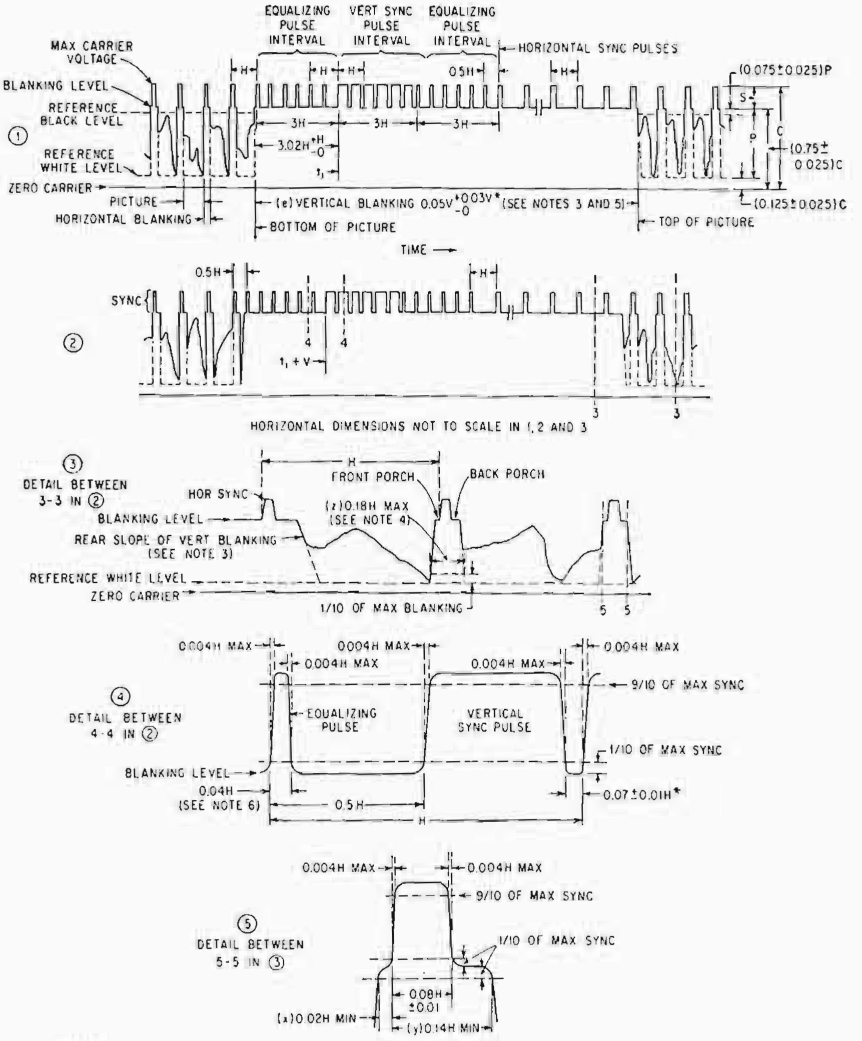
1 H=TIME FROM START OF ONE LINE TO START OF NEXT LINE.
2 V=TIME FROM START OF ONE FIELD TO START OF NEXT FIELD.
3 LEADING AND TRAILING EDGES OF VERTICAL BLANKING SHOULD BE COMPLETE IN LESS THAN 0.1H.
4 LEADING AND TRAILING SLOPES OF HORIZONTAL BLANKING MUST BE STEEP ENOUGH TO PRESERVE MINIMUM AND MAXIMUM VALUES OF (x+y) AND (z) UNDER ALL CONDITIONS OF PICTURE CONTENT.
*5 DIMENSIONS MARKED WITH ASTERISK INDICATE THAT TOLERANCES GIVEN ARE PERMITTED ONLY FOR LONG TIME VARIATIONS AND NOT FOR SUCCESSIVE CYCLES.
6 EQUALIZING PULSE AREA SHALL BE BETWEEN 0.45 AND 0.5 OF AREA OF A HORIZONTAL SYNC PULSE.
7 COLOR BURST FOLLOWS EACH HORIZONTAL PULSE, BUT IS OMITTED FOLLOWING THE EQUALIZING PULSES AND DURING THE BROAD VERTICAL PULSES
8 COLOR BURSTS TO BE OMITTED DURING MONOCHROME TRANSMISSION.
9 THE BURST FREQUENCY SHALL BE 3.579545MC. THE TOLERANCE ON THE FREQUENCY SHALL BE ±10 CYCLES WITH A MAXIMUM RATE OF CHANGE OF FREQUENCY NOT TO EXCEED 1/10 CYCLE PER SECOND PER SECOND.
10 THE HORIZONTAL SCANNING FREQUENCY SHALL BE 2/455 TIMES THE BURST FREQUENCY.
11 THE DIMENSIONS SPECIFIED FOR THE BURST DETERMINE THE TIMES OF STARTING AND STOPPING THE BURST, BUT NOT ITS PHASE. THE COLOR BURST CONSISTS OF AMPLITUDE MODULATION OF A CONTINUOUS SINE WAVE.
12 DIMENSION "P" REPRESENTS THE PEAK EXCURSION OF THE LUMINANCE SIGNAL FROM BLANKING LEVEL, BUT DOES NOT INCLUDE THE CHROMINANCE SIGNAL. DIMENSION "S" IS THE SYNC AMPLITUDE ABOVE BLANKING LEVEL. DIMENSION "C" IS THE PEAK CARRIER AMPLITUDE
13 REFER TO TEXT FOR FURTHER EXPLANATIONS AND TOLERANCES

Fig. 2a. FCC television synchronizing waveform for color transmission.

meter, as above. Section 73.689(a)(2)(i) outlines the direct method of operating power measurement which is similar to the visual transmitter measurement with the exception that the aural transmitter shall be unmodulated during the measurement. This dummy load measurement also allows the power to be measured at varying levels to obtain a plot of output power versus RF transmission-line meter readings to allow for conformance with the plus 10 minus 20 percent power limits allowed as specified in Section 73.689(b)(2). Information developing the output power by the indirect method must be supplied on Form 302, Section II-C-5, and the direct measurement determination may also be supplied.

Antenna and Transmission Line

The next portion of Form 302 requesting exhibit information asks for data on the antenna system. Full information recording the special characteristics of the antenna, if any, should be included here. The same holds true for the case where emergency antennas and transmission lines are provided.



NOTES

1. H = TIME FROM START OF ONE LINE TO START OF NEXT LINE
2. V = TIME FROM START OF ONE FIELD TO START OF NEXT FIELD
3. LEADING AND TRAILING EDGES OF VERTICAL BLANKING SHOULD BE COMPLETE IN LESS THAN 0.1H
4. LEADING AND TRAILING SLOPES OF HORIZONTAL BLANKING MUST BE STEEP ENOUGH TO PRESERVE MINIMUM AND MAXIMUM VALUES OF (x + y) AND (z) UNDER ALL CONDITIONS OF PICTURE CONTENT

*5. DIMENSIONS MARKED WITH ASTERISK INDICATE THAT TOLERANCES GIVEN ARE PERMITTED ONLY FOR LONG TIME VARIATIONS AND NOT FOR SUCCESSIVE CYCLES

6. EQUALIZING PULSE ARE SHALL BE BETWEEN 0.45 AND 0.5 OF AREA OF A HORIZONTAL SYNC PULSE
7. REFER TO TEXT FOR FURTHER EXPLANATIONS AND TOLERANCES

Fig. 2b. FCC television synchronizing waveform for monochrome transmission only.

Frequency Monitors

Section II-C-8-b requests an exhibit explaining any difficulties that may have caused the frequency monitor of the station to indicate excessive frequency deviation and the measures that have been taken to correct this deficiency. In addition, information is requested as to "outside" readings of the operating frequencies that may have been taken by means other than the station's own frequency monitor. Even though the station may be using a frequency monitor, it is still necessary to check against an "outside" standard to ensure that the long-time drift of the monitor is periodically corrected. This can be done at the station by comparing the station monitor readings with a signal received from WWV or WWVH or by having the frequency of the station measured by an independent frequency-measuring service. For either of these cases the "outside" measurements should be described in detail and, of course, the station monitor should be corrected if found in error.

The performance of the visual transmitter is the subject of Sec. II-C-9. In essence, the exhibits submitted in response to II-C-9 should show that the visual transmitter meets all the required transmitter and operational characteristics outlined in Part 73, Subpart E, of the rules.

Variation of Output

Variation of output as specified in Section 73.682(a)(16) is the peak-to-peak change in signal amplitude during a period of one frame. Variation of output results from such things as hum, noise, and incorrect low-frequency response. The rules state that the variation of output at sync peak level and at blanking level shall not exceed 5 percent of the average of the peak signal amplitude.

Method of Measurement

A sample of the transmitter output signal shall be detected, and the resulting video signal viewed on an oscilloscope. Means for establishing a zero reference must be provided. The sync peak should be calibrated in terms of peak power. The height of the highest and lowest sync peaks and the highest and lowest blanking levels shall be measured. Their respective differences shall not exceed 4.5 percent of the highest sync peak. This will assure less than 5 percent variation of the average peak signal amplitude. The overall accuracy of the measuring equipment shall be sufficient to allow measurement of variation of amplitude with an accuracy of ±1 percent of the total peak amplitude. The input test signal shall contain a slightly nonsynchronous 60-Hz sine wave whose peak-to-peak amplitude is not less than 75 percent of the excursion from reference black to reference white.

Overall Attenuation

A measure of overall attenuation versus frequency is requested for frequencies from zero to 4.75 MHz. This measurement is detailed in Section 73.687(a)(1) and (2); 73.699 fig. 11 of the rules and regulations and is, in essence, a diode measurement of the transmitter output when the transmitter is fed a video sweep signal. The limits of this measurement are also established in the rules. It is specified that this measurement be made into the antenna system (for color), but if the characteristics of the antenna and the dummy load have been measured to be substantially the same (as in the power measurement), a case can be made for the use of the dummy load in place of the antenna if this makes the measurement more convenient.

Method of Measurement

Section 73.687(a)(4) states that the attenuation characteristics of a visual transmitter shall be measured by application of a modulating signal to the transmitter input terminals in place of the normal composite television video signal. The signal applied shall be a composite signal composed of a synchronizing signal to establish peak output voltage plus a variable frequency sine wave voltage occupying the interval between synchronizing pulses. (The "synchronizing signal" referred to in this section means either a standard synchronizing wave form or any pulse that will properly set the peak.) The axis of the sine wave in the composite signal observed in the output monitor shall be maintained at an amplitude 0.5 of the voltage at synchronizing peaks. The amplitude of the sine wave input shall be held at a constant value. This constant value should be such that at no modulating frequency does the maximum excursion of the sine wave, observed in the composite output signal monitor, exceed the value 0.75 of peak output voltage. The amplitude of the 200 kHz sideband shall be measured and designated 0 dB as a basis for comparison. The modulation signal frequency shall then be varied over the desired range and the field strength or signal voltage of the corresponding sidebands measured. An an alternate method of measuring, in those cases in which the automatic dc insertion can be replaced by manual control, the above characteristic may be taken by

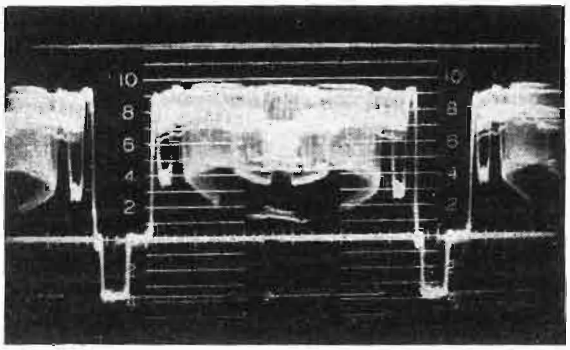


Fig. 3. CRO photograph of H presentation.

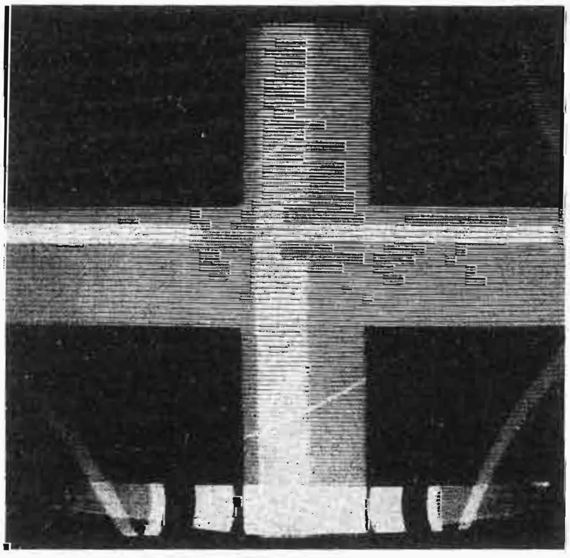


Fig. 4. Photograph of pulse cross display.

the use of a video sweep generator and without the use of pedestal synchronizing pulses. The dc level shall be set for midcharacteristic operation.

The use of a sideband analyzer provides both for this measurement plus considerable additional information helpful in assessing plant performance and preventative maintenance needs. The diode measurement can be checked against the double sideband display and discrepancies due to phase errors and equipment nonlinearities easily discerned.

Field Strength or Voltage of Upper and Lower Sidebands

Section 73.687(a)(3) states that the field strength or voltage of the upper and lower sidebands is to be measured for modulation frequencies from 200 kHz to 5 MHz for the lower sideband and from 200 kHz to 8 MHz for the upper sideband. It should be noted at this time that the rules require measurements of spurious emissions removed in frequency in excess of 3 MHz above or below the respective channel edge as per Section 73.687(a)(1) and these measurements can often be performed at the same time as the upper and lower sideband measurements. In that it may be extremely difficult to make actual field-strength measurements to obtain the above data reliably, it is noted in the rules that measurements made using a probe in the transmission line feeding a dummy load will be accepted. In the measurement of the upper and lower sidebands, it is imperative that the input to the transmitter be held constant throughout the measurement. The detector for this measurement can be an accurately calibrated field-strength meter or a receiver system utilizing a substitution signal generator for calibration. In either case care must be taken to ensure that the field-strength meter or the receiver has a passband characteristic sufficiently narrow to allow only the sideband being measured to register. This is particularly important when the 200 kHz component is being sampled, for this is the reference for the entire measurement. The upper and lower sideband measurement can also be made using a sideband analyzer, but if this is done, great care must be taken to calibrate the device for amplitude linearity. The analyzer is not a perfectly linear device, and if it is used for this measurement, the use of calibrated attenuators is required to obtain the accuracy of measurement desired. The receiver or field-strength meter provides a much more rigorous proof of performance than the analyzer, but the analyzer is most helpful in making a rough check of the system prior to precise measurements.

Throughout the measurement of the upper and lower sidebands the transmitter is adjusted to operate at midcharacteristic and the output is monitored to ensure that 0.75 peak output voltage is never exceeded. Ideally there should be an oscilloscope bridged across the input to the transmitter to monitor the input level at a constant voltage and a demodulator and a modulation monitor on the output to make sure that the modulation limits are not exceeded.

During the setup for this measurement special attention should be paid to the frequencies of minus 1.25, minus 3.58, minus 4.25, plus 4.75, and plus 7.75 MHz. These frequencies are the boundaries of the sideband characteristics (−1.25 and +4.75 MHz down 20 dB), lower sideband of the color subcarrier (−3.58 MHz down 42 dB) as per Sections 73.687(a)(3); 73.699, Fig. 5a, and out-of-band radiation beyond 3 MHz above and below the assigned band edges (−4.25 and

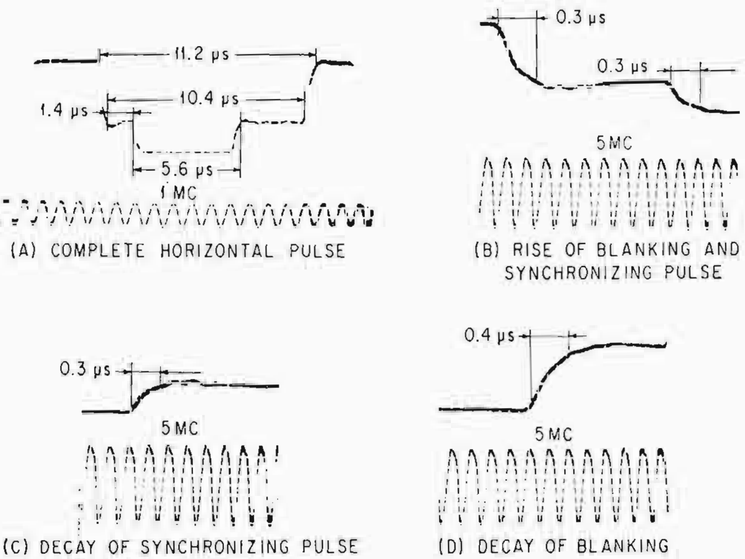


Fig. 5. Waveform showing horizontal synchronizing pulse timing.

+7.75 MHz 60 dB below the peak power) see Section 73.687(i)(1). The region beyond minus 4.25 and plus 7.75 MHz should then be checked to ascertain that there are no spurious signals in these regions. This out-of-band measurement can also be made by applying test-pattern modulation to the transmitter and searching the out-of-band region with the receiver or field-strength meter used above.

Method of Measurement

It is recommended that the sideband characteristic of a visual transmitter be measured by the application of a modulating signal to the input terminals of the transmitter in place of the normal composite television video signal. The signal applied shall be a composite signal consisting of the normal television synchronizing pulses plus a variable-frequency sine wave occupying the intervals between at an amplitude of 0.45 of the voltage of the synchronizing pulse peaks. The amplitude of the applied sine wave shall be maintained at a constant value such that at no modulation frequency does the maximum peak of the sine wave exceed 0.75 of the peak output voltage. The amplitude of the upper 200-kHz sideband when using a 200-kHz modulating frequency shall be measured by means of a field-strength meter or equivalent and used as the reference level. The modulating frequency shall then be varied over the range from 200 kHz to 8 MHz, and the corresponding amplitudes of the upper and lower sidebands measured.

As an alternate method of measuring in those cases in which automatic dc insertion can be replaced by manual control, the above characteristics can be taken by the use of a signal generator and without the use of blanking and synchronizing pulses. The transmitter operating level shall be set for midcharacteristic operation −0.50 of the voltage corresponding to synchronizing peak.

Out-of-band Emissions

Section 73.687(i)(1) states that "all emissions removed in frequency in excess of 3 MHz above or below the respective channel edge shall be attenuated no less than 60 dB below the visual transmitted power." The measurements described above determine the voltage of the upper and lower sidebands and not the relationship of these values to the transmitter peak power. To relate measurements of this type to the transmitter peak power for the purpose of determining compliance with the out-of-band requirements, additional calculations are required. It is necessary to (1) add an additional 6 dB to the measured value to cover the case of one sideband of a 100 percent modulated amplitude-modulation system, (2) add 3.5 dB to compensate for the modulation index of 75-15/90, and (3) add 6.9 dB to correct for the fact that the axis of the modulation is at a point equal to 45 percent of carrier peak and not at carrier peak. Thus, the emission below peak transmitted power is determined by establishing the voltage level below the 200-kHz point (assuming that it is the maximum point) as above and adding to that value a correction of 16.4 dB to relate this figure to emission below the peak transmitted power.

Attenuation of RF Harmonics

The out-of-band emissions requirements also cover radio-frequency harmonics for both aural and visual transmitters. It is specified that these shall be as low as the state-of-the-art permits and in no case attenuated less than 60 dB below the visual peak transmitted power. There are a number of methods that can be used to measure the level of the radio-frequency harmonics, and the simplest is the use of a field-strength meter that has sufficient selectivity and rejection of the fundamental to allow accurate measurements. It is also possible to use a fundamental rejection filter with a field strength meter that does not have sufficient isolation at the fundamental frequency. A second method which can be used is the substitution method wherein a calibrated receiver, fundamental rejection filter and a substitution signal generator are used to simulate a calibrated field-strength meter. A third method utilizes rejection notch filters, heterodyning oscillators, IF amplifier, and a detector. Any of the above systems are acceptable to the FCC provided sufficient data are included with the measurement to attest to the accuracy of the method used.

In all cases the harmonic measurements should be made in the transmission line following the harmonic filters, if used. Measurements are not required beyond 1,000 MHz for transmitters on Channels 2 to 13 or beyond 3,000 MHz for Channels 14 to 83.

TRANSMITTED SIGNAL WAVEFORM

Transmission standards for the transmitted signal waveform are fully detailed in Sections 73.687(a)(7) and (8); 73.682(a)(5) and (6); 73.699 (Figs. 5, 5a, 6 and 7) of the rules as shown in Figs. 2a and 2b. Section II-C-9-b of Form 302 requests an exhibit demonstrating conformance to these standards. It also notes that "Until the form of these measurements may be specified by the Commission, the character of this data is left to the discretion of the applicant."

As in all other data required, the burden of proof is on the applicant. The FCC has accepted many different presentations covering this proof

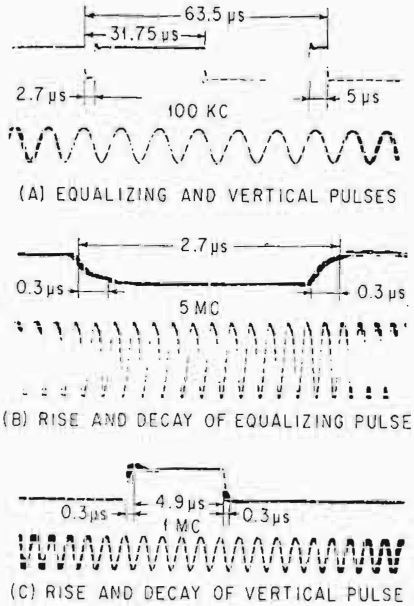


Fig. 6. Waveform showing vertical synchronizing pulse timing.

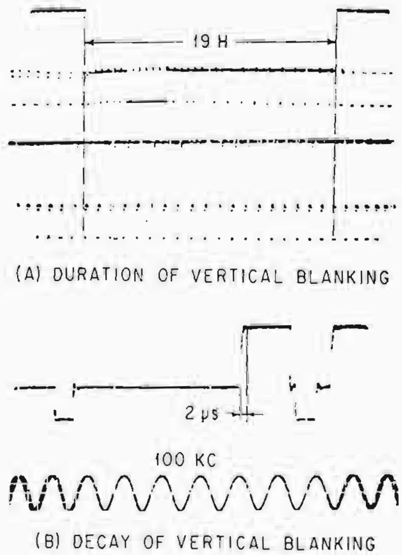


Fig. 7. Waveform showing vertical blanking pulse timing.

of conformity to the rules, but not all of them are of the type that gives definite information. It has been thought by some that the submission of a waveform or pulse-cross photograph (Figs. 3 and 4) taken from the CRO fed by the station demodulator will suffice to show conformity to the transmitted-waveform requirement. A careful check of the resolution possible in such a photograph and an analysis of the technique involved show that the errors possible in interpreting such a display are far greater than the tolerances allowed in the rules.

A simple and straightforward method of preparing such an exhibit is simply to extend the normal maintenance techniques for the sync generator. Measure all the pertinent waveforms accurately on an oscilloscope having the facility for the addition of timing pulses and having sufficient rise time, magnification, and line-selection ability to show individually the section of the signal being studied (Figs. 5 through 7).

Since the source of the synchronizing waveform is the main studio generator, the first part of this test should carefully measure the signals as they arrive at the transmitting plant. This is a normal maintenance procedure of the television plant and checks out not only the alignment of the sync generator but the processing and distribution amplifiers that may be used in the master control location and the studio-to-transmitter circuit. After it has been determined that the sync signal arriving at the transmitter plant is "standard" it is fed to the transmitter. The transmitted characteristics can then be measured using a probe in the output transmission line to the antenna or the dummy load feeding a calibrated demodulator and oscilloscope. An example of this technique and a method of reporting the measurement are shown in the sample "proof" below.

Transmitted Test Pattern

Section II-C-9-c of Form 302 requests that an exhibit be prepared containing a photograph of the transmitted test pattern from a receiver or a monitor connected to the transmitter output. This is a straightforward task easily accomplished. The addition of one other photograph, that of the test pattern signal that is fed to the input of the transmitter, will add a wealth of information to the "proof." A comparison of the "in" and the "out" can then be made to see if any degradation in the "out" test pattern is caused by the transmitter or is present in the incoming signal.

For color transmission there are a number of measurements required that are not listed on Form 302 but are noted in FCC mimeographs and detailed in Sections 73.687(a)(5) and (9); 73.682 (a)(5) of the rules. Conformity to the color-transmission standards requires measurements of transfer characteristic, differential gain, differential phase, and envelope delay as well as all the previously measured transmission characteristics.

Transfer Characteristic

Low-frequency linearity and differential gain is defined in Section 73.687(a)(9) of the rules as the transmitter transfer characteristic and can be measured rather simply. The rules state that the transfer characteristic shall be substantially linear and assigns no values to the degree of linearity. It behooves the color broadcaster to maintain maximum linearity for faithful color transmission. Extreme variations in linearity will also affect the fidelity of the monochrome transmissions. A stairstep generator is the simplest tool for this type of measurement. This unit along with a high-pass filter and an oscilloscope will allow accurate measurements of linearity or transfer characteristics to be made in very short order. Such a measurement is described below in the sample "proof." Once again it is advisable, while making this measurement on the transmitter system, to make a similar measurement on the overall studio-transmitter system for the information of the technical staff. Submission of this extra data is not required, but it allows a check to be made to ensure that there is no predistortion of linearity being used to compensate for the deficiencies of one or more elements of the transmitter plant.

Low-frequency Linearity

Low-frequency linearity is defined as that characteristic which describes the change in RF output signal amplitude resulting from and corresponding to a change in input signal amplitude. No FCC specification is given, but it is advisable as a minimum standard to keep the linearity within 1.5 dB for 10, 50 or 90 percent average picture level when using a stairstep signal having 10 steps of equal amplitude covering the reference-white to blanking-level region.

Method of Measurement

The visual transmitter shall be fed a composite signal consisting of synchronizing pulses and a stairstep signal having at least 10 steps of equal amplitude. The test signal shall be sufficient to modulate the visual transmitter to reference white while maintaining rated blanking level and rated visual transmitter output power. With the use of a linear display monitor of the RF signal or of the RF envelope, the amplitudes of the different steps are compared using the greatest amplitude step as the reference. The linearity will be the ratio, expressed in decibels, of the amplitude of the tallest step to the amplitude of the shortest.

Differential Gain

Differential gain is the difference in gain of the system for a small high-frequency sine-wave signal at two stated levels of a low-frequency signal upon which it is superimposed. With no specific FCC specification, but interpreting the color-signal specification in Sections 73.682 (a)(20), 73.699 (Fig. 8) of the rules. It is advisable that the differential gain be maintained below 1.5 dB for 10, 50, and 90 percent average picture levels.

Method of Measurement

The visual transmitter shall be fed a composite signal consisting of synchronizing pulses and a low-frequency signal with a superimposed 3.58 MHz sine-wave signal whose peak-to-peak amplitude is 20 percent of the low-frequency signal amplitude between blanking and reference white. This composite test signal shall be sufficient to modulate the visual transmitter to reference white while maintaining rated blanking level and rated visual transmitter output power. With the use of a linear demodulator, the visual transmitter output is sampled, detected, and passed through a high-pass filter to an oscilloscope or any other suitable means of observing the 3.58-MHz component of the test signal. Any deviation from a constant amplitude display of the 3.58-MHz signal when viewed at the line-rate frequency is the differential-gain variation. The differential gain at any point is the ratio, expressed in decibels, of the amplitude of the maximum amplitude region referred to the amplitude of the point under consideration.

Differential Phase

Conformity with Section 73.682(a)(20) regarding color-signal specifications can be further assured by a measurement of differential phase. Differential phase is the difference in phase shift through the system for a small high-frequency sine-wave signal at two stated levels of a low-frequency signal on which it is superimposed. When interpreting these color standards, it is advisable to adjust the station equipment so that the differential phase shall be less than 7° at 3.58 MHz when the reference burst region of a 50 percent average picture level signal is used as reference. In addition, the total differential phase between any two levels shall not exceed 10°.

Method of Measurement

The visual transmitter shall be fed a composite signal consisting of synchronizing pulses and a low-frequency signal with a superimposed 3.58-MHz sine-wave signal whose peak-to-peak amplitude is 20 percent of the low-frequency-signal amplitude between blanking and reference white. This composite test signal shall be sufficient to modulate the visual transmitter to reference white while maintaining rated blanking level and rated visual transmitter output power. With the use of a diode demodulator, the visual transmitter output is sampled, detected, and passed to any suitable phase-measuring equipment. The differential phase error is the difference in phase of the 3.58-MHz wave between the burst region of the composite signal and any other level under consideration.

If the station is capable of generating local color signals and has a color-bar generator and Vectorscope, compliance with the color-signal specifications can be proved by a measurement of the phase and amplitude of the transmitted color bar, I and Q signals.

Although color specifications are under Transmission Standards in the rules and not specifically listed as a transmitter characteristic, it is usually satisfactory to make these measurements at the transmitter plant. The same measurements should, however, be made from the studio plant to ensure that the transmission of color signals will be proper under the normal program routing. If it can be done, these measurements should be made from the main studio, checking the entire system for conformity to the transmission standards as the synchronizing waveforms were checked above.

As an added reminder, care must be taken during all the above measurements to assure that the transmitter and all the input equipment in the transmitting plant and in the component links between the studio and the transmitter are operating at their normal settings. The input to the transmitter modulator should be adjusted for the normal program excursions, and the output signal as viewed from the station demodulator should indicate that there is no overloading of the circuits. In brief, normal conditions should prevail.

Envelope-Delay

At this writing, the only practical method of making envelope-delay measurements is through the use of a device known as an envelope-delay measuring set. This measurement is outlined briefly in the sample "proof" below and more fully in the instructions for the use of the instrument. There are instruments presently under development which will provide simpler methods of making this measurement, and industry committees are at work attempting to develop simple coincidence checks to ascertain compliance with the requirements of Section 73.687(a)(5) of the rules. Graphical analysis of square-wave measurements can be used in making this check, but it is an extremely time-consuming effort, requiring a host of accurate measurements and resulting in answers whose possible errors may exceed the tolerances allowed in the rules.

If equipment to measure the envelope-delay characteristics of the transmitter is not available, reference can be made to the fact that the envelope-delay correction filters installed for the particular transmitter have been designed and adjusted by the manufacturer to provide the proper overall envelope-delay characteristic. The approximate accuracy of this adjustment can be checked by observing the fidelity of a color-bar test signal and also by checking a square-wave signal for equality of "ringing" before and following a transition when the signal is observed through an ideal demodulator. Even though the envelope-delay-correction filters are passive, an attempt should be made at the earliest opportunity to make an actual measurement of the overall system to ensure that the proper predistortion and correction are being made. It is hoped that new devices for this measurement will be available shortly.

Envelope-delay is the first derivative of the phase vs. angular velocity characteristic at a particular frequency. In essence it is a measure of the coincidence of arrival of chrominance and luminance information and, per the FCC specifications, the predistortion introduced to produce this coincidence in a color receiver.

Method of Measurement

Envelope-delay measurements shall be made with commercial envelope-delay-measuring equipment under the same operating conditions as described above for overall attenuation measurements. The RF diode can be used for measurements above 1.25 MHz. (Further information is given in the sample "proof" below.)

It must be kept in mind here, as above, that even though the specifications in the rules are for the transmitter, the envelope delay in the entire studio and link system should be kept within the FCC tolerances in order to provide the highest fidelity of color transmission within the specifications of the NTSC system. For the benefit of the station the envelope delay of this entire system should be measured periodically as both a maintenance tool and a proof of performance.

Section II-C-10 of Form 302 requests exhibits describing fully measurements of performance of the aural system including "all circuits between the main studio microphone terminals and the antenna output, including telephone lines pre-emphasis circuits and any equalizers employed except for microphones, and without compression if a compression amplifier is installed." Sections 73.687(b)(1), (2), (3), (4), (5), (6), (7) list the operational characteristics required of the system and further recommend that none of the three main divisions of the system (transmitter, studio-to-transmitter circuit, and audio facilities) shall and further recommend that none of the three main divisions of the system (transmitter, studio-to-transmitter circuit, and audio facilities) shall contribute more than half of the allowable total degradation for the entire system. This requires that not only the system as a whole be measured but that measurements be made separately on each of the three main divisions.

Audio-frequency Response

The measurement of the audio-frequency response of the aural system is a straightforward type of measurement but requires modifications of the usual "amplifier" testing techniques to truly measure the performance of the aural transmission system. Since there is a difference in peak voltages reached by pure sine-wave and normal program signals for equivalent volume-indicator readings, adjustments of the input level of the test signals should be made to compensate for this difference. One method is to use an "elevated" level 10 dB above normal (-50 dBm at microphone input) to simulate 100 percent modulation. This technique will measure the frequency response for normal program transmission and not simply the response of the system to sine waves. The detailed procedure for this measurement is described in the sample "proof" below.

Distortion

System distortion should be measured with the same setup used for the frequency-response measurement above to save time and minimize setup errors.

FM and AM Noise

Frequency-modulation noise on the carrier is the residual frequency modulation resulting from disturbances produced in the transmitter itself within the band of 50 to 15,000 Hz. The level is expressed as the ratio of the residual frequency swing in the absence of modulation to the full-frequency swing with modulation as weighted by the effect of a standard 75-μ sec deemphasis circuit. FM-noise-level measurements can be made with the distortion-measurement equipment used for the above measurement.

Method of Measurement

The frequency-modulation noise level can be obtained by demodulating a sample of RF output of the transmitter and comparing the rms voltage developed by the demodulator in the absence of modulation voltage to the rms voltage obtained with 100 percent, 400 Hz modulation. The audio input terminals of the transmitter shall be shunted by a resistance equal to the transmitter input impedance. The frequency-response characteristic of the demodulator shall be within ± 1 dB of the standard 75-μ sec deemphasis curve from 50 to 15,000 Hz.

The amplitude-modulation noise level on an aural transmitter carrier is the ratio of the rms value of the amplitude-modulation components (50 to 15,000 Hz) of the carrier envelope to the rms carrier value in the absence of applied modulating voltage.

Measurement of the carrier amplitude-modulation noise level can be accomplished by the use of a linear peak-carrier-responsive AM detector with 75-μ sec deemphasis coupled to the output of a transmitter. Readings are made of the dc voltage and the rms value of the ac component across the detector load resistor. The dc voltage must be multiplied by 0.707. These measurements shall be made in the absence of modulating voltage. The audio input terminals of the transmitter shall be shunted by a resistance equal to the transmitter input impedance. Equipment for this measurement is commercially available or can be assembled by the station.

In all cases, the equipment used for any of the measurements should be identified by manufacturer, type, and serial number, and if composite, a general description of the device should be included in the "proof."

THE PROOF-OF-PERFORMANCE

Herein follows a composite sample "proof" made up from six "proofs." A composite of these "proofs" was chosen rather than a sample of one "proof" in order to illustrate as comprehensively as possible the method of proving performance.

(SAMPLE PROOF-OF-PERFORMANCE)

STATION CALL, CITY

AURAL AND VISUAL
PERFORMANCE MEASUREMENTS

REPORT (NUMBER)

(DATE)

(EXAMPLE)

STATE OF — — —
SS:
COUNTY OF — — —

(include here qualifications of
engineer making measurements)

Subscribed and sworn to before
me this — — — day of — — — (Notary)

(Note: Affidavit not required if engineer performing or directing measurements signs Form 302, Section II, page 2, attesting to validity of measurements.)

SUMMARY

This report details aural and visual performance measurements made at television station (call), (city), (state), following the installation of ______ in accordance with Television Broadcast Station Constructing Permit ______________, dated____________. The measurements reported herein are submitted as engineering exhibits associated with application for television broadcast station license for station (call), and establish that the (call) transmitter and studio equipments are operating in full conformity with the Rules and Regulations as established by the Federal Communications Commission and in effect as of this date.

INTRODUCTION

In association with Section II of subject application for license this exhibit answers fully all questions pertaining to the operation and technical performance of (call). All of the measurements reported herein were made on the complete transmitting plant and reflect the true and normal operation of television Station (call) for the effective radiated power specified in Construction Permit ______, dated ___________. Construction authorized by this permit was begun on ____________ and was completed on ___________. In addition to the measurements specified in Form 302 additional measurements have been made to ensure that the entire plant meets the more rigid requirements for color transmission and they are described herein.

TRANSMITTER POWER-OUTPUT DETERMINATION (SECTION C-5)—(EXAMPLE)

The power output of both the visual and aural transmitters was measured by the use of a calibrated dummy-load wattmeter, the impedance of which was measured and found to be substantially equivalent to the transmitting-antenna system impedance. Impedance measurements of the dummy-load wattmeter and the antenna system were made with a General Radio Type 1602-A admittance meter to establish that the impedance of the antenna system was equivalent to that of the dummy load wattmeter for power-determination purposes. The VSWR of the dummy load was found to be less than 1.05 in a 51.5-ohm line over the 54-to 60-MHz band, and the antenna system VSWR was 1.11 or less over the 54- to 60-MHz band as shown in Fig. P-1. The wattmeter

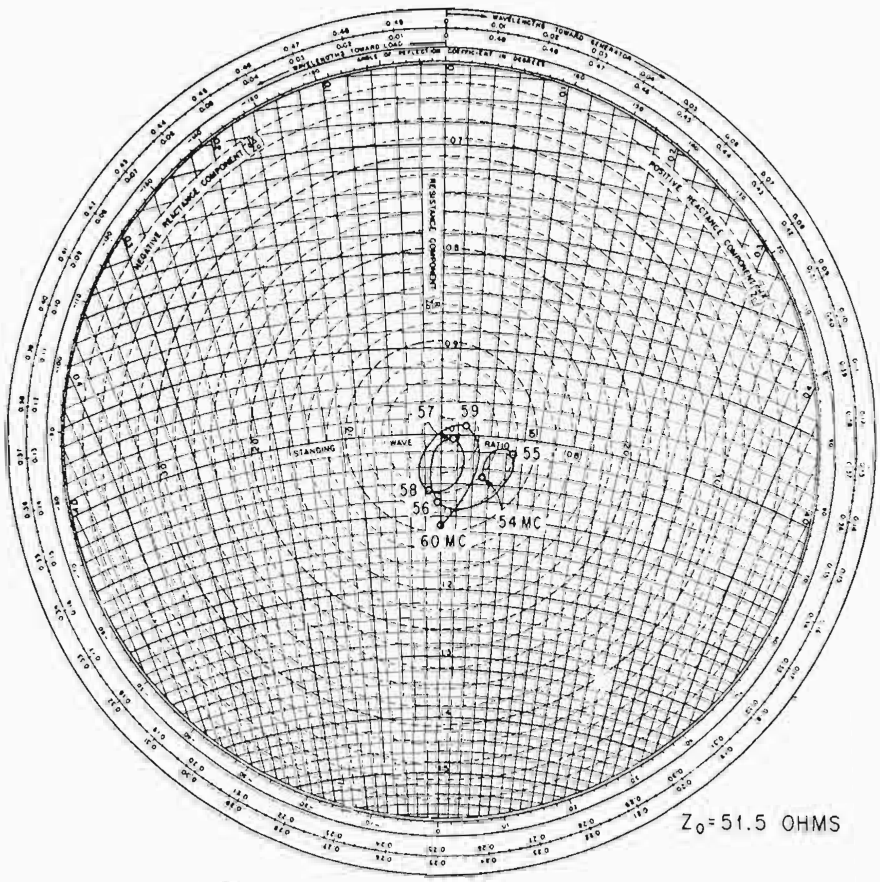


Fig. P-1. Measured impedance of antenna at diplexer input.

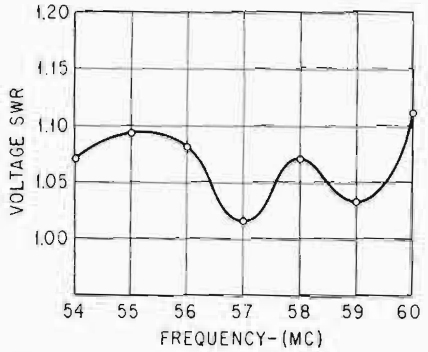


Fig. P-2. Voltage standing-wave ratio of antenna and transmission line.

(General Electric Co. Model 19193) contains a calibrated voltmeter which reads average power directly. The visual transmitter is equipped with a peak-reading voltmeter coupled to the output transmission line as well as a reflectometer which indicates the forward and reverse voltage in the transmission line. The aural transmitter also contains a reflectometer unit for the measurements of forward and reverse voltage in the output transmission line. Fig. P-2 shows the voltage standing-wave ratio of the antenna system and transmission lines. This figure was obtained from the data plotted in Fig. P-1.

In measuring the power output of the visual transmitter, the output of the transmitter vestigial sideband filter was connected directly to the dummy-load wattmeter. The transmitter was then modulated with an all-black picture and the standard 25 percent sync. The average power was read on the wattmeter indicator, and the peak power (power during sync pulse) was obtained by multiplying the average power by a factor of 1.68. Reflectometer readings were noted for several adjustments of transmitter power output, and a graph of the relationship was prepared. This graph is presented in Fig. P-3 and serves as a calibration of transmitter peak power output during normal operation.

The power output of the aural transmitter was measured by connecting the transmitter output

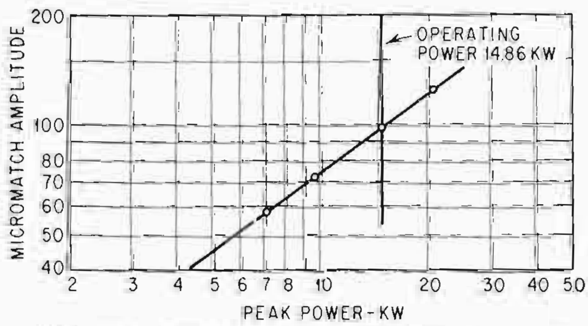


Fig. P-3. Reflectometer calibration in visual transmitter.

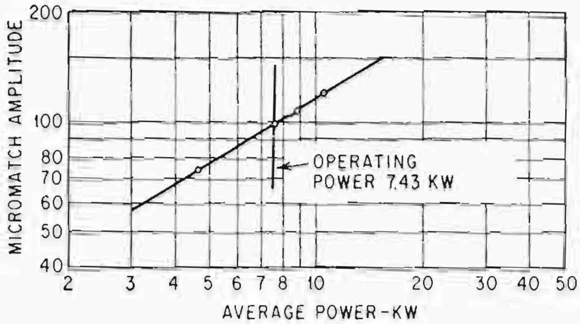


Fig. P-4. Reflectometer calibration in aural transmitter.

directly to the dummy-load wattmeter, described above. The efficiency factor F was determined from this measurement and used in completing paragraph II-C-5 of FCC Form 302. The transmitter was adjusted for a number of different operating levels, and the average power was read directly from the indicating meter of the dummy-load wattmeter. A plot of the transmitter output vs. aural reflectometer reading is presented as Fig. P-4. Thus calibrated, the reflectometer reading serves as an indication of transmitter output power during normal operation.

The (call) antenna system has a VSWR of 1.11 or less over the 54- to 60-MHz band. This means that the reflection coefficient is less than 0.052 and that the power reflected from the antenna system is less than $(0.052)^2$, or 0.27 percent of the power reaching the antenna. Therefore, the reflectometer and peak-reading voltmeter give a true measure of the power entering the antenna system.

After the measurements described above had been made, the visual transmitter was adjusted to give a peak output power of 11.7 dBk (14.8 kw) at the output of the diplexer. The power gain of the antenna system is 5.65 dB at visual frequency, and the transmission-line efficiency is 86 percent, representing a loss of 0.67 dB. The diplexer being a hybrid device has a negligible loss and, accordingly, this combination results in an effective radiated power of 16.7 dBk (46.8 kw) as specified in the construction permit.

The aural transmitter was adjusted for an output of 8.7 dBk (7.4 kw) average power with an antenna gain of 5.65 dB and a transmission-line efficiency of 86 percent, representing a loss of 0.67 dB, thus giving an effective radiated power of 13.7 dBk (23.4 kw).

ANTENNA AND TRANSMISSION LINE (SECTION II-C-6) — (EXAMPLE)

There are complete regular and auxiliary transmitting facilities at the (call) plant as well as complete regular and auxiliary antenna and transmission lines. Either transmitter can be fed

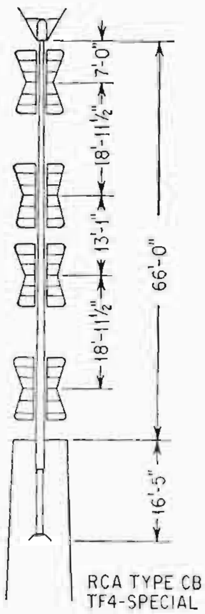


Fig. P-5. Transmitting antenna (designed for null fill-in).

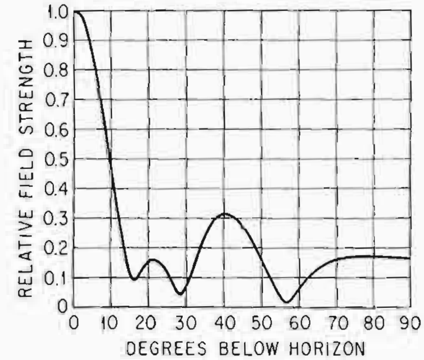


Fig. P-6. Calculated vertical radiation pattern.

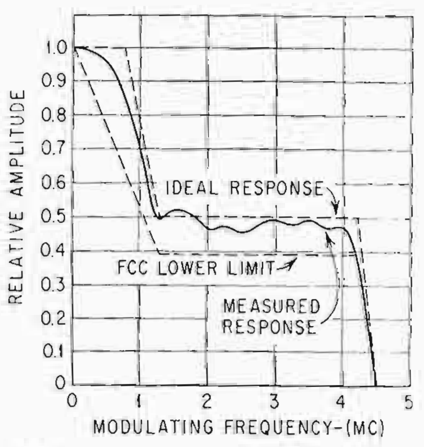


Fig. P-7. Over-all attenuation vs. frequency of visual transmitter (as measured with a diode on the RF transmission line).

to either antenna by means of a patch panel. The auxiliary antenna and transmission line are described in the application for construction permit (File No. and date)

The regular transmitting antenna is an RCA Type CB-TF4-special. The essential mechanical details of this antenna are shown in Fig. P-5. This antenna is designed for null fill-in, and the calculated vertical-radiation pattern is shown in Fig. P-6.

FREQUENCY MONITORS (SECTION II-C-8) — (EXAMPLE)

In addition to regular readings of the station visual and aural frequencies made on the station monitors, measurements have been made by (Name) Measurements Company, (Address), (City), (State), for the purpose of adjusting the station monitors, with the following results:

Transmitter	T & T Radio Measurements Company, measurement cycles	Station monitor measurement cycles
Visual	55,250,040	55,250,100
Aural	59,750,060	59,750,100
Visual	55,250,030	55,250,000
Aural	55,750,050	59,750,050

The assigned frequency is 55,250,000 Hz for the visual transmitter and 59,750,000 cycles for the aural transmitter.

PERFORMANCE DATA-VISUAL TRANSMITTER (SECTION II-C-9) VARIATION OF OUTPUT—(EXAMPLE)

The peak-to-peak variation of transmitter output within one frame of the video signal was measured while the transmitter was being fed with a 60-Hz sine wave and standard synchronizing signals and was found to be 4 percent of the average sync peak amplitude.

OVERALL ATTENUATION VERSUS FREQUENCY (SECTION II-C-9-a-1) — (EXAMPLE)

Fig. P-7 is a plot of the measured overall attenuation versus modulation frequencies from 0 to 5 MHz. These data were obtained by feeding the transmitter input system (containing all corrective equipment required to meet the FCC rules and regulations) with a video sweep signal with the transmitter operating at midcharacteristic, and observing the output of a diode coupled to the RF transmission line feeding the antenna system. This plot was prepared by taking data from the CRT of a Tektronix Type 524-D oscilloscope using inserted single-frequency marker signals for

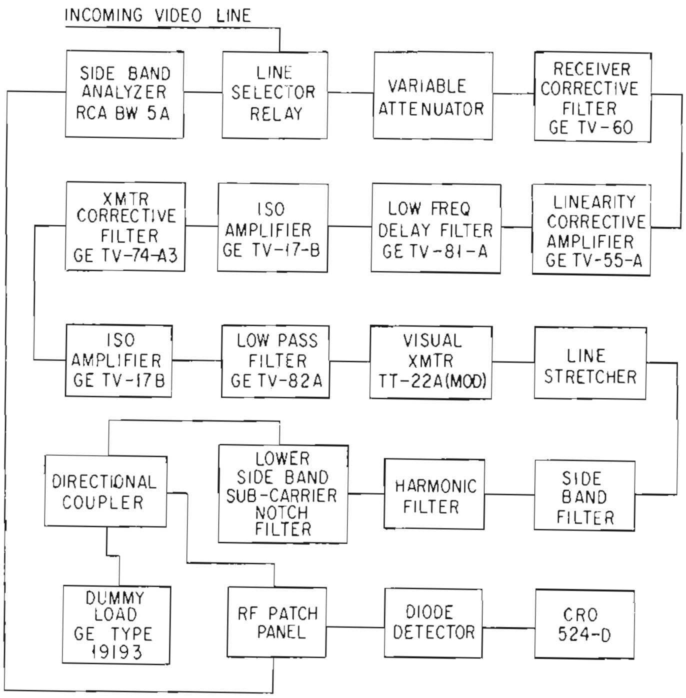


Fig. P-8. Block diagram for over-all attenuation measurements.

frequency determinations. Fig. P-8 is a block diagram of the equipment setup used in making these measurements.

FIELD STRENGTH OR VOLTAGE OF UPPER AND LOWER SIDEBANDS (SECTION II-C-9-a-2) — (EXAMPLE)

Fig. P-9 is a plot of the relative voltage amplitude of the (call) transmitter upper and lower sidebands from 5 MHz below carrier to 8 MHz.

These measurements were all made at the output of the transmitter which was connected to the dummy load. The measuring equipment was set up as shown in Fig. P-10. The field-strength meter was tuned successively to the upper and lower sideband for each modulating frequency used, the input being held constant at all frequencies, and the amplitude was recorded. As shown by Fig. P-9 the attenuation of the upper and lower sidebands of the (call) transmitter fully meets the Commission's Rules concerning the relative levels of upper and lower sidebands also shown on Fig. P-9.

OUT-OF-BAND EMISSIONS—(EXAMPLE)

Section 73.687(i) of the rules states that "all emissions removed in frequency in excess of 3 MHz above or below the respective channel edge shall be attenuated no less than 60 dB below the visual transmitter power." As shown in Fig. P-9 the voltage amplitude for a frequency 4.25 MHz below carrier, relative to a 200 kHz reference, is 57.8 dB down. To relate this measured value to the actual emission, relative to visual transmitted peak power, it is necessary to (1) add an additional 6 dB for the case of one sideband of a 100 percent modulated amplitude-modulation system, (2) add 3.5 dB to compensate for the modulation index of 75-15/90, and (3) add 6.9 dB to correct for the fact that the axis of the modulation is at a point equal to 45 percent of carrier peak and not at carrier peak. Thus, the emission

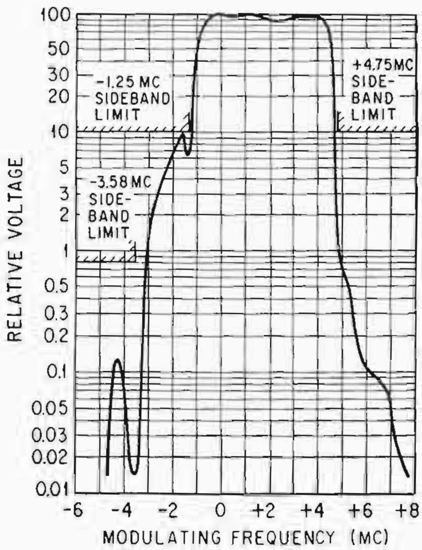


Fig. P-9. Measured voltage amplitude of upper and lower sidebands.

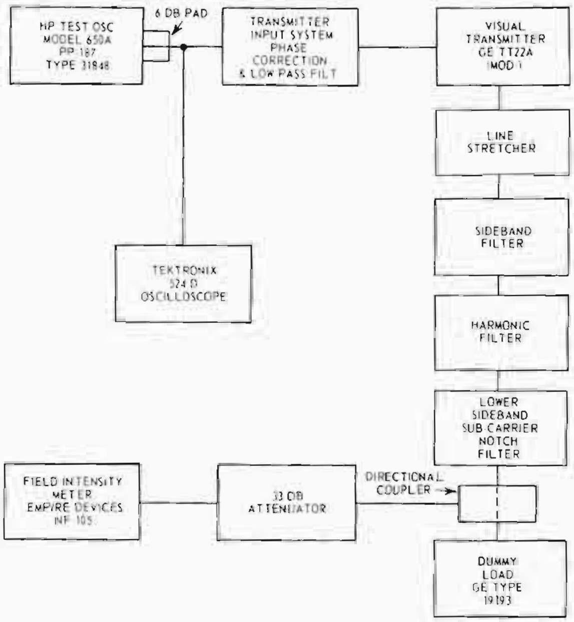


Fig. P-10. Block diagram of equipment used for measuring voltage of upper and lower sidebands.

at −4.25 MHz is at least 57.8 dB + 6 dB + 3.5 dB + 6.9 dB = 74.2 dB below visual transmitted peak power.

In the case of the upper-band-edge requirement, Fig. P-9 shows a measured value of −77.2 dB for a frequency 7.75 MHz above visual carrier. Adding the correction factors, as above, the emission is 77.2 dB + 6 dB + 3.5 dB + 6.9 dB = 93.6 dB below transmitted peak power.

ATTENUATION OF RF HARMONICS — (EXAMPLE)

Fig. P-11 shows the equipment setup that was used for the measurement of the attenuation of RF harmonics in the output of the aural and visual transmitters.

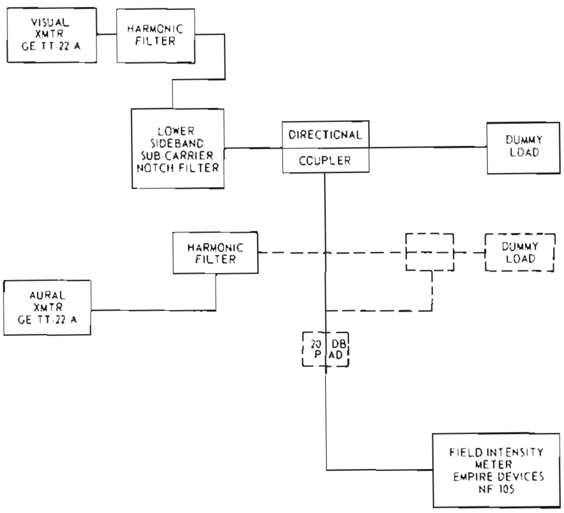


Fig. P-11. Block diagram of equipment used to measure attenuation of RF harmonics.

Using the equipment shown in Fig. P-11, measurements were made of the attenuation of the aural and visual harmonics with the transmitters feeding a General Electric Type 19193 dummy load. A directional coupler was used to probe the transmission line in these measurements. The variations of output voltage versus frequency of this coupler were compensated for during these measurements. The results of these measurements are shown in Figs. P-12 and P-13 and prove that the harmonic attenuation of the (call) transmitters are well within the Commission's requirements.

TRANSMITTED SIGNAL WAVEFORMS (SECTION II-C-9-b) — (EXAMPLE)

The FCC Rules and Regulations specify that the transmitted waveforms shall conform to Sections 73.682(a)(5), 6; 73.687(a)(7), 8; 73.699 Fig. 2, 5, 5a, 6, and 7, as modified by vestigial sideband operation. Synchronizing and blanking pulse durations and slopes are specified, not taking into account the effects of vestigial sideband operation.

A studio camera was set up in typical fashion, but with the pedestal control adjusted to give a maximum white picture and the gain reduced to eliminate noise. This signal with sync was fed to the transmitter through the normal master control routing, and the transmitter was modulated in the normal fashion. The signal was so adjusted that blanking was 75 percent of sync and white was 10 percent of sync. An RF diode probe in the antenna transmission line was used to feed a Tektronix 524-D oscilloscope, and photographs

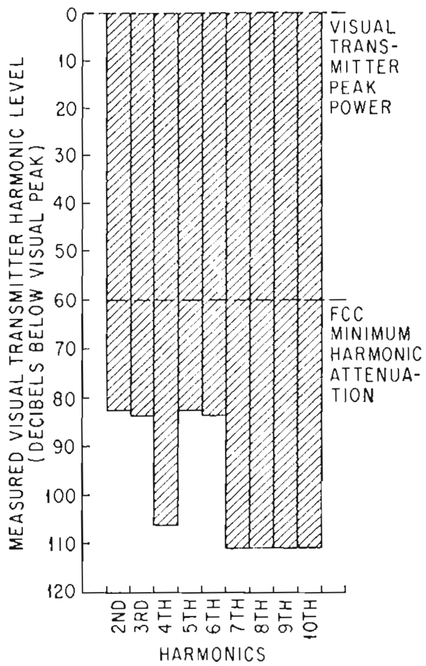


Fig. P-12. Measured visual transmission-line harmonic content.

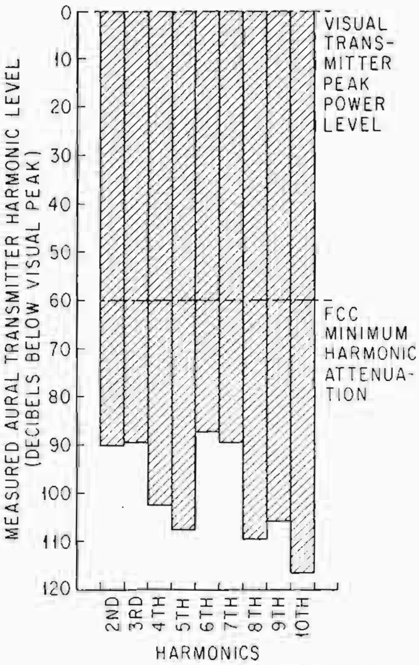


Fig. P-13. Measured aural transmission-line harmonic content.

TABLE 1
Analysis of Synchronizing Waveforms

Portion of synchronizing signal	Measured[a] times	FCC rules & regulations specifications
Duration of horizontal blanking (10% black)	11.0μsec	11.44μsec max
Duration of horizontal blanking (90% black)	10.9μsec	10.48μsec min
Duration of horizontal pulse	5.8μsec	5.08 / 4.45 μsec
Rise of horizontal pulse	0.183μsec	0.254μsec max
Decay of horizontal pulse	0.196μsec	0.254μsec max
Rise plus decay of horizontal blanking	0.62μsec	0.957μsec max
Duration of front proch	1.42μsec	1.27μsec min
Duration of equalizing pulse	2.6μsec[b]	2.54μsec
Rise of equalizing pulse	0.195μsec	0.254μsec max
Decay of equalizing pulse	0.152μsec	0.254μsec max
Rise of vertical pulse	0.21μsec	0.254μsec max
Decay of vertical pulse	0.21μsec	0.254μsec max
Duration of serration in vertical pulse	4.7μsec	3.81 / 5.08
Duration of vertical blanking	20 H	17.8 H / 20.4 H
Decay of vertical blanking	2.5μsec	6.355μsec max
Back porch from horizontal pulse to start of color burst	0.6μsec	0.381μsec min
Number of cycles in color burst	8½ Hz	8 Hz min
Rise of vertical blanking not listed but observed to be same as decay.		

[a] The measured times are for waveforms at the output of the transmitter and, therefore, include the effects of the vestigial sideband system.

[b] The area of the equalizing pulse should be 45 to 50 percent of the horizontal pulse. It was measured from the photograph to be 49 percent of the horizontal pulse.

were taken of pertinent waveforms. Timing signals were also inserted in the oscilloscope. These photographs were enlarged to a convenient size, and graphical measurements made of the pertinent durations and slopes. These data are presented in Table 1 along with the requirements of the rules. Some of the rise and decay times do not conform exactly with those specified in the rules, and these discrepancies are attributable to the vestigial-sideband operation which is known to lengthen the rise and decay times of pulses of this type. These rise and decay times of the signals fed into the transmitter system were measured and found to be within the specifications of the rules and regulations. Table 1 listed the output-waveform characteristics only.

PHOTOGRAPH OF TRANSMITTED TEXT PATTERN (SECTION II-C-9-c) — (EXAMPLE)

Fig. P-14 is a photograph of a (call) test pattern, taken from a monitor connected to the input of the visual transmitter. Fig. P-15 is a photograph

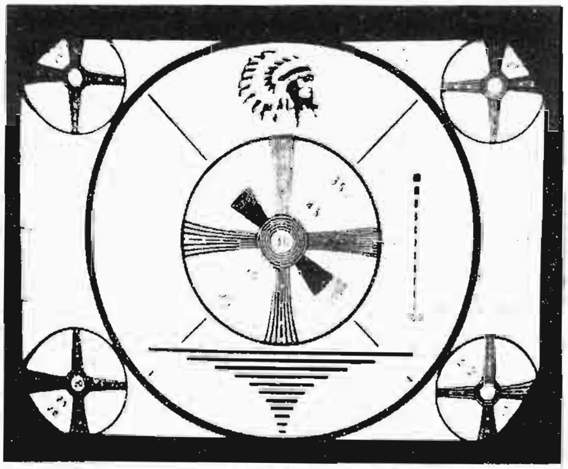


Fig. P-14. Photograph of test pattern—transmitter input.

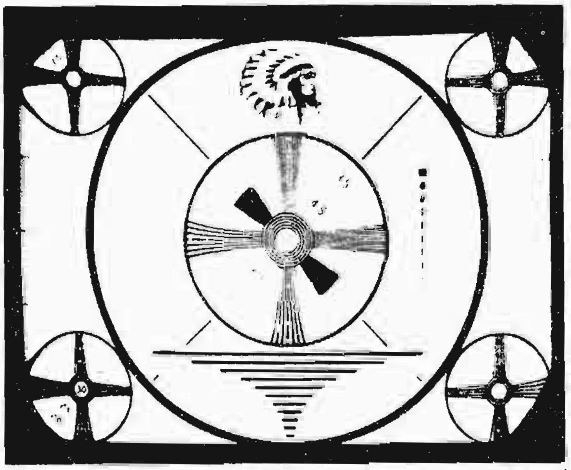


Fig. P-15. Photograph of test pattern—transmitter output.

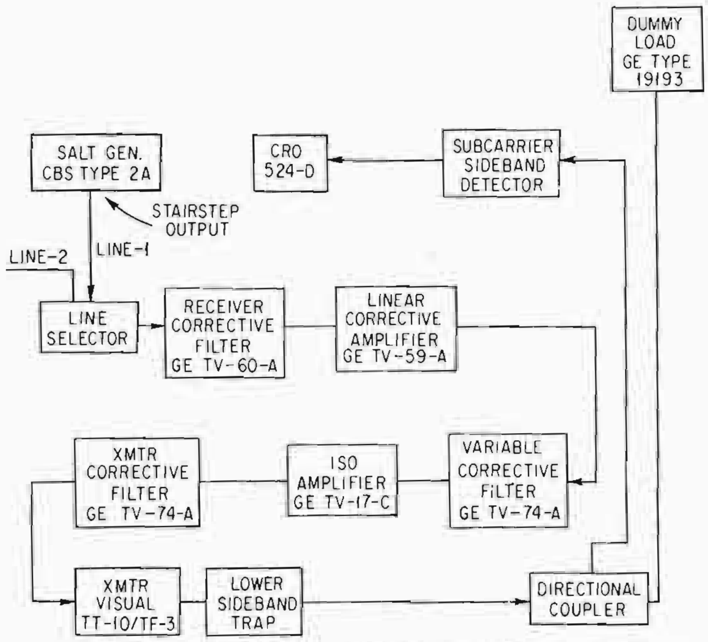


Fig. P-16. Block diagram for transfer-characteristic measurements.

of a (call) test pattern, taken from a monitor fed by the station demodulator coupled to the output transmission line feeding the dummy load.

TRANSFER CHARACTERISTICS — (EXAMPLE)

The transmitter transfer characteristic was measured using a stairstep generator and associated equipment as shown in Fig. 16. During this test, a 50 percent duty cycle was maintained, as preliminary checks showed no significant differences in transmitter transfer characteristic for the 10, 50, or 90 percent duty cycle. The results shown in Fig. P-17 indicate that the relationship between the RF output and the video signal input is substantially linear between reference-black and reference-white levels.

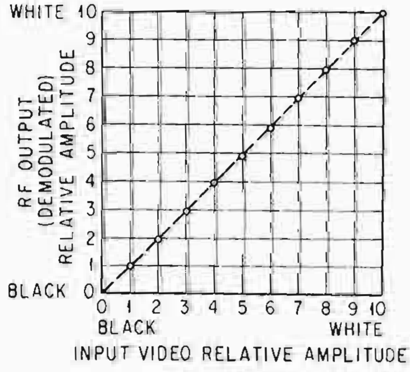


Fig. P-17. Measured transfer characteristic.

DIFFERENTIAL PHASE—(EXAMPLE)

The differential phase or phase-versus-amplitude characteristic of the transmitter was measured using a CBS-2A SALT sweep-amplitude-linearity-test generator feeding the video system input as shown on Fig. P-16. Using a stairstep signal (sync with 10 steps, each step containing a superimposed 3.58 MHz sine wave with a peak-to-peak amplitude of 20 percent of the total amplitude of the 10 steps) feeding the input system, the output of the dummy-load dirational coupler is fed into the sideband phase detector, where the "stripped" 3.58 MHz signal is "bucked out" by an external 3.58 MHz signal from the SALT generator through the use of a calibrated phase shifter. The balancing of these signals is observed on the cathode-ray tube of a Tektronix Type 524-D oscilloscope. Measurements were made at three different duty cycles, 10, 50, and 90 percent, and the maximum phase shift between the black step and the white step was measured and is as follows.

Duty cycle, %	Phase shift between steps 1 and 10 Modulator output, deg	Transmitter-output, deg
10	1.0	6.5
50	2.0	9.0
90	2.0	4.5

COLOR SIGNAL CHARACTERISTICS — (EXAMPLE)

Color-bar amplitudes and phase angles were measured at the input to the transmitter and compared with signals taken from the station demodulator connected to the output transmission line. The results, listed below, indicate that amplitudes and phase angles fall within the limit specified in the Commission's rules and regulations.

Color bars	Transmitter input		Demodulator output	
	Amplitude	Angle	Amplitude	Angle
Burst	0.40	0	0.40	0
Yellow	0.65	+1	0.62	+1
Red........	1.0	+3	1.0	+4
Magenta ...	0.98	0	0.96	+2
Q..........	0.40	−2	0.45	−2
Blue	0.65	−3	0.65	−1
I...........	0.40	0	0.45	+1
Cyan.......	1.0	+3	0.96	+4
Green......	0.98	−1	0.90	0

ENVELOPE-DELAY MEASUREMENTS — (EXAMPLE)

Fig. P-18 is a block diagram of the equipment setup used for measuring the phase envelope delay of the visual transmitter. Fig. P-19 shows the measured envelope delay and the FCC limits for color transmission.

AURAL TRANSMITTER PERFORMANCE (SECTION II-C-10) — (EXAMPLE)

Performance measurements of aural transmitters are to include a typical chain of equipment from a microphone input to transmitter output. Fig. P-20 contains a block diagram of the equipment setup and pertinent data concerning the conditions under which these performance measurements were made.

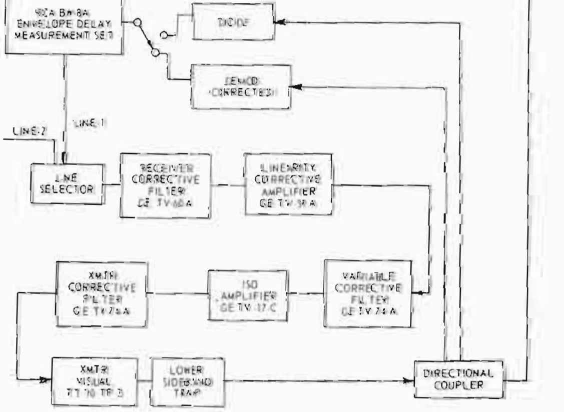


Fig. P-18. Block diagram for phase envelope-delay measurements.

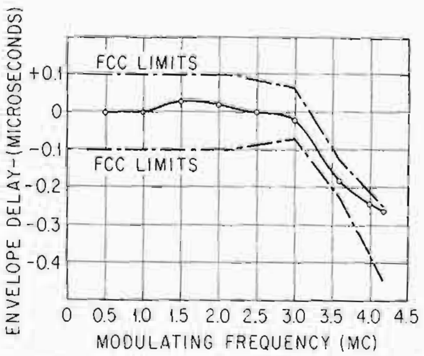


Fig. P-19. Envelope delay of radiated signal.

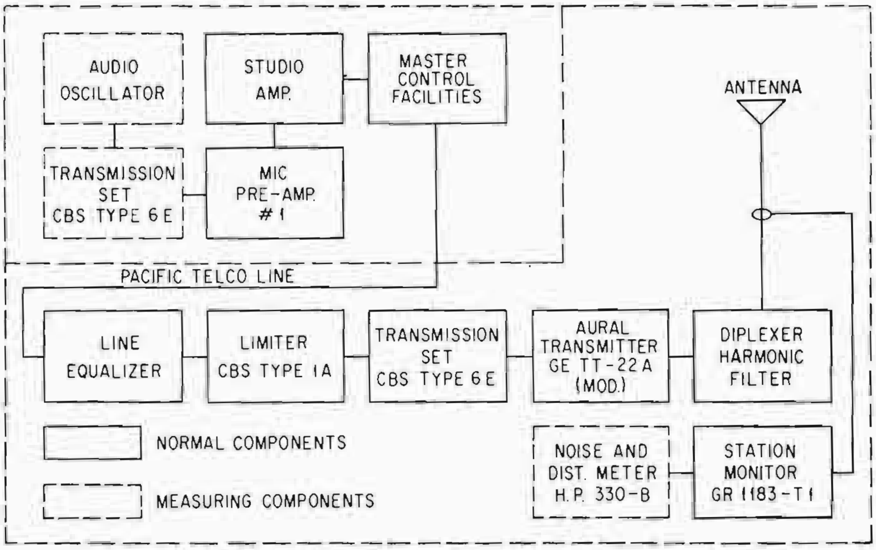
FREQUENCY RESPONSE, DISTORTION, AM AND FM NOISE (SECTION II-C-7-a, b, c, d) — (EXAMPLE)

Since there is a difference in peak voltages reached by pure sine-wave and normal program signals for equivalent volume indicator readings, an "elevated" level of 10 dB above normal (−50 dBm at microphone input) was used throughout the system shown in Fig. 20 to simulate 100 percent modulation. With sine-wave input the normal settings of all controls produced 100 percent modulation. The limiting circuit of the limiting amplifier was completely disabled during all of these measurements.

A constant level of —50 dBm (for the condition of 100 percent modulation) was fed to the microphone preamplifier at all frequencies involved, and the transmission set attenuator at the transmitter input was adjusted so that the modulation as indicated on the modulation monitor was always 100 percent. The attenuator settings were recorded at each measurement frequency, and the distortion was measured for each frequency. This procedure was repeated with microphone input levels reduced so as to produce transmitter modulation levels of 50 and 25 percent, respectively. Fig. P-21, P-22, and P-23 are plots of the system frequency response, and Fig. P-24 shows the system distortion for the three modulation levels used.

AM and FM noise levels were measured with a reference frequency of 400 Hz, with the following results: AM Noise Level = −52 dB below 100% modulation; FM Noise Level = −58 dB below 100% modulation.

It is recommended in the rules and regulations that none of the three parts of the system, studio, studio-transmitter link, and transmitter, contribute more than half of the total degradation allowed for the entire system. Each part of the system was measured, and it was determined that no one part of it does contribute more than half of the allowable degradation.



BLOCK DIAGRAM OF MEASURING SET-UP

CONDITIONS FOR MEASUREMENT

STUDIO	TRANSMITTER	ANTENNA
NO. D	TYPE GE TT-22A	TRANSMISSION LINE
INPUT TO PREAMP. NO. 1	POWER 7.43 KW	OUTPUT POWER 7.43 KW
GAIN SETTING (MIXER) 11	PLATE VOLTAGE 7300 VLTS	TYPE RCA CB-TF-4 SPEC.
GAIN SETTING (MASTER) 11	PLATE CURRENT 2.6 AMPS	POWER GAIN 3.66
PROGRAM LINE REGULAR (REGULAR OR SPARE)	FIL. VOLTAGE 12.0 VLTS	

MEASURING EQUIPMENT

	MANUFACTURER	TYPE	SERIAL NO.
AUDIO OSCILLATOR	HEWLETT-PACKARD	201-B	815
DISTORTION AND NOISE METER	HEWLETT-PACKARD	330-B	
TRANSMISSION MEASURING SET	DAVEN	6-E	E-75092
DECADE ATTENUATOR			
AM DEMODULATOR	GENERAL RADIO	1932 P-1	149

Fig. P-20. Measurement data, TV aural data sheet 1.

25% MODULATION

	30 CPS	50 CPS	100 CPS	400 CPS	1000 CPS	5000 CPS	10000 CPS	15000 CPS
ATTENUATOR READING-DB	*	2.8	3.0	4.3	5.0	11.6	19.2	21.4
CONSTANT**	*	5.5	5.5	5.5	5.5	5.5	5.5	5.5
FREQUENCY RESPONSE	*	-2.3	-2.5	-1.2	-0.5	6.1	13.7	15.9

50% MODULATION

	30 CPS	50 CPS	100 CPS	400 CPS	1000 CPS	5000 CPS	10000 CPS	15000 CPS
ATTENUATOR READING-DB	*	2.5	3.0	4.3	5.1	11.5	19.1	21.2
CONSTANT**	*	5.6	5.6	5.6	5.6	5.6	5.6	5.6
FREQUENCY RESPONSE	*	-3.1	-2.6	-1.3	-0.5	5.9	13.5	15.6

100% MODULATION

	30 CPS	50 CPS	100 CPS	400 CPS	1000 CPS	5000 CPS	10000 CPS	15000 CPS
ATTENUATOR READING-DB	*	2.7	3.6	4.2	5.1	11.5	19.1	21.3
CONSTANT**	*	5.6	5.6	5.6	5.6	5.6	5.6	5.6
FREQUENCY RESPONSE	*	-2.9	-2.0	-1.4	-0.5	+5.9	+13.5	15.7

* NOT REQUIRED BY FCC

** ADD OR SUBTRACT AN ARBITRARY CONSTANT TO BRING THE RESPONSE CURVE WITHIN THE REQUIRED TOLERANCE SHOWN ON FM DATA SHEET-3

OUTPUT NOISE LEVEL (FM) 58 db BELOW 100% MODULATION (± 25 kc FM at 400 cps)

OUTPUT NOISE LEVEL (AM) 55 db BELOW 100% MODULATION (2% at 400 cps)

Fig. P-21. Over-all audio-frequency-response data and output-noise-level data, TV aural data sheet 2.

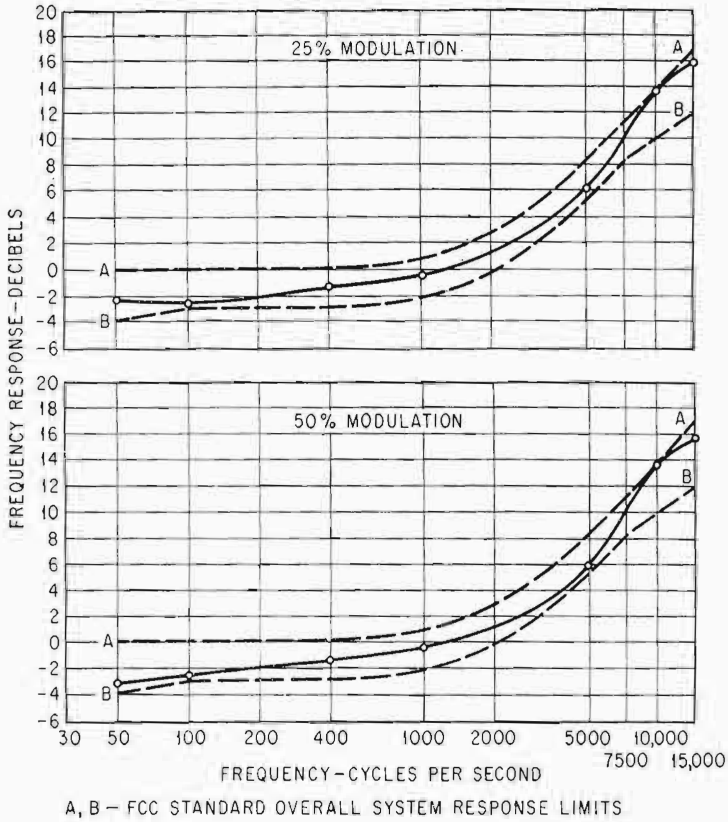


Fig. P-22. Over-all audio-frequency-response graphs, TV aural data sheet 3A.

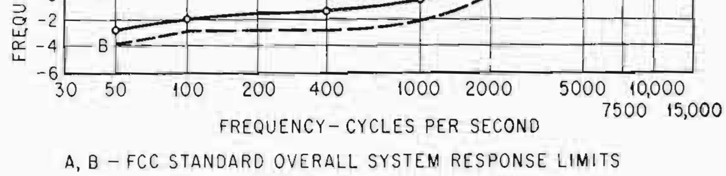
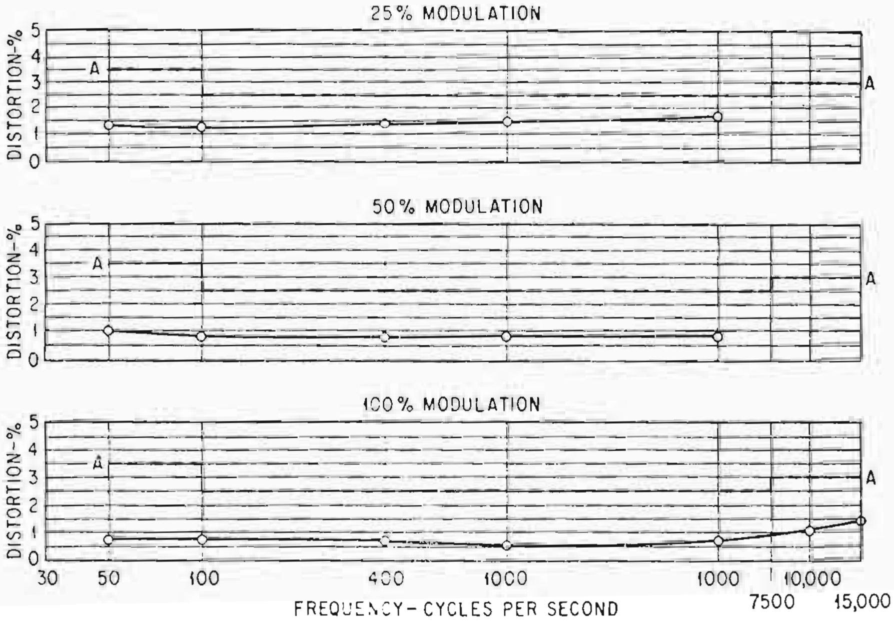


Fig. P-23. Over-all audio-frequency-response graph, TV aural data sheet 3B.

	50 CPS	100 CPS	400 CPS	1000 CPS	5000 CPS	10,000 CPS	15,000 CPS
25% MODULATION	1.4	1.3	1.4	1.5	1.7	*	*
50% MODULATION	1.0	0.8	0.8	0.9	0.9	*	*
100% MODULATION	0.8	0.8	0.7	0.6	0.7	1.0	1.4



*- NOT REQUIRED BY FCC

A - FCC STANDARD OVERALL SYSTEM TOTAL HARMONIC DISTORTION LIMITS

Fig. P-24. Audio-frequency harmonic distortion, TV aural data sheet 4.

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The Control of Audio Levels

On July 9, 1965, the Federal Communications Commission adopted a Report and Order (Docket No. 14904) and a "Statement of Policy Concerning Loud Commercials." To assist broadcast stations in making every reasonable effort to comply with these new requirements, the NAB Engineering Advisory Committee and its Subcommittee on Loudness have considered methods of implementing this FCC policy.

In view of the complex and subjective nature of loudness as applied to broadcast program material, the FCC Policy Statement recommends that licensees take appropriate steps prior to broadcast to review (pre-screen) recorded commercials as the best means of avoiding excessive "loudness" in broadcast commercials.

The National Association of Broadcasters, working with the NAB Engineering Advisory Committee and its Loudness Subcommittee, has prepared a Standard Loudness Reference Recording which is being made available to the broadcasting industry. The objective of this Recording is to provide an industry standard which may be used as a common denominator against which loudness of any program element can be judged.

Such a standard, when properly used, can provide individual broadcast station operators (AM, FM and/or TV) with a convenient means of pre-screening program material prior to broadcast to ascertain that all program elements have a reasonably uniform maximum loudness. Extension of acceptance of the NAB Standard Loudness Reference Recording through allied industries (i.e., program producers and recording companies) will contribute materially toward assuring that all recorded material furnished the broadcasting industry is prepared in its original form with reasonably uniform maximum loudness.

The NAB Standard Loudness Reference Recording consists of (a) 60 seconds of noise one octave side centered on one kHz and (b) three minutes of a male speaking voice, with both noise and voice adjusted to peak at reference level on the VU meter. The noise record is intended for gain and level adjustment of the reproducing equipment. The Standard Loudness Reference is the record of the male voice.

Four documents have been prepared or included to assist the user in deriving optimum benefits from the NAB Standard Loudness Reference Recording—"NAB Guidelines for Loudness Review," Loudness vs. Volume," "Automatic Audio Level Control" and the FCC Statement of Policy Concerning Loud Commercials. The Guidelines include a recommended practice for applying the NAB Standard Loudness Reference Recording as an aid in evaluating the loudness of broadcast program material. Other procedures leading toward the same objective will undoubtedly suggest themselves to the user. The significance of the difference between the terms "loudness" and "volume" as applied to broadcast program material is described in the paper "Loudness vs. Volume." The application and use of various devices for control of audio level in broadcast systems is described in the paper entitled "Automatic Audio Level Control." The Commission's policy statement is self-explanatory.

NAB GUIDELINES FOR LOUDNESS REVIEW

In that loudness is a relative matter, it is desirable in evaluating loudness to have a reference of loudness against which a judgment can be made. Accordingly, the NAB has established a "Standard Loudness Reference Recording," made at normal level. This recording will serve as a uniform reference against which "recorded commercials and other material" may be compared for subjective loudness.[1] The methods of using this reference and conditions recommended for review of commercials and other materials are contained in the following Recommended Practice.

A. Recommended Practice for Use of NAB Standard Loudness Reference Recording

1. *Scope*

This recommended practice specifies the method and conditions under which the NAB Standard Loudness Reference Recording is to be applied as an aid in evaluating loudness of broadcast audio material.

[1]A station's practice in the origination of live program material should be compatible with recorded material.

2. *Application*

Under the same or exactly equivalent conditions of equipment and environment, a presentation in sequence shall be made of:

(a) a fifteen-second, or longer, portion of the NAB Standard Loudness Reference Recording;

(b) the audio material whose loudness is to be evaluated; and

(c) a ten-second, or longer, portion of the NAB Standard Loudness Reference Recording.[2]

An observer, or observers, whose judgment has been found from experience to be objective shall make a determination as to the loudness of audio material in question as compared to the NAB Standard Loudness Reference Recording. If the loudness of the audio material being reviewed is considered excessive under the terms of the FCC Policy Statement, the audio material should not be broadcast without modifications.

3. *Environmental Conditions*

In monitoring critically for relative loudness of announcements vs. the NAB Standard Loudness Reference Recording, it is important that listening conditions be as similar as possible to those existing for the average audience during broadcast. The reviewer should also have the proper mental attitude and avoid pre-occupation with other matters, if an objective appraisal of so subjective a matter as relative loudness is to be accomplished. The space in which the reviewing operation is carried on should provide conditions comparable to the home. It should be neither excessively noisy nor abnormally quiet.[3] An average room with carpeting or an acoustic ceiling should be adequate.[4] The judgment should be made at a normal home listening level, (approximately 65 to 75 dB above acoustic reference level with "A" weighting as measured on a Standard Sound Level Meter).

4. *Reproducing Equipment*

The reproducing system should be of good quality but not necessarily broadcast standard. It should duplicate the performance of a good quality TV or radio receiver to provide listening conditions found in the home.

[2]It is recognized that in practice, there may be other methods of achieving results equivalent to those obtained by the foregoing.

[3]That is, a room whose noise level is approximately 35 to 45 dB above the acoustic reference level with "A" weighting, as measured on a Standard Sound Level Meter.

[4]Provided, of course, that a film projector or other source of noise does not increase the room noise level.

LOUDNESS VERSUS VOLUME

The American Standard Volume Indicator[5] has been in use in this country for some thirty years. Perhaps because of this long devotion to a particular measuring technique, broadcasters sometimes tend to confuse "loudness" with "volume". While somewhat related, loudness and volume are really two quite different things.

With the adoption of the FCC Report and Order (Docket No. 14904) and a "Statement of Policy Concerning Loud Commercials," a clear understanding of the difference between loudness and volume is essential. A review of the significance of these two terms should help to clarify their relationship.

Volume

Volume is a purely empirical term evolved to meet a practical need. It cannot be defined in precise mathematical terms involving the familiar units of current, voltage, and power. The electrical amplitude of audio program material does not lend itself to measurement with the usual root-mean-square, average or peak reading voltmeters used for the measurement of periodic waves. In the communications field this fact led to the concept of a value known as "volume." American Standard S1.1-1960, Sec. 2.17, defines the term as follows: "The volume level in an electric circuit is the level, as measured on a standard volume indicator, of a complex wave such as produced by speech or music."

Volume is simply the reading of an instrument, known as a Volume Indicator (colloquially; "VI" or "VU meter") which has specific *dynamic* and electrical characteristics, a specified means of calibration, and a prescribed method of reading.[6] Readings made with a standard volume indicator are commonly called volume levels. Volume indicators are not intended to measure loudness, although there is a rough relationship between relative volume level and relative loudness.

Loudness

American Standard S1.1-1960 states that "Loudness is the intensive attribute of an auditory sensation, in terms of which sounds may be ordered on a scale extending from soft to loud."

[5]Chinn, Gannett, and Morris, "The New Standard Volume Indicator and Reference Level," Proc. IRE, 28:1:1 (Jan., 1940).

[6]Howard A. Chinn, "The Measurement of Audio Volume," *Audio Engineering*, 35:9:26 and 35:10:24 (Sept. and Oct., 1951, respectively).

In other words, loudness is a subjective experience which has no equivalent in physical terms. It is the magnitude of the auditory sensation produced by a sound. In the past, it has sometimes been assumed that the sensation is proportional to the number and strength of the nerve pulses reaching the brain from the inner ear in a unit of time. Except for certain kinds of sounds (e.g., continuous tones), it is now generally recognized that the sensation of loudness also involves the psychological reaction of the listener to the nature of the sound.

The judgment of the loudness of program material (as distinguished from the loudness of tones) is a two-dimensional function. The two attributes are (a) sensory or physiological loudness and (b) perceptual or psychological loudness.

Sensory loudness is related to the nerve pulses which, upon reaching the brain, cause a sensation of loudness. The loudness of most tones and noises is largely determined by this phenomenon. Perceptual loudness, on the other hand, is related to the previous emotional conditioning of the listener to the sound being produced.

Sensory vs. Perceptual Loudness

A few examples will help to distinguish between sensory and perceptual loudness. For example, a person interested in a particular radio or television program may adjust the sound reproduction level for comfortable listening. Another person in the same room who is trying to concentrate upon a difficult passage in a textbook would probably object to the program material as being too loud. Thus, the same sound is judged to be normal by one listener and loud by another, although both are subjected to the same variations in sound pressure. This is a case where, although the sensory loudness is the same, the perceived loudness is quite different depending upon the viewpoint of the listener.

Another example is the apparent loudness of a person who is shouting compared to one talking in a normal conversational manner. Even though the sound pressures produced by both voices may be adjusted until they are essentially alike, the shouting voice will generally be perceived as louder than the conversational one.

Other examples are well known to broadcasters. For instance, there are a number of processing techniques that make the apparent or perceptual loudness of speech seem louder than would otherwise be the case. These include the use of rapidly paced, shouting, or strident voice delivery, the addition of reverberation, amplitude compression, restricted bandwidth, and other forms of response-frequency equalization. Exactly why this kind of processing produces sounds that seem louder than unprocessed material is not exactly known. It is evident, however, that psychological conditioning plays an important role in a person's assessment of the loudness of certain sounds.

In recent years considerable work has been undertaken to determine the characteristics of the auditory ear-brain system. At this point, sensory or physiological loudness is a reasonably well understood phenomenon which can be measured with good statistical accuracy. Further, electronic instruments have been both devised and proposed for the measurement of physiological loudness.

On the other hand, since an instrument can be provided with only rudimentary psychological insights, it is not reasonable to expect a meter to measure accurately perceptual or psychological loudness.

The Measurement of Loudness

From the foregoing, it should be clear that the measurement of loudness is not a simple matter even at this point in history. Further, the standard volume indicator was never intended to be a loudness meter as reference to the original paper describing the instrument will verify. (See Footnote 1.) Basically, the standard Volume Indicator measures amplitudes in a special way that is determined by the electrical and dynamic characteristics of the Volume Indicator (or VU meter). Depending upon the nature of the sound and the previous psychological conditioning of the listener, volume measurements and perceived loudness are probably related with some to-be-determined degree of accuracy. Very preliminary indications are that, in some cases, the order of the correlation is probably no better than perhaps 10 dB which, as far as broadcast operations are concerned, is really no correlation at all. Thus, in the absence of a loudness meter reliance must be placed upon the judgment of skilled observers when it is desired to equate the loudness of two or more program elements, particularly where they are quite different in nature. It is with this thought in mind that the NAB Standard Loudness Reference Recording is being made available. It provides a common denominator against which the loudness of any program element can be judged. Thus, if the loudness of all program elements is made to sound equal to the NAB Standard Loudness Reference Recording, then, when reproduced serially in any combination, these elements should sound about equally loud.

AUTOMATIC AUDIO LEVEL CONTROL

The automatic control of audio level is a widely used and accepted practice in broadcasting today. When properly used it is capable of controlling peak levels (or peak modulation) in a manner that is substantially superior to manual methods. When improperly used it can cause objectionable distortion of waveform, amplitude range, and even dynamic range.[3] Further, automatic methods are not a substitute for good judgment, such as is required when determining a pleasing balance between multiple sources of sound.

There are three basic types of automatic audio level controls. One type senses waveforms in excess of a given amplitude and, by means of a signal derived from this sensing, causes a modification in gain of the device in accordance with some pre-established relationship. These devices are often known as automatic gain control[3] amplifiers. Below the threshold amplitude the gain of the device is fixed and, hence, the input-output relationship is linear. Above the threshold the output increases at a materially slower rate than does the input because of a progressive reduction in gain. In addition, since the gain of the device is a function of the loudest signal, weak signals that are closely associated in time with a loud signal are also reduced in level. Thus, although the original balance is maintained, weak signals may be reduced below the level originally intended. This would be an indication of excessive dynamic range in the program material with respect to the limitations of the aural broadcast system. It should be noted that the amplitude range requirements and limitations are quite different for AM, for TV, and for FM broadcasting.

A second type of automatic level control device is the limiter[7] which, by nonlinear action or by essentially instantaneous changes in impedance, limits or modifies waveforms above some predetermined threshold value. This type of device has the fundamental disadvantage of producing both harmonic distortion and cross-modulation of the audio frequency waveform to which it is applied. A low-pass filter can reduce the effect of higher order distortion, but it cannot affect the cross-modulation of the lower frequency components.

A third type of device is the compressor amplifier. Compression is defined as the "process in which the effective gain applied to a signal is varied as a function of the instantaneous signal magnitude, the effective gain being greater for small than for large signals."[8] This device is akin to an automatic gain control amplifier except that in the latter, as noted above, the gain modification in the form of reduction only takes place after the signal exceeds a given amplitude and the gain does not restore to normal maximum immediately with a reduction of signal amplitude.

True compressor amplifiers usually find application in certain communications and some recording applications. They are usually associated with an "expander" amplifier having conjugate gain characteristics with signal amplitude. They are not normally used in broadcasting plants. Accordingly, they are not discussed further herein.

Automatic gain control amplifiers, however, are used in a variety of forms. These and limiters are discussed further in the following paragraphs.

Limiters

Limiters are widely used in voice communication services for increasing average voice modulation levels. It has also been offered to and used by broadcasters for providing a sharp limit on modulation, especially in connection with preemphasized programs on TV aural and FM transmitters.

Limiters are sometimes used with, or as a part of, an automatic gain control amplifier. When employed in this manner, objectionable distortion may be avoided when the device is adjusted to clip not more than a very few decibels from excessive audio peaks. If, however, the unit is permitted to clip normally encountered peaks by more than 3 or 4 dB, serious distortion can be caused in an otherwise high-fidelity system. The use of a limiter in place of the modulation limiting form of automatic gain control amplifier should not be permitted in a broadcast transmitting system.

Automatic Gain Control Amplifiers

There are a great variety of automatic gain control amplifiers in general use. Their differences reside primarily in their attack and release times, their compression ratios, their operating logic and the purpose they are designed to serve. The attack times of typical units normally range from microseconds to milliseconds. The release times, on the other hand, range from hundreds of milliseconds to seconds. Compression ratios range from less than 2 to 1 up to as much as 20 to 1.

In a continuing effort to devise a wholly satisfactory automatic device, many kinds and many combinations of circuit logic have been incorporated in commercially available devices. These

[7]For definition, see "IRE Dictionary of Electronics Terms and Symbols." (Pertinent extracts included in Appendix.)

[8]IRE Standard No. 53 IRE 11.S1.

include signal delay, amplitude discrimination, memory, and frequency-spectrum modification. Because of this proliferation, and the complexity of some of the operating logic, it is not possible to present a meaningful summary of the many subtypes of automatic gain control amplifiers currently available. A common application for this kind of device is the automatic modulation "limiter" often used at broadcasting transmitters to prevent aural overmodulation.

Automatic Gain Control Amplifier Application

Fully as important as the selection of the proper automatic level control device for a given application is the manner in which a given unit is operated. If not properly adjusted, an automatic device can completely negate the best efforts of the most skilled sound technician. The following examples will serve to illustrate the point.

Frequently, in dramatic acts and in comedy sketches, there are passages where the action takes place with the sound consisting only of relatively low level background noises or music. If such audio material is routed through a badly overcontrolled automatic level control device or system, the desired effect can be lost due to the increase of level under these circumstances.

A somewhat less extreme but more frequent case is also encountered both in dramatic and musical programs. Here medium level passages may be increased in level by an automatic device to the point that, when a crescendo, a fortissimo, or a loud sound effect is encountered, there is no headroom left for further increase in volume. The effect upon the discerning listener is likely to be one of disappointment with the performance.

The reverse condition, however, in which insufficient average program level or modulation is maintained because of a lack of sufficiently uniform level is one which can also cause dissatisfaction with the aural broadcast heard under unfavorable or noisy conditions. Thus, automatic level control should be arranged and so adjusted as to maintain satisfactorily uniform levels to overcome noise but should also avoid excess modulation and reduction of desired amplitude range or aural contrast.

Problems such as those just enumerated may be largely avoided by judicious use of automatic level adjusting devices. For example, in transmitter applications the automatic device should be used primarily as a means to avoid overmodulation. A properly designed automatic modulation limiter operated so as to effect a gain reduction of say 6 dB on program peaks should effectively control maximum modulation levels on most transmitters. Gain reduction in excess of 6 dB is unnecessary to the modulation control function and tends to reduce the amplitude range of the program.

An automatic modulation limiter should be operated so as to have a gain reduction of about 6 dB on maximum program peaks for two reasons. One is that most such limiters have a ratio of compression in the operating range of approximately 10 to 1, which means that an increase in level of 6 dB in the control range is converted to an increase of only 0.6 dB. This will permit the FCC specification of 85 to 100 per cent modulation on maximum peaks to be complied with readily. The other is the fact that the gain reduction indications of most meters are usually greater by 2 or 3 dB than the actual dB reduction in gain of the amplifier. Thus, it usually requires at least a few dB indications on the meter for control to be effective.

Another form of automatic control quite similar to the modulation limiter is the automatic level control or automatic gain control. This device, while fundamentally similar, is used for a different purpose and in a different manner than the automatic modulation limiter. There are two differences in design or operating characteristics. First, the automatic level control has a much slower gain restoration time than the modulation limiter. It may be as much as 10 to 20 secs. as compared to something less than 1 sec. for the modulation limiter. Second, the ratio of compression in the operating range is much less severe, being in the order of 3 or 4 to 1.

The automatic level control has been used with gain reductions of as much as 20 dB (i.e., for a compression ratio of 3 to 1, an input level increase of 30 dB results in an output level increase of only 10 dB). The use of excessive automatic gain reduction or control range does create the possibility of raising noise level during pauses in programming. Correctly used and adjusted, the automatic level control will maintain program level from a studio in much the same manner as would a skilled studio technician except that it usually does it better. It should be emphasized, however, that uniform program or modulation level is not necessarily synonymous with uniform loudness which is a highly complex and subjective function of the reproduced program.

APPENDIX

Extracts from "IRE Dictionary of Electronics Terms and Symbols," published by the Institute of Radio Engineers, Inc., 1 East 79th Street, New York 21, New York, 1961:[9]

Amplitude Range. The ratio, usually expressed in decibels, between the upper and lower limits of program amplitudes which contain all significant energy contributions.. (58 IRE 3.S1)

Dynamic Range. The ratio of the specified maximum signal level capability of a system or component to its noise level, usually expressed in decibels. (58 IRE 3.S1)

Automatic Gain Control (AGC). A process by which gain is automatically adjusted as a function of input or other specified parameter. (58 IRE 3.S1)

Limiter. A transducer whose output is constant for all inputs above a critical value. (48 IRE 2, 11, 15.S1; 52 IRE 17.S1)

FEDERAL COMMUNICATIONS COMMISSION STATEMENT OF POLICY CONCERNING LOUD COMMERCIALS

1. During the past two years, the Commission has studied intensively the problem of loud commercials in television and radio. We are told by industry engineers, broadcasters and others that subjective loudness of commercials cannot be electronically measured, and therefore the Commission cannot act to prevent them. However, in hundreds of complaints from the public we are also told that some commercials are objectionably loud, often louder than adjacent programming—and often so objectionably loud that listeners are compelled to turn the volume down.

2. We conclude today in our Report and Order in the inquiry proceeding (Docket No. 14904) that objectionably loud commercials are a substantial problem, are contrary to the public interest, and that their presentation is to be avoided.[10]

3. The purpose of this policy statement is threefold—to set forth our policy and the policy we expect licensees to follow in this respect, to detail some of the practices which are common causes of loud commercials, and to advise licensees not knowingly to broadcast commercials involving such practices. All licensees are expected to take appropriate measures to assure strict adherence to this policy. The Commission, through its complaint procedure or by spot checks at renewal time, will determine whether licensees are carrying out their obligations in this respect, and will take whatever action is appropriate on the basis of such review.

4. Among the practices which the Commission has identified as often causing loud commercials, and which licensees shall avoid, are the following:

(a) *Excessive modulation* on commercials as, for example, through inadequate control-room procedures. We are today amending our modulation rules to make it clear that minimum modulation on peaks of frequent recurrence need not be as much as 85 percent if a lesser level is required to avoid objectionable loudness.

(b) *Excessive volume compression* resulting from the use of automatic gain control, or similar devices—particularly in the broadcast of pre-recorded commercial material which may have been prepared with extensive compression and other electrical processing. Extensive compression permits material to be broadcast at a higher than normal average level of modulation. At lease on pre-recorded commercial material, a maximum of 6 dB compression in broadcasting is recommended.

(c) *Excessive use of other electrical processing devices,* such as filters, attenuators and reverberation units—again, particularly where prerecorded material is being presented.

(d) *The use of prerecorded commercials* which have been subjected to excessive compression, filtering, attenuation, "equalization" or reverberation (echo).

(e) *Voice commercials presented in a rapid-fire, loud and strident manner;* and

(f) *The presentation of commercial matter at modulation levels substantially higher than the immediately adjacent programs.* A maximum of 4 dB increase (40 percent to 60 percent to 100 percent modulation) is recommended.

To make sure that such practices are avoided, licensees are to adopt adequate control-room procedures to prevent them, and to take appropriate steps to provide for prescreening recorded commercials for loudness.

5. Much of the loud commercial problem arises in connection with the broadcast of prerecorded commercials. In fulfilling their obligations in this area, braodcasters are expected to take reasonable steps to get the cooperation of the recording industry so as to prevent the presentation of loud commercials.

6. We now turn to a brief discussion of the matters referred to above.

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[9]The Dictionary is out-of-print; the Institute of Radio Engineers (IRE) has been superseded by the Institute of Electrical and Electronics Engineers (IEEE), whose address is 345 East 47th Street, New York, N.Y.

[10]As industry parties point out, there is not no acoustic or electrical tool for determining precisely whether or not a given sound is objectionably loud. Nevertheless, it has been repeatedly held that objectionable or excessive loudness is both a proper subject for preventive governmental action, and a condition sufficiently definable for its existence to be established for legal purposes. See, for example, Kovacs v. Cooper, 336 U.S. 77 (1949); Ex parte Trafton, 271 S.W. 2d 814, 160 Tex. Cr. 407 (1954), and Thompson v. Anderson, 153 P. 2d 665, 107 Utah 331 (1944).

Minimum Modulation Requirement

7. One argument advanced by some broadcasters is that they are prevented by our rules from avoiding loud commercials, because the rules require modulation on peaks of frequent recurrence to be at least 85 percent thus prohibiting the operator from reducing the transmitter gain even if necessary to eliminate loudness. We do not so construe the rules. However, in order to make this matter completely clear, we are today amending the modulation rules (Sections 73.55, 73.268 and 73.687(b)) to provide that, while in general modulation should not be less than 85 percent on peaks of frequent recurrence, it may be reduced to whatever level is necessary to avoid objectionable loudness in commercial and other material, even if this is substantially less than 85 percent on peaks. We expect television and radio broadcasters to observe this practice where necessary to avoid loud commercials.

Control Room Procedures

8. Presentation of loud commercials is due partly to inadequate or lax control-room procedures. One cause is inaccurate reading of or inattention to the modulation monitor (required by our rules) or the widely-used volume unit (VU) meter. Another aspect is excessive reliance on automatic gain control (AGC) or peak-limiting devices, which, unless properly regulated, are likely to result in loud commercials. Broadcasters are to adopt control-room procedures adequate to prevent the presentation of loud commercials which result from these deficiencies or practices. Attention is invited to a description of accepted procedures in the IRE (now IEEE) Standards on American Practice for Volume Measurement of Electrical Speech and Program Waves, 1953 (53 IRE 3.S2).

Compression and Other Processing

9. One contributing cause to the problem of loud commercials is the use of moderate amounts of volume compression, which permits material to be broadcast at a higher than the normal average level of modulation without having peaks exceed 100 percent on the modulation meter. Compression in broadcasting, when used in moderation, appears to be desirable; but excessive use thereof, particularly in the broadcast of commercial material, is unquestionably undesirable and a major factor in causing objectionable loudness. Broadcasters are to exercise care in using devices causing compression. It is recommended that an appropriate maximum amount of compression is 6 dB, at least in broadcasting prerecorded commercials. Certainly, as a general rule, no more compression should be used in broadcasting a commercial than in presenting preceding material. Similar care should be used in connection with employment of other processing devices, such as attenuators, filters, or reverberation units. *Particular care is to be exercised when the commercial material has been prerecorded,* where substantial amounts of compression and other processing may have been used in the recording. The combination of such processing in recording and in broadcasting—e.g., what might be called "compression on compression"—may, when carelessly used, produce what one broadcaster has termed "a rather overwhelming effect" in terms of loudness. Therefore, the use of further compression or other electrical processing in broadcasting such commercials is to be avoided to the extent necessary to prevent objectionable loudness, and the amount thereof which may properly be used may well be substantially less (e.g., 6 dB of compression less) than that which is appropriate for other types of material.

Use of Recorded Commercial Material; Prescreening

10. Compression, filtering, "equalization," reverberation, and other processing are extensively used in recording commercial material, along with a generally high-volume level of recording. Again, these techniques when used in moderation serve desirable purposes, such as protecting equipment, producing a recording of good technical quality, and producing distinctive effects other than loudness. But it appears that sometimes they are used extensively for no other purpose than to produce loud commercials. *Broadcasters are to exercise care in the presentation of recorded material in which such processing has been used resulting in an effect of excessive loudness.* Under the revised modulation rules, where a commercial has been prescreened and found too loud, a licensee should reduce modulation below 85 percent where necessary to avoid objectionable loudness. Also as mentioned above, care is to be exercised in use of any further electrical processing in broadcasting recorded commercial material.

11. We note in "A Guide for Advertising Agencies and Television Stations in handling Materials for SPOT TELEVISION COMMERCIALS," a joint recommendation of the Station Representatives Association and the American Association of Advertising Agencies, that film, tape and slides should be in the hands of licensees 48 hours in advance of use. The Guide further suggests that materials should be

examined by the station on receipt for "damage, defects and completeness." Clearly this contemplates delivery in adequate time to permit prescreening.

12. We are aware that in actual practice these guidelines are not always observed. However, we expect broadcasters to adopt appropriate practices and procedures to provide time for prescreening, not only for damage, defects and completeness, but for loudness.

13. We recognize that to require each station, large or small, to prescreen all commercials for loudness may impose some burden. The small radio licensee can engage in extensive spot prescreening, and, if a loud commercial escapes prior detection through this process, he can be alert to the need for prescreening further commercials from the same source. Further, we suggest that the organizations, state or national, which represent advertisers, station representatives, agencies and licensees, should consider the establishment of a group to prescreen and label commercial material as to loudness for the industry.

Strident Delivery

14. One common source of complaint is commercials which are delivered in a loud, rapid and strident manner, with the maximum number of words crammed into the time period and all delivered at or close to maximum peak modulation. Presentation of such material is to be avoided.

Contrast with Preceding Program Material

15. Aside from differences resulting from varying degrees of electrical processing used in different types of material, another common source of complaint is the contrast between loudness of commercials as compared to the volume of preceding program material—e.g., soft music or dialogue immediately followed by a rapid-fire, strident commercial. Such contrasts are to be avoided. For guidance, it is recommended that a maximum of 4 dB increase over the immediately preceding program segment (40 percent to 60 percent to 100 percent modulation) is appropriate for general observance.

Conclusion

16. We conclude that the presentation of objectionably loud commercials is contrary to the public interest. Therefore, to the extent it is within their control, broadcasters have an affirmative obligation to see that such material is not presented. In today's Report and Order we recognize that loudness—the impression created in the listener—is to a degree the result of factors beyond the broadcaster's control and varies as between individual listeners (for example, a reaction to a particular product or a particular sound effect other than volume). But we conclude that objectionably loud commercials result in large measure from factors of a technical or partly technical nature which are within the broadcaster's control, and which are not adequately controlled simply by adherence to our rules in the various broadcast services limiting modulation to 100 percent on peaks of frequent recurrence. While there is no evidence that broadcasters in substantial numbers deliberately "boost the power" in presenting commercials, neither is there indication of any concerted, industrywide effort to deal with the problem. While most complaints of loud commercials are directed to television rather than radio (particularly at prerecorded commercials), the problem is by no means confined to television.

17. We have set forth above the broadcaster's general affirmative obligation, and specific practices and policies to which we expect strict adherence. The list of specifics is not intended to be all-inclusive, and there may well be other steps that can be taken. What is called for is a good faith effort on the part of licensees to prevent the presentation of commercials which are too loud. In setting forth this policy statement, we recognize the underlying importance of advertising to the American system of broadcasting, and the legitimate interest of the advertiser in presenting his message attractively and understandably, and in drawing attention to what he has to say. But these are not irreconcilable alternatives.

18. We note with pleasure a recent suggestion by the American Association of Advertising Agencies that its Subcommittee on Commercial Production might assist in dealing with this problem, by screening commercials referred to it by the Commission about which loudness complaints have been received. We appreciate this offer of assistance, and if the circumstances appear appropriate we will take advantage of the suggested procedure.

19. We also appreciate the consideration and attention being given this problem by the N.A.B. Engineering Advisory Committee. It is understood that investigations and studies are to be made by this committee, regarding the technical considerations that may be involved in the matter of "loudness" and also as to the possibility of developing a new volume measuring meter. The technical staff of the Commission is, of course, ready to cooperate in this endeavor as may be requested.

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