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NATIONAL ASSOCIATION OF BROADCASTERS

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VIDEOTAPE

LABORATORY CONTRIBUTIONS TO THE SOLUTION OF CERTAIN PROBLEMS ENCOUNTERED IN TELEVISION TAPE RECORDING

by Ross H. Snyder
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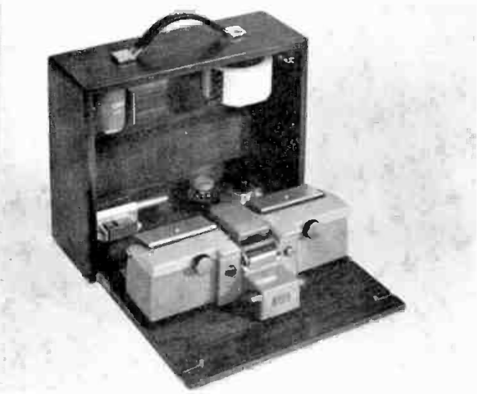
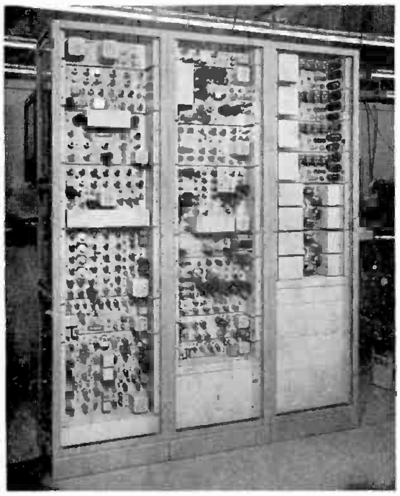
Ampex Corporation

A Paper Presented at the Convention of the National Association of Broadcasters

March, 1959



Splicer is provided with convenient carrying case, complete with operating supplies.



Color equipment adds only one rack (left) to basic VR-1000 electronics, forms integrated whole recorder/reproducer, capable of precision performance in color or monochrome.

The Videotape* recorder is making its fourth appearance this year, at your 1959 Convention. It's beginning to fell like reporting to members of the family, when we come before you.

At your 1956 Convention the Ampex Videotape recorder made its first public appearance, when it was shown that a full hour of four megacycle picture and high-fidelity sound could be recorded on a 12-1/2 inch reel of 2-inch tape, and replayed instantly, looking as live as the original broadcast. Seven months later, the CBS Television Network began the first regularly-scheduled Videotape re-broadcast, when Douglas Edwards' evening news program began to be replayed from tape, on the West Coast. Then, at your Convention in 1957, it was possible to display the ability to interchange tapes among recorders, and to copy tapes, from one recorder to another, with completely satisfactory replay of the copies. Within weeks after that it was shown that recorded television tapes could be cut and spliced, permitting many of radio's audio tape techniques to be adapted for television. Late in 1957, the production VR-1000 Videotape recorder began to come off the assembly lines, the first going to KING-TV in Seattle. When the Videotape recorder checked-in with you at your 1958 Convention, it was in full color. Last year, also, it was shown that a number of tapes, each recorded on a different machine, could be spliced together in a long series of tape sequences, and then stably replayed, under automatic control.

Now, in mid-March, 1959, more than three hundred Videotape recorders are in use in more than eighty-five television installations. Of these, fourteen are color-converted, and still more are leaving the color assembly area regularly. Production of monochrome Videotape recorders now exceeds two, every working day.

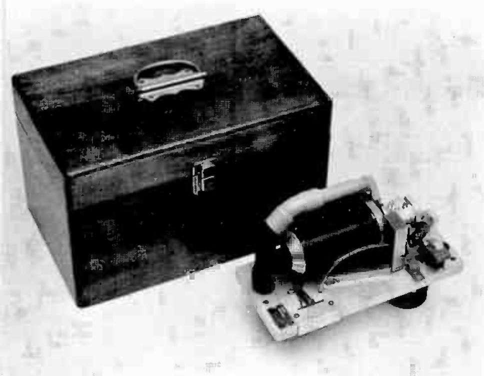
Planned Progress

From the earliest to the most recent VR-1000, a large number of changes have been made. Thanks to the generosity of the broadcasting industry, whose engineers have offered unlimited time and effort to report in detail to the Videotape recorder's designers their new findings, new uses, and solutions to problems as they arose, it has been possible to revise and up-date all machines.

*TM AMPEX CORPORATION

Service Bulletins Key to Coninuous Improvement

A series of Service Engineering Bulletins has been issued, as internal changes have been made in the design and circuitry of the VR-1000. These have given detailed instructions, step by step, on the means of making the same changes in previously-manufactured recorders. For example, last summer in the laboratory a method of improving the horizontal stability of the reproduced Videotape picture was developed. After the manner of the alteration had been reduced to its simplest form, it was ordered into then-current production, and a Service Bulletin was issued. Where horizontal stability had been in some cases marginal, it could be shown a few months ago that this was no longer a problem. The whole improvement however was not made by the circuit changes. Head improvements were also involved.



More than 2500 of these VR-1000 plug-in head assemblies have been manufactured.

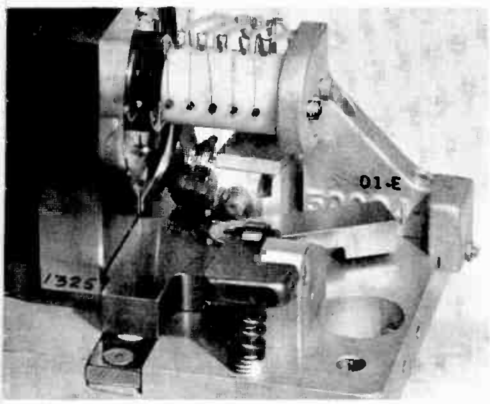
Improvements in Heads

Central to the performance of any rotary-head television tape recorder is the head, itself. More than 2500 of these have now been manufactured. The first heads were hand-assembled, from pieces fabricated under a microscope lens. In today's terms, they were crude samples, but the experience gained in making them was the key to their quantity production, during the year just past.

The entire Videotape head assembly is a plug-in device, which is periodically returned to the factory, and exchanged there for a completely reconditioned assembly. The limited life of the 14,400 rpm head structure probably has been a blessing in disguise, for much the largest part of the improvement which has taken place in television tape recording performance has been accomplished through refinement in the construction of the heads. Because these do return to the factory, on a sure and steady basis, it has been possible to incorporate automatically into every recorder in service, the very latest improvements as the laboratory released them.

The improvement in horizontal stability which was widely noticed last Fall was largely the result of improvements in the dynamics of the rotary head structure, first intensively checked in the laboratory, then ordered into production, then automatically incorporated into all head assemblies, as they were exchanged.

Even such basic performance parameters as signal-to-noise ratio are deeply and vitally affected by head construction. The specification on signal-to-noise ratio, at the beginning of Videotape recorder production, was 30 decibels, peak-to-peak video to r.m.s. noise. While most early-production machines were somewhat better than this, a recent check of machines in field service proved that the average recorder is now delivering 36 decibels, with a minimum of 34 in the survey. The highest figure obtained was 40 decibels. Much the largest part of this improvement is the result of changes in the head structure, although very great credit must also be given to those who have steadily improved the tape, itself.



Improvements have been made in control-track head, center.

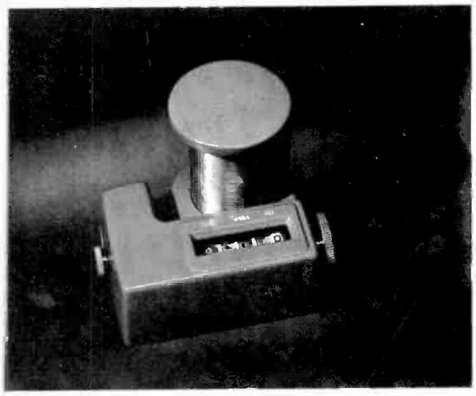
The latest changes to be made in the head structure are in the control-track assembly. A new and more rigid mounting has been devised, specifications have been further tightened on vertical location, tilt, and azimuth alignment, and a new chisel-shaped head was gone into production. The effect of the change in shape is to increase the unit pressure at the point of recording and reproduction, so as to increase the uniformity both of the recorded and reproduced signal.

Detailed changes have also been made in the audio head structure. The main purpose of the alteration in the configuration of the head supporting posts has been the reduction of maintenance. It was found that oxide particles, gradually accumulated from the passage of tape over the head posts, if not removed regularly, were capable of scratching the finely-finished surface of the tape, and producing disturbances in the picture. Several dozen of the VR-1000's in the field are in operation as much as fourteen hours each day. The necessary maintenance for these might not always be conveniently possible. The arrangement now is such that less oxide accumulation occurs, and the necessary period between cleansing is very much longer.

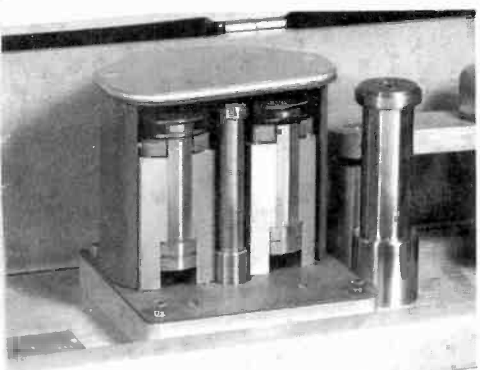
These new audio stacks, like all other recently introduced changes in the machine, are made available to owners of earlier-production equipment, and plug into the same sockets as those previously used.

Improvements in Operation

Operation, too, has received special attention. The Videotape recorder, first used mainly for network clock-time delay, rapidly expanded in its applications. As the machines went into service in dozens of independent and affiliated stations, they began to be used for



ape Timer rapidly and accurately locates previously
ogged points inside reels of tape, gives precise indi-
ation of recorded program time.

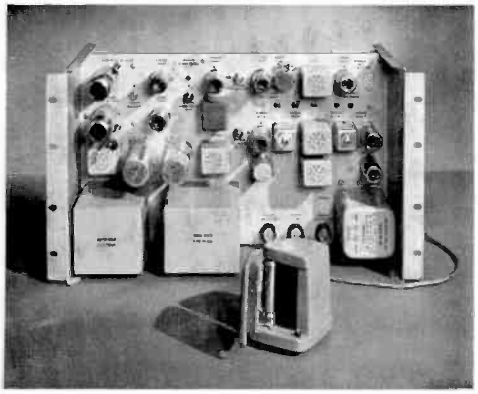


anges in VR-1000 audio head assembly reduce oxide
cumulation. New cue track erase and record/play-
ck heads trace track on lower edge of 2-inch tape.

the recording of commercials, not only for insert into network programs, but also for repeated local presentation. It became obvious that, for this service, and for other new uses of the machine, it would be important to provide an accurate means of locating, within a given reel of tape, exactly the recording which might be desired at any given time. A precise means of measuring off the tape also appeared to be desirable. An optional accessory, therefore, was developed. This is the Tape Timer. It can be installed on new equipment, or as accessory to earlier-production equipment, like all other VR-1000 improvements. Installation requires only removal of the Right Hand Idler, drilling of a relatively uncritical hole for the locating pin, and installation of the Tape Timer in place of the Idler. The Tape Timer is accurate within fourteen-hundredths of one percent, or five seconds in one hour. This degree of accuracy is maintained, even though the machine may be placed in fast-forward or rewind mode many times among readings. The scale reads in hours, minutes, and seconds, as befits a device whose purpose is to measure the stock in trade of television broadcasting, the hours, minutes, and seconds which represent the cents and dollars earned by the machine.

Cue and Erase Facility

The preparation of commercials and the assembly of programs likewise, it was felt, would be benefitted by the availability of a limited-quality separate sound-track, to be used for cueing or coding. The improvements in control-track, which have already been mentioned, easily permitted the insertion, between the bottom of the vertical video tracks and the top of the horizontal control track a 20-mil directly-recorded sound-track. This Cue-Track, while of limited frequency and dynamic range, is entirely satisfactory for the recording of voiced instructions, which appear at their own separate output, and cannot be accidentally mixed with outgoing audio. It is felt that this cue track will also be useful with automatic relay devices, for the control of associated external equipment, or for automatic control of the Videotape recorder itself, as, for example, automatic rewinding, automatic re-cueing, and so forth. Applications of the cue track will come immediately to mind when it is realized that tones originally recorded at frequencies in the 400 cycle region can easily be reproduced, even at top rewind or fast-forward tape velocities. Suggested uses include



ssociated equipment for the VR-1000 includes 2-nch automatic erase head. Electronics chassis nounts in front of console, provides current and mplification both for cue track and erasing function.

Erase head mounts at left of VR-1000 tape transport mechanism, Tape Timer at right. Installation is fast and easy; each unit replaces a tape idler.

ew over-console Monitor Mount saves floor space, aces at eye-level Waveform Monitor, Monitor elector Panel, Picture and Sound Monitors.

the recording of a series of tone bursts for later control of the recorder in automatic replay, for example, four for rewind, three for fast-forward, and two for stop, in an automatic rewind and cue sequence.

The Cue Track is provided with its own erase head, located on the same head-supporting post as the audio erase head, and a record/reproduce head, on the same stack as the audio record/playback head. This equipment is supplied with the necessary recording current, and provided with the necessary playback amplifier, by a chassis which is mounted on the rack supports in the front of the console. This chassis also contains the high-power oscillator which provides current for an automatic two-inch erase head. The cue track and erase features are combined in a single optional accessory. The erase head, like the other equipment which has been added from time to time to the VR-1000 availability list, may be installed on previously-purchased recorders, or may be ordered installed on new equipment. Erasure is accomplished by means of a two-inch head in a housing at the left of the video head structure, replacing the Left Hand Idler. This housing completely encloses the erase head, the idler, and the necessary tape guides. It may be snapped open for cleansing, at the touch of a finger.

Operation of the erase head is automatic, upon engagement of the record button. It is possible to connect a separate over-ride switch which will activate the erase head independently of the record facility, although machines are not normally factory-assembled with this connection, in view of the obvious danger of accidental erasure. The erase facility is particularly valuable where a number of short takes have been taped, some of which have been accepted, and other rejected, and when it is desired to remove and replace undesirable recorded material. Both the cue and erase kit and the tape time may be installed on the same machine, erase head at the left of the tape transport, tape timer at the right. Each presents finished, matching appearance when installed.

As a further aid to operational convenience and space-saving, the video laboratory has designed an over-console monitor mount, designed to suspend at eye-level the picture monitor, waveform monitor, sound monitor, and a new monitor selector panel, with self-illuminating indicator pushbuttons.

Videotape Commercials

These new facilities have made possible considerable expansion of the use of the television tape recorder in the production of commercials, first for network insertion, next, as machines became more widely used in individual stations, as often-repeated local commercials, and, more recently, as commercials of premium quality, but not of premium price, for placement by agencies on Videotape-equipped stations. Several firms, previously exclusively producers of film commercials, have equipped themselves with Videotape recorders, and are now syndicating commercials on tape. At least two new firms have been formed, which specialize exclusively in television tape recording. One of these, Videotape Productions of New York, Inc., demonstrated a startling cosmetic commercial in January of this year. With live television appearance, the girl in the commercial appeared before, during, and after use of the sponsor's product, lap-dissolving from "before" to "during", and from "during" to "after"! The sponsor, of course, was used to obtaining these effects with film but never with live television. Here's how it was accomplished:

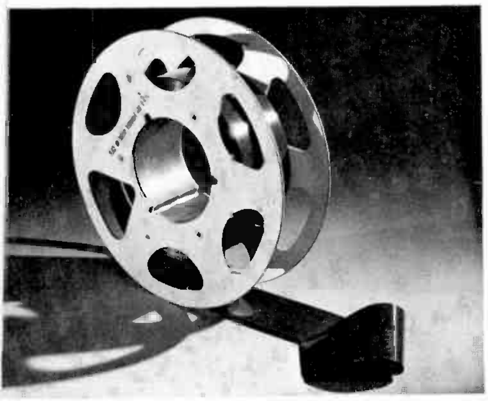
> The model was first taped in the "before" sequence, with a generous portion of black sync following the sequence; she then prepared herself for the third or "after" sequence, and, after a portion of black sync, went on-camera for the third part of the sequence. The sections of black, after the first sequence and before the third sequence, were then spliced together, so that black, intervening between "before" and "after" was exactly the length desired for the sequence "during" the cosmetic application. The tape was now threaded on one machine, while the model stood by with the live camera in the studio; the tape was rolled, while a copy was made on a second machine. Toward the end of the first sequence, with the camera locked to sync from the tape recorder, the feed to the second recorder was lap-dissolved from tape-playback to live camera, and the "during" sequence recorded as the model applied the makeup. Toward the end of the second sequence, a second lap-dissolve was executed from live camera

to tape. On the second recorder, the whole sequence appeared, "before" lap-dissolving into "during", lap-dissolving in turn into "after". Copies of this tape were then made and distributed. In the tapes which were distributed, sequences "1" and "3" were copies of copies, while the second sequence was a copy from an original tape. Through careful control over the quality of the recording, release tapes were obtained which were so free of defect that critical observers were unable to detect which was the third-generation portion of the material. These tapes were, of course, intended for replay on Videotape recorders at many different times and places.

Standardization Essential to Interchangeability

Results of this kind can be obtained only through the most careful cooperation between the engineering laboratory and the manufacturing facility, and between the manufacturer and the users of the equipment. The broadcasting industry has clearly seen the necessity for establishing and maintaining standard methods of operating these new machines. Charles P. Ginsburg, in his address to this Convention last year, explained in detail the mechanical and electrical adjustments which determine the degree of fidelity which is obtainable in tapes which are interchanged among Videotape recorders. Standardization, he demonstrated, is required in the degree of tip-projection which is employed in recording and reproducing tapes, in the height of the concave tape guide, and in the precision of the 90° angles among the four heads on the rotating head structure. Throughout the first year and a quarter of Videotape recorder production, standards have continually been tightened on factory adjustment of head height and head quadrature. In current production, where specification calls for quadrature errors to be limited to less than 0.1 microseconds, average measured error is at 0.05 microseconds. Preservation of this standard, we believe, is essential to the continued free interchangeability of television tape recordings. Early in the development of the Videotape recorder, Ampex engineers invented an electronic method of correcting quadrature misalignment by means of adjustable delay-lines in the record and playback circuits. While the method certainly proved to be one possible solution of the problem, it was rejected because of the urgency of standardization. During these first years of television tape recording, it was felt, broadcasters would have quite enough new maintenance procedures to follow, without adding that of maintaining quadrature adjustment, particularly if a hidden trap existed in the adjustment method.

Where the delay-line adjustment method was used, experimentally, it was found that considerable misalignment could be compensated without the operator's knowledge that misalignment was present. The hazard to standardization thus presented is not easily seen. It may be understood by following through the reasons for our rejection of the variable delay-line method of adjusting quadrature. For the sake of interchangeability it is desired that all tapes be recorded as if their heads were in perfect quadrature alignment. Therefore, if loose quality-control methods are to be tolerated, with wide variations in actual quadrature alignment of the heads, it would be necessary to provide individual delay-line adjustment in each of the four recording circuits, so as to lay down a track as if the heads were actually in perfect physical alignment. If these same imperfect heads, or others of equally loose tolerances, were to be used in playback, then tapes which were recorded in perfect quadrature would reproduce improperly. Therefore, delay-lines would also have to be provided in the playback circuits. Now, suppose the delay-lines in the record-circuit were to be improperly adjusted, so that the resulting tape were recorded as if the heads were considerably out of proper quadrature; a relatively simple adjustment of the playback delay-lines would permit linear playback of the improperly-recorded tape, and could easily give the impression that the machine were in proper operating condition. Such a situation might easily develop, we felt, whenever the recorders were especially busy, as we certainly hoped that they would be. Such tapes, while playable after individual adjustment, would be entirely unsuitable for splicing. This is the point where danger occurs to standardization. If television tapes were to become widely and commonly interchanged, we felt that this danger must be avoided, even though the cost of correct mechanical precision manufacture might be higher. Thus, the more difficult solution was chosen, and correction of the potential error at its source was undertaken. The hazard of unintentional dilution of interchangeability standards in this new and promising television medium was thus avoided. We urge again, during this critical year of the growth of tape syndication, that there be no toleration of loosening standards, and that the capability of tapes to be interchanged and inter-spliced should not be endangered by the adoption now of electrical compensation methods for adjustments which ought, rightly, to be accomplished with the necessary precision as a responsibility of the manufacturer, not the user.



ndustry standard Videotape* Head Alignment Tape s supplied with every VR-1000.

Recorded Tape as Alignment Standard

Preservation of the ability to interchange tapes depends also upon the industry's agreement on a standard way of adjusting such dimensions as tape-guide height and projection of head tips. These dimensions can, of course, be set by independent means to predetermined and agreed-upon positions. But the easiest way to check a machine quickly, and to arrive rapidly at the desired settings, is to use a standard recorded tape. Instrumentation and labor are reduced greatly. The tapes, of course, must be precisely uniform, and their production is therefore centralized in a single laboratory. Each is checked against a single standard, before release. Every new Videotape recorder is accomplished by an alignment tape.

A Look Toward the Future

As we report-in to the N.A.B. family, at the end of the third year of commercial Videotape recorder development, it seems appropriate to look also to the future. Television tape recording may certainly be said to have come of age when more than 300 recorders are in regular use in more than eighty-five television installations.

Stereo for TV

Stereophonic sound has now also come of age. With stereophonic tapes, both home users and broadcasters have explored the possibilities in stereo. With the advent of stereophonic discs, a little over a year ago, stereo became a mass market item. More and more broadcasters began to schedule FM/AM stereo broadcasts and, last Fall, the National Broadcasting Company began to experiment with TV/AM stereo.

Ampex Videotape* Cruiser brings mobility to recorded live television.

The results have justified further use of this medium, while proposals are now taking form not only for FM multiplex stereo, but also for a form of TV multiplex stereo sound. The equipment necessary for Videotape recording with stereophonic sound is already in existence. One such machine is in commercial use today, and others can be made available as needed. The stereo-modified Videotape recorder places two stereophonic sound-tracks in precisely the same area which has heretofore been used for the single sound channel which is normal to television broadcasting. The gaps of the separated record/playback heads are held precisely in line, so that tapes thus recorded are compatible for playback on normal single-channel machines. The precision of this alignment is such that when both channels are tracked by a normal single wide head, a precise A + B signal emerges from the sound playback system. Thus, insofar as stereo is in the future of TV, the Videotape recorder is already adapted for it.

Tele-Productions on Tape

It is obvious that the next big step for television tape recording is in the direction of syndicated programming. The first steps in this direction have already been taken. "Divorce Court", a highly successful local production of KTTV, Los Angeles, has been syndicated on tape to more than 15 stations, with live local quality, yet in syndicated form. There is good reason to believe that several programs, now regularly produced on photographic film, will appear this Fall on tape. While the reasons for the change will be largely economic, yet many of the reasons will be purely technical. The immediacy and liveness of tape reproduction is the first and most obvious of its technical advantages; in this, tape reproduction unlike film, is uniquely identified with television. But, unlike television, taped television is free of the danger of fluffs and unexpected disruptions. Tape shares the advantage which film has, in being spliceable.

Mobility in TV Tape

But if it is to be widely used, in syndicated production service, tape must acquire more of the advantages of film. Among these is mobility. A beginning has already been made in this direction. Two or three cameras, full control facilities, and television

npex Videotape* Cruiser contains recorder, two
). camera chains, control and maintenance facil-
es and power generating equipment.

'. E. Davis, Ampex Professional Products Divi-
ion Marketing Manager, points out to Neal K.
IcNaughten, Division chief, the "symbol of leader-
hip in television's new dimension", the new Ampex
'ideotape trade-mark.

tape recording apparatus, complete with local AC power supply, can all be contained in a bus of the size and type which is found frequently in airport service. One of these, constructed for demonstration purposes, has already displayed its ability to "bring back alive" television recordings taken on-location, even tapes made with the Videotape Cruiser in motion. The cruiser is here in Chicago at your convention, ready to prove to you the success of this experiment.

Synchronizing Tape Picture

Still more special facilities, however, will be required, as tape moves more and more into syndicated television program production. Primary among these new devices will be means of inter-synchronizing two or more Videotape recorders, so that lap-dissolves and other special effects may be accomplished among their several outputs. Inter-syching of two or more Videotape recorders, with the precision required for split-screen, lap-dissolve, wipes, and other effects, will require precision line-by-line synchronization of the rotary heads of the several recorders. This development is well along, already, and successful demonstration has been made of breadboard system for its accomplishment. The outlook is bright, indeed, for the eventual adoption of magnetic tape as the preferred and commonest means of producing high-quality low-cost television entertainment.

PROCEEDINGS OF THE 14TH ANNUAL NAB ENGINEERING CONFERENCE

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THE PRESENT STATUS OF STEREOPHONIC BROADCASTING

FOR DELIVERY TO NAB ENGINEERING CONFERENCE

APRIL 4, 1960

BY C. G. LLOYD, FORMER CHAIRMAN, N.S.R.C.

Stereophonic music, first from tapes and then from records, has added a new dimension to the enjoyment of the listener. It has also created considerable technical interest as evidenced by the 12 papers presented at the recent Institute of Radio Engineers Convention in New York. Many of these concerned stereo broadcasting systems, equipment and receivers. Stereo is regularly broadcast in some locations by the use of two stations, one AM and one FM, or both FM, to provide the two channels necessary to produce the spatial effect of stereophonic music. Using two stations, of course, requires two receivers (sometimes in one enclosure) and is wasteful of spectrum space when the service can be provided using one station, one broadcast channel and one receiver. To have such a service makes it necessary, of course, that there be at least a nationally, if not an internationally, approved system so that the plans of the broadcasters and the receiver manufacturers can be meshed to provide the enjoyment which the listener deserves.

In the Fall of 1958, Dr. W. R. G. Baker suggested to the Board of Directors of the Electronic Industries Association that an industry committee be set up to analyze the various possible stereo broadcast systems, to sort out the technical facts pertaining to amplitude-modulated stereo, frequency-modulated stereo and TV sound stereo and to present these to the Federal Communications Commission for decision. The National Stereophonic Radio Committee (NSRC) was the result of this suggestion.

It is the purpose of this paper to bring you up to date with the report of the NSRC which was sent to the Federal Communications Commission on March 14, 1960. In addition, the paper will outline some of the system characteristics and some of the problems which lie ahead.

NATIONAL STEREOPHONIC RADIO COMMITTEE

The organization structure of the National Stereophonic Radio Committee is given in Appendix I.

The NSRC has received for consideration 14 proposals for FM systems and, in addition, there are at least 7 for AM and 4 for TV Sound. Priority was given to a study of the proposed FM systems because of FCC Docket 12517 which pertains to an inquiry ".....to permit FM broadcast stations to engage in specified non-broadcast activities on a multiple basis.......". The original closing date for the submission of comments was June 10, 1959 but, because the non-broadcast activities (background music service, storecasting, paging systems, etc.) included parts of the FM channel which might be required for stereo, the date was extended to March 15, 1960.

FACTORS TO BE CONSIDERED

Some of the factors which will be considered by the FCC in their choice of a stereo broadcast system are as follows:

1.) Compatibility, which is the feature of a system permitting existing (monophonic) receivers to provide a satisfactory composite of the stereophonic signals.

2.) Signal-to-noise. This will be important not only for stereo receivers but, perhaps to an even greater degree, for monophonic receivers because of the numbers already in use.

3.) Stereo effect. This, of course, is the reason for a stereo broadcast and the resulting spatial illusion must be satisfactory.

4.) Receiver complexity, as well as six other important receiver considerations which are listed under the synopsis of the report of Panel 4.

5.) Transmitter complexity (see Panel 3 synopsis).

6.) Utilization of spectrum space. This is the question of whether the stereo signal leaves other space available in the FM channel for "non-broadcast activities", many of which are an essential source of income to the FM station.

7.) Effect of propagation. Field tests will show the effect of multipath propagation, ignition interference, etc.

FM STEREO SYSTEMS WITH FM SUBCARRIERS (TABLE 1)

Panel 1 on System Specifications has done an outstanding job in analyzing the systems. Some of the pertinent figures which affect over-all performance have been extracted from their work.

Table 1 shows four proposed FM systems which use an FM subcarrier to convey the directional information. A stereo signal is usually made up of information in two channels, one from the left of the stage or studio and one from the right. These are called L and R. You will note that three of the four systems use L + R for the main channel, which is the channel now used and which can still be picked up by existing FM receivers. These three systems are, therefore, completely compatible in that they provide a fully satisfactory balanced signal to existing receivers. The fourth system approaches compatibility by a combination of L and R signals. All systems provide full bandwidth on their main channel with varying degrees of modulation being used. The higher the modulation, the better the signal-to-noise ratio on an existing or monophonic receiver. The directional information takes different forms with one of the systems providing full bandwidth, two restricted bandwidth, and the EMI System an unusual type of "steering" signal with a bandwidth of about 100 cycles.

E.M.I. stands for Electric & Musical Industries Ltd. in England. Their system uses a steering signal which is the ratio of the left signal to the combined signals, after both signals have been weighted to favor the higher frequencies and hence the initial transients of a sound. It takes advantage of the "precedence effect" by which the human ear locates the direction of a source by the direction of the sound first heard from that source.

The figures on resulting signal-to-noise have been calculated by a subcommittee of Panel 1 on "Theoretical Considerations". The availability of parts of the channel for other purposes is given but the practical aspects of using them this way, because of potential crosstalk must be tried out in field tests.

FM STEREO SYSTEMS WITH AM SUBCARRIERS (TABLE 2)

Two FM systems using amplitude-modulated subcarriers are listed here. In addition, five systems have been proposed using switching or sampling between the two channels at rates from 15 KC to 100 KC. These will actually result in signals similar to the Zenith proposal. One system was proposed recently without sufficient time to study it, and uses both amplitude modulation and frequency modulation of the FM station carrier. A previous General Electric system proposed transmission of the subcarrier (AM) because this results in the least expensive receiver. Because the monophonic signal-to-noise performance is not as good when the subcarrier is transmitted, the General Electric Company has filed with the FCC the NSRC System #4a. The receiver for this system is still quite simple requiring only one tube between the discriminator and the two audio systems.

TV SOUND STEREO SYSTEMS (TABLE 3)

Table 3 gives four proposed systems for television sound. These have not been studied by Panel 1. You will notice varying bandwidths for the main channel and also for the directional information. Changes have undoubtedly been made since system parameters shown in this Table were submitted.

AM STEREO SYSTEMS (TABLE 4)

Table 4 shows the main features of the 7 proposed AM Stereo systems which Panel 1 had barely started to study. This table may not be correct in all details because of changes made since their submission. CBS and Philco are similar in that they use two carriers in quadrature and either modulate one with L information and one with R information or modulate one with L + R information and one with L - R information. The resultant signal is the same with either form of modulation and results in the carrier being amplitude-modulated with L + R information giving a compatible signal and the carrier being phase-modulated by the L - R information. Four other systems use FM for the L - R information. Since phase-modulation and frequency-modulation differ only in the frequency characteristic of the modulating wave, the CBS and Philco systems bear a strong family resemblance to the General Electric, RCA and Westinghouse systems. EMI is different in that it again uses a 100-cycle bandwidth steering signal and the Kahn system is different in that it uses single sideband techniques to put the L channel on one sideband and the R channel on the other.

PRESENT STATUS OF NSRC

CBS decided not to join in the work of the NSRC from the start. RCA initially participated and then later decided to withdraw. Both organizations felt that, because of their network affiliations, a TASO-type organization would be necessary before they could participate. The TASO-type organization was that adopted by the Television Allocations Study Organization wherein FCC lawyers were present at all meetings. NSRC proceeded without CBS and RCA but when it appeared that the work would be severely handicapped by their non-participation, EIA proposed a TASO form of organization to the FCC on October 15, 1959. The FCC replied January 27, 1960 saying that they could not accede to this request. EIA decided to place the Committee on a standby basis, a decision with which I fully concur. Reports of the work to date were submitted to the FCC on March 14, 1960. Highlights of these reports are as follows:

PANEL 1 - System Specifications

Clarification of the information in the principal systems has already been covered in the foregoing. This came from the work of the main panel and its eight subcommittees as follows:

1.) Subcommittee 1.1 - System Classification
2.) Subcommittee 1.2 - Definitions
3.) Subcommittee 1.3 - Theoretical Considerations
4.) Subcommittee 1.4 - FM-AM Systems
5.) Subcommittee 1.5 - FM-FM Systems

6.) Subcommittee 1.6 - Method of Testing Stereophonic Cut-off Frequency

7.) Subcommittee 1.7 - Matrixing Methods

8.) Subcommittee 1.8 - Final Report

PANEL 2 - Interconnecting Facilities

This Panel has determined that stereo information must be transmitted as L and R information. The state-of-the-art does not permit the close delay tolerances necessary if L + R and L - R were to be transmitted. A tolerance of 1 millisecond, as the difference between L and R signals, has been tentatively set. Panel 2 has also stated that frequency shift between channels (as would occur if different telephone carrier oscillators were used) is not tolerable and phase shift between channels must be held to a relatively low value, tentatively set at 40°. They state that consideration of the problem of stereo networking has revealed that it is somewhat more complicated than was at first thought and that development effort would need to be applied in order to provide a nationwide network of stereo circuits similar in extent to that now available for monophonic transmission.

PANEL 3 - Broadcast Transmitters

This Panel concludes that none of the FM systems studied require major modifications to the transmitter equipment. It should be pointed out that the system requiring the FM carrier to be amplitude modulated as well was submitted too late to be studied by Panel 3 but would undoubtedly provide complications. This Panel warns that many existing transmitters and antennas will not prove satisfactory for use with more than one subcarrier because of crosstalk problems.

PANEL 4 - Broadcast Receivers

This Panel studied 20 factors affecting the use of receivers on stereophonic broadcasts. These 20 were then reduced to 7 factors as follows:

1.) Complexity
2.) Ease of Factory Adjustment
3.) Ease of Field Adjustment
4.) Stability
5.) Ease of Tuning
6.) Ease of Use of Adapters
7.) Radiation

They provided signal-to-noise test specifications and arrived at a method for evaluating receivers but did not have the opportunity to evaluate all of the proposed FM receivers.

PANEL 5 - Field Testing

The work of this Panel lies ahead. The FCC have requested that they proceed with field tests and Panel 5 has agreed to do this.

PANEL 6 - Subjective Aspects

The report describes tests made at the Bell Telephone Laboratories where on separation (the apparent spatial separation of different sound sources) 50% of the observers were able to detect the effect of 19 db. of crosstalk. In checking the effect of eliminating higher frequencies in the L - R signal, still maintaining full bandwidth for the L + R, tests were made with L - R frequencies sharply attenuated above 8 KC per second. In one test selection in which tambourines, triangles and cymbals were predominantly on the right side in the original information, 38% of the observers could detect a difference between stereo with the limited bandwidth L - R signal and the original stereo, but 100% of the observers said it still bore a good spatial resemblance to the original. In another test run from an Afro-Cuban tape, with maracas especially prominent in the right channel, 50% of the observers could detect a difference but 100% said it still bore a good spatial resemblance.

PROBLEMS AHEAD

Field tests are, of course, most important before any system is decided upon. It is proposed to use a test tape with specially selected stereo material and to record the results in at least two locations, one of which will have low signal strength, and one or both will have ignition interference, multipath propagation, etc. It is very likely that Station KDKA-FM in Pittsburgh will be used for these tests and possibly other stations as well. Each proponent who wishes to have his system field tested will be expected to provide the necessary equipment to be associated with the transmitter and the necessary receivers and to demonstrate that these can be readily set up for use.

The Federal Communications Commission will then have the decision to make as to the relative importance in the public interest of the various factors on page 2. The work done to date by the NSRC should be of invaluable assistance to the FCC in carrying out this difficult task.

CGLloyd:FLS
March 29, 1960

Attachments:

Appendix I	- NSRC Organizational Structure
Table 1	- FM Stereo Systems with FM Subcarriers
Table 2	- FM Stereo Systems with AM Subcarriers
Table 3	- TV Sound Stereo Systems
Table 4	- AM Stereo Systems

APPENDIX I

NATIONAL STEREOPHONIC RADIO COMMITTEE ORGANIZATIONAL STRUCTURE

ADMINISTRATIVE COMMITTEE:

Chairman:	W. R. G. Baker	- 601 Scott Ave., Syracuse, N.Y.
Vice Ch.:	D. B. Smith	- Philco Corporation
Members:	D. G. Fink	- Philco Corporation
	A. N. Goldsmith	- 597 Fifth Ave., New York 17, N. Y.
	I. J. Kaar	- Hoffman Electronics Corporation
	A. V. Loughren	- Airborne Instrument Laboratories

NATIONAL STEREOPHONIC RADIO COMMITTEE:

Chairman:	F. R. Lack	- Director, EIA Engineering Department
Former Ch:	C. G. Lloyd	- General Electric Company
Vice Ch:	R. N. Harmon	- Westinghouse Broadcasting Co., Inc.
Secretary:	V. M. Graham	- Electronic Industries Association

COORDINATION COMMITTEE:

Chairman: D. G. Fink - Philco Corporation

Scope: This Committee shall coordinate the activities of the Panels, shall prepare definitions, and shall prepare NSRC Reports and all Press Releases for the approval of the NSRC.

PANEL 1 - SYSTEM SPECIFICATIONS

Former Chairman: C. J. Hirsch - Formerly, Hazeltine Research Corporation, Presently, Radio Corporation of America

Acting Chairman: W. T. Wintringham- Bell Telephone Laboratories

Scope: Panel 1 shall consider system proposals for compatible stereophonic broadcasting; shall identify the technical issues in said proposals and refer them where necessary to other panels for detailed study; shall formulate a consistent set of transmission specifications for each form of broadcasting; and shall provide an overall evaluation of the system performance implied in the specifications.

PANEL 2 - INTERCONNECTING FACILITIES

Chairman: Axel Jensen - 21 Mea Drive, Berkeley Heights, N. J.
Vice Ch: J. M. Barstow - Bell Telephone Laboratories

Scope: Panel 2 shall study and recommend technical characteristics of interconnecting lines, networks, studio-transmitter links and related stereo-transmission facilities between program origination points and the transmitters proper, said characteristics to include tolerable limits on crosstalk, relative time delay, frequency response, gain, and such other matters as must be controlled to assure a stereo signal of adequate quality at the transmitter input.

APPENDIX I (CONTINUED)

PANEL 3 - BROADCAST TRANSMITTERS

Chairman: Ralph N. Harmon - Westinghouse Broadcasting Co., Inc.
Vice Ch.: H. G. Towlson - General Electric Company

Scope: Panel 3 shall study the system proposals referred to it by Panel 1 with particular regard to (1) the feasibility of the proposed transmission methods and (2) methods of adapting the proposals to existing broadcast transmitters.

PANEL 4 - BROADCAST RECEIVERS

Chairman: J. N. Benjamin - David Bogen Company
Vice Ch.: F. B. Williams - Motorola, Inc.

Scope: Panel 4 shall study the system proposals referred to it by Panel 1 with particular regard to (1) the performance of existing monophonic receivers when tuned to the stereophonic signal and signals (receiver compatibility), (2) the performance of stereophonic receivers designed for the stereophonic signal (stereo performance) and (3) the performance of stereophonic receivers when tuned to monophonic signals (reverse receiver compatibility).

PANEL 5 - FIELD TESTING

Chairman: A. Prose Walker - National Association of Broadcasters
Vice Ch.: R. H. Beville - Radio Stations WWDC and WWDC-FM

Scope: Panel 5 shall study and compare the system proposals referred to it by Panel 1 and the existing services with particular regard to coverage, interference effects and other matters related to channel utilization; and shall conduct field tests with the advice and assistance of the other Panels.

PANEL 6 - SUBJECTIVE ASPECTS

Chairman: Dr. A. N. Goldsmith - 597 Fifth Ave., New York 17, New York
Vice Ch.: Dr. M. R. Schroeder - Bell Telephone Laboratories

Scope: Panel 6 shall provide to the other panels the available scientific information on the subjective aspects of the stereophonic reproduction of sound.

TABLE 1

FM STEREO SYSTEMS WITH FM SUBCARRIERS

SYSTEM		MAIN CHANNEL			SUBCARRIER			
NSRC #	PROPONENT	SIGNAL	BAND-WIDTH KC	% MOD	SIGNAL	BAND-WIDTH KC	FREQ KC	SWING KC
1)	CROSBY	L+R	15	50	L−R	15	50	±25
2a.	CALBEST	L+R	15	80	−R	7	29.5	±9.5
2b.	MULTIPLEX	2L −R	15	70	2R−L	8	41	±9.5
3	EMI	L+R	15	90	$\frac{L'}{L'+R'}$	0.150	22	±0.5

NSRC #	SUBCARRIER % MOD OF MAIN CARRIER	S/N LOSS C F NORMAL FM (db)		SPECTRUM AVAILABLE (KC)
		MONO	STEREO	
1.)	50%	6	13	—
2a.	20%	2	14.5	39.5 − 75
2b.	20%	3	14L,20R	58 − 75
3	10%	<1	<1	25 − 75

TABLE 2

FM STEREO SYSTEMS WITH AM SUBCARRIERS

	SYSTEM	MAIN CHANNEL			SUBCARRIER *		
NSRC #	PROPONENT	SIGNAL	BAND-WIDTH KC	% MOD	SIGNAL	BAND-WIDTH KC	FREQ KC
4.	ZENITH	L+R	15	90	L−R	15	39
4a	GENERAL ELECTRIC	L+R	15	90	L−R	15	38

	% MOD OF MAIN CARRIER		S/N LOSS CF NORMAL FM (db)		SPECTRUM AVAILABLE (KC)
NSRC #	SIDEBANDS	PILOT	MONO	STEREO	
4.	93 1/3	6 2/3 @ 19.5 KC	< 1	20	58-75
4a	90	10% @ 19 KC	< 1	20	58-75

* BOTH ARE DOUBLE SIDEBAND SUPPRESSED CARRIER

TABLE 3
TV SOUND STEREO SYSTEMS

SYSTEM	MAIN CHANNEL			SUBCARRIER			
	SIGNAL	BAND-WIDTH KC	% MOD	SIGNAL	BAND-WIDTH KC	FREQ KC	NOTES
EMI	L+R	15	>90	$\frac{L'}{L'+R'}$	0.1	22	A
GENERAL ELECTRIC	L+R	15	62 1/2	L−R	15	23.6	B
MOTOROLA	L+R	12	85	L−R	0.3-4	23.6	C
PHILCO	L+R	7	95	L−R	0.5-7	15-75	D

NOTES:

A SAME AS FM SYSTEM

B DOUBLE SIDEBAND AM
(LOWER SIDEBAND FREQ LIMITED)

C ±5 KC SWING FM

D LOWER SIDE BAND SUPPRESSED CARRIER

TABLE 4
AM STEREO SYSTEMS

SYSTEM	L+R INFORMATION	L-R INFORMATION	
		BANDWIDTH KC	HOW OBTAINED
CBS	NORMAL AM		PHASE MOD
PHILCO	NORMAL AM	0.3	PHASE MOD
GENERAL ELECTRIC	NORMAL AM	0.3-4	$\pm$4 KC FM
RCA	NORMAL AM		$\pm$0.5 KC FM
WESTINGHOUSE	NORMAL AM	0.3-3	$\pm$3 KC FM
EMI	NORMAL AM	0.1	$\pm$0.2 KC FM
KAHN	(L ON ONE SIDEBAND, R ON THE OTHER)		

4

SINE SQUARED PULSES IN TV SYSTEM ANALYSIS

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ENGINEERING DEVELOPMENT

SINE SQUARED PULSES IN TV SYSTEM ANALYSIS

Introduction

Delineation of suitable signals for accurately appraising the performance of a particular transmission system always offers a challenge. This is particularly true of wideband systems, e.g., radar, microwave, computers, television, etc. Furthermore, the greater the number of criteria used to judge a system the greater the complexity of a test signal or alternatively the greater the number of individual test signals which must be used.(1) Additionally there is the further complication of trying to evaluate overall system performance while the circuit is in use. (2)

The nature of television signals is such that the system must meet the most rigorous of standards especially when color television signals are being transmitted.(3) Among the various distortions which can affect a color signal are amplitude and phase versus frequency, linearity of amplification versus signal level, differential gain and phase, and transient response. Thus far, suitable signals are available for testing the amplitude versus frequency response by means of multiburst, linearity by means of stair steps, and differential gain and phase by means of modulated stair steps. Recently the $\sin^2$ pulse has begun to be accepted here in the United States.(4) This signal offers some interesting possibilities not only in transient evaluation of television systems but in the areas of envelope delay and linearity testing as well.

The pioneer work on all the techniques to be described have long been known to numerous investigators in England and on the Continent. (5,6,7,8,9) In fact, Eurovision broadcasting would certainly be much more difficult without $\sin^2$ pulse testing techniques. The magnitude of the problem may be appreciated when one considers the fact that three scanning rates of 405 lines, 625 lines, and 819 lines are currently in use in various countries, all of whom are actively engaged in broadcasting programs which originate with any one or more of the three scanning rates.

Theory of Waveform Choice

Like other test signals discussed above, the $\sin^2$ pulse does not supercede nor replace other test signals. It has its specific uses which supplement and augment functions of other test signals. Initially the $\sin^2$ pulse was intended to provide a very specific need for a transient test tool. As such, it appears to be particularly well chosen since it permits an accurate evaluation of the performance of a system when that system is being subjected to the same form of data as it is when transmitting actual picture data. Cooper has shown (10) that scanning horizontally across a vertical black-to-white transition with a conventional camera tube whose beam has a finite diameter does not result in an abrupt change in output signal voltage. Instead the change is somewhat "S" shaped having sharp knees at the bottom and top with reverse curvature in the middle. The whole transition closely resembles the peak to peak excursion of a sinuscid. See FIGURE 1.

Further investigation shows that the frequency of the sine wave is limited by and is equal to the system bandwidth for conventional camera tubes. Actually, the period of the sine wave from the camera tube is equal to two times the period represented by the beam diameter. This period represents the maximum resolution of the camera tube. This resolution is somewhat higher than that possible in the conventional 4 mc/s system. The pulse suitable for testing such a system has a frequency of 4 mc/s. It is common practice to define the test pulse in terms of T, its half amplifude duration (h.a.d.). See FIGURE 2. The relationship between system bandwidth f and T is given by:

$$f = \frac{1}{2T}$$

For a 4 mc/s system, T= 0.125 usec. It is also common practice to set the

For a 4 mc/s system, T=0.125 usec. It is also common practice to set the pulse on the conventional synchronizing waveform. Thus the pulse has a repetition rate of line frequency.

Pulse Spectrum

Fourier analysis for such a waveform shows that there are components in its spectrum spaced every 15,750 cycles/sec extending up to a frequency $f=\frac{1}{T}$. The general shape of the spectrum amplitude closely approximates the response of a low pass filter. At $f=\frac{1}{2T}$ the amplitude of the component is down 6db in power from the fundamental amplitude. At $f=\frac{1}{T}$ the spectrum amplitude is zero and remains at least 35db down from the fundamental amplitude for all higher frequency components. See FIGURE 3. Thus the test pulse has accurately predictable and controllable components which test the system in the frequency range of normal use. This is one essential difference between $\sin^2$ pulse testing and the usual square wave test signal. The square wave has components which extend way beyond the bandwidth required. These components cause overshoot, ringing, and phase shift which do not normally occur on picture data. As a result, the transient response will appear much worse than it really is or else the system bandwidth must be vastly and unnecessarily extended to make the square wave response appear satisfactory.

Not only does the $\sin^2$ pulse test the system in the proper frequency range, but it also does so more rigorously. As is well known, the ideal bandwidth limiting of a perfect system results in a Heaviside step having a Gibb's overshoot of 8.9%. The same system causes 13% overshoot in a $\sin^2$ pulse as it becomes $\frac{\sin x}{x}$ in shape. See FIGURE 4. As a result, the $\sin^2$ pulse makes a more sensitive test means than the square wave.

Further, the group delay characteristic of the pulse is constant to a frequency well above $\frac{1}{2T}$. Thus extremely precise symmetry around the pulse maximum amplitude axis exists. This makes the pulse particularly sensitive to phase distortion. Additionally the type of phase shift occurring in a system is clearly shown by the pulse. If high frequency delay is less than for low frequencies, a ripple occurs on the leading side of the pulse. See FIGURE 5. If the opposite type of delay exists, the ripple follows the pulse.

Reproducability of Pulse

A further advantage to the $\sin^2$ pulse is the fact that pulse generators can be easily built which generate pulses whose actual shape deviates less than 1% from the true mathematical $\sin^2$ pulse shape. See FIGURE 6 and 7. This means that it is possible to have all test pulses alike.(6,11,12). Furthermore, the essential active element is a blocking oscillator whose output closely approximates an isosceles triangle. This impulse is shaped into a $\sin^2$ pulse by means of a passive network. Once the filter elements have been properly measured and assembled, the desired pulse shape will be assured for wide variations in tube characteristics. It should be noted that this is in marked contrast to square wave generators whose waveforms do not have constant shapes during tube aging nor the same shape for a group of generators.

Testing Techniques

Transient testing of wideband systems creates the demand for several test pulses each of which is sensitive to distortions occurring in different portions of the system bandwidth. To assure proper transmission of the vertical component, a test signal must be capable of revealing frequency response and particularily the phase response of the region around 60c/s.

Proper performance of clamper amplifiers is likewise essential. It is highly desireable to have some test means for evaluating pulse tilt at line frequency so as to be able to test such amplifiers. Additionally, the testing of the system in both its midband and upper frequency portiohs is necessary.

Hence it has become common practice to utilize four test signals. The common 60c/s square wave and submultiples is used to determine the performance of systems components which do not have clampers in them. The amount of tolerable tilt is engraved on a scope graticule so that one may quickly judge the acceptibility of a component.

The second test waveform is a shaped bar type of signal commonly called "window" in this country. The bar has a duration of approximately one half line. The rise and fall edges of the bar are given a $\sin^2$ shape corresponding to the 2T pulse. Thus there are no components in the bar spectrum having frequencies above 4 mc/s. As a result, no ringing can appear on the bar due to upper bandwidth limitation. This signal is particularily sensitive to distortions from line frequency to several hundred kilocycles. As a result, malfunctioning of clampers which cause smear or streaking in a picture may be observed and properly corrected.

The third test signal is the 2T $\sin^2$ pulse. It, like the shaped bar, contains no data above 4 mc/s. It has a (h.a.d.) of 0.25 usec for a 4 mc/s, bandwidth system. It is particularily sensitive to distortions occurring in the spectrum between about 0.5 and 2 mc/s. As such it is well suited for routine adjustments of a system where it is not possible or desirable to make a detailed system analysis.

Finally the fourth or T pulse is reserved for the upper region of the spectrum. It has a (h.a.d.) of 0.125 usec. for the 4 mc/s system. Its spectrum is 6db down in power at 4 mc/s and is zero at 8 mc/s. It therefore does contain sufficient data to permit evaluating the transient conditions in the region of cutoff in the sideband filter of the transmitter where excessive phase shifts may occur.

It is conventional to transmit the shaped bar during the last half of a horizontal line and to precede it with either the T or 2T pulse on the same pedestal. See FIGURE 8. The generator usually has a switch for selecting the desired pulse.

Rating Factor

It was recognized quite early in the investigations in Europe that little correlation existed between transient and steady state testing since mathematically time and frequency domains are related by transforms e.g., LaPlace, Heaviside, Fourier, Mellin, etc. This means that no assurance could be given that for example doubling the system bandwidth would produce improvement in picture quality. Further, a broad dip of a couple of db. at say 50 kc/s will cause far more waveform distortion than a very sharp hole of 5 or 10 db. at say 500 kc/s. In order to try to establish order, the Post Office Department and the BBC conducted a series of interesting tests. A group of about twenty television engineers were chosen as subjective observers. A scanner and monitors were set up and a sequence of different test slides were chosen. The circuit between the scanner and the monitors was distorted in a particular manner. The slides were viewed on the monitors and evaluated on a scale of five. A $\sin^2$ pulse was then fed through the circuit and its waveform photographed. Numerous forms of distortion were introduced and individually treated in the same manner. Separate steady state measurements were also made.

With these data it was possible to evolve what is termed a rating factor for the system. The rating factor is a number assigned a system based upon the quality of $\sin^2$ pulse transmission. For certain forms of distortion, a 5% rating factor may produce a totally useless picture. A 3% rating factor is usually acceptable for remote circuits or complete systems. Some of the newer circuits in England have rating factors of 0.25%.

Routine Test

One virtue of the rating factor is that two different methods of evaluating circuit performance are possible. The "routine-test" method permits evaluations of remote circuits and daily tests of transmission equipment. It consists of a few simple measurements using a standard oscilloscope and the use of the following table:

Features	1%	2%	3%	4%	5%	6%
Half-amplitude duration, maximum (us)	.185	.190	.195	.200	.205	.210
Ringing Frequency, minimum (mc/s)	4	4	4	4	4	4
First Lobe (negative), leading or trailing (%)	10	12	14	16	18	20
Second lobe (positive), leading or trailing (%)	6	8	9	10	11	12

Acceptance Test

The second method of circuit evaluation is by the "aceeptance test." Photographs of the system output waveforms are taken and include an 8 mc/s, sinewave as a time base. The waveform is divided into intervals of 0.125 usec. starting with the axis of maximum pulse amplitude as zero. A comparator microscope is used to measure the waveform ordinates at each time interval. All ordinates are normalized using the maximum pulse amplitude as unity. A time series is then formed of these data. It is the realization of the time-series that makes the $\sin^2$ pulse such a powerful tool both for analysis and synthesis. With it one is able to answer such questions as:

1. Given the individual time-series (responses) of each of a chain of different circuits to a specified signal. What would be the overall response of the chain to the same signal? Thus if we know for example the time-series for NY to chicago, Chicago to Denver, and Denver to Los Angeles, individually, we can compute the NY to Los Angeles response.
2. Given the waveform responses of the whole and one part of a chain of networks to a specified signal, what response would the remaining part have to the same signal? This is essentially a statement of the equalizer problem. If the desired response is known as well as the response of the circuit alone, it is possible to determine the response which an equalizer must have to correct for the circuit deficiencies.

Equalizers

Considerable work has been done on the design of equalizers for providing a wide range of equalization for correcting waveform responses. One type (13) which is particularly suitable for correcting remote circuits or other temporary applications makes use of the echoes occurring on tapped delay lines. This is a manually adjustable device and optimum equalization is obtained by visual inspection of the equalizer output as adjustments are made.

Another equalizer has also been developed which permits manually optimizing the response. The various adjustable components are calibrated. From the readings it is possible to design a fixed equalizer having the same time response which may then be substituted for the adjustable equalizer.

Vertical Interval Testing

The EIA in making recommendations for Vertical Interval Test Signal transmission suggested that such signals be confined to the last 12 usec of line 17 and all of lines 18, 19 and 20 of the vertical blanking interval. Line 1 of Field 1 begins with the first equalizing pulse. Line 1 of Field 2 begins ½ line after the first equalizing pulse.

In addition to uses already discussed it should be pointed out that the $\sin^2$ pulse and bar signal may be transmitted during lines 18, 19 or 20 of the vertical blanking interval so as to provide a constant means of evaluating system performance. This technique had its origins in Germany in 1952, (14) and has become widely used in Europe and here.

Envelope Delay in Color Systems

There is another area where it appears that the $\sin^2$ pulse may have some application. The FCC standards for color television include an envelope delay specification. There is belief in some quarters that the original intent was to assure the same time delay for the luminance as for chrominance component of the signal. If this is the object, then a very simple technique has been proposed (15) wherein a T pulse (h.a.d.) of 1 usec., or a 2T (h.a.d.) of 2 usec for Q-channel testing modulated by subcarrier sine wave during alternate lines. Thus the T pulse has a duration of 3.58 cycles of subcarrier and the 2T pulse a duration of 7.16 cycles. Since lines having the $\sin^2$ pulse alternate with lines having the modulation it is possible to superimpose the two waveforms by proper adjustment of the oscilloscope. If the time delay for the pulse (luminance component) is different from the modulation (chrominance component), they will not register and the difference in delay may be easily determined. Further, this same presentation shows whether the frequency response of the system is flat since again complete registry should occur.

Linearity Testing

As indicated earlier the $\sin^2$ technique may be used for linearity testing. This is perhaps misleading and still the technique makes use of conventional $\sin^2$ shaping filters so it is included for the sake of completeness.

The conventional signal used for testing linearity is the stair step. Usually ten steps are used. For the proposed test the number of steps is first reduced to five and the signal is introduced into the system. At the output the signal is differentiated so that spikes all having a common base result. This signal is fed into a $\sin^2$ pulse shaping filter so as to bandwidth limit the noise and is then presented on an oscilloscope. It is a simple matter to see whether all five pulses have identical amplitude (the case for perfect linearity).

The shaping filter should be such as to produce a 2.75 usec h.a.d. pulse in the conventional manner. The response is 6db down at 182 kc/s and zero 364 kc/s. If more steps are used it becomes necessary to use narrower pulses which in turn have wider bandwidth and consequently introduces more noise with consequent error.

Conclusions

As was indicated at the beginning this paper is intended as a survey of the uses of the $\sin^2$ pulse; to try to show where it may provide more direct means of evaluating circuits; and finally to establish techniques for general picture enhansement. The equipment for some uses is complex, for others it is relatively simple. There is, however, a great amount of material available in the literature and more will doubtless appear (16). In broad perspective the $\sin^2$ pulse is a powerful tool. It can reveal many deficiencies. It requires a certain amount of education and experience to appreciate its full potential.

It would be very difficult indeed to give credit to all the various workers who have made contributions to this broad subject. However, the following people have shown me work being pursued in their laboratories while I was in Europe in 1955 and 1958.

Dr. ARA Rendall, Mr S N Watson and Mr Geoffrey G Gouriett of the BBC; Drs. N W Lewis and J M Linke and Mr I F Macdiarmid of the Post Office Research Station at Dollis Hills, London. Dr. R Jacob of Sender Freies, Berlin, and Mr P Denis of Radiodiffusion et Television Francaise, Paris.

I should also like to express appreciation to Mr A L Hammerschmidt, Vice-President of Engineering and Facilities Administration and to Mr George M Nixon, Director of the Development Laboratory for valuable suggestions during the preparation of this paper.

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16. I. F. Macdiarmid, "Waveform Distortion in Television Links". The Post Office Electrical Engineers Journal. (British), 1959, Vol. 52, Parts 2 and 3, July and October.

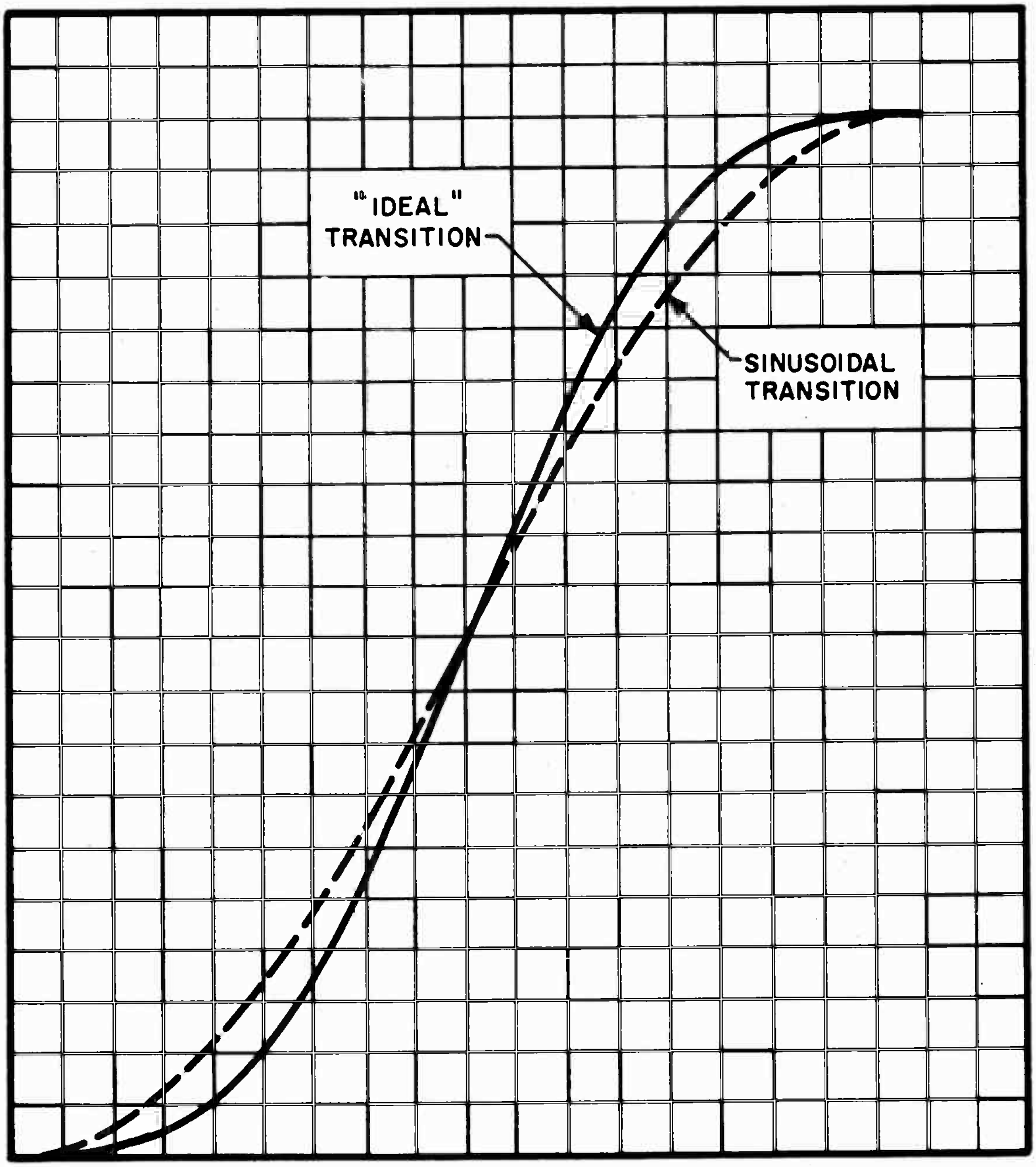


FIG. 1

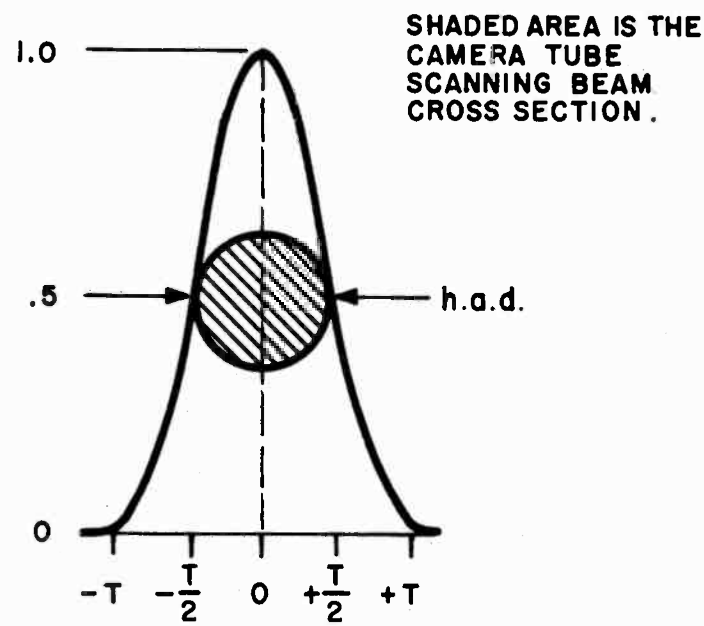
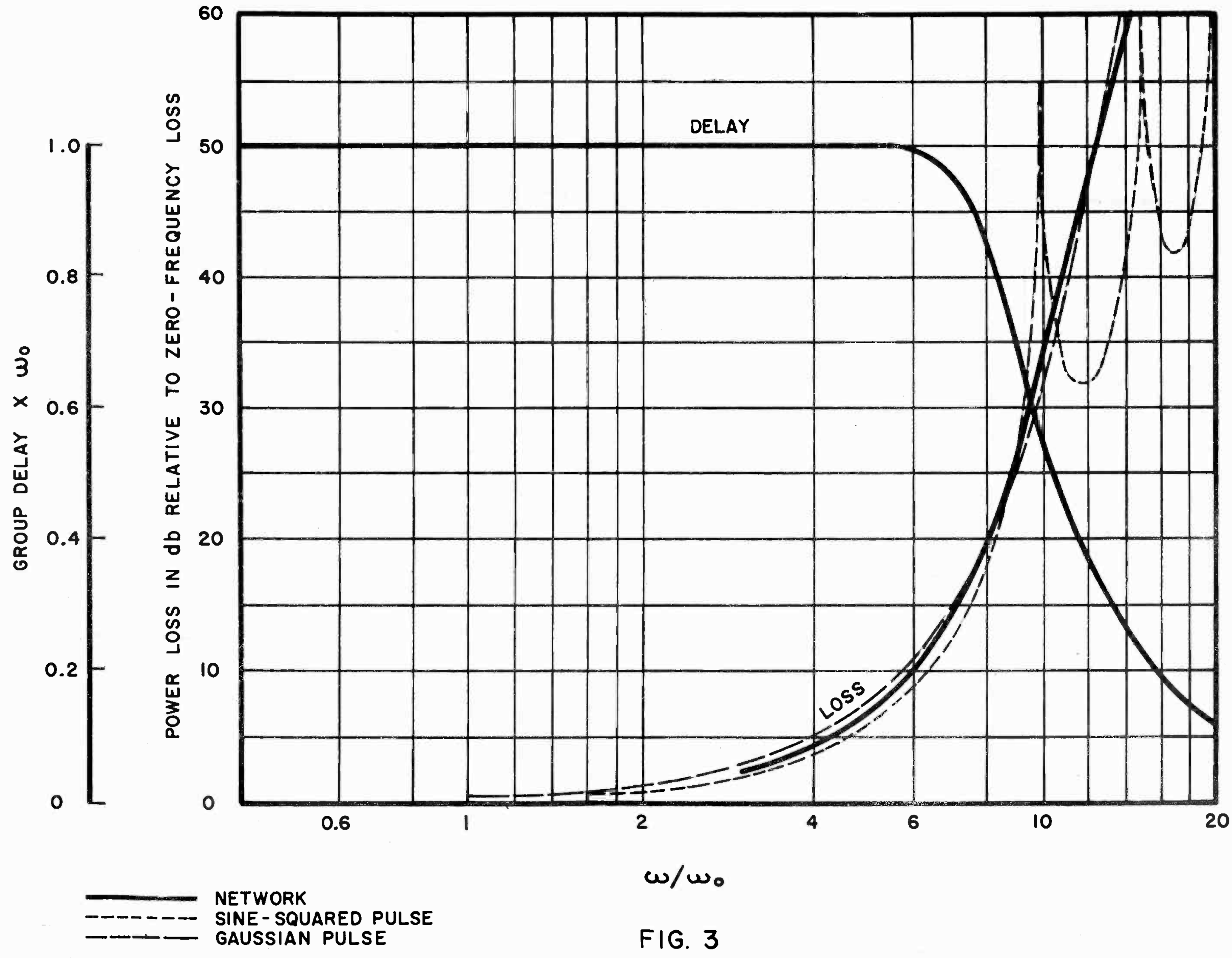

SHADED AREA IS THE
CAMERA TUBE
SCANNING BEAM
CROSS SECTION.
1.0
.5
0
h.a.d.
-T
-T/2
0
+T/2
+T

FIG. 2



GROUP DELAY X ω_0
0
0.2
0.4
0.6
0.8
1.0
POWER LOSS IN db RELATIVE TO ZERO-FREQUENCY LOSS
0
10
20
30
40
50
60
DELAY
LOSS
0.6
1
2
4
6
10
20
ω/ω_0
NETWORK
SINE-SQUARED PULSE
GAUSSIAN PULSE

FIG. 3

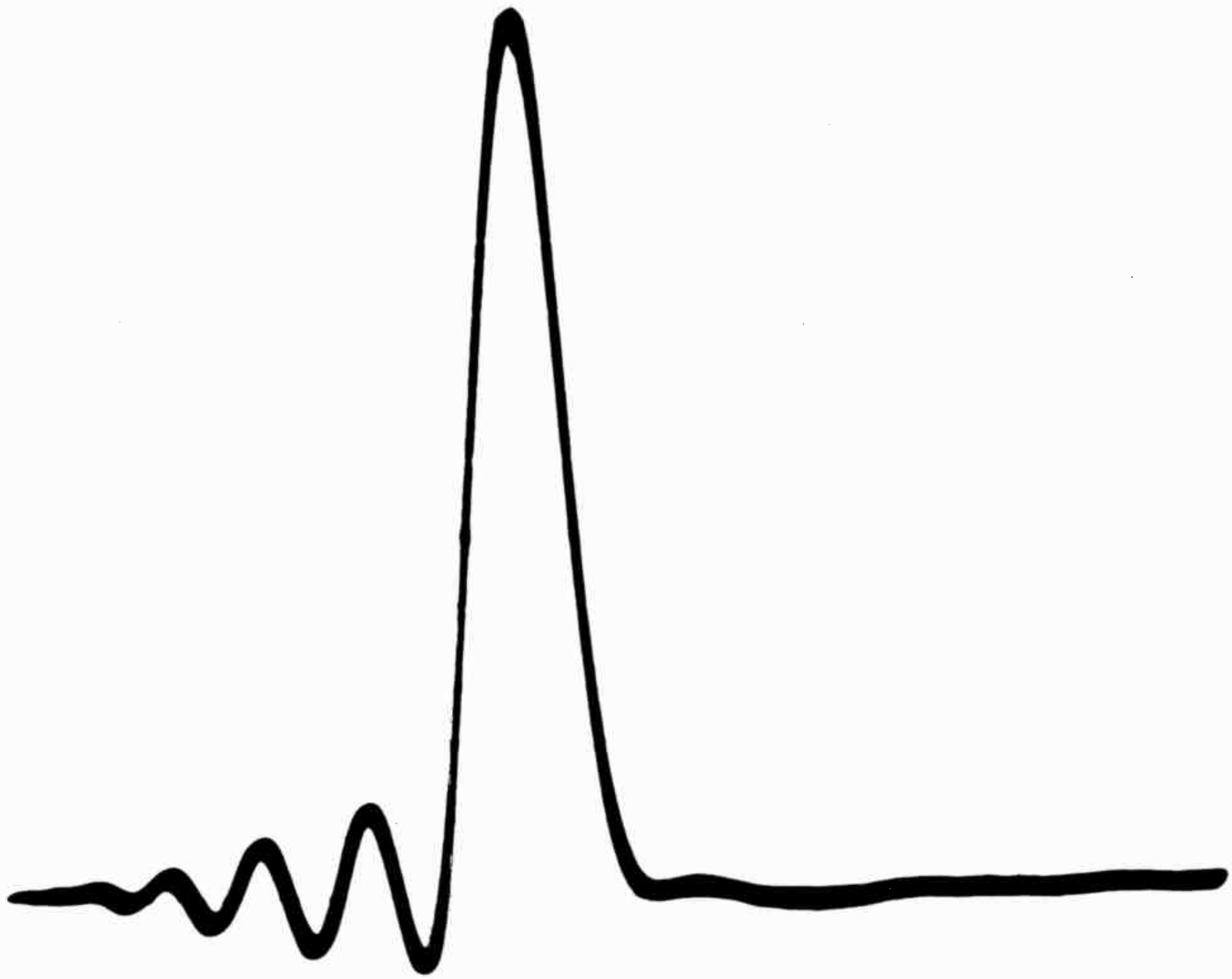
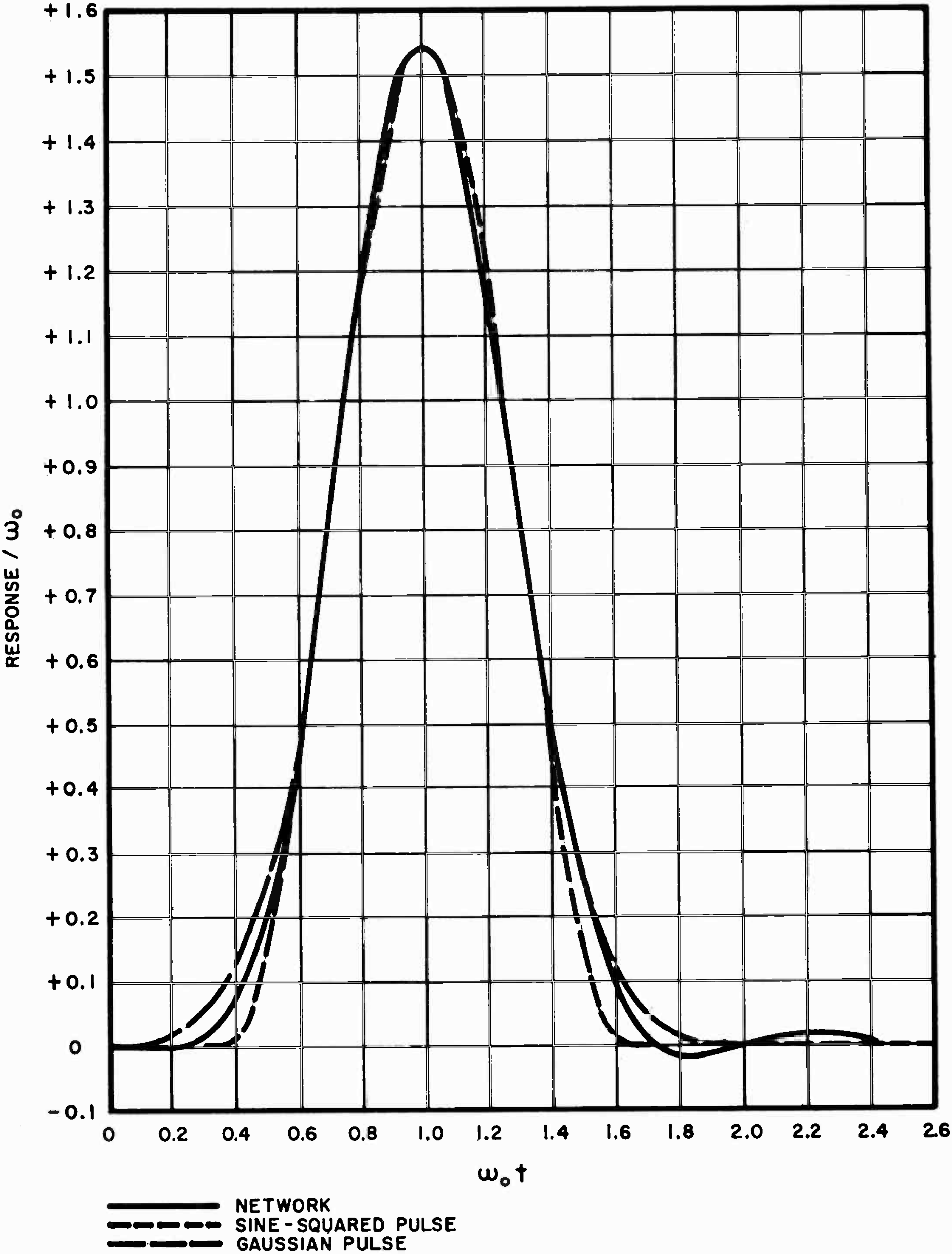


FIG. 5



+1.6
+1.5
+1.4
+1.3
+1.2
+1.1
+1.0
+0.9
+0.8
+0.7
+0.6
+0.5
+0.4
+0.3
+0.2
+0.1
0
-0.1
RESPONSE / ω₀
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4
2.6
ω₀t
NETWORK
SINE-SQUARED PULSE
GAUSSIAN PULSE

FIG. 6

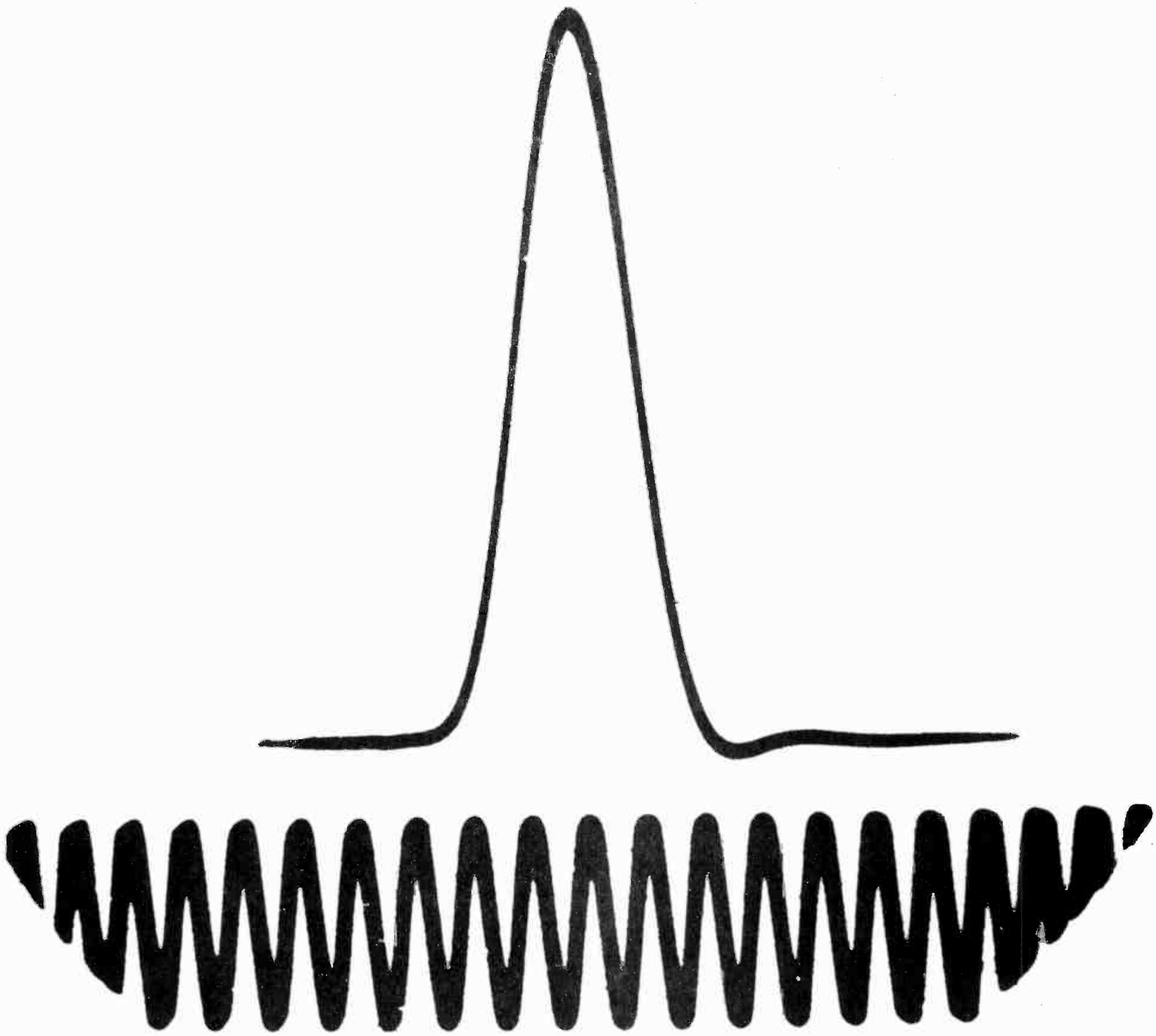


FIG. 7

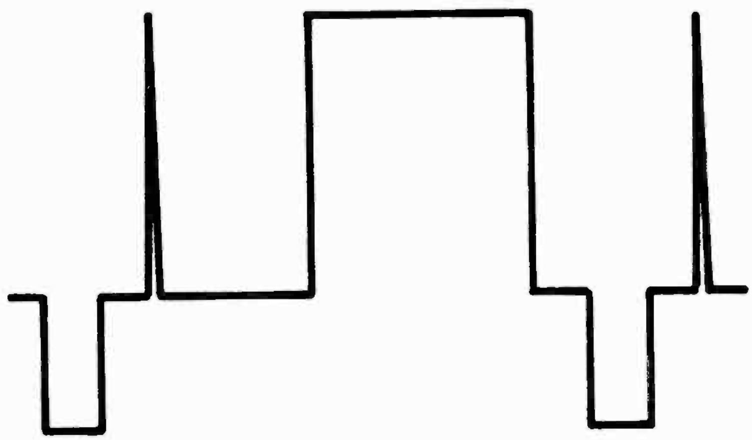


FIG. 8

Improving Picture Quality Through Phase Equalization

By: R. S. Jose
Broadcast Transmitter Engineering
Radio Corporation of America

Most broadcasters are often aware that picture quality is affected, usually deleteriously, when comparison is made between a live camera monitor and the normal house receiver.

It is the purpose of this paper to examine some of the factors having to do with the broad area of phase characteristics leading to this situation and to show what can be done to minimize the degradation.

If a TV picture is to be transmitted faithfully, the components of that picture must not be altered by the system in phase or amplitude over the frequency spectrum utilized in transmitting that picture. As is well known, to do this in a brute force manner by making all components of the system "flat" to the extent that each individual system element contributes negligible alteration requires excessive bandwidth so that spectrum conservation measures leading to the vestigial sideband system were adopted.

In such a system, the amplitude of the video signal components are changed at various points in the system, and the overall system amplitude response from the camera to the kinescope grid is reasonably uniform. However, there are a number of system elements which do produce phase alteration along with amplitude variation which produces an overall non-constant phase. Among these, for example, are the vestigial sideband filter and the receiver. There is picture degradation associated with this non-uniform phase, but until the advent of color it received little attention, as the monochrome degradation was not deemed serious and in addition the state of the art was such as to preclude convenient precise measurement and correction of the phase characteristic.

With the requirements imposed in meeting color TV standards and with the advent of recently developed equipment, the neglected phase characteristic can approach a degree of familiarity once reserved for amplitude response. Its measurement with precision, its correction and picture improvement associated with that correction can be handled and observed quite easily.

To discuss the phase characteristic more meaningfully, the generally accepted terminology needs to be established. A perfect television system would possess a phase characteristic which is directly proportional to frequency, as in Slide 1. This is generally referred to as a linear phase characteristic. An actual system might be generally linear but with deviations from linearity. (Refer to slide) To give these deviations more weight and meaning, the slope at every point of the phase versus frequency can be plotted. The slope is the phase shift at a particular frequency divided by that angular frequency ($\frac{\Omega}{2\pi f}$). This has the dimension of time with the magnitude of microseconds usually and is commonly referred to as time delay. If the system phase characteristic is perfectly linear, the above quotient is a constant; therefore, the delay has a fixed value at any video frequency. This is equivalent to saying that all frequency components of a video signal are delayed by an equal amount of time in passing through the system. A still more refined way of examining the variations in phase is to examine the phase spectrum in small increments or packages. By taking a small (incremental) change of frequency and dividing the amount of phase shift change which occurs over this frequency increment by the angular frequency increment ($\frac{\Delta \theta}{2\pi \Delta f}$) the result still has the dimensions of time again microseconds usually and is called group delay or envelope delay. Again, if the phase characteristic is linear, the amount of phase change is the same for equal frequency increments at any video frequency so that it may be seen that in a perfect system the envelope delay is constant.

Having established the background let us now turn to the performance of the system. The response of a non-compensated vestigial sideband transmission system to a 100 kc square wave is shown in Slide 2. The anticipatory transients or leading white, the low frequency smear component following the transition, and the unsymmetric ringing are all due to non-uniform system envelope delay.

The amplitude, phase and delay characteristic of the typical system are shown in Slide 3. The upper left curve is the amplitude response of the transmitter (T) and receiver (R). The associated phase characteristic of each is shown at the upper right and the super-imposed amplitude and phase response of these two elements shown at lower right. The equivalent video phase and delay characteristics of the two system elements are shown at lower right. In the latter, it is this variation from ideal that produces the defects on the square wave shown earlier. Note that the most drastic errors in phase and delay occur when the amplitude response changes most rapidly - in the cut-off region of the VSBF filter just below visual carrier and in the sound trap frequency (4. 5 mc above visual carrier) in the receiver. This relationship holds as a general principle from network theory - amplitude variation in the majority of cases is accompanied by phase (and envelope delay) change over a greater range of frequency than is involved in the amplitude change and the amount of change is proportional to the amount of amplitude variation.

The overall delay characteristic can be obtained by algebraically summing the contributions of the individual elements. Slide 4 shows the measured contribution of delay distortion of the transmitter modulator alone and of the transmitter. Note that since these two components are relatively flat amplitude-wise the delay error over the video band is relatively small, as will be seen by comparison in some of the later figures.

Slide 5 shows the measured delay after the VSBF, again for an uncompensated case. This figure shows the correlation between two methods of measurement which will be explained later. Here again, where the VSBF has a relatively flat amplitude response, the delay distortion in the single sideband region is reasonably low except at the very high end. The filter introduces constant overall delay of approximately -0. 15 us sec.

Slide 6 shows the calculated response of a transmitter plus a filterplexer. The same to-be-dealt-with-later two methods of measurements are shown. This figure shows the low frequency distortion due to the cut-off of the filter. Also, the high frequencies show delay distortion due to the filter's amplitude notch at picture carrier plus 4. 5 mc. This is similar in character though not in precise value to the sound notch in the receiver and shows the general nature of the compensation which will be required. It further illustrates the dependence of the delay characteristic on the amplitude characteristic.

In passing, it is to be noted that the studio and terminal equipment has such a wide band flat response that little delay distortion is contributed by this equipment. The proof of this is the high quality of the picture fed to the visual transmitter.

Since the objective for distortless transmission is to achieve no delay variation, some correction of the foregoing is necessary. The delay associated with the high frequency sound notch of the receiver is compensated according to a standard curve shown in Slide 7. This represents the complementary delay of a figure arrived at by calculation and by a number of measurements of typical receivers. It is assumed, by NTSC system stipulation, that the receivers compensate themselves internally for any low frequency delay error. Therefore, no low frequency receiver equalization correction is provided. Since the low frequency amplitude response due to the VSBF is known and controlled within limits, the delay correction for its delay distortion can be established therefrom in accordance with the previously mentioned relationship and correction provided.

Therefore, in practice the commercially available delay equalizers have two principal overall sub-divisions - one for the high frequencies and one for the low. The functional division and elements are shown in Slide 8. Within these sub-division there are fixed delay equalizers to correct the known delay distortion such as contributed by the VSBF and by the receiver. Each has variable sections for touching up the delay in individual cases where the fixed sections do not do all that could be desired.

One approximate method of adjusting the variable equalization and evaluating the system is to use a square wave as the video input signal and adjust the equalizers for the best square wave output from a vestigial sideband demodulator. This approach results in practice in a square wave output which is shown in Slide 9. It is evident that the phase correction has improved the transition by removing the low frequency smear component, reducing the ringing amplitude and distributing it equally on each side of the transition. This approach may produce a good subjective system performance but does not give any quantitative results. Further observation is necessary to determine the color performance of a system so adjusted, particularly the delay match of the low frequency luminance information and high frequency chrominance information. It does not cover the demonstration of compliance with the FCC regulation which specifies the delay characteristic in terms of microseconds over the video frequency range.

Direct measurement of the envelop delay for quantitative determination of the characteristic has several advantages over the square-wave approach. The system delay compensation and variable equalization can be adjusted precisely. The delay characteristic of each element of the system can be measured, which would be difficult if not impossible using square waves. In addition, the transmitter system delay characteristic can be measured in accordance with the FCC regulations.

While it is possible to measure the system phase characteristic and compute therefrom the delay characteristic it is an exceedingly cumbersome procedure, particularly as regards instrumentation to achieve the precision required.

A sweep method has been employed but commercially available equipment does not provide a low frequency delay reference as required by the FCC and so therefore provides only a partial answer, the rest being supplied by a square wave as usually done at present.

There is now available a unit which satisfies this need, and in addition to being compact requires, no special skill to operate.

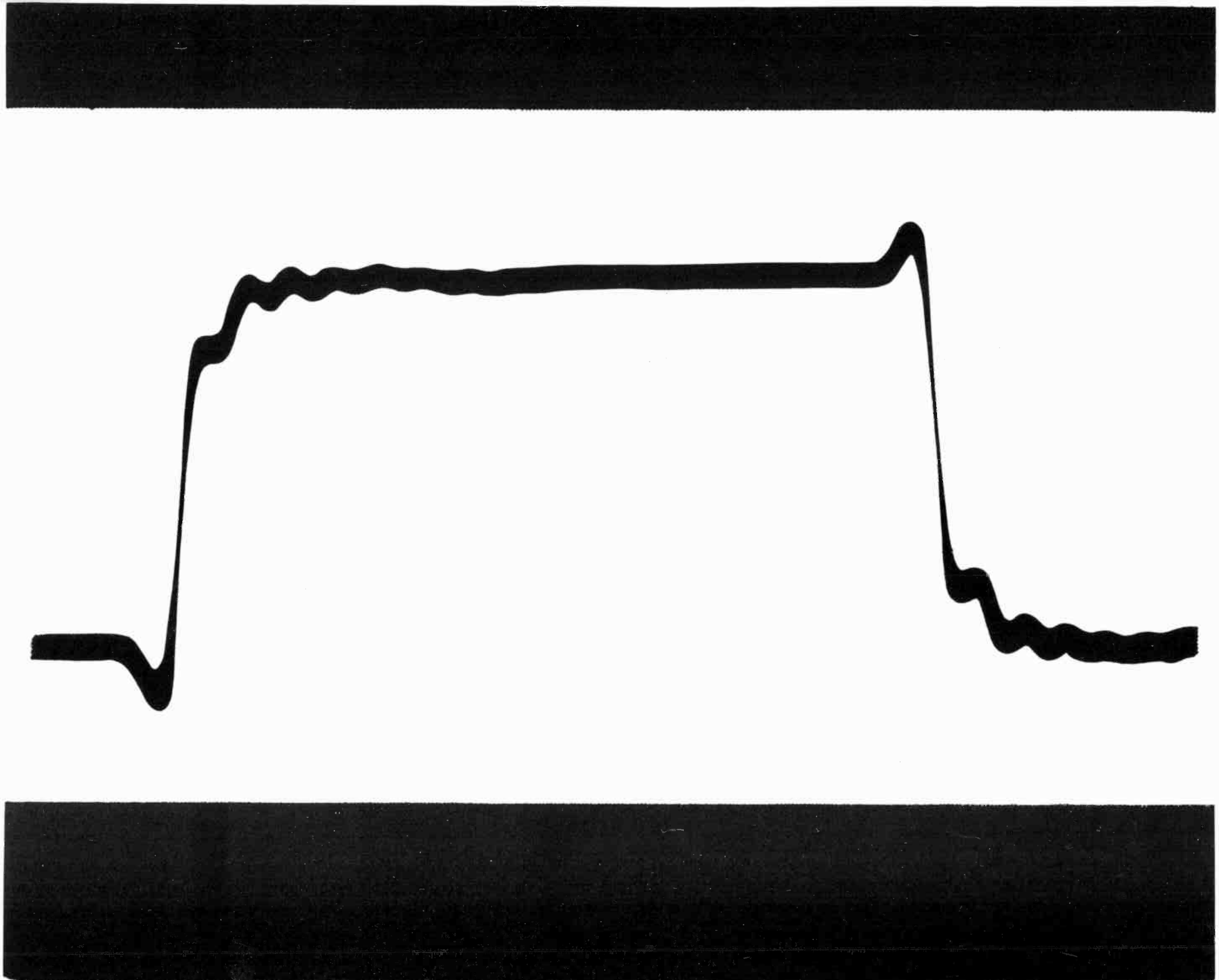
Because of the mechanism of its operation, it produces delay measurements referenced to low frequencies. This is in accord with the FCC requirement, and therefore the results can be utilized in connection with proof of performance data. This unit is the RCA BW-8A Envelope Delay Test Set.

In some of the figures shown earlier, this unit was used to make the measurements from which the figures were prepared. It will be remembered that in some cases two curves were shown, one labeled "diode" and the other "BW-4A." The BW-4A is RCA's type number for its vestigial sideband demodulator. This referred to the demodulator used to supply video to BW-8A from the transmission line and was shown to establish that both gave essentially similar results in the single sideband region of frequencies. The difference was marked in the double sideband region where unequal amplitude sidebands, due to the effect of the VSBF, gave an error in delay reading when using the diode. However, at very low modulating frequencies, where the sideband amplitude unbalance is small, the two demodulators give substantially identical results.

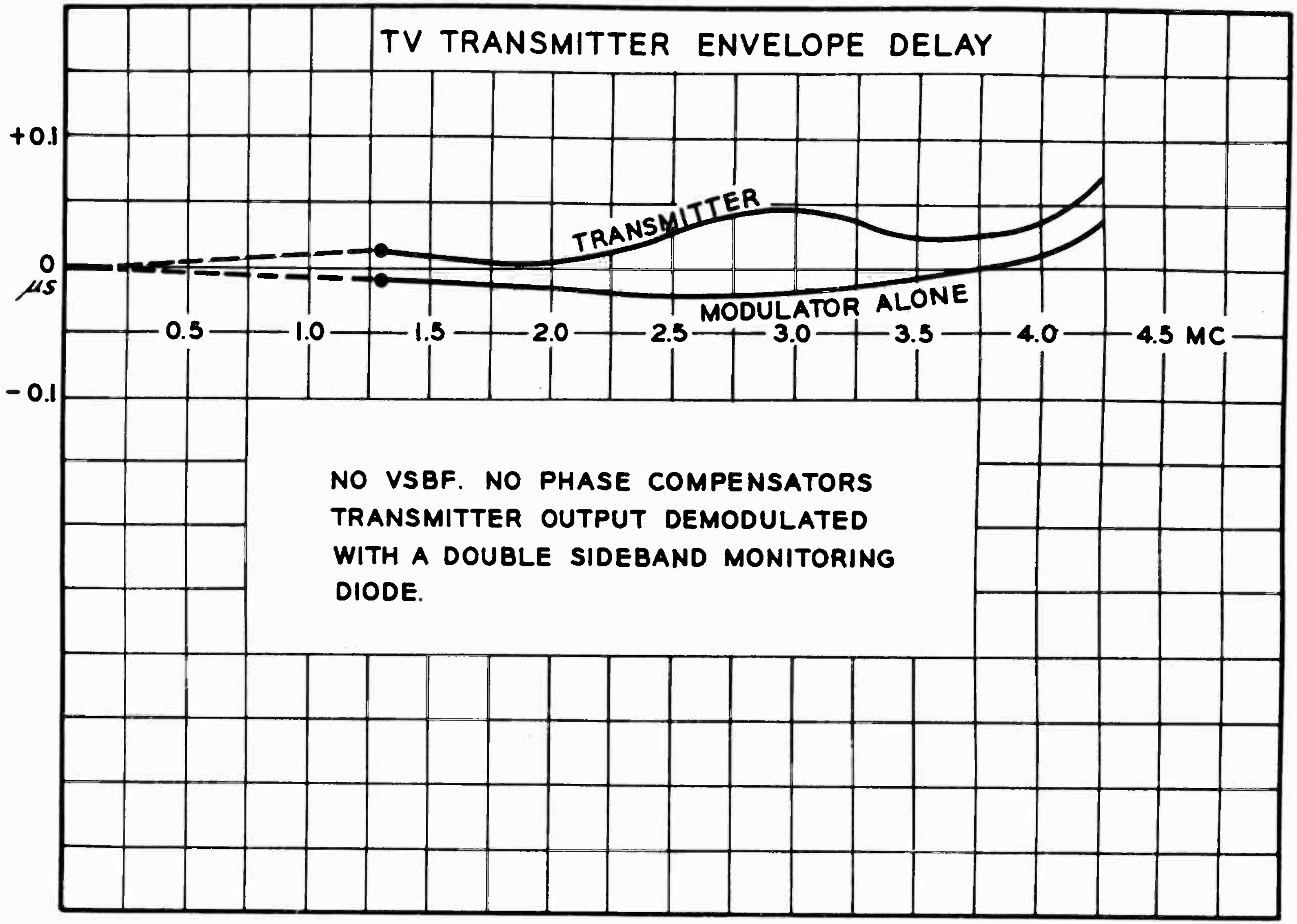
While it is advisable to use the vestigial sideband demodulator for monitoring and delay measurement, the much simpler diode can be used as a check on the demodulator performance and in routine measurement.

Slide 10 shows the overall transmitter delay characteristic, as measured with the envelope delay curve tracer. Shown in dotted lines is the system tolerance allowed by FCC regulation of which the transmitter has been accorded 80%. The ripples at the higher video frequencies are typical but occupy a small part of the allowable variation.

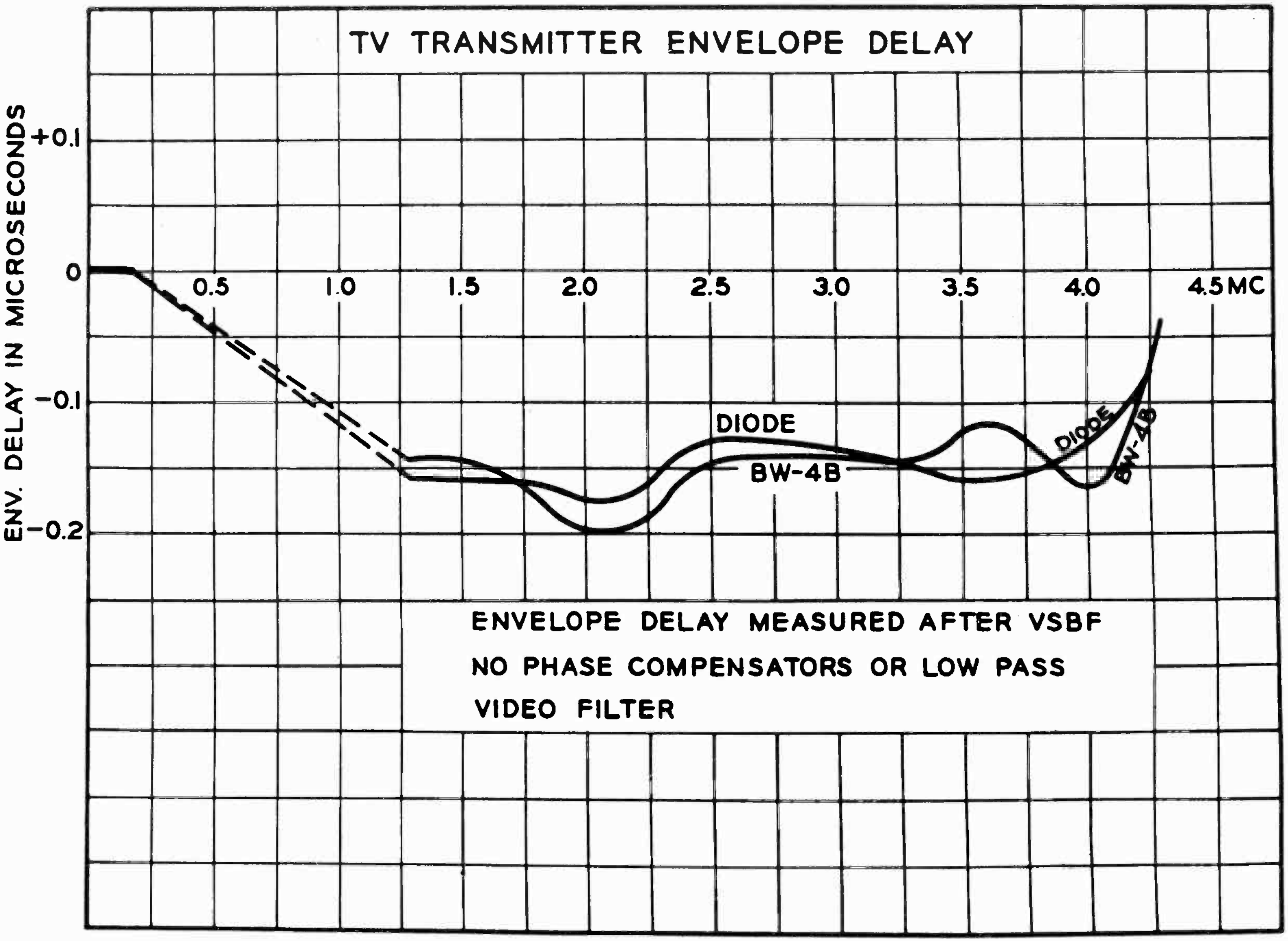
A system so adjusted will show an observable improvement in picture quality, both monochrome and particularly color, in A-B test or side-by-side comparison with an uncompensated system.



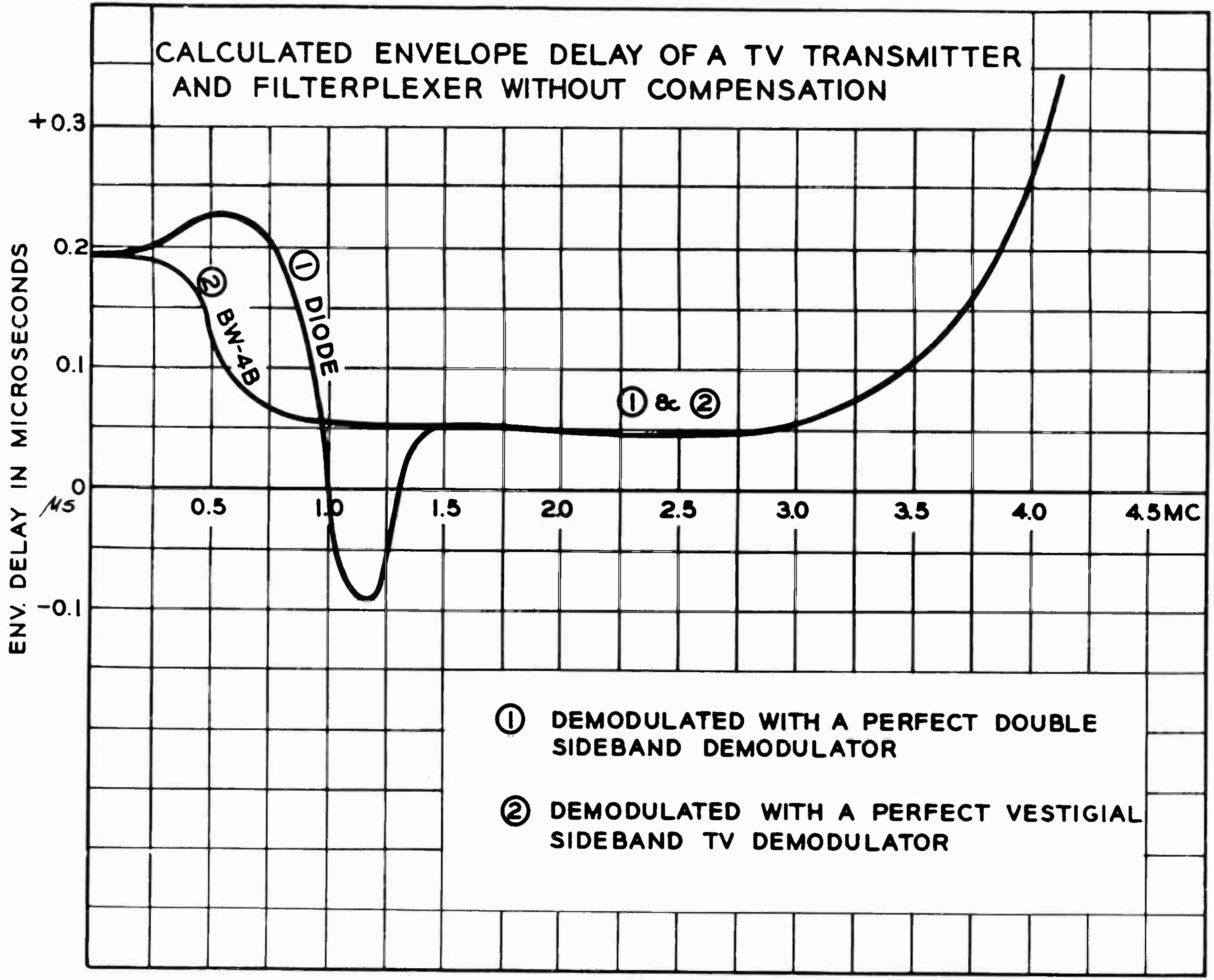
Slide 2 - **Typical uncorrected TV system response of 100 kc square wave.**



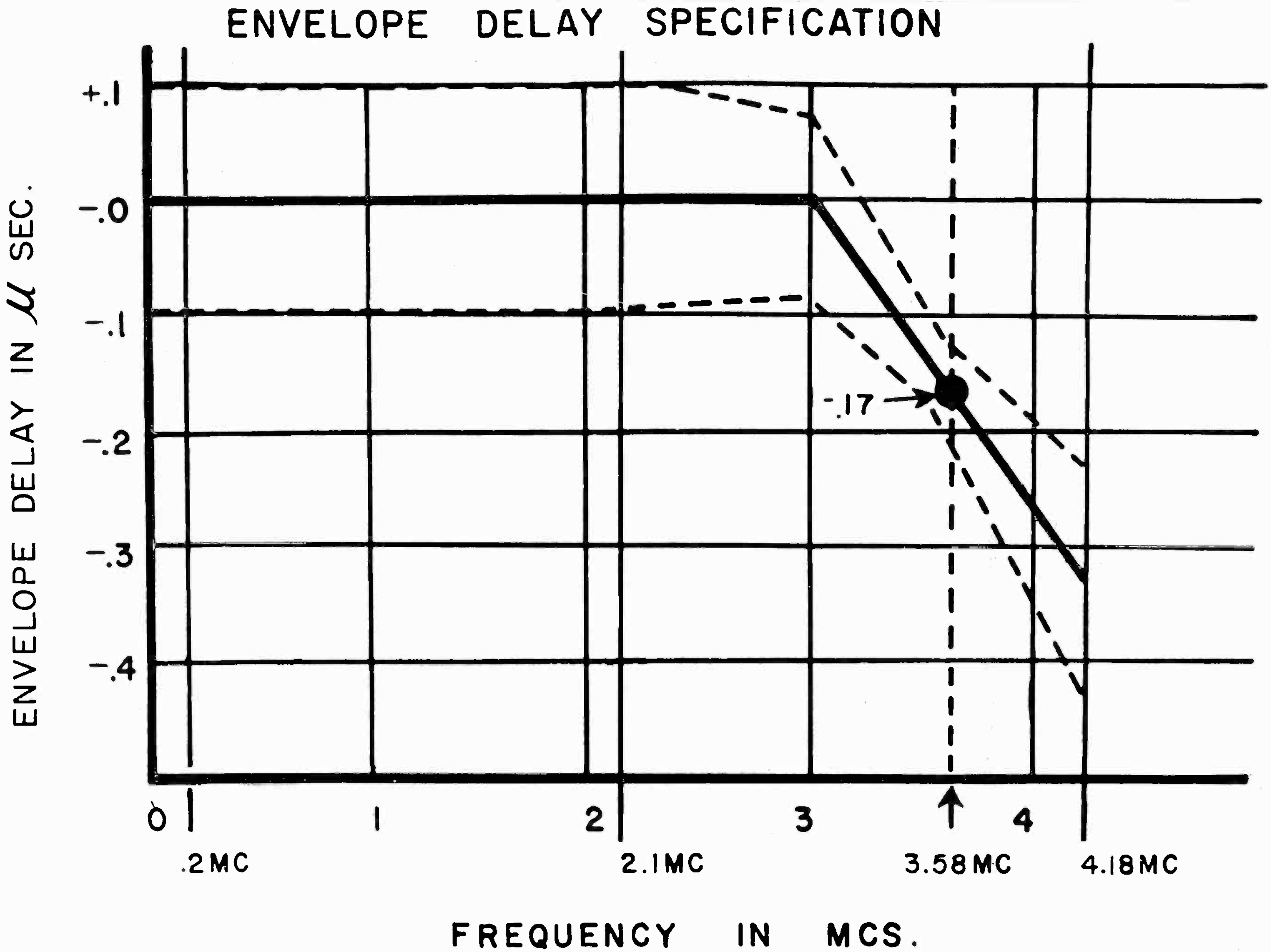
Slide 4 - Measured envelope delay of TV transmitter visual modulator and overall transmitter characteristic.



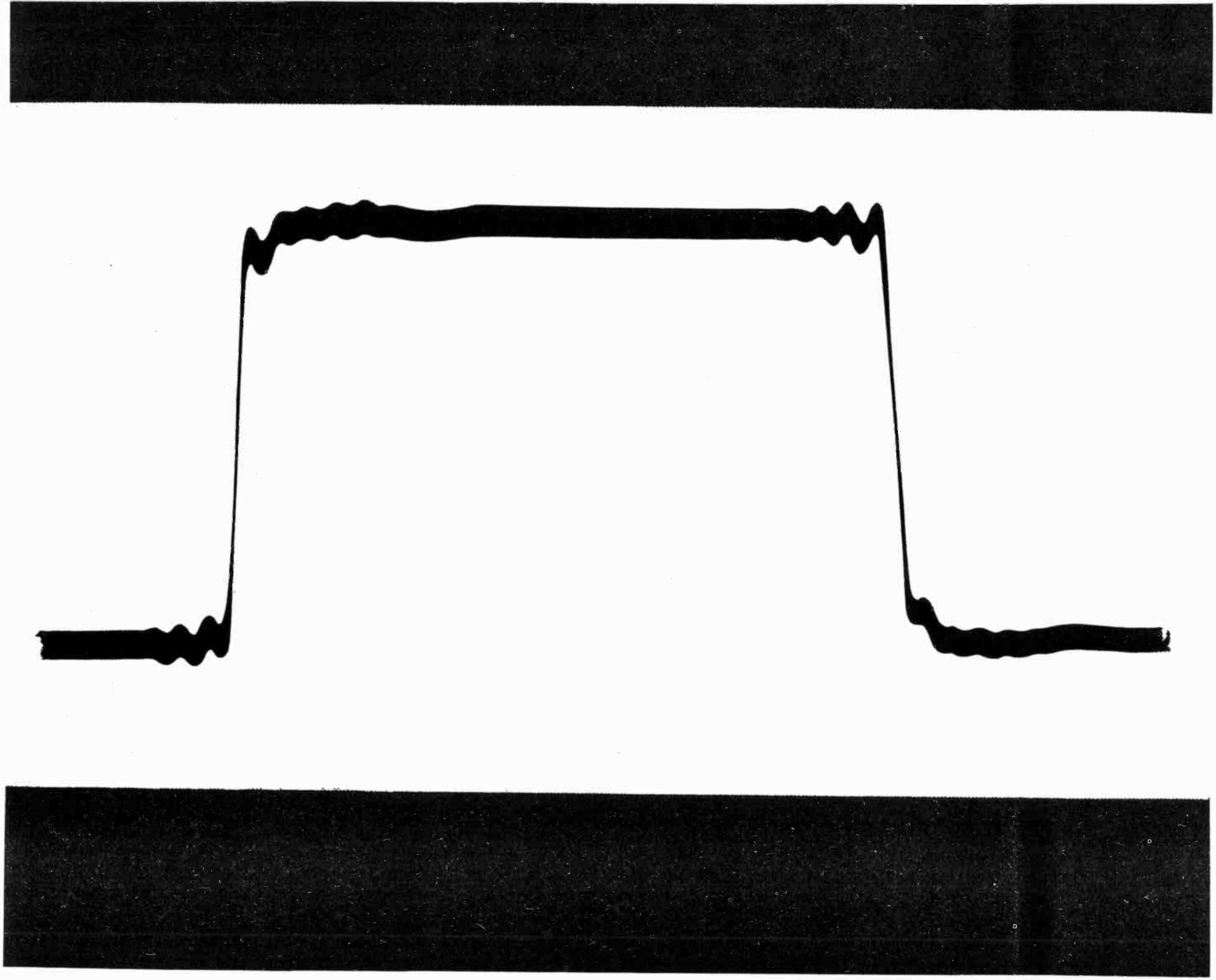
Slide 5 - Measured uncompensated TV transmitter envelope delay at output of sideband filter using both diode and vestigial demodulators.


CALCULATED ENVELOPE DELAY OF A TV TRANSMITTER
AND FILTERPLEXER WITHOUT COMPENSATION
+0.3
0.2
0.1
0
-0.1
µs
ENV. DELAY IN MICROSECONDS
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5MC
② BW-4B
① DIODE
① & ②
① DEMODULATED WITH A PERFECT DOUBLE SIDEBAND DEMODULATOR
② DEMODULATED WITH A PERFECT VESTIGIAL SIDEBAND TV DEMODULATOR

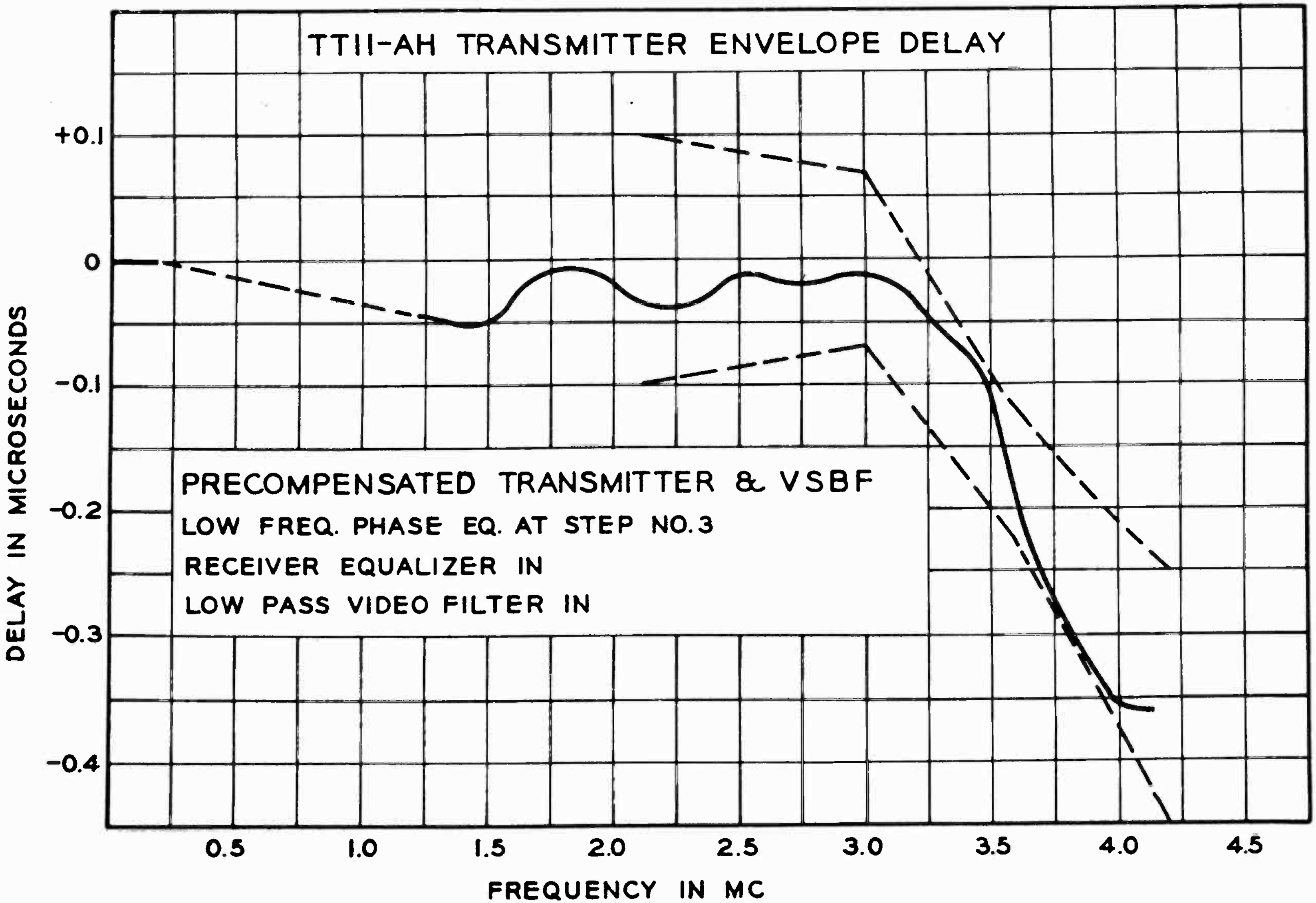
Slide 6



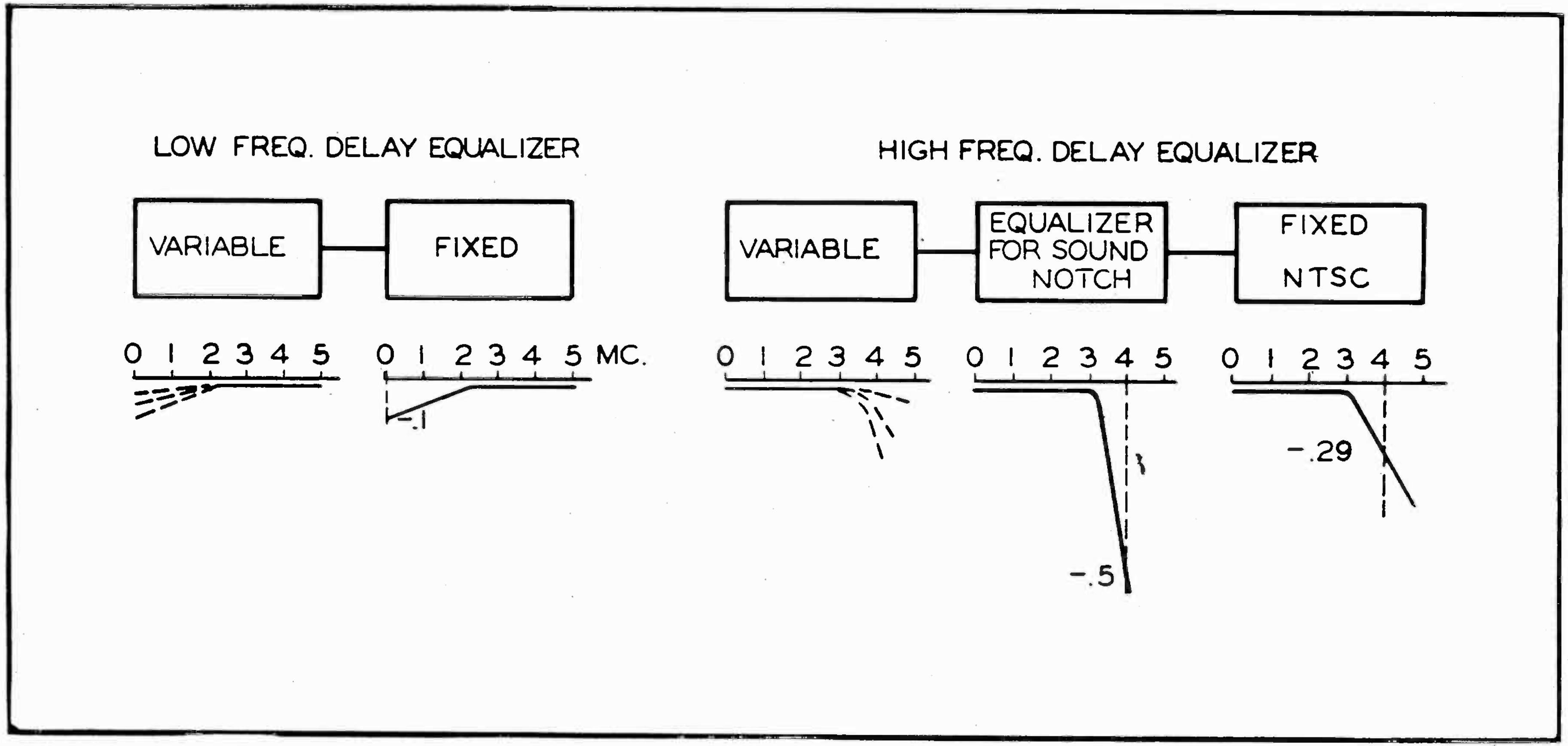
Slide 7 - FCC transmitter envelope delay curve for color TV transmission.



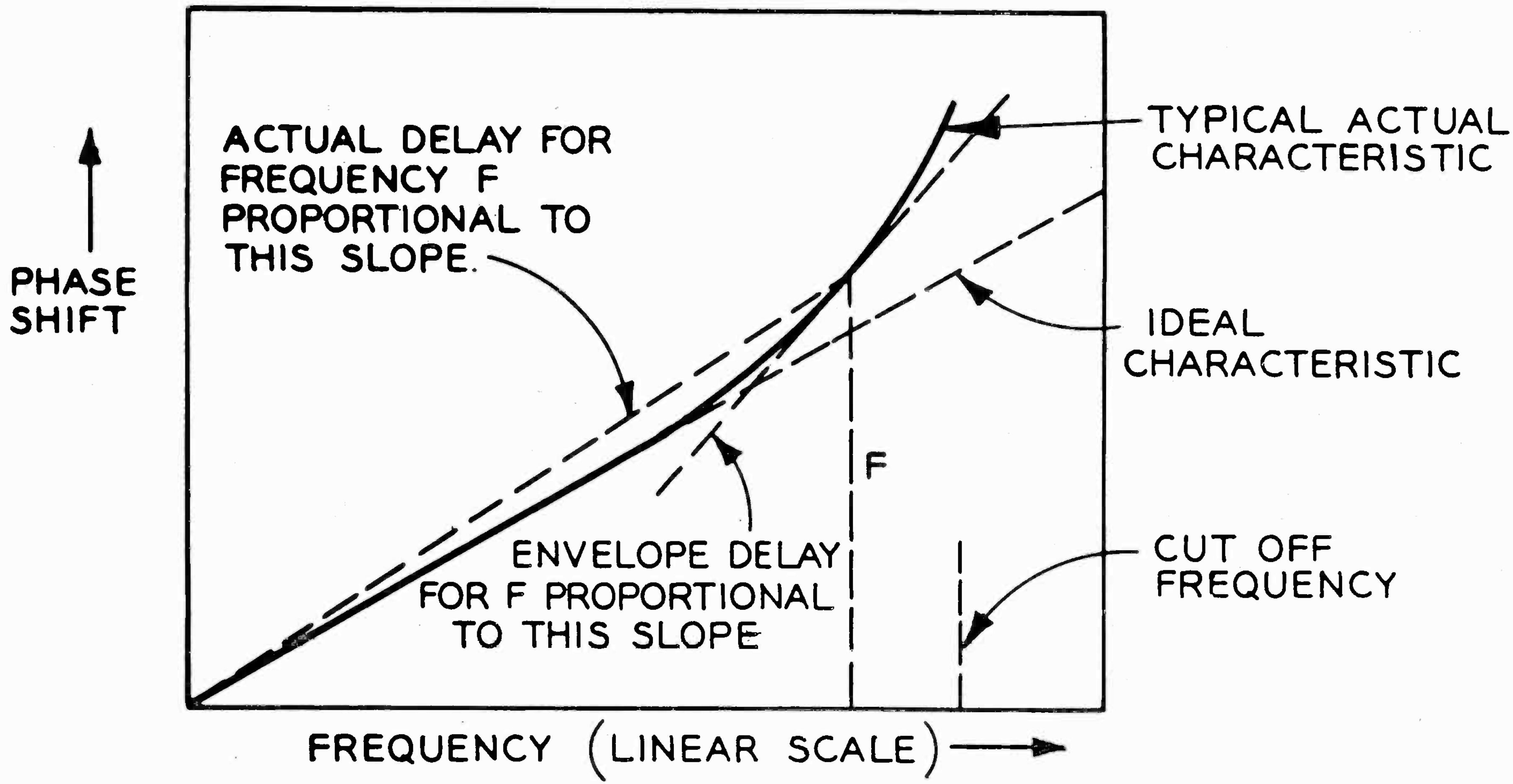
Slide 9 - **Typical phase corrected TV system response of 100 kc square wave.**



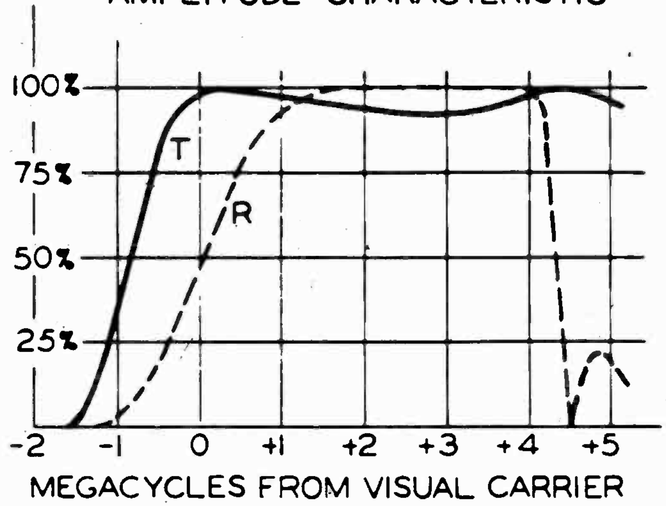
Slide 10 - Measured envelope delay characteristic of RCA TT-11AH Transmitter



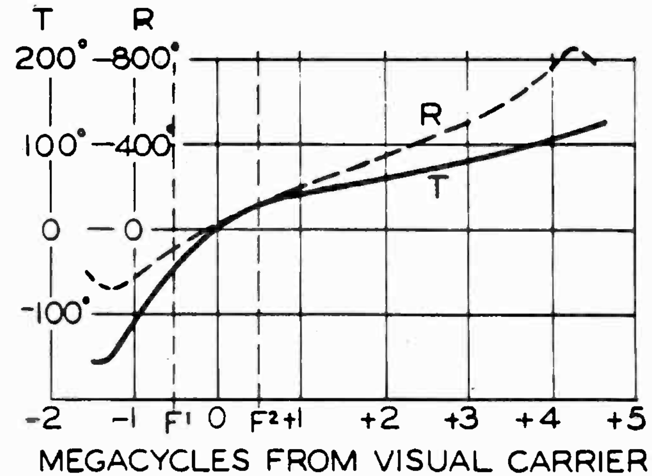
LOW FREQ. DELAY EQUALIZER
VARIABLE
FIXED
0 1 2 3 4 5
0 1 2 3 4 5 MC.
-.1
HIGH FREQ. DELAY EQUALIZER
VARIABLE
EQUALIZER FOR SOUND NOTCH
FIXED NTSC
0 1 2 3 4 5
0 1 2 3 4 5
0 1 2 3 4 5
-.5
-.29

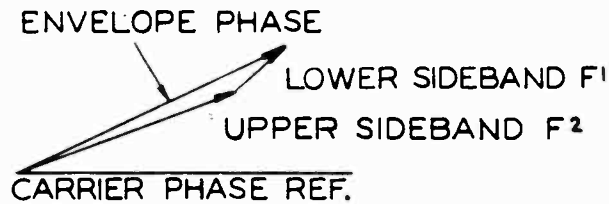

PHASE SHIFT
ACTUAL DELAY FOR FREQUENCY F PROPORTIONAL TO THIS SLOPE.
TYPICAL ACTUAL CHARACTERISTIC
IDEAL CHARACTERISTIC
F
ENVELOPE DELAY FOR F PROPORTIONAL TO THIS SLOPE
CUT OFF FREQUENCY
FREQUENCY (LINEAR SCALE)

AMPLITUDE CHARACTERISTIC

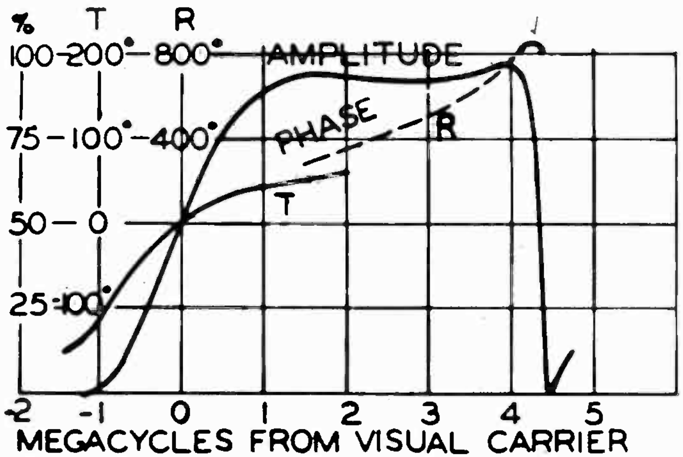


PHASE CHARACTERISTIC

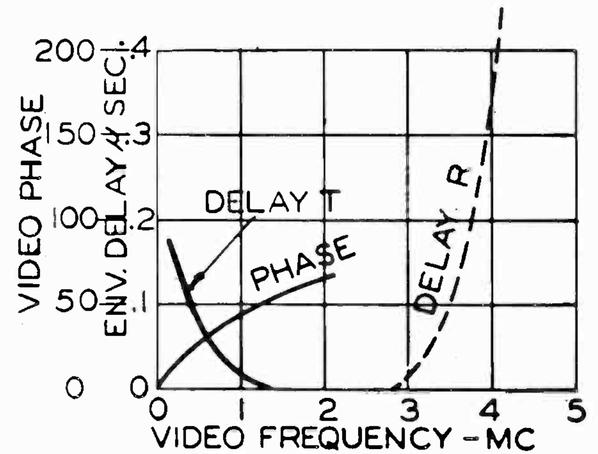




SYSTEM CHARACTERISTICS



NOTE: DELAYS ADJUSTED TO ZERO AT MIDBAND



Engineering
Department
Publications

CBS TELEVISION NETWORK

A New Approach to Balanced Audio Levels

Robert B. Monroe

(Presented at NAB Engineering Conference, April 4, 1960)

A NEW APPROACH TO BALANCED AUDIO LEVELS

by Robert B. Monroe

In the past, television viewers have registered complaints that portions of television programs are sometimes unpleasantly loud. Late in 1957, in keeping with its policy of presenting programs in the most pleasing manner possible, the CBS Television Network undertook an extensive study of television audio volume levels. This study was for the express purpose of fully exploring the reason for these complaints.

This paper presents the findings of the study and describes a new approach to the problem of achieving balanced audio levels in television broadcasting.

I. STUDY OF TELEVISION SOUND LEVELS

The new CBS study of television audio levels, which was an extension of similar studies undertaken some years ago,[1,2,3] got underway late in 1957 with the establishment of an observation point in the CBS Television Network Engineering Laboratory where television programs could be monitored in an environment acoustically similar to the average home living room. To further simulate home listening conditions, the monitoring volume was maintained at a level similar to that normally used in the average home.

The laboratory observation point was fully equipped with measuring equipment to analyze and measure audio program material. Programs could be monitored by wire line directly from the originating studio or off-the-air, the latter signal having passed through the transmitter and its associated peak-limiting amplifier.

Observation of programs continued over a period of several months. During this time, a permanent record of audio levels was made by means of a recording volume indicator, the continued use of which has proven very valuable in regular operation. Where levels were considered questionable, magnetic-tape recordings were made to permit more detailed analysis.

II. OBSERVATIONS AND FINDINGS

It has been the usual practice in both radio and television broadcasting to transmit audio program material at a uniform peak volume level as read on a standard volume indicator.[4,5,6] At first consideration, it might be thought that this practice would automatically result in all portions of the program material sounding equally loud. However, this is not always the case. The standard volume indicator was designed expressly for measuring the electrical magnitude of audio program signals for network program transmission purposes. It indicates the volume[7] of an audio program signal, not its loudness. Inasmuch as loudness is subjective in nature, it does not readily lend itself to measurement. Accordingly, even though two program sequences may produce the same deflection on the standard volume indicator, it does not follow that they will sound equally loud.

Quite early in this study of television audio levels, it became evident that, as listeners had reported, some television program material did sound louder than other material. The "loud" material included filmed program inserts in live programs, some program opening and closing announcements, and some station-break announcements.

A. Reasons for Loudness Discrepancies

As the study continued, it was found that there are three distinct reasons for differences in the loudness of various portions of programs:

1. Modification of Audio Waveform. One of the factors influencing the apparent loudness of audio program material was found to be the use of techniques that alter the waveform (and hence the subjective effect) of an audio signal. The following practices all result in the altered audio signal sounding louder than the original even though both are transmitted at the same peak value as measured by a standard volume indicator:
   a. Volume Compression. Program material that has been compressed, thereby restricting its original amplitude range, will sound louder than similar uncompressed program material.
   b. Reverberation. Reverberant program material will sound louder than program material that is acoustically dead. This principle was the basis of

J. P. Maxfield's "Liveness in Broadcasting" technique[8] introduced in 1947 and still in common use in radio broadcasting and phonograph record manufacture. Maxfield reported the possibility of a 6 to 8 db apparent increase in loudness using acoustically live program pickup techniques.

c. Bandwidth Restriction. When wave filters are employed to attenuate low frequencies, a considerable portion of the energy is removed from an audio signal and its level, as read on a standard volume indicator, must often be raised if standard transmission level is to be maintained. Furthermore, most of the remaining sound energy occurs in the middle-frequency range where the ear is most sensitive. Program material so restricted in bandwidth will, therefore, usually sound louder than full-bandwidth program material (although it suffers in faithfulness of reproduction). By the same token, sounds having predominantly mid-frequency components will exhibit a similar apparent greater loudness.

The above techniques are often employed (individually or severally) in producing the soundtrack of sound-on-film television program inserts. To a considerable extent, these practices account for such filmed inserts sounding louder than the unmodified live-studio sound pickup.

2. Listener Reaction. Another factor that influences the apparent loudness of television program material is associated with listeners' subjective reactions to certain types of sound, such as:

a. Irritating Sounds. An irritating voice, like any irritating sound, often seems louder than a pleasant one even though both may be reproduced at the same volume level.

b. Strident Delivery. Speech delivered in a rapid-fire, strident manner with few pauses, if any, sounds louder than speech delivered in a more conversational manner.

In this study of audio levels it was noted that program material delivered in a rapid, urgent manner by an announcer or performer with a slightly irritating quality in his voice invariably sounded louder than more normal adjoining portions of a program.

3. Program Peaking Practices. The third and perhaps the most important single factor that was found to influence the loudness of television program material is the program peaking practice employed in controlling audio levels at the audio console of the originating studio. Over ten years ago, after extensive investigation, program transmission standards were established by CBS[9] in order to produce programs with audio levels as pleasing as possible to the listener.

Occasional cases of loudness discrepancies resulting from incorrect program peaking practices were observed during this study indicating that the program transmission standards were not being observed. However, unlike loudness discrepancies resulting from the reasons discussed in the preceding paragraphs, loudness discrepancies resulting from incorrect program peaking practices are readily visible as nonstandard deflections of the volume indicator.

III. A SOLUTION

As indicated above, a most important requirement in achieving pleasing sound levels is good control of audio program peaks at the audio control console of the originating studio. Nevertheless, good audio control in itself will not reduce excessive loudness when it is caused by (a) the use of techniques that modify the audio waveform, or (b) the reaction of listeners to certain sounds. Other means must be used to make these types of program material match other portions of the program in loudness.

During this investigation, a relatively simple method of improving television audio level discrepancies was found. This new method entails the use in each studio of an automatic-gain-control amplifier with special, carefully chosen, gain-reduction characteristics and an associated gain-reduction meter. The new method also entails revising operating techniques to take into account readings of the gain-reduction meter. This new and highly effective approach to balancing television audio levels is described in some detail in the following paragraphs.

A. Automatic Gain Control

An automatic-gain-control (AGC) amplifier is one which automatically reduces its gain when an audio signal passing through it exceeds a predetermined threshold level. By its fast and automatic action, the AGC amplifier provides an excellent means of holding varying audio signals at a safe level. The associated gain-reduction meter indicates in decibels the amount by which the gain of the amplifier has been reduced to handle an audio signal that exceeds the threshold level.

Such an automatic level-controlling device is of considerable help in controlling widely varying audio levels and helps the audio operator do a better job of controlling a show. However, the automatic level-controlling action, in itself, does nothing to balance loudness differences that do not indicate as such on a volume indicator. On the other hand, the gain-reduction meter associated with the AGC amplifier does provide a new monitoring means which supplies quantitative data that permit the operator to make simple adjustments that will equalize loudness discrepancies.

Assume an AGC amplifier is installed in a studio audio channel and adjusted so that gain reduction takes effect one-half decibel below the volume-indicator reference point. If the audio operator now controls program levels in such a manner that 6 db of gain reduction is indicated on normal program material, but no gain reduction is indicated on louder-than-normal program material, loudness discrepancies will be greatly alleviated or even entirely eliminated. This balancing of unequal loudness levels is brought about in two ways. First, the protection against excessive volume indicator deflections afforded by the AGC amplifier gives the operator confidence to transmit normal program material at a higher average volume level. Second, the small amount of resulting compression applied to the signal slightly increases its apparent loudness.

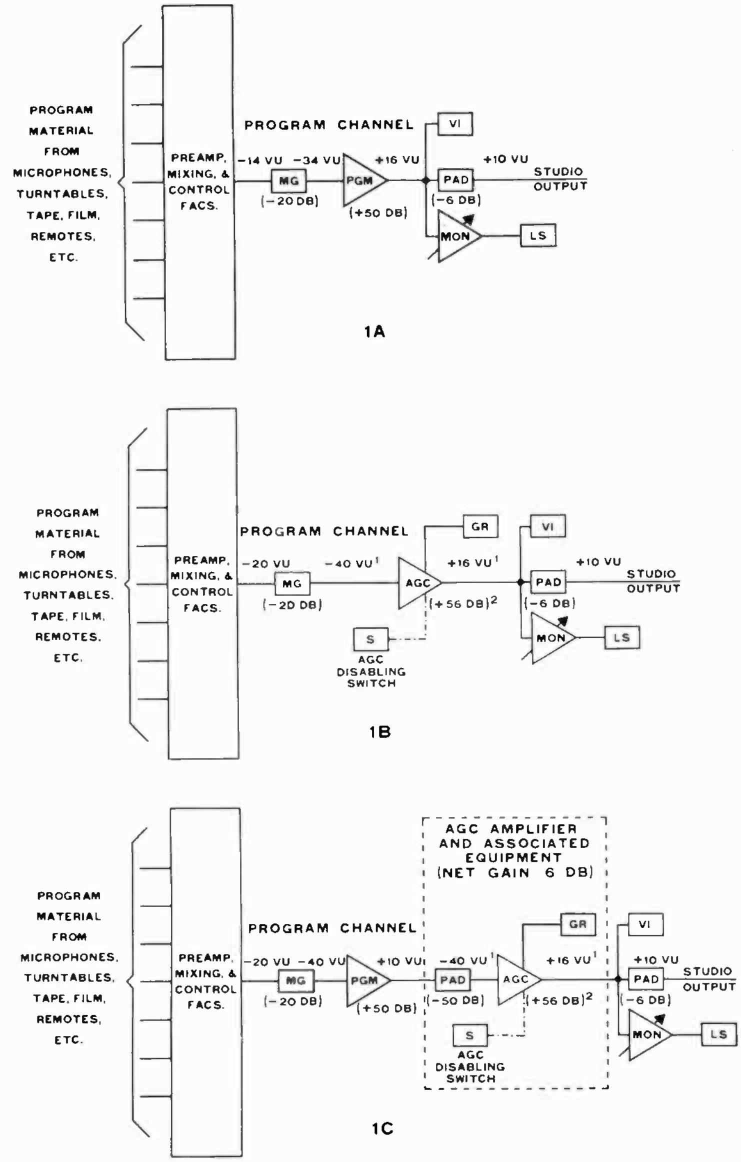
The method of balancing audio levels outlined above reduces itself to the following general operating rules:

1. Use 6 db of gain reduction on program material of normal loudness.
2. Use no gain reduction on louder-than-normal program material.

These generalized operating rules are set forth in more detail in Section C below.

B. Application of AGC

Basically, a studio audio system provides facilities for mixing, amplifying, and controlling audio program material from studio microphones, film projectors, transcription turntables, and other program



LEGEND

AGC	AUTOMATIC-GAIN-CONTROL AMPLIFIER	(+56 DB)	GAIN OR LOSS OF EQUIPMENT, NORMAL OPERATING SETTING.
GR	GAIN REDUCTION METER	+10 VU	PROGRAM LEVEL
LS	MONITORING LOUDSPEAKER	1	PROGRAM LEVEL SHOWN IS APPROXIMATE, SEE FIG. 3 FOR EXACT LEVEL.
MG	MASTER GAIN CONTROL	2	GAIN SHOWN IS GAIN BELOW THRESHOLD OF GAIN REDUCTION.
MON	MONITORING AMPLIFIER		
PAD	RESISTANCE ATTENUATION NETWORK		
PGM	PROGRAM AMPLIFIER		
S	AGC DISABLING SWITCH		
VI	VOLUME INDICATOR		

FIG. 1

Simplified single-line diagram of studio audio systems. (A) shows a typical studio audio system with a conventional constant-gain program amplifier. (B) shows the same studio audio system modified to use an AGC program amplifier. At times, it is desirable to retain an existing audio system intact and add AGC by merely introducing an AGC amplifier following the program amplifier. Such an arrangement is shown in (C).

sources. A monitoring loudspeaker is provided for aural monitoring to achieve the desired balance, while a volume indicator provides the visual monitoring means to adjust the studio output to the standard transmission level. Fig. IA shows a simplified single-line diagram of a typical studio audio system.

<u>I. Adding AGC to Studio Channel.</u> Fig IB shows the typical studio audio system of Fig. IA modified to employ AGC. In this case, the constant-gain program amplifier has been replaced with an AGC amplifier together with its associated gain-reduction meter and a switch for disabling the AGC action when desired. The gain of the AGC program amplifier (at program levels below the threshold of gain reduction) has been set 6 db higher than that provided by the constant-gain program amplifier in Fig. IA. This increase in gain compensates for the 6 db lower gain under conditions of 6 db gain reduction, i.e., the net program channel gain with 6 db gain reduction is the same as the constant-gain system of Fig. IA.

Fig. IC shows an alternate method of adding AGC to a studio channel with minimum changes to the existing system. In this case, the AGC amplifier follows, rather than replaces, the existing program amplifier. A resistance attenuation pad is used to restrict the AGC amplifier net gain below the threshold of gain reduction to 6 db.

<u>2. Modified Gain-Reduction Characteristics.</u> Conventional AGC amplifiers have gain-reduction characteristics of the general shape shown in Fig. 2. As this figure shows, the amplifier gain is constant up to the threshold point. From the threshold point on, gain reduction takes place at a rate determined by the slope of the amplifier's input-output curve.

Early in the experiments, it was found that gain-reduction characteristics of conventional AGC amplifiers were not completely suitable for this application. When used, a sudden sharp sound, such as the banging of a gavel, would be followed by a short but noticeable period of low-level audio. This was the result of excessive gain reduction on unanticipated high program peaks.

This difficulty was solved by modifying the amplifier characteristics as shown in Fig. 3. With these modified characteristics, only a limited amount of gain reduction (in this case a maximum of 6 db) can be obtained after which the amplifier gain again becomes constant, but with 6 db lower gain. Therefore, excessive gain reduction can never, intentionally or unintentionally, be applied since the maximum available is 6 db. When this modest limit is placed on the gain reduction, the automatic gain adjustments of the amplifier can never be detected.

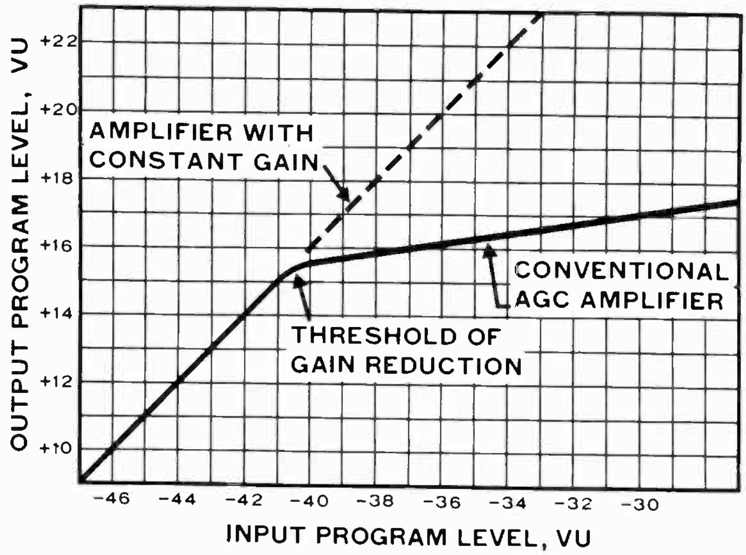


FIG. 2

Characteristics of a conventional AGC amplifier.

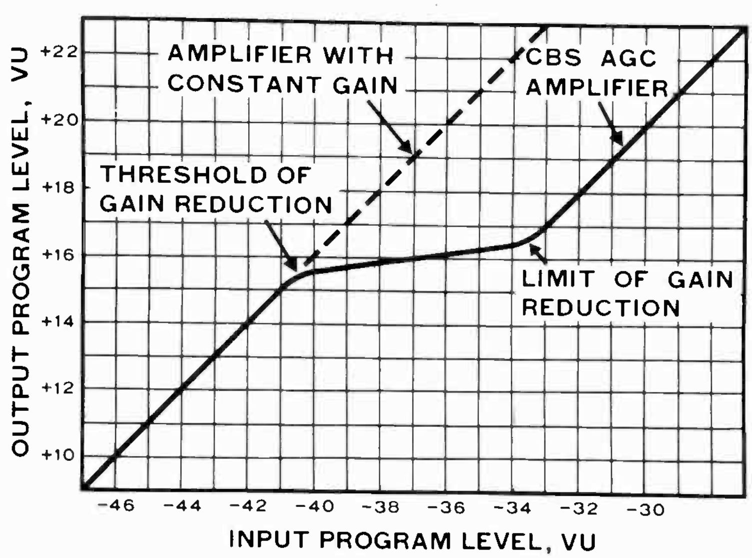


FIG. 3

Characteristics of the CBS AGC amplifier which limit gain reduction to a maximum of 6 db. The levels shown are program levels. Amplifier set-up is accomplished using a sine-wave signal 4.5 db higher than the indicated program levels.

Because of the usual 6 db line pad, an amplifier output level of +16 vu is required to deliver a transmission level of +10 vu to the studio outgoing program line. As can be seen, an increase in input level of 7 db is required to increase the amplifier output level from +15.5 to +16.5 vu. This corresponds to 6 db of gain reduction.

The amplifier has an attack time of 25 milliseconds and a recovery time of 0.5 seconds.

It should be noted that in both conventional AGC amplifiers and the CBS AGC amplifier, the exact point at which the threshold of gain reduction occurs is dependent upon the peak factor of the input signal. The points shown on Figs. 2 and 3 are for average program material.

C. Operation

When an AGC amplifier has been installed in a studio channel for the purpose of balancing audio levels, a revision of program transmission standards is required. These revised standards must take into account the readings of the new gain-reduction meter which is used along with the volume indicator in controlling program levels. (Fig. 4). Revised CBS program transmission standards developed for this purpose are given in Table I. Complete understanding of the principles involved and strict adherence to the revised standards by operating personnel is essential.

D. Additional Benefits

In addition to the improvement in sound transmission already described, the use of gain reduction as detailed above will also provide the following additional benefits:

1. Listeners have sometimes reported that musical portions of programs sound too loud,[9] i.e., music sounds louder than speech. The AGC amplifier, together with the revised program transmission standards, will also improve or entirely eliminate this loudness discrepancy.
2. By automatically controlling unanticipated high program peaks, the AGC amplifier permits the audio operator to do a better audio mixing job.

IV. CONCLUSION

The method of balancing television sound levels described above has proven so effective that automatic-gain-control amplifiers have been included in the control room audio facilities of all CBS-owned

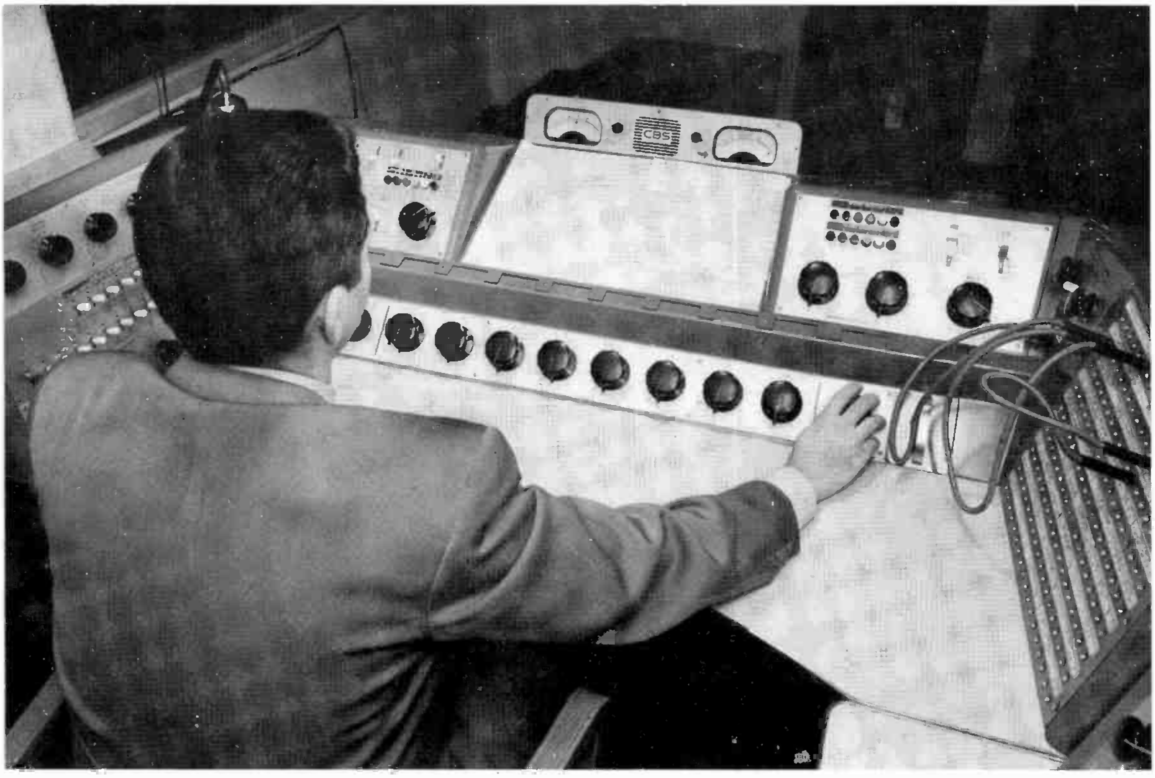


FIG. 4

An audio control console modified for AGC. The meter to the left is the volume indicator, the one to the right is the gain-reduction meter.

The gain-reduction meter was formerly a second volume indicator. It has been equipped with dual scales (vu & gain reduction) and can be quickly restored to its original volume indicating function in the emergency audio channel by operation of the small switch at its left. The other small switch to the right of the volume indicator serves to disable the automatic-gain-control when desired.

TABLE I

REVISED CBS AUDIO PROGRAM TRANSMISSION STANDARDS FOR TELEVISION

		VI PEAKS	GAIN REDUCTION
A. SPEECH (live)	1. Normal passages	Peaks of 100	6 db
	2. Low-level passages	Not less than 40	None
B. MUSIC (live) C. RECORDED PROGRAMS (film, transcriptions, and magnetic tape) D. COMMERCIALS (both recorded and live*) E. PROGRAM OPENINGS AND CLOSINGS, STATION-BREAK ANNOUNCEMENTS	1. Normal passages	Peaks of 100	None
	2. Low-level passages	Not less than 40	None
F. SYMPHONIC MUSIC	1. Normal passages	Peaks of 100	None
	2. Pianissimo passages	Must always move VI	None
G. APPLAUSE AND AUDIENCE REACTION		Maximum peaks of 70	None

H. TRANSITION

The transition from a low-level passage to a normal-level passage (or vice versa) must be in steps of not more than 4 db, preferably less (i.e., peaks of 40, then 60, and finally 100, or vice versa). Similarly, two succeeding passages (voice, then music, or voice, then a sound effect, etc.) must not differ in level by more than 4 db, preferably less, even when a contrast is intentional.

I. PEAKING PRACTICE

Peaking program material according to the prescribed standards means gaining in such a manner that the maximum VI peaks reach the specified values as frequently as possible without being inconsistent with the program content. It is understood that occasional peaks beyond the prescribed values are unavoidable, but these are to be kept to a minimum.

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* Excluding live commercials presented in a conversational manner. These should be treated as in A.

television stations. Since this was done, listener complaints of loudness discrepancies have been effectively eliminated. Furthermore, careful listening tests have shown that since this new equipment was installed and the revised transmission standards put into effect, transitions from sequence to sequence and from program to program are quite smooth with no noticeable change in loudness.

It is believed that the use of AGC amplifiers in the manner described marks another step forward in television broadcasting and represents one more technical advance to make television viewing as pleasant as possible.

This CBS Television Network project was under the general direction of A. B. Chamberlain, Director of Engineering, and R. S. O'Brien, Director of Audio-Video Engineering. It was carried out under the immediate direction and with the active collaboration of Howard A. Chinn, Chief Engineer. Acknowledgement is hereby made to D. R. Wells for his patient and meticulous laboratory work on this project.

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8

EFFECTS OF TOWER LIGHTING AND ISOLATION CIRCUITS UPON THE IMPEDANCE OF VARIOUS AM TOWERS

14TH NAB
BROADCAST ENGINEERING CONFERENCE
CHICAGO, ILLINOIS
MARCH 1960

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THE EFFECTS OF TOWER LIGHTING AND ISOLATION CIRCUITS UPON TOWER IMPEDANCE OF VARIOUS AM TOWERS

Perhaps some of you have measured antenna impedances and found them to vary when you connected the tower lighting or isolation circuits. Or, perhaps, you have investigated apparent transmitter efficiencies in the range of 90 to 110%. Tower lighting or isolation circuits frequently cause such conditions to exist.

During the course of our consulting work, we had encountered these conditions and antenna resistance changes up to 50% due to the effects of tower lighting isolation circuits. It was, therefore, deemed advisable to investigate these effects in more detail.

To this end, special equipment was set up to measure the antenna impedance of KSTR, Grand Junction, Colorado, which operates on an assigned frequency of 620 kilocycles. Impedance measurements of the KSTR 300 foot tower over the entire broadcast band, provided an opportunity to study the effects of tower isolation circuits for effective antenna heigths which varied with frequency from 0.15 to 0.5 wavelength. The investigation consisted of tower impedance measurements without isolation circuits and then with various tower isolation circuits connected.

Tower lighting isolation circuits commonly encountered consist of the following types:

1. A single dual-wound choke. This choke is often supplied in diameters of approximately 5 inches and lengths up to 18 inches with a two layer winding. One winding connects each side of the AC circuit to the tower lights. Some chokes are triple wound to accomodate a third tower circuit. A simple schematic showing the connection of a single dual-wound lighting choke is shown in Figure 1.

2. SOMETIMES TWO OF THESE CHOKES ARE USED IN TANDEM. A SCHEMATIC OF TANDEM CHOKES IS SHOWN IN FIGURE 2. IT WILL BE NOTED THAT THE NEUTRAL SIDE OF THE TOWER LIGHT IS SHOWN TIED TO THE TOWER SO THAT THE TOWER ISOLATION CHOKE FUNCTIONS AS A STATIC DRAIN CHOKE.

3. AN ENTIRELY DIFFERENT MEANS OF TOWER LIGHTING ISOLATION IS PROVIDED BY THE TRANSFORMER ISOLATION TYPE OR SO-CALLED "AUSTIN" TRANSFORMER. TRANSFORMER ISOLATION IS SHOWN IN FIGURE 3.

THE TOWER ISOLATION CHOKES FREQUENTLY ENCOUNTERED HAVE A HIGH VALUE OF INDUCTANCE ON THE ORDER OF 350 MICROHENRIES. THE TRANSFORMER ISOLATION UNITS CONSIST OF A LARGE DOUGHNUT SHAPED PRIMARY WINDING CONNECTED TO THE 60 CYCLE POWER LINE. THE TOWER LIGHTS ARE SUPPLIED WITH CURRENT FROM A SECONDARY DOUGHNUT WINDING LOCATED IN THE FIELD OF THE PRIMARY BUT SPACED SEVERAL INCHES FROM IT.

THE EFFECTS UPON TOWER IMPEDANCES OF TOWER LIGHTING CHOKES MAY BE THOUGHT OF AS A HIGHLY INDUCTIVE CIRCUIT WITH A SIGNIFICANT AMOUNT OF CIRCUIT RESISTANCE AT THE R.F. FREQUENCY. THE EFFECT IS FURTHER COMPLICATED BY A DISTRIBUTED CAPACITANCE EFFECT. THE MATHEMATICS FOR CALCULATING THE EFFECTS OF SUCH TOWER LIGHTING CHOKES IN THE RANGE WHERE THE OPERATION IS CRITICAL, IS QUITE DIFFICULT. HOWEVER, THEIR PERFORMANCE MAY BE OBTAINED EASILY AND RAPIDLY WITH A RADIO FREQUENCY BRIDGE. THE TRANSFORMER ISOLATION CIRCUIT ON THE OTHER HAND SHUNTS THE ANTENNA IMPEDANCE WITH A CAPACITANCE OF APPROXIMATELY 30 MICROMICROFARADS. THE EFFECTS, THEREFORE, OF THE TRANSFORMER ISOLATION IS MORE READILY CALCULATED. IT SHOULD BE NOTED THAT TRANSFORMER ISOLATION DOES NOT PROVIDE A STATIC DRAIN. THIS MUST BE ADDED.

THE MEASUREMENTS OF THE KSTR TOWER WERE MADE UNDER THE FOLLOWING CONDITIONS:

A. NO LIGHTING ISOLATION

B. One tower lighting choke

C. Two tower lighting chokes in tandem

D. Tower shunted by a 30 micromicrofarads capacitor to simulate the transformer isolation.

The measurements of the KSTR tower with the various forms of tower lighting isolation described above, were performed using a General Radio type 916-AL radio frequency bridge. The signal generator consisted of a very stable master oscillator followed by a power amplifier to isolate the effects of the bridge on the oscillator. A built-in electronic voltage regulator maintained the oscillator frequency and output very stable. The detector consisted of a very selective, well sheilded, superheterodyne receiver. The switching arrangement was set up to disconnect the tower lighting circuits or to permit connecting one choke, two chokes in tandem, or the shunt capacitance.

Figure 4 is a plot of the base tower resistance for the entire broadcast band as shown by a broken curve. The solid curve is a plot of the resistance obtained with a single dual-wound tower lighting choke connected. It will be noted that the tower resistance showed a maximum change from 765 ohms down to 48 ohms at a frequency of 1275 kilocycles, corresponding to a tower height of approximately 0.4 wavelengths. This represents a <u>drastic</u> change of <u>93.8%</u>. It is to be noted that the variation of tower resistance within the one quarter wave region was fairly small.

In Figure 5 it will be seen that when two tower lighting chokes were used in tandem, a great deal less change in antenna resistance occurred. In fact over a broad band from 0.25 to 0.35 wavelength of tower height close agreement was obtained with basic tower resistance.

Figure 6 shows how transformer isolation effects tower resistance. This system proved inferior to the two chokes in tandem, although vastly superior to the single choke commonly utilized. Very little change in

ANTENNA RESISTANCE OCCURRED OVER ONLY A SMALL RANGE OF APPROXIMATELY .2 TO .25 WAVELENGTH ANTENNA HEIGHT. AT ALL OTHER ANTENNA HEIGHTS, THE TRANSFORMER CAUSED A SIGNIFICANT CHANGE IN MEASURED ANTENNA RESISTANCE. WHILE THE EFFECT UPON TOWER REACTANCE MAY NOT BE AS SIGNIFICANT AS TOWER RESISTANCE FOR NON-DIRECTION OPERATION, IT IS QUITE IMPORTANT IN DIRECTIONAL ANTENNA WORK. FIGURE 7 SHOWS THE EFFECT UPON THE MEASURED TOWER REACTANCE OF A SINGLE TOWER LIGHTING CHOKE ISOLATION CIRCUIT. AGAIN THE TOWER REACTANCE WITHOUT ANY ISOLATION CIRCUIT IS SHOWN AS A DASHED CURVE. THE TOWER REACTANCE OBTAINED WITH A SINGLE CHOKE CONNECTED IN THE TOWER LIGHTING CIRCUIT IS SHOWN BY THE SOLID CURVE. HERE THE EFFECT IS EXCEEDINGLY GREAT. FOR INSTANCE, AT 1375 KILOCYCLES CORRESPONDING TO AN ANTENNA HEIGTH OF APPROXIMATELY .420 WAVELENGTH, THE REACTANCE CHANGED FROM A NEGATIVE 438 OHMS UP TO A POSITIVE 380 OHMS. THIS CHANGE OF 818 OHMS REPRESENTS A PERCENTAGE CHANGE OF 187%. AGAIN, THE USE OF TWO CHOKES IN TANDEM GREATLY REDUCES THE ADVERSE EFFECT OF THE TOWER LIGHTING CIRCUIT UPON THE MEASURED TRUE REACTANCE, AS SHOWN IN FIGURE 8. SIMILARLY, FIGURE 9 ILLUSTRATES THE EFFECT OF TRANSFORMER ISOLATION UPON THE TOWER REACTANCE. AGAIN, THE ISOLATION TRANSFORMER, WHILE RADICALLY BETTER THAN A SINGLE CHOKE, MEASURED INFERIOR TO THE TWO CHOKES IN TANDEM.

IT MAY BE NOTED, HOWEVER, THAT IN CRITICAL AREAS OF TOWER HEIGTH CONSIDERABLE RESISTANCE AND REACTANCE VARIATIONS OCCURRED WITH THE USE OF THESE TYPES OF TOWER LIGHTING ISOLATION CIRCUITS.

OTHER FORMS OF ISOLATION ARE NORMALLY USED TO PREVENT LOSS OF RADIO FREQUENCY POWER IN AM TOWERS, WHEN OTHER RADIO SERVICES SHARE THE SAME TOWER. FIGURE 10 ILLUSTRATES A CIRCUIT WHICH ISOLATES A FM ANTENNA FROM AN AM TOWER. HERE THE OUTER CONDUCTOR OF THE COAX LINE IS TIED TO THE TOWER NEAR THE TOP WHILE A LENGTH OF LINE OF APPROXIMATELY ONE QUARTER WAVE LENGTH LONG (AT the AM frequency) is insulated from the tower. A capacitor is frequently connected from the base of the tower to the coax outer conductor at the point where it is also connected to ground. This length of insulated line, together with the tower, forms a one-quarter wave resonant circuit having the top end shorted with resulting high impedance at the open lower end. This high impedance formed by the one-quarter wave stub serves to isolate FM or TV service from the AM tower. In practice the grounding point and/or the top point, which is tied to the tower, is moved until the measured AM antenna impedance shows that it is unaffected by the presence of the FM or other service.

In Figure 11 a sampling loop is isolated from the tower merely by insulation. This type of sampling loop isolation is frequently utilized in single tower non-directional antenna systems. However, frequently it has been found that insulated sampling loops appreciably change the measured antenna impedance, often due to a significant capacitance coupling effect. Several cases of radical pattern distortion have been encountered even in simple two tower directionals. Figure 12 illustrates a paralell resonant type of isolation for sampling loops. In this system one side of the pick-up loop and the outer conductor of the coax line is tied to the tower. Indeed, the line is bonded to the tower at frequent intervals. At the base of the tower, the coax line is connected to a large coil formed by the coaxial cable. This coaxial coil must be tuned close to resonance if the tower impedance is to be unaltered by the pickup loop. It has been found that improper tuning of such tank circuits permits attainment of wide variations of tower impedances. However, where these circuits are properly tuned, no undesireable effects have been encountered.

ALTHOUGH TIME DID NOT PERMIT, NOR DID THE MANUFACTURER CARE TO SUPPLY A TUNABLE RESONANT CHOKE FOR TOWER LIGHTING ISOLATION, NEVERTHELESS, THIS FORM MAY BE ENTIRELY SATISFACTORY.

CONCLUSION:

REGARDLESS OF THE TYPE OF TOWER ISOLATION CIRCUIT EMPLOYED, THE PERFORMANCE MUST BE THOROUGHLY CHECKED. IT IS HOPED THAT THE BROADCAST EQUIPMENT SUPPLYERS WILL MAKE MORE SUITABLE ISOLATION CIRCUIT SYSTEMS AVAILABLE.

Vir N. James

VIR N. JAMES

MEASURED ANTENNA IMPEDANCE

KSTR TOWER - HEIGHT 300'

F(KC)	Tower Height / Wave Length	Tower Only R	Tower Only X	2 Chokes R	2 Chokes X	1 Choke R	1 Choke X	Trans. R	Trans. X
517	.158	11.3	-153	12.2	11.8	13.9	13.4	11.0	10.8
620	.189	18.7	-86.7	19.1	18.6	20.1	19.7	18.2	17.9
655	.200	22.2	-63	22.8	21.9	23.7	23.0	20.2	19.9
675	.206	24.6	-50	25.2	24.5	26.0	24.6	24.6	24.0
705	.215	28.1	-30	29.2	30.0	30	28.7	28.9	28.2
725	.221	31.3	-17.2	32.3	33.0	33	32.9	32	31.0
755	.230	36.5	+5	37.4	36.9	37.9	38.3	37.5	36.9
775	.236	41	19	41.5	41.1	42	43	42	40.8
805	.246	48	41	48.9	48.2	49	50	50	50
825	.252	53.2	55	54	52.8	54.5	54.1	56	55.1
845	.258	60	70	60	58.9	60.2	59.7	62.9	63
875	.267	71	94	71	70.1	73	72.1	76	77
900	.275	82	113	81.5	82.3	84	83	87	87
925	.282	95.7	135	95.2	95.7	98	97.3	102.2	101.6
955	.291	114.5	162	114	113.8	121	120	123.3	123.0
980	.299	134	186	131	132.1	146	145	148	147
1000	.305	153.5	207	151	206	171	208	170	206
1025	.313	185	231	184	230	215	232	206	232
1055	.322	231	261	231	259	290	253	267	259
1075	.328	271.5	275	272	275	359	252	312	274
1105	.337	340	294	350	294	490	229	400	283
1125	.343	400	299	410	299	580	254	475	278
1155	.352	496	292	530	287	633	-95	580	240
1175	.359	575	268	620	238	580	-300	655	149
1205	.368	690	164	720	138	353	-332	740	-7
1225	.374	730	90.8	767	55	214	-326	770	-109
1255	.383	760	-50	787	-116	83.3	-205	782	-222
1275	.389	765	-146	750	-232	48.1	-71.4	770	-290
1305	.398	750	-263	668	-380	57.3	+177	712	-374
1330	.406	700	-330	565	-414	119	306	590	-420
1355	.414	603	-416	465	-431	281	374	460	-439
1375	.420	515	-438	394	-436	493	380	383	-440
1400	.427	435	-444	325	-435	760	318	315	-434
1425	.435	350	-442	269	-422	862	29	265	-421
1455	.444	285	-428	218	-403	730	-316	214	-403
1475	.450	249	-415	187	-389	607	-410	189	-389
1505	.459	207	-395	153	-367	423	-465	158	-368
1525	.466	182.2	-380	134	-351	336	-464	139	-352
1555	.475	154	-356	114	-326	251	-448	119	-329
1575	.481	138	-339	101	-308	210	-421	108	-311
1610	.491	117.2	-311	86	-269	163	-357	92	-280

SINGLE CHOKE
TOWER LIGHTING ISOLATION

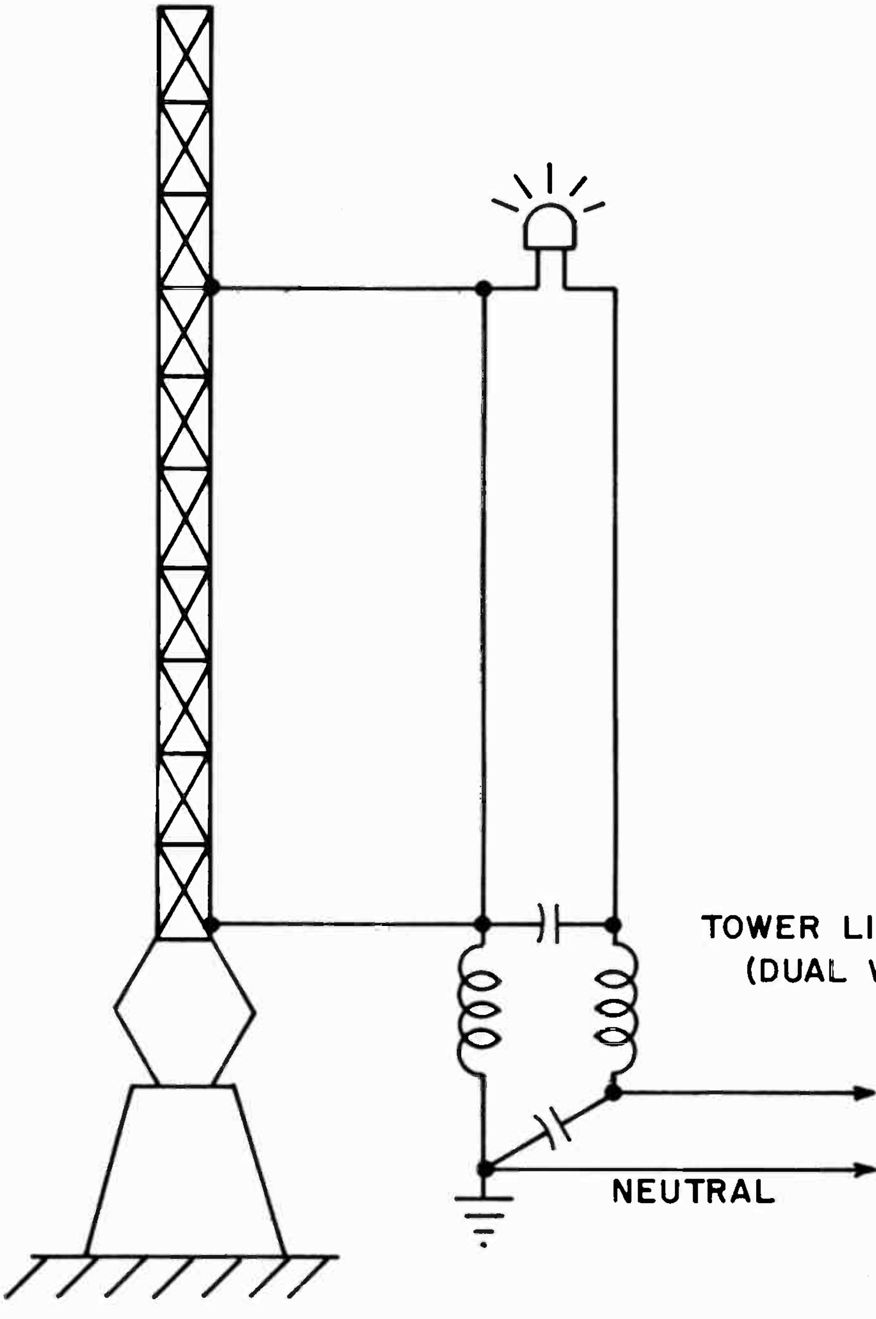

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FIGURE 1
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TANDEM CHOKES
TOWER LIGHTING ISOLATION

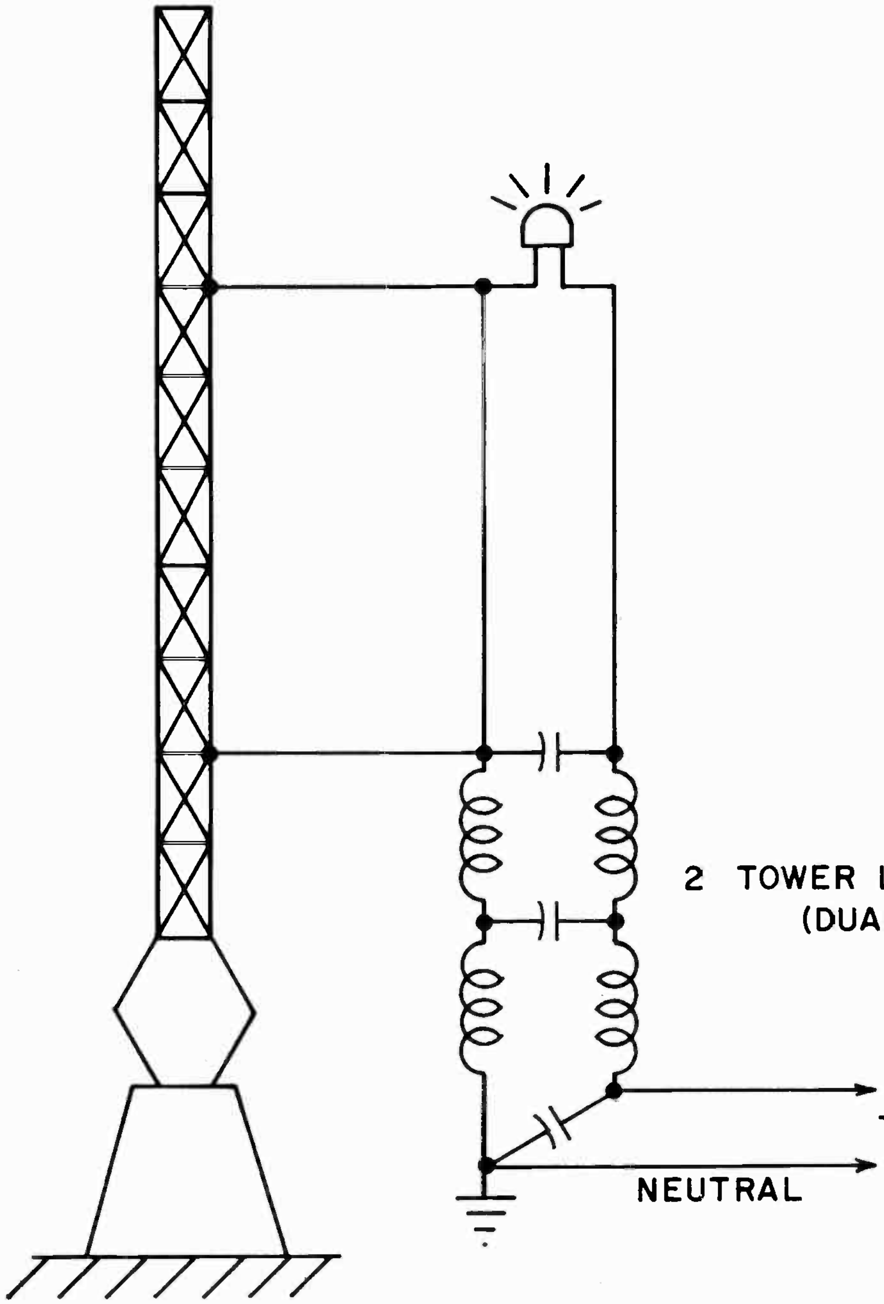

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FIGURE 2
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TRANSFORMER
TOWER LIGHTING ISOLATION

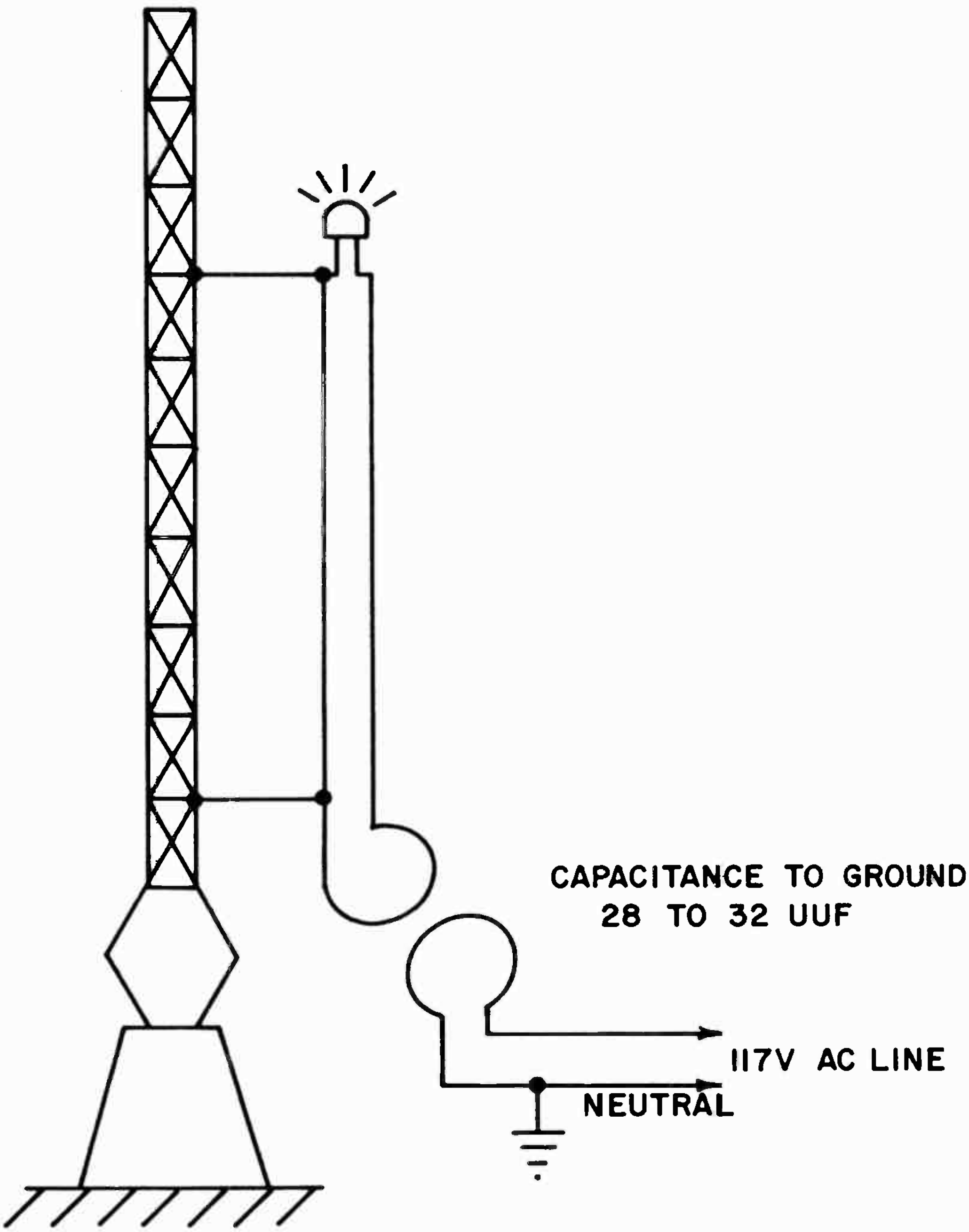

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FIGURE 3
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TOWER RESISTANCE VARIATION
1-CHOKE ISOLATION CIRCUIT

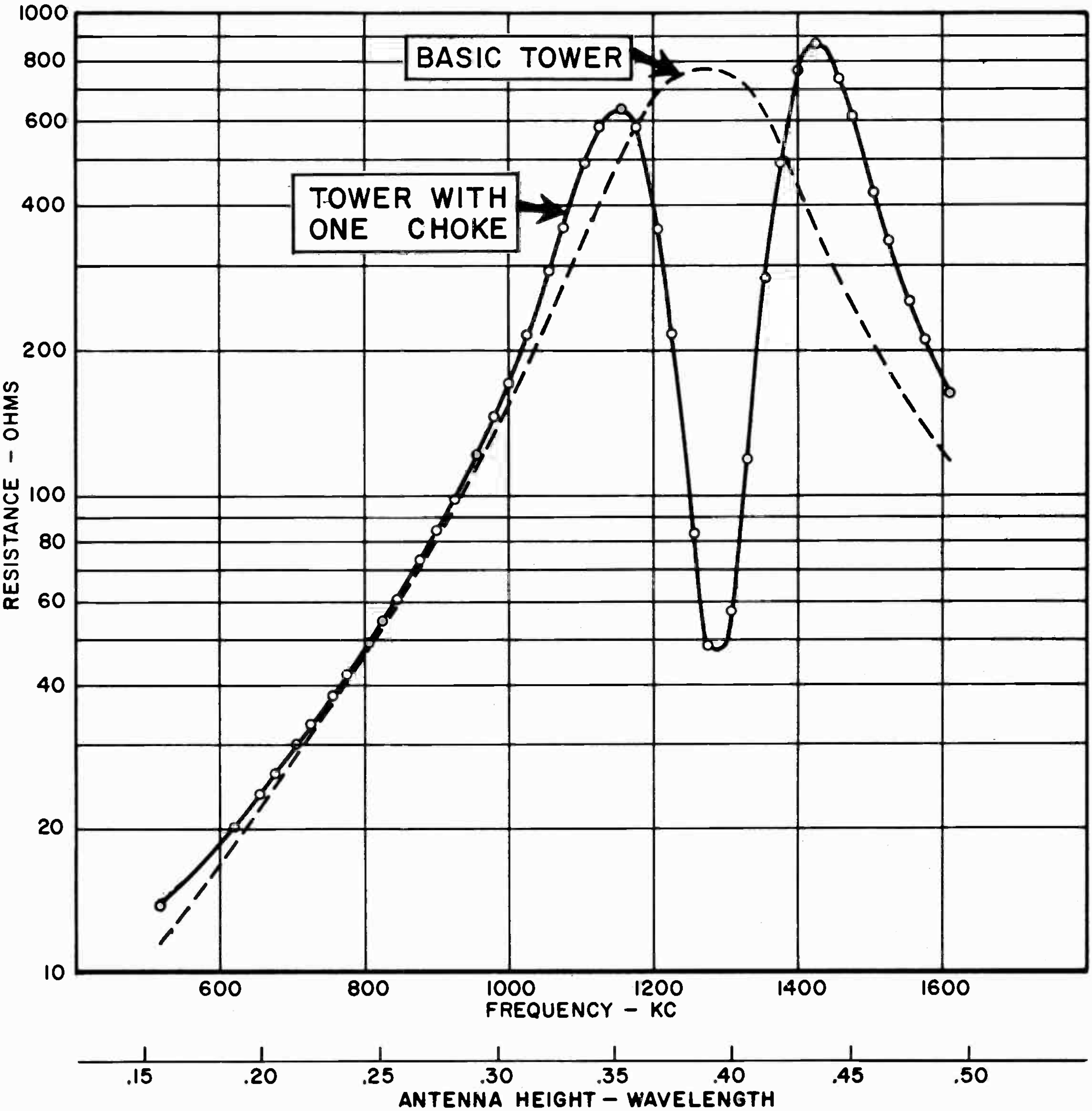

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FIGURE 4
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TOWER RESISTANCE VARIATION
2-CHOKE ISOLATION CIRCUIT

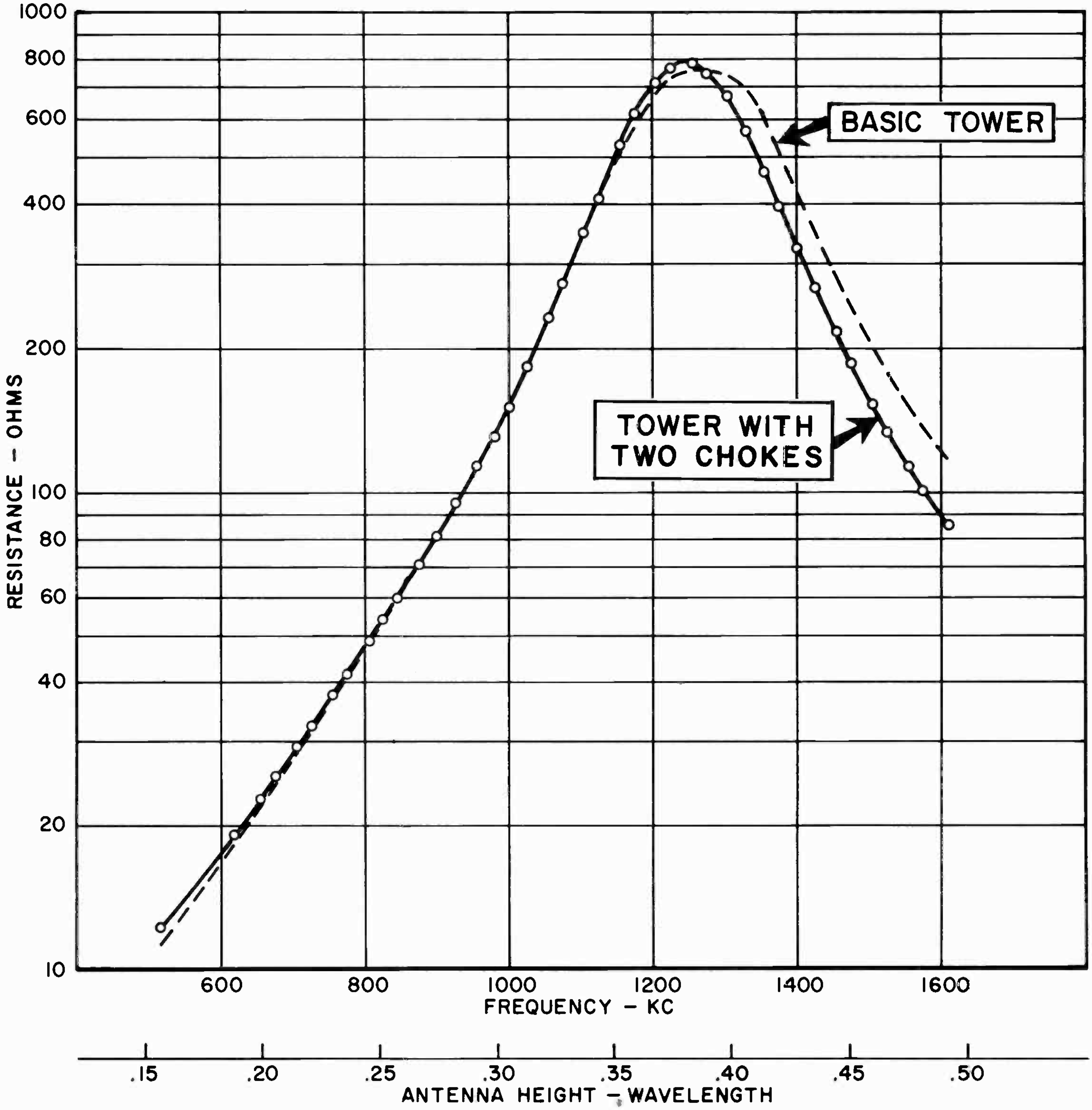

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FIGURE 5

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TOWER RESISTANCE VARIATION
TRANSFORMER ISOLATION CIRCUIT

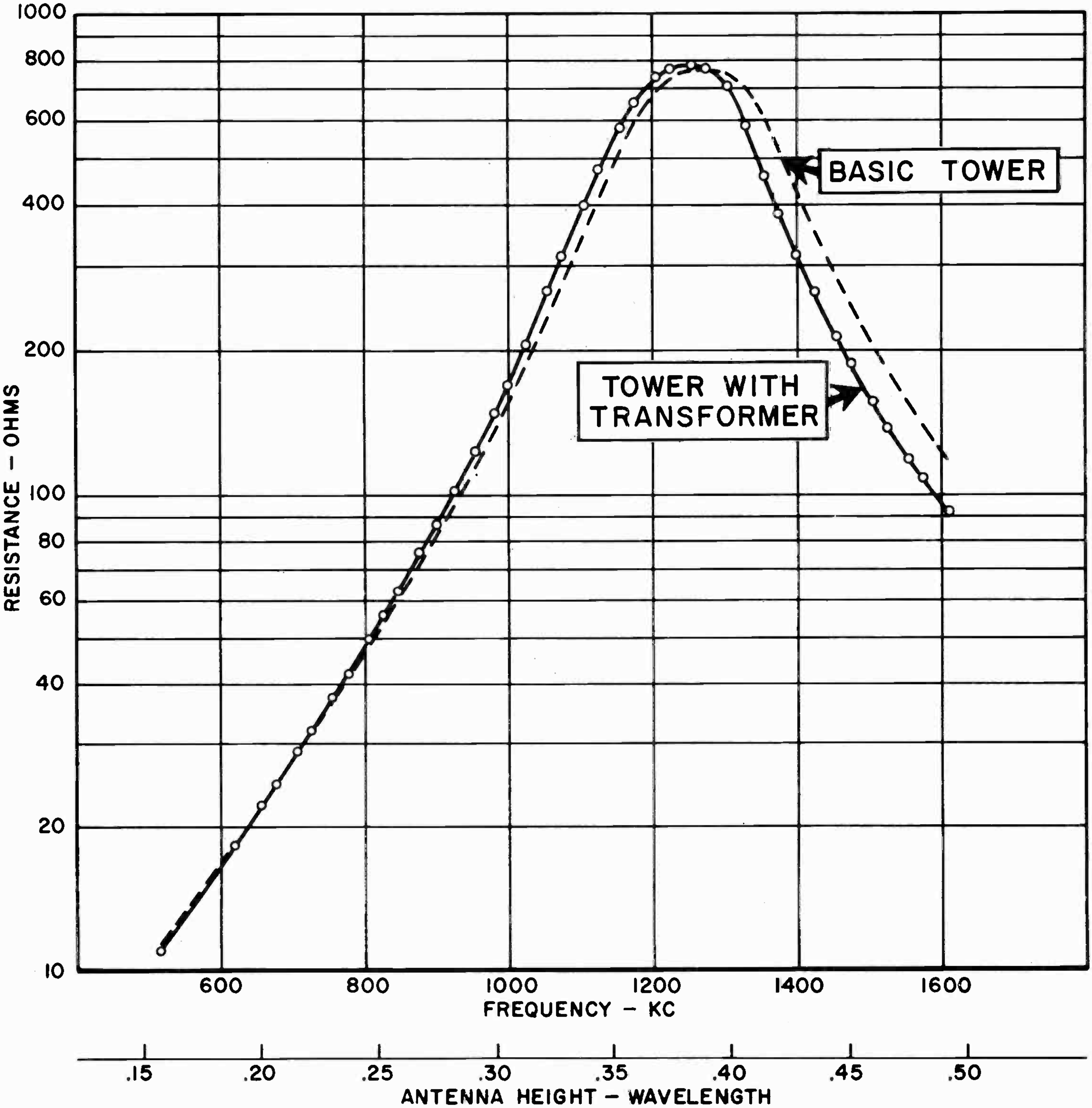

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FIGURE 6
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TOWER REACTANCE VARIATION
1-CHOKE ISOLATION CIRCUIT

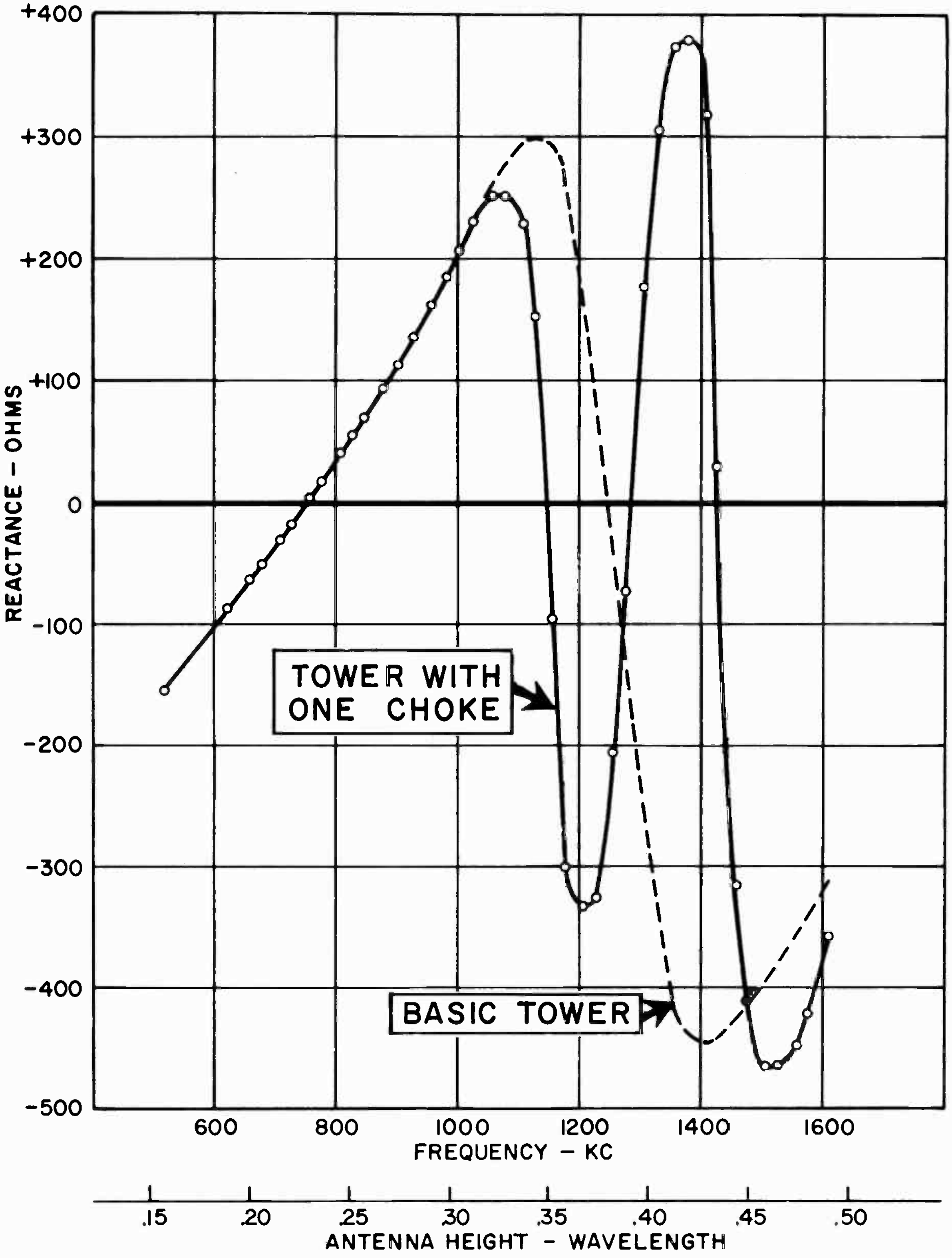

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FIGURE 7
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TOWER REACTANCE VARIATION
2-CHOKE ISOLATION CIRCUIT

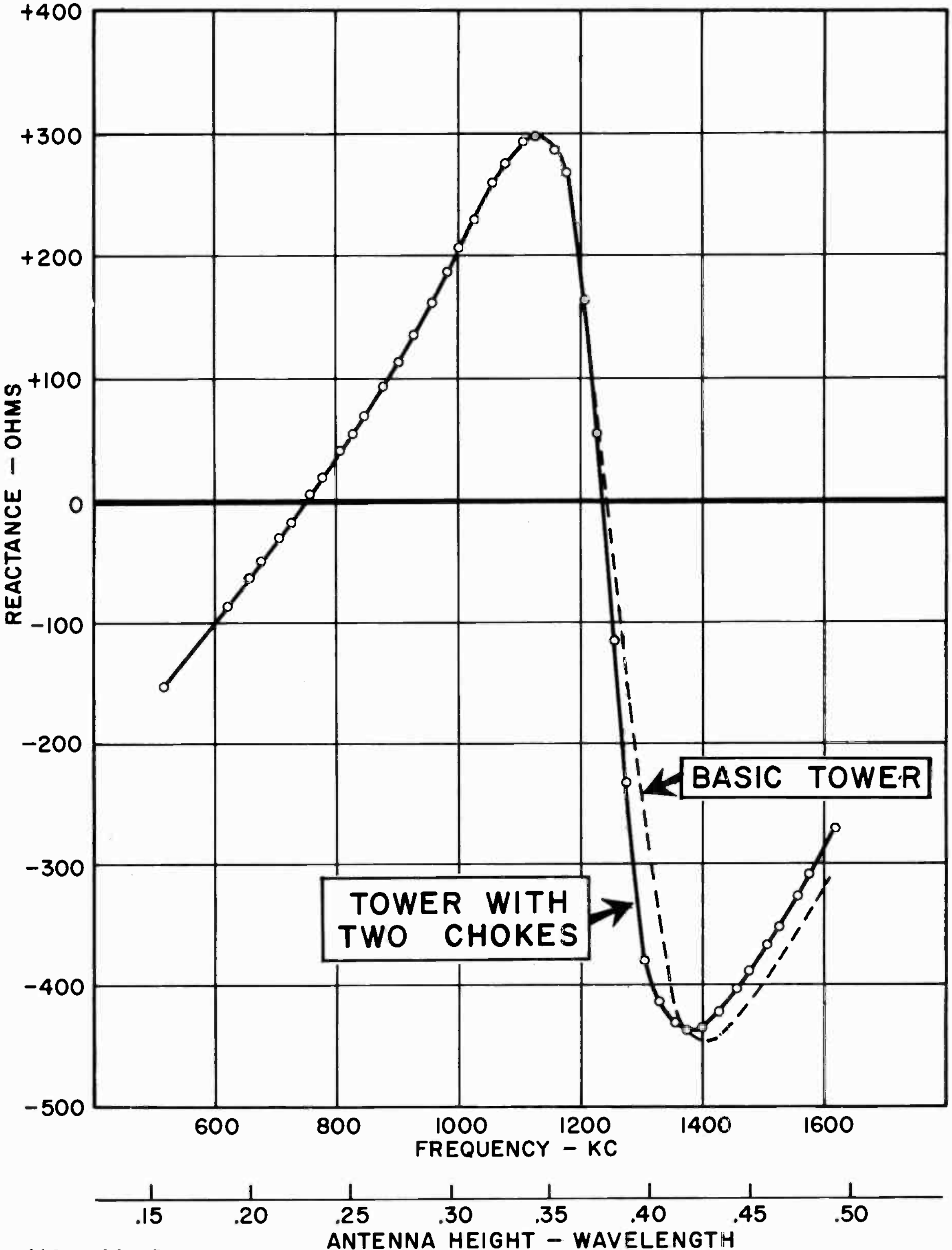

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FIGURE 8

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TOWER REACTANCE VARIATION
TRANSFORMER ISOLATION CIRCUIT

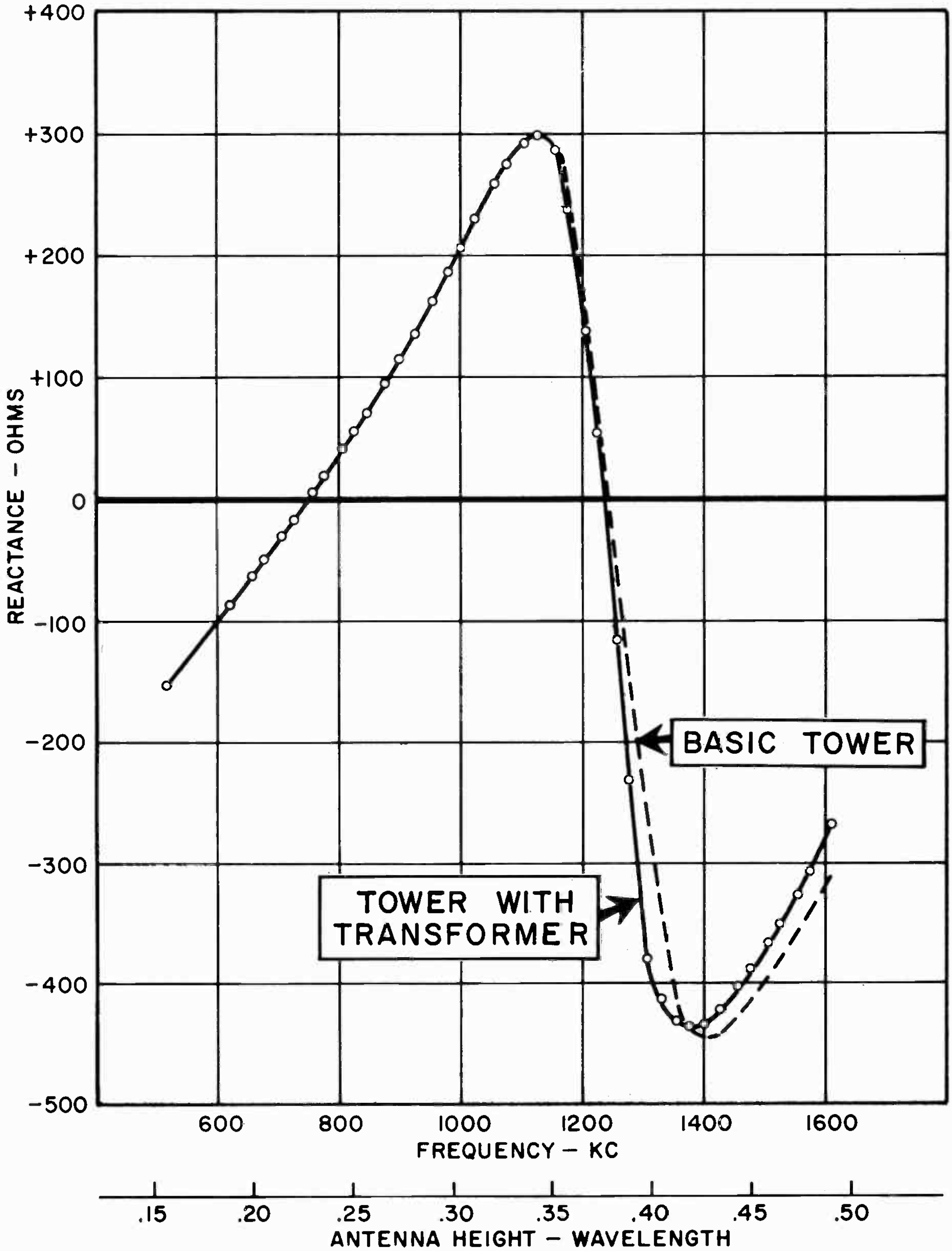

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FIGURE 9

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1/4-WAVE LINE ISOLATION

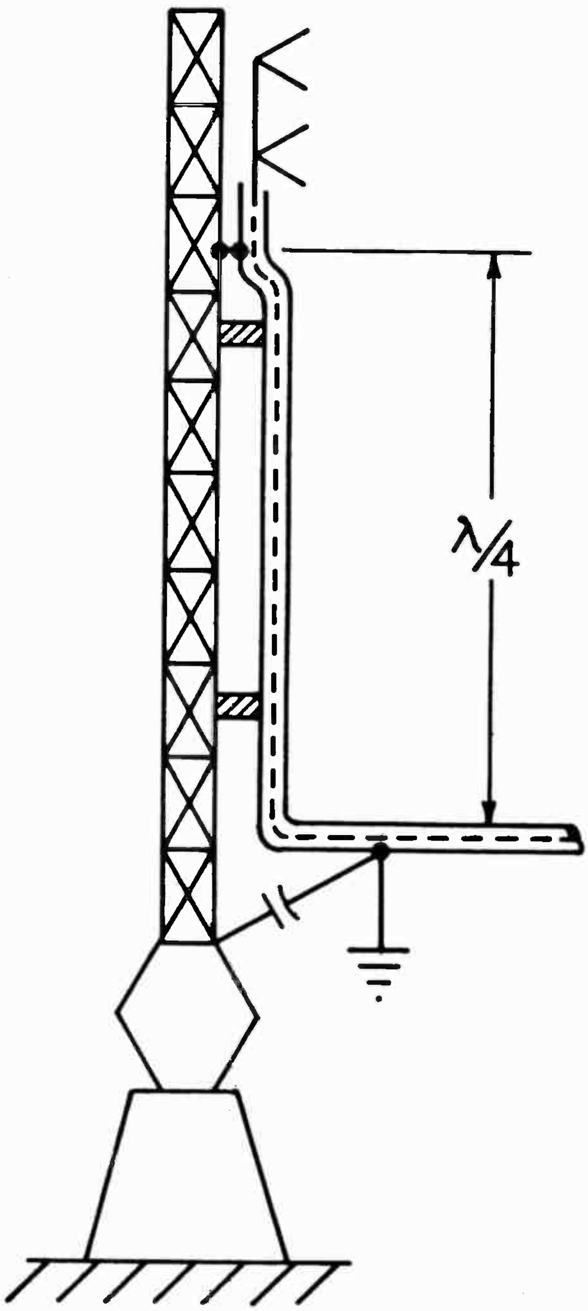

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FIGURE 10
MARCH 1960

INSULATED
SAMPLING LOOP ISOLATION

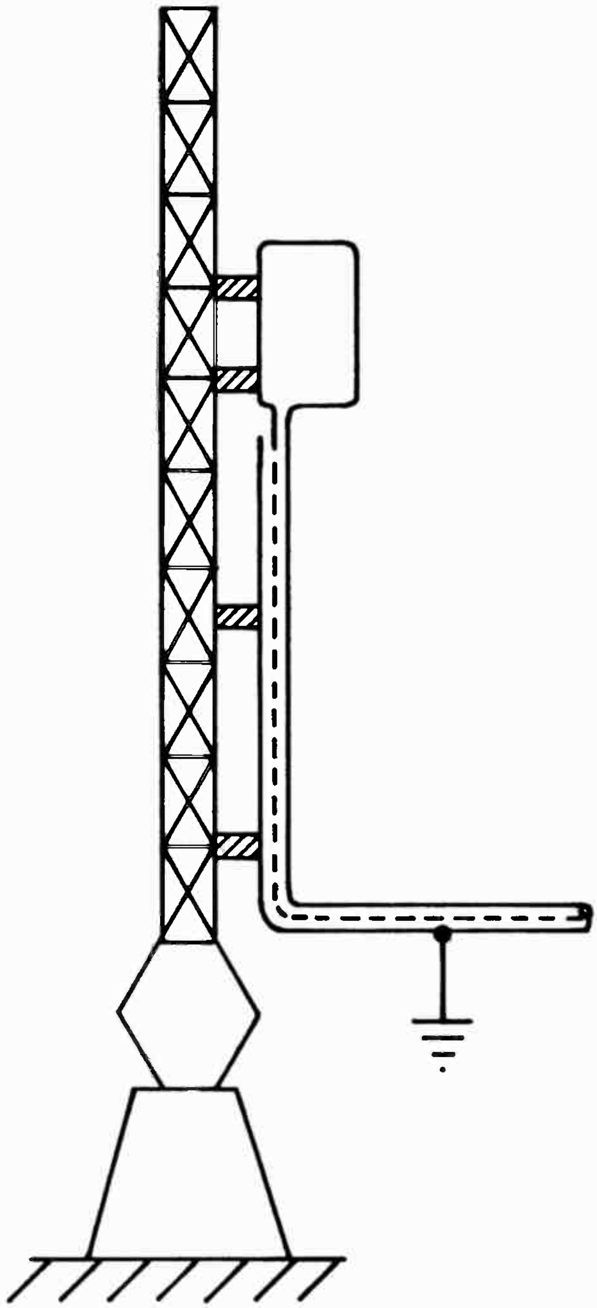

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FIGURE II
MARCH 1960

PARALLEL RESONANCE ISOLATION

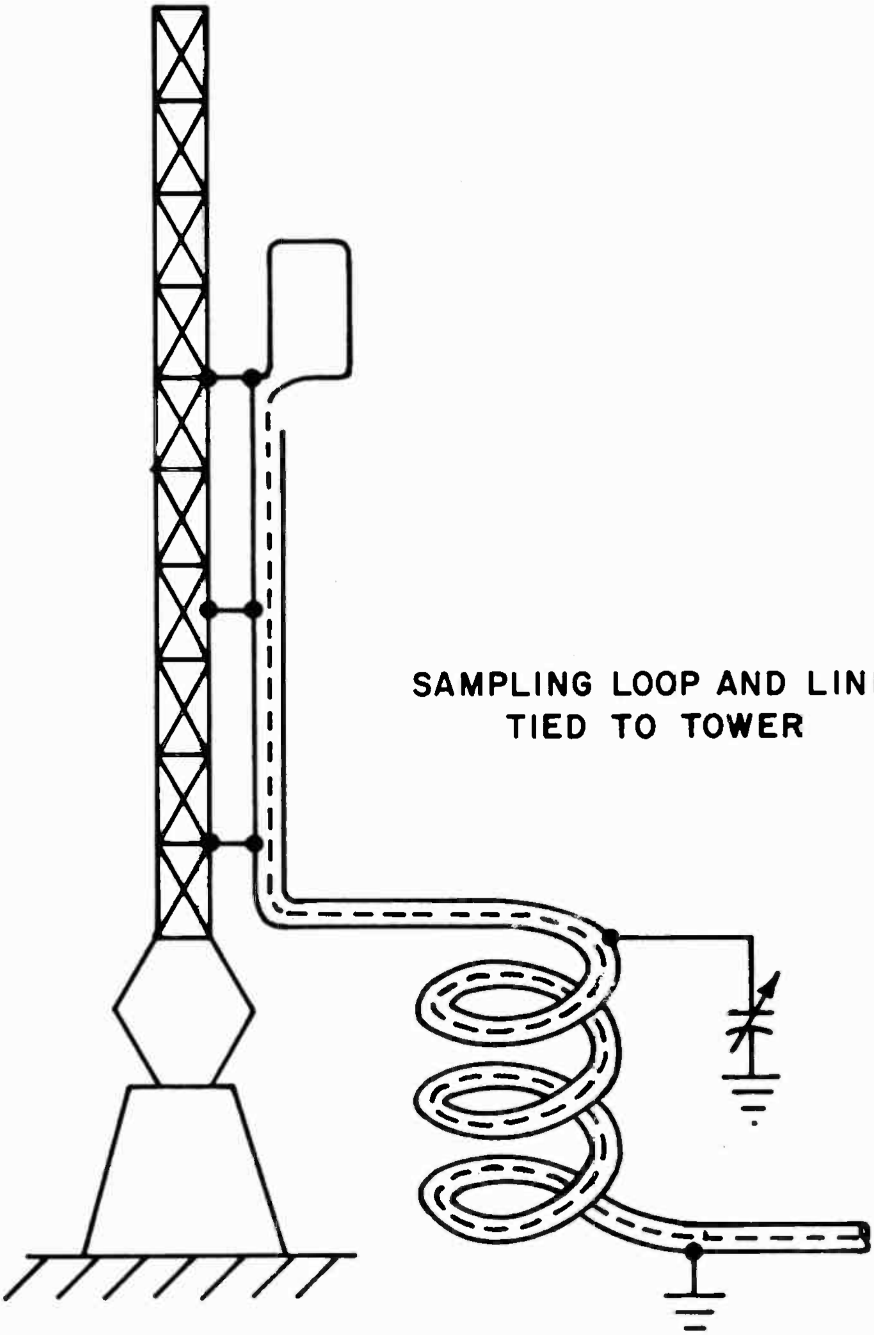

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FIGURE 12
MARCH 1960

TUNNEL DIODES AS AMPLIFIERS AND SWITCHES

by

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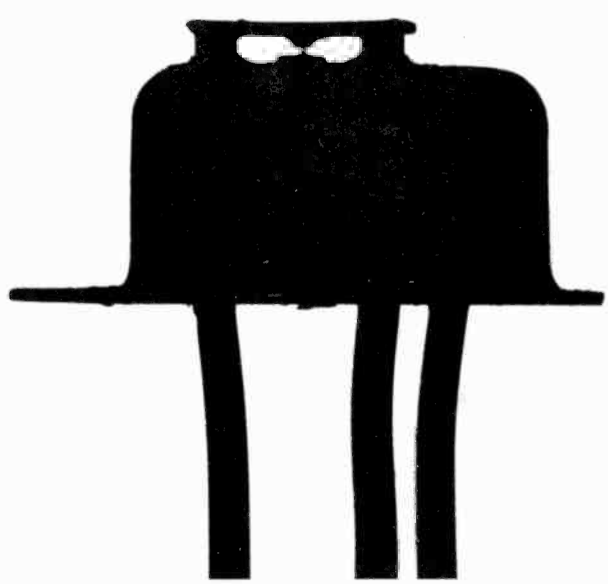
Fast, inexpensive, resistant to nuclear radiation, and having low noise capabilities, the tunnel diode is a new semiconductor device presently challenging the imagination of the electronics industry. This device, judiciously put to use, can reduce equipment size, weight, complexity and cost while improving performance and reliability.

Device Characteristics

The tunnel diode, so-called because of its use of the quantum mechanical tunneling principle is inherently a negative conductance device. As such, it is particularly well-suited for operation as a sine-wave or relaxation oscillator. Its unique "S" characteristics make it extremely useful for current sensing, current reference and as both the active and memory switching element in computer circuitry. Due to its region of relatively linear negative conductance, it can also be used as an amplifier. In general, its inherent high speed, resistance to nuclear radiation, low operating power requirements, and wide operating temperature range can make it a valuable asset in a large variety of applications.

ECG-488 3/60

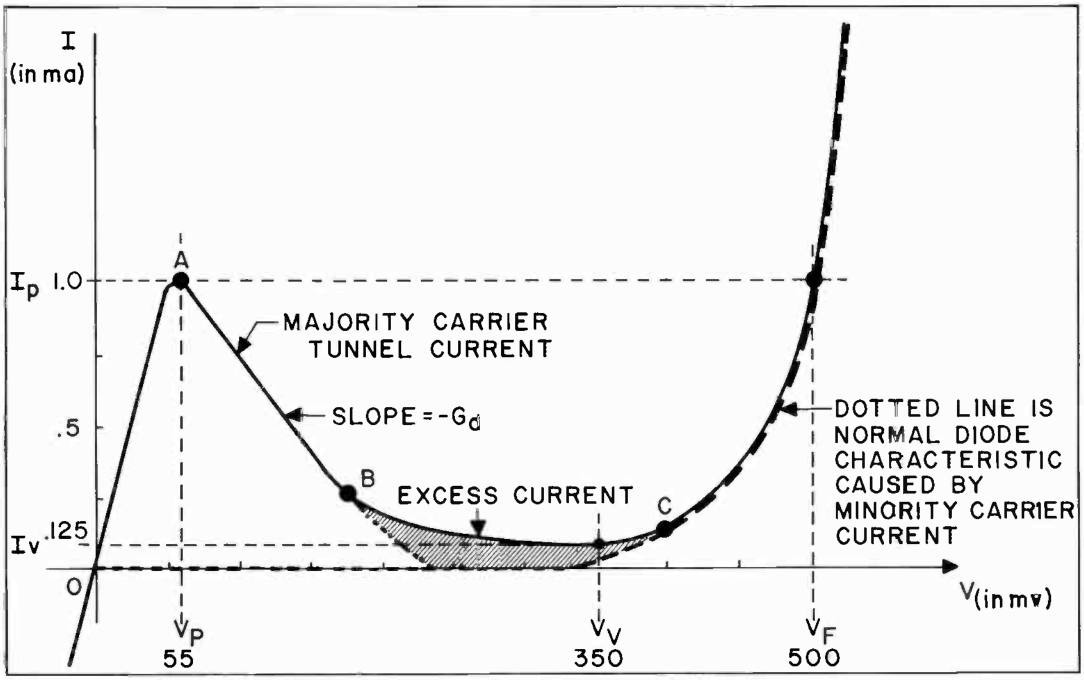
The structure of a typical tunnel diode is shown in Figure 1. The tunnel diode, seen in the center of the photograph, is mounted on a standard TO-18 transistor header directly between two of the lead posts. Contact to the top of the diode is made by a thin strip running between the tops of the two lead posts. This structure offers the advantage of a minimum inductance in a single-ended package, since the two leads connected to the top strip can be paralleled to reduce the series inductance. Another significant advantage of this structure is its mechanical strength. This is extremely important in the case of low current, low capacity diodes where the diameter of the junction can be extremely small. For example, a high performance diode with a peak current of one milliampere will have a diameter of less than 3×10^{-4} inch.



Side View of Typical Tunnel Diode Structure

FIGURE 1

The voltage-current characteristic of a germanium tunnel diode is shown in Figure 2 together with the important DC parameters. The dotted line in this figure shows a normal diode characteristic resulting from minority carrier current. It is seen that the tunnel diode follows this characteristic beyond point C. In the lower voltage region below point C and in the reverse biased state the diode current consists of majority carriers which tunnel through the narrow PN junction with the speed of light. The speed of the quantum mechanical tunneling gives the device its high frequency capabilities as compared to conventional diodes and transistors which rely on the relatively slow phenomena of drift or diffusion for their operation.



Static Characteristic Curve of Germanium Tunnel Diode

FIGURE 2

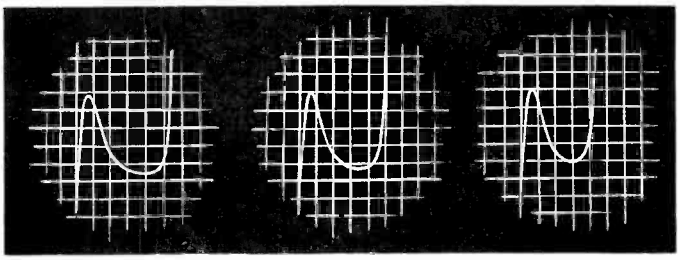
A relatively linear negative conductance region exists between point A (the peak point) and point B in Figure 2. Between point B and point C the current is greater than the sum of the theoretical majority and minority currents. The current in this region, identified as the excess current, can not, as yet, be completely explained. Intuitively the excess current or valley current should be low and therefore the highest peak point to valley point current ratio seems desirable. There are some tangible reasons for this also. The greater this ratio, for any given value of peak point current, the greater will be the available output current swing. For example, a tunnel diode with a peak current of one milliampere and a peak to valley current ratio of 8 will have an available current swing of 1.0 - 0.125 = 0.875 ma. The peak current of a tunnel diode can be chosen at will and held to within tight limits. Germanium tunnel diodes have been made with peak currents between 100 μa and 10 amperes and tolerances on peak current can be maintained to within 10% or better on a production basis. However, the peak voltage, Vp, valley voltage, Vv, and forward voltage, Vf, are determined by the semiconductor material and are largely fixed. For germanium these voltages are respectively 55 mv, 350 mv and 500 mv typical at 25°C. For silicon, the voltages are 75 mv, 450 mv, and 750 mv, while for the recently announced gallium arsenide units the voltages are 150 mv, 500 mv and 1200 mv. Higher voltages offer the advantage of wider dynamic range and higher output power for applications where these are important.

The magnitude of the negative conductance is equal to the slope di/dv of the voltage current characteristic. For a one milliampere germanium tunnel diode the negative conductance is between 0.006 and 0.010 mho corresponding to a negative resistance between 100 ohms and 160 ohms. If tunnel diodes are to be used in linear amplifiers, the value of the negative conductance must be closely controlled.

Temperature Characteristics

Varation of the tunnel diode parameters with temperature is a matter of extreme importance to the circuit designer. Figure 3 shows the voltage-current characteristic of a typical germanium tunnel diode at temperatures of -55°C, 25°C, and 100°C. Note that the peak voltage, valley voltage and forward voltage all decrease with increasing temperature while the valley current increases with increasing temperature. The peak current may increase or decrease with temperature depending on the doping agents and the resistivity of the semiconductor material. For the diode shown in Figure 3, the peak current is a maximum at approximately 25°C and decreases at higher and lower temperatures.

(A) Amb. Temp. of -50°C (B) Amb. Temp. of +25°C (C) Amb. Temp. of +100°C



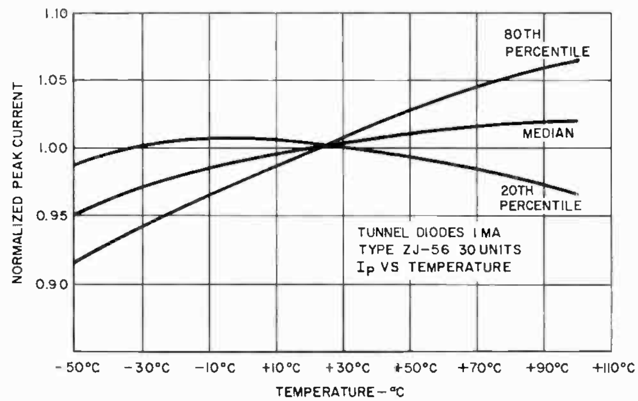
Voltage-Current Characteristic Curves of a Typical Germanium Tunnel Diode

FIGURE 3

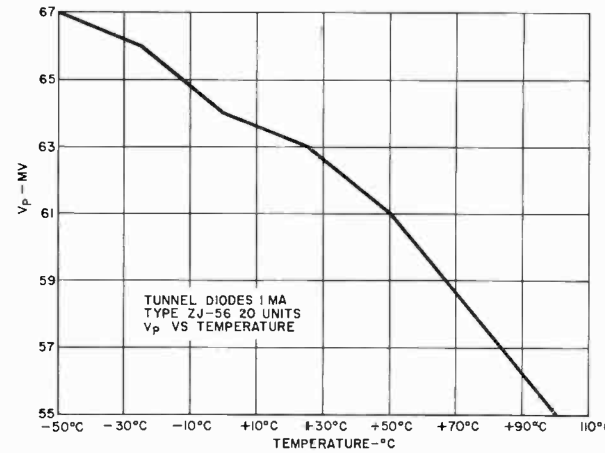
Each application generally has a different temperature problem. For example, in switching circuits the primary concern is the stability of the peak current since it determines the switching threshold, although the changing forward voltage can affect the amplitude of the output voltage.

In oscillators where matching is not required, it may be important only to make sure that at the lowest operating temperatures the device is driven from a voltage source which requires that the resistance of the source supplying the voltage to the tunnel diode is much less than the negative resistance of the diode. Oscillators have been operated successfully over a temperature range from 4°K to over 573°C, a remarkably wide operating range. In amplifiers where some degree of match between the diode conductance and the circuit conductance is required it is obvious that this match must be maintained over the required operating temperature range. Stable amplification can be achieved by using either negative feedback or direct temperature compensation with thermistors or other temperature sensitive devices.

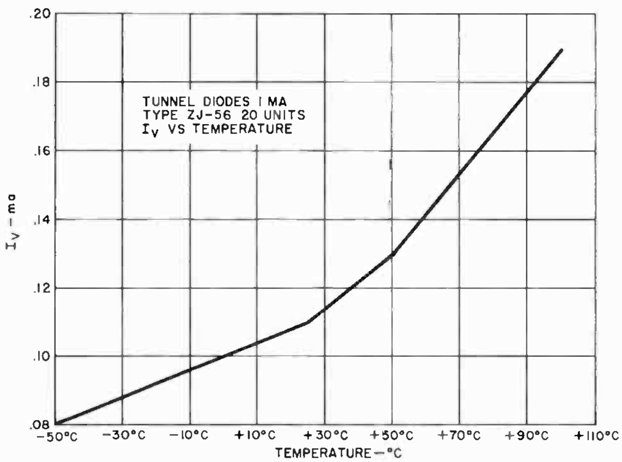
The variation of the important DC parameters between -50°C and 100°C is shown in Figure 4 for a 1 milliampere germanium tunnel diode. Note that the peak point voltage has a temperature coefficient of -0.08 millivolts/$^{\circ}$C and the forward voltage has a temperature coefficient of -1.0 millivolts/$^{\circ}$C as compared with a value of -2.5 millivolts/$^{\circ}$C for the forward drop of a conventional diode or transistor.



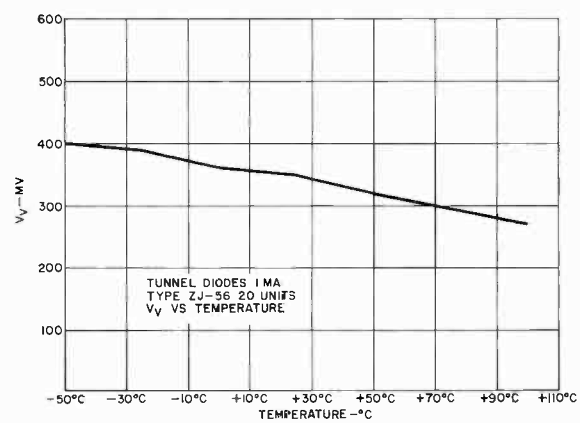
(A) Normalized Peak Point Current Vs. Temperature



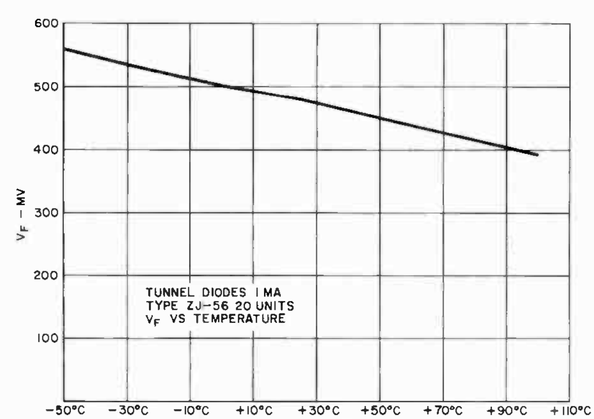
(B) Peak Point Voltage Vs. Temp.



(C) Valley Point Current Vs. Temp.



(D) Valley Point Voltage Vs. Temp.



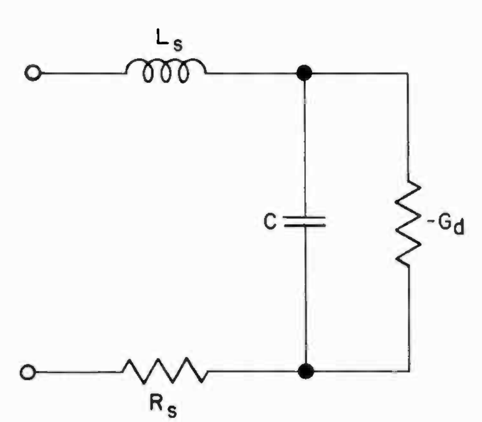
(E) Forward Voltage Vs. Temp.

DC Characteristics of Germanium Tunnel Diodes
as a Function of Ambient Temperature

FIGURE 4

Frequency Limitations

The small signal equivalent circuit for the tunnel diode when biased in the negative conductance region is shown in Figure 5. The inductance, L_s, in the equivalent circuit is relatively low and is determined primarily by the inductance of the leads. A small amount of series resistance, R_s, is also present which is determined by the bulk resistance of the semiconductor material. The capacity, C, is primarily due to the capacity of the junction although a small portion of the capacity is due to the leads and the package. The negative conductance, $-G_d$, in the equivalent circuit is equal to the slope of the voltage-current characteristic at the particular bias point under consideration. The value of the negative conductance can be assumed to be independent of frequency, the chief limitations in the frequency response of the tunnel diode being determined by the parasitic elements in the equivalent circuit (R_s, L_s, C).



TYPICAL VALUES OF "ZJ56" PARAMETERS	
SERIES INDUCTANCE, L_s *	$6 m\mu h$
TOTAL CAPACITANCE, C *	$7 \mu\mu fd$
SERIES RESISTANCE, R_s	1ohm
NEGATIVE CONDUCTANCE, G_d	.01 mho
NEGATIVE RESISTANCE, r_d	100ohm
PEAK POINT CURRENT, I_p	1ma
VALLEY POINT CURRENT, I_v	.1ma
PEAK POINT VOLTAGE, V_p	55mv
VALLEY POINT VOLTAGE, V_v	350mv
FORWARD VOLTAGE, V_f	500mv
* 1/8 INCH LEAD LENGTH	

Small Signal Equivalent Circuit and Typical Values of Parameters

FIGURE 5

Two significant frequency figures of merit can be assigned to the tunnel diode:

(a) resistive cut-off frequency $f_{go} = \frac{|Gd|}{2\pi C}\sqrt{\frac{1}{R_s\,|Gd|} - 1}$

(b) self-resonant frequency $f_o = \frac{1}{2\pi}\sqrt{\frac{1}{L_s\,C} - \left(\frac{Gd}{C}\right)^{-2}}$

Both of these frequencies are derived from the equivalent circuit of Figure 5. The resistive cut-off frequency is the frequency at which the real part of the diode admittance measured at its terminals goes to zero. The tunnel diode can not amplify above this frequency. The self-resonant frequency is the frequency at which the imaginary part of the diode admittance goes to zero. It should be pointed out that both frequencies are reduced by external circuit components and therefore the highest possible operating frequency is very circuit dependent. In a transistor package the tunnel diode is limited to frequencies below 1 Kmc, this limit being due primarily to the lead inductance. Microstrip or microwave packaging, owing to its inherently lower inductance, can raise the frequency capabilities by an order of magnitude or more.

Noise Performance

In the tunnel diode, one of the major contributions to noise is shot noise. The noise figure in a correctly designed amplifier can be in the range of 3 or 4 db provided that the source conductance is matched to the negative conductance of the tunnel diode. The noise figure is also dependent on the load conductance which might be a mixer or converter stage and be relatively noisy. It is possible, however, to connect the tunnel diode in parallel with the input of a VHF stage and obtain both reduced noise and increased gain. The noise figure is given by the equation:

$$N.F. = 1 + \frac{20\ Idc}{Gg} + \frac{T_1 \cdot G_1}{T_g \cdot G_g}$$

where I_{dc} is the DC bias current through the tunnel diode, G_g and G_1 are the conductances of the generator and load, and T_g and T_1 are the effective noise temperatures of the generator and load. From this equation it can be seen that it is desirable to make G_g large and G_1 small. To achieve high gain it is necessary that $G_g + G_1$ be very nearly equal to the conductance of the diode, G_d. Thus to minimize the noise figure it is desirable to make G_g very nearly equal to G_d. The value of I_{dc} should be chosen as low as possible, consistent with a reasonable value of G_d. To satisfy this requirement, tunnel diodes with high values of peak current to valley current ratios are desirable.

Nuclear Radiation Effects

Encouraging results have been obtained from preliminary investigations of the effects of nuclear radiation on the characteristics of tunnel diodes. Under a doseage of 3×10^{14} NVT (90% thermal, 10% fast), no apparent change in the electrical characteristics were observed except for the noise figure which increased by approximately 20% at the point of maximum negative conductance and by 100% near the valley point.

At a doseage of 5 x 10^{15} NVT, the valley current increased by about 25% while the other DC characteristics had not changed. The noise figure increased by a factor of 3 at the point of maximum negative conductance while the noise figure in the vicinity of the valley point was immeasurably high. In general, the radiation resistance of tunnel diodes appears to be considerably higher than tubes or transistors and should be of definite value for military applications.

Linear Amplifiers

On examination of the voltage current characteristics of the tunnel diode as shown in Figures 2 and 3, it is evident that for amplifier circuits the bias must be supplied from a voltage source in order to sustain a stable operating point. The bias point should be located near the center of the negative conductance region provided that the noise performance is not at a premium. Biasing at the center of the negative conductance region allows the greatest possible dynamic range to be achieved.

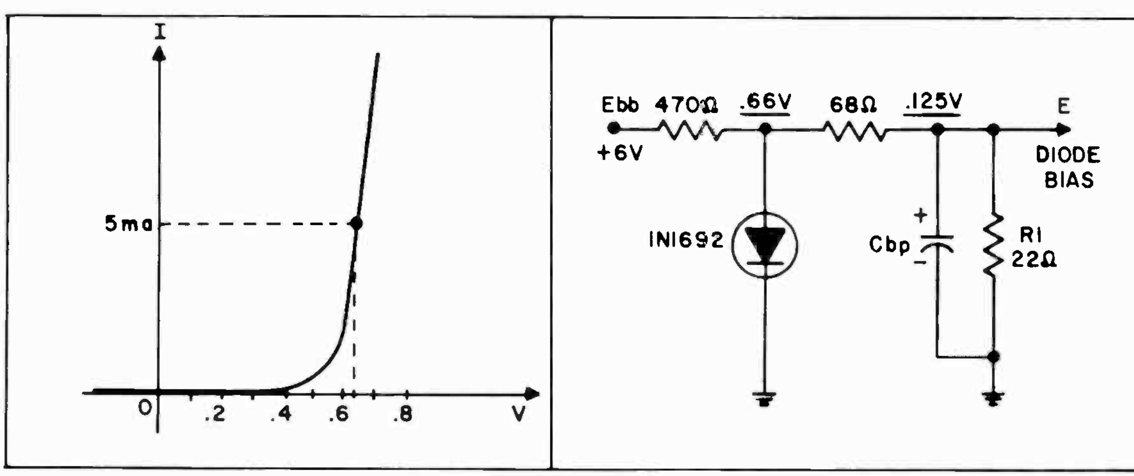
The greatest problem in biasing tunnel diodes is due to the fact that the negative conductance region is not perfectly linear. In amplifier circuits it is necessary to match the diode conductance closely to the circuit conductance if high gain is to be achieved. Slight variations in bias point with the consequent variations in diode conductance can cause large changes in circuit gain. Hence it is important to ensure a very stable bias voltage. Some of the possible methods for obtaining stable, low impedance supply voltages are;

(1) the use of mercury cells.

(2) the use of negative feedback.

(3) the use of forward biased diodes as voltage regulators.

An example of the use of forward biased diodes for bias stabilization is shown in Figure 6. Here an inexpensive silicon diode is biased heavily in the forward direction so that it exhibits a low voltage and a low dynamic resistance. A low impedance voltage divider is used to reduce the diode voltage to the value desired for biasing of the tunnel diode.



Silicon Diode Used as Regulator for Bias Supply

FIGURE 6

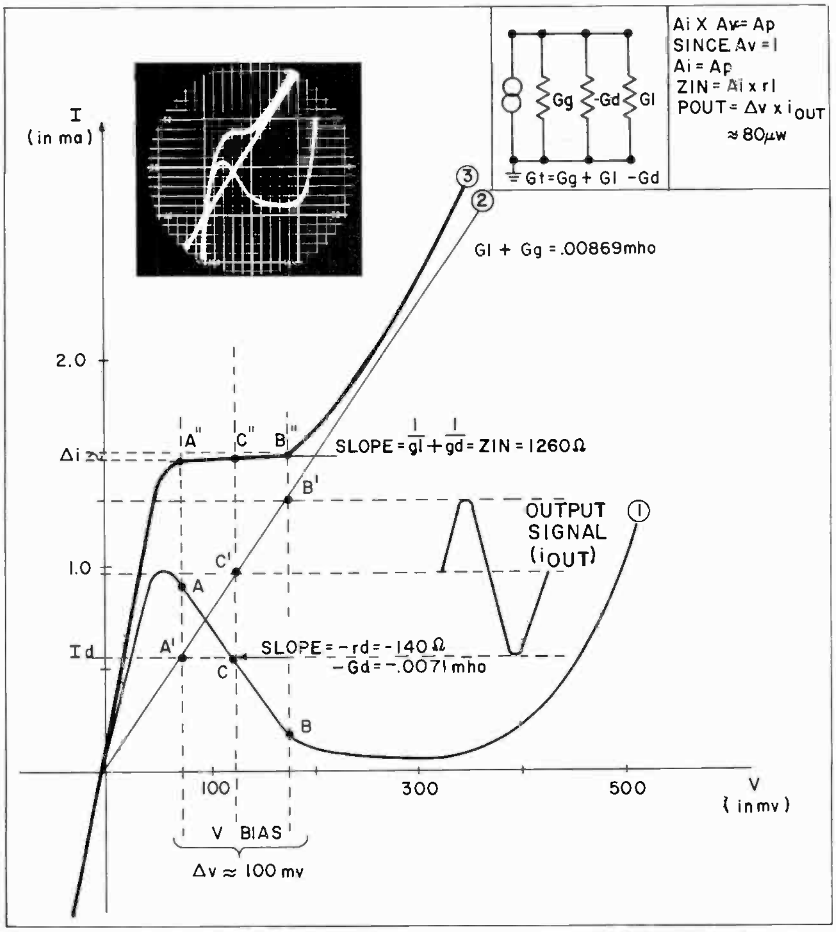
A graphical analysis of the operation of a parallel amplifier stage is shown in Figure 7. The voltage-current characteristic of the tunnel diode is represented by curve 1, the net circuit conductance is represented by curve 2 and the resultant input characteristic of the over-all amplifier stage is represented by curve 3. It is seen that the slope of the input characteristic in the active region (between A'' and B'') is close to horizontal indicating a high input impedance. The value of the input impedance is given by;

$$Z_{in} = \frac{1}{G_T} = \frac{1}{G_g + G_1 - G_d}$$

and the available power gain would be given by:

$$PG_{av} = \frac{4G_g G_1}{G_T^{\ 2}}$$

It can be seen both graphically and mathematically that to obtain a high



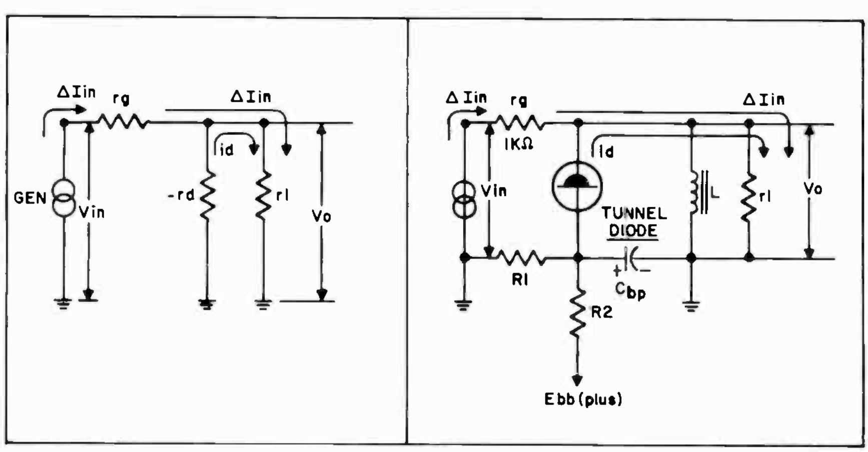
Graphical Analysis of Parallel Amplifier Stage

FIGURE 7

value of available power gain it is necessary for Z_{in} to be very large and positive. This requires $G_g + G_1$ to be very nearly equal to but larger than G_d. Since the voltage is the same across all the conductances in the circuit, the voltage gain of the parallel circuit will be unity.

The closer $G_g + G_1$ is to G_d, the greater is the current amplification obtained. A similar graphical analysis can be applied to the series connection resulting in a "low" input impedance circuit and voltage gain.

Figure 8 shows an audio amplifier circuit yielding about 30 db gain. It is much more difficult to build a low frequency amplifier circuit, incidentally, since the tunnel diode is inherently trying to oscillate at a very high frequency.



Parallel Amplifier Stage and Equivalent Circuit

FIGURE 8

The use of audio components and audio type layouts, generally result in enough stray inductance to enable the circuit to oscillate freely at high frequencies since bypassing is not a simple matter in the UHF range. Additional circuit stability criterias therefore are:

1) f_o of the circuit to be equal or above f_{go} to avoid self-oscillations.

2) The sum of the load and generator conductances must be nearly equal to, but always greater than the negative conductance of the diode (in the parallel type circuit).

3) The total DC loop conductance must be larger than the negative conductance (voltage source).

4) All above requirements must remain satisfied over a range of supply voltages and temperature conditions.

Amplifier circuits have been built anywhere from audio frequencies up to 225 Mc/s yielding gains in the 30 db range with excellent bandwidth. As an example a 100 Mc/s circuit was built having 32 db gain with a BW of 20 Mc/s.

Switching Circuits

One of the most promising areas for the application of tunnel diodes is in switching circuits, particularly in large scale computers where the tunnel diode can economically perform both the logic and memory functions. Here the tunnel diode offers the advantages of small size, low operating power, high speed, a potential low cost and high reliability.

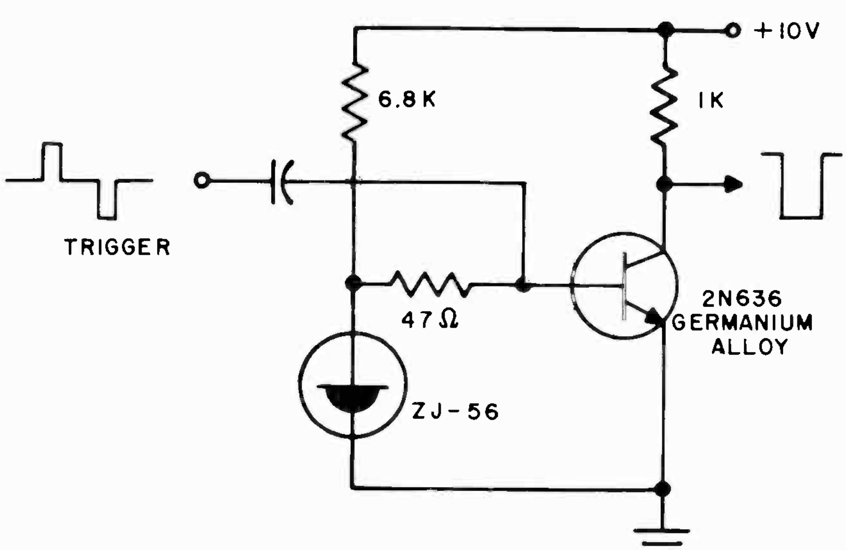
It is possible to form a simple bistable circuit by connecting a tunnel diode in series with a voltage source and a single resistor. For bistable operation it is only necessary that the load line formed by the voltage source and resistor intersect the diode characteristic curve of Figure 2 and 3 at two points where the characteristic curve has a positive slope. These two points represent the two stable states of the circuit. If a larger series resistance is used, the diode can be considered to be biased from a constant current source. A constant current bistable load line would be represented in Figure 2 or 3 by a horizontal line lying between the peak point and the valley point. As an example, consider a constant current load line of 0.7 ma in Figure 2. The diode would have approximately 30 millivolts across it in the "on" state and approximately 470 millivolts across it in the "off" state. In the "on" state the current through the diode consists entirely of majority carriers transported across the junction by the tunneling mechanism, while in the "off" state the current through the diode consists entirely of minority carriers transported across the junction by diffusion.

The diode can be triggered from the "on" state to the "off" state by means of a current pulse which temporarily increases the current through the diode to a value greater than the peak current. Similarly the diode can be triggered from the "off" state to the "on" state by means of a current pulse which temporarily reduces the current through the diode to a value less than the valley current. The switching speed is very high and is determined chiefly by the junction capacity and the amount of charge available from the triggering pulse. If a constant current load line is used with a trigger of minimum amplitude, the rise time of the voltage across the diode between the 10% and 90% points will be given approximately by;

$$t_r = \left(\frac{V_F - V_P}{I_p - I_v} \right) C$$

Using the typical parameters for the ZJ56 listed in Figure 5, the rise time is calculated as 3.5 mμs, which is in close agreement with measured values. Since V_F, V_P and $C/(I_P - I_V)$ are largely independent of I_P, the rise time will also be independent of I_p. The rise time can be decreased by reducing the radio $C/(I_P - I_V)$ or the radio of C/G_d. Switching speeds of less than 1 mμs have been measured for 10 ma versions of the ZJ56.

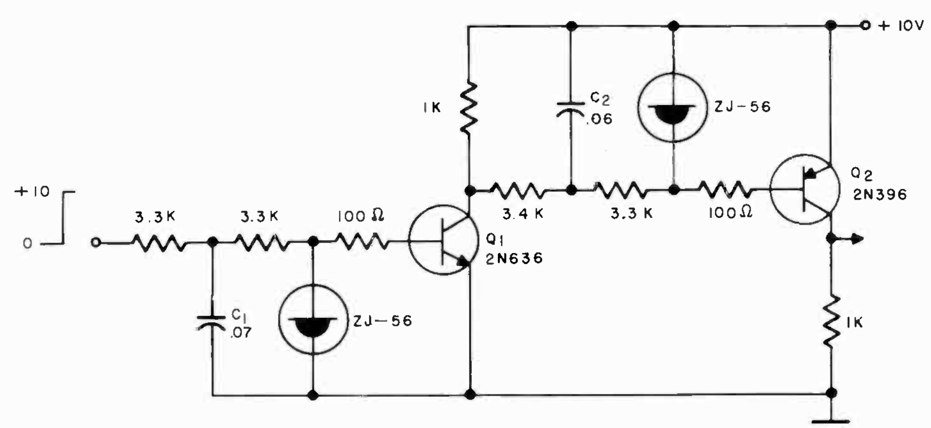
The voltage of the germanium tunnel diode in the "off" state, V_F, is approximately 0.50 volt which is considerably higher than the base to emitter voltage of a germanium alloy transistor (approximately 0.30 volt with a base current of 1 ma). Accordingly, it is possible to switch a PNP or NPN germanium alloy transistor directly with the output from a germanium tunnel diode. This permits the tunnel diode to be used in conjunction with conventional transistors to form many useful types of switching circuits. One example is the simple flip-flop circuit shown in Figure 9. In this circuit a current which is lower than the peak current is supplied by the 6.8K resistor. When the tunnel diode is "on" a low voltage exists at the base of the transistor and the transistor will be off. If a positive pulse occurs at the input, the current through the tunnel diode increases above the peak current and the tunnel diode switches to the high voltage state. The tunnel diode will remain in the high voltage state and the major portion of the current from the 6.8K resistor will be diverted into the base of the transistor causing it to turn on and the voltage at its collector will fall to a very low value. Similarly, a negative pulse at the input will cause the current in the tunnel diode to drop below the valley current and cause the tunnel diode to switch to its low voltage state which in turn will cause the transistor to turn off. The 47 ohm resistor serves to bias the tunnel diode above the valley point voltage when it is in its "off" state and also serves to prevent the tunnel diode from loading the trigger pulse thus increasing the switching speed of the transistor.



Bistable Circuit Using Tunnel Diode and NPN Germanium Alloy Transistor

FIGURE 9

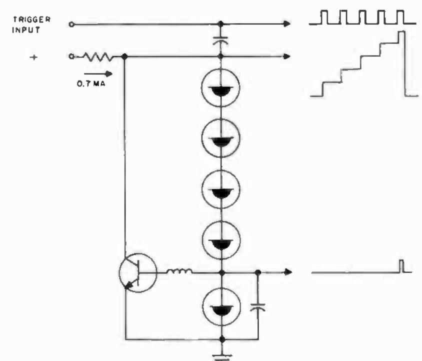
The time delay circuit shown in Figure 10 permits any number of consecutive time delays to be obtained with relatively simple circuitry. The timing cycle is initiated by applying a step voltage of +10 volts at the input. The capacitor, C_1, is charged through the 3.3K resistor and the current through the first tunnel diode increases in proportion to the voltage on C_1. When the current through the tunnel diode increases to the peak current, the tunnel diode will switch to its high voltage state and cause Q1 to turn on. The voltage at the collector of Q1 will then fall from +10 volts to a low value and a similar timing sequence will be initiated for the second stage. Note that the second stage is a complementary version of the first stage. At the end of the second timing sequence, Q2 will turn on and the voltage at its collector will rise from zero to +10 volts. For the circuit shown each time delay is approximately 100 μsec. A multiple phase oscillator can be obtained by connecting an odd number of stages in a closed loop.



Tunnel Diode Time Delay Circuit with Two Cascaded Complementary Stages

FIGURE 10

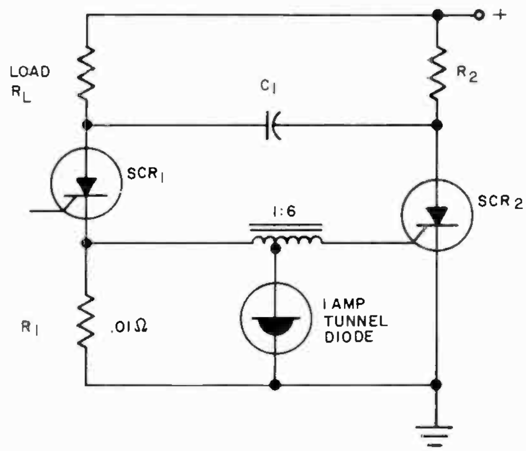
A simple 5:1 pulse frequency divider is shown in Figure 11. Here five tunnel diodes are connected in series and biased from a current source which has a lower value than the peak current of any of the diodes. The bottom diode is selected to have a higher peak current than any of the other diodes in the circuit. Each time a positive pulse occurs at the input one diode is switched from its low voltage state to its high voltage state. When the fifth pulse occurs the bottom diode is switched to its high voltage state and turns on the NPN transistor which resets the circuit by diverting the current from the tunnel diodes and causing them all to revert to their low voltage state. The capacitor across the bottom diode and the inductance in series with the base of the transistor serve to delay the signal to the transistor so that complete switching can occur. The waveform appearing across the tunnel diodes is a staircase with a risetime determined by the risetime of the trigger pulse. The operating frequency is limited chiefly by the switching speed of the reset transistor. A circuit using an avalanche transistor has been built which can perform the reset function in approximately 2 mμs.



Series Connected Tunnel Diodes Used for 5:1 Pulse Frequency Divider or Staircase Wave Generator

FIGURE 11

The tunnel diode has many applications in current sensing and current limiting circuits for power equipment. An example of the use of a high current tunnel diode as the reference element in a silicon controlled rectifier circuit breaker is shown in Figure 12.



Tunnel Diode used as Current Sensing Element
in Silicon Controlled Rectifier Circuit Breaker

FIGURE 12

When the load current increases above the limiting value the voltage across the 0.01 ohm current sensing resistor will exceed the peak point voltage and cause the tunnel diode to switch to its high voltage state. The voltage swing of the tunnel diode will be stepped up by the autotransformer to a value which is high enough to fire the silicon controlled rectifier, SCR2. When SCR2 fires, a negative voltage is coupled to SCR1 by the capacitor C1 which causes SCR1 to turn off and interrupt the load current in 20 μsec. or less. The chief advantage offered by the tunnel diode in this application is its ability to be triggered at a very low voltage level. This in turn results in a very low power loss in the current monitoring resistor.

DETERMINING THE OPERATIONAL PATTERNS OF DIRECTIONAL TV ANTENNAS

A report on certain experiments conducted
by the Television Allocation Study Organization

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DETERMINING THE OPERATIONAL PATTERNS OF DIRECTIONAL TV ANTENNAS

Frank G. Kear and Stephen W. Kershner

SUMMARY

In January of 1959 the Television Allocations Study Organization authorized its Committee on Directional Antennas to conduct field tests on directional TV antennas looking toward development of a means whereby the operational antenna pattern could be determined and to explore the effect of reflections and anomalous propagation on the degree of directivity actually obtained as compared with that calculated.

Tests were subsequently carried out at WBZ-TV in Boston, Massachusetts, and at WKY-TV in Oklahoma City, Oklahoma, with special directional antenna systems possessing various degrees of directivity. Measurements were made at distances varying from a few miles from the transmitter to well over 100 miles from the transmitter. Within the limits imposed upon the tests by the choice of sites, nature of the terrain, and a limited period of observation, it was found that propagation conditions did not materially affect the directivity of the array, even at distances where the scatter fields were of appreciable magnitude.

In the course of these measurements and tests, a procedure was developed whereby the operational antenna pattern could not only be determined, but also rechecked at suitable intervals thereafter.

INTRODUCTION

In the field of television broadcasting, vertical directivity of the transmitting antenna system has long been employed in order to make the most efficient use of the available radiated power. However, with few exceptions directivity in the horizontal plane has been avoided. Two of the factors behind this reluctance to use directional antennas for TV were: (1) The absence of a tested and acceptable procedure for proving the performance of a TV antenna pattern and for making subsequent checks thereon, and (2) the uncertainty as to the extent to which the directivity could be maintained in the suppression area under conditions of serious local reflections or tropospheric scatter.

In its study of the overall problems of Television Allocations, it became evident to the members of TASO that antennas with horizontal directivity would be useful in allocation if dependence could be placed upon their performance. It was apparent that, in the limited time available to TASO, it would be impossible to make an exhaustive study of all of the factors affecting the performance of directional antennas under all combinations of local and distant terrain conditions. However, it was agreed that even a limited amount of information would be valuable and a special group was appointed to review the problem and make recommendations as to the best possible procedure.

This initial study led to the formation of a "Committee on Directional Antenna Tests" which was charged with preparing a program of tests on directional antennas, the results of which may be expected:

> "First, to form the basis for establishing procedures for determining the extent to which the operational antenna pattern corresponds (1) with the

antenna pattern as measured at the antenna test site, and (2) with the antenna pattern previously calculated or otherwise determined to be required for the site in question.

"Second, to provide corroborative detail on the extent to which the behavior of the distant field (100 km or more) from a TV directional antenna is determined by the directivity of the operational antenna pattern."

During this same period the Association of Maximum Service Telecasters had independently decided to conduct tests on directional TV antennas and upon the formation of the Directional Antenna Committee, the tests which AMST had proposed were made a part of the TASO program.

The Westinghouse Broadcasting Company, Inc., indicated their willingness to make the facilities of television station WBZ-TV available for some of these tests and the licensee of WKY-TV in Oklahoma City also agreed to cooperate in the project. WJMR-TV in New Orleans offered the use of their experimental operation on Channel 12 but the experimental authorization was terminated prior to initiation of the tests.

WBZ-TV possessed a unique advantage in that it employed separate antennas for visual and aural transmission. This meant that the aural pattern could be directionalized to some extent without seriously affecting the overall television service rendered by the station. It provided maximum power-height (FCC Zone I) so that observations could be conducted over substantial distances in order to observe the effect of diffraction and scatter.

WKY-TV was a valuable acquisition since they had proposed to purchase a new antenna for emergency use and they now agreed that it could be modified to permit rotation while installed. An additional calibrating or reference antenna could also be added to this structure and the overall performance of the combination could be measured carefully on the test range before delivery to WKY-TV. Measurements made at the site after installation of the antenna would therefore permit comparison between the antenna patterns measured at the test range and the performance after erection at the transmitter site.

The program of tests finally proposed by the Committee was approved by the appropriate body of TASO and funds for the test program were allocated. The tests at WBZ-TV were made during the early part of 1959, terminating in time to move the measuring equipment and personnel to Oklahoma City for the tests at WKY-TV. These tests were conducted during the fall of 1959 and were concluded in December of that year. A description of the tests and the results obtained follow.

MEASUREMENT OF THE PERFORMANCE OF THE ANTENNA AT TELEVISION STATION WBZ-TV

The antenna installation for WBZ-TV consists of two three-section superturnstile antennas mounted one above the other on a 1107-foot tower which is located approximately 8 miles southwest of Boston, Massachusetts. For the purposes of this test the upper antenna was used as an experimental directional antenna for aural transmissions on 71.74 mc.

Separate transmission lines were installed to connect the north-south and east-west superturnstile elements to a special power dividing network installed in the transmitter building. This network was designed to provide either "non-directional" operation with normal 50-50 power division or directional operation with a power ratio of 20 db between the two sets of superturnstile elements. For both modes of operation the normal 90^0 phase relationship was maintained. The high power elements were oriented at a true bearing of approximately 351.5^0 and this was the expected direction of minimum radiation from the directional antenna. During the period of the field measurements the power dividing network was switched to provide alternate 15-minute periods of "non-directional" and directional operation with the same power input from the aural transmitter. Figure 1 shows the expected radiation patterns in terms of relative voltage based on pattern shapes for single superturnstile elements supplied by RCA.

The field measuring program consisted of obtaining three types of measurements. Figure 2 is a map showing the expected direction of minimum signal and the locations at which the field measurements were obtained. The first type of measurements comprised field strength measurements for both directional and "non-directional" operation made along four radial routes from the transmitter at distances ranging from 9.0 to 50.4 miles. At each measuring location a continuous mobile recording of the signal was made over a distance of approximately 100 feet. These measurements were made with a half-wave dipole receiving antenna mounted 30 feet above the road surface. At each location recordings were obtained over the same path for both directional and "non-directional" operation during adjacent 15-minute periods.

The second type of measurements consisted of field strength measurements made at locations traversing a "cross minimum" route at distances ranging from 18.6 to 21.8 miles. These measurements were made in the same manner as described above for the radial field strength measurements.

The third type of measurements consisted of time recordings of signal strengths at several fixed locations over periods ranging from 7 to 18 days. At each location the signal was recorded for alternating fifteen-minute periods of "non-directional" and directional operation.

Figure 3 shows the results of the measurements made along the four radial paths from the transmitter. For each location the median signal levels were determined from the recorder charts for directional and "non-directional" measurements along the same path. The ratio of these median values expressed in db is plotted vs. distance from the transmitter station. The average ratio and the standard deviation for each direction are indicated on the graphs. The standard deviation was less than 0.8 db for all four radial directions.

Figure 4 shows the ratios obtained from the cross minimum measurements along with the average ratios obtained from the radial measurements and the average ratios obtained at the six fixed measuring points. The solid curve shows the average of the measured data, and the dashed curve shows the expected ratio based on the computed antenna patterns of Figure 1. It should be noted that the expected ratio (DA/ND) in the direction of minimum radiation is 17 db instead of 20 db because the maximum radiation from the directional antenna is 3 db greater than from the "non-directional" antenna.

Table 1 summarizes the results of the measurements obtained at the six fixed locations where time recordings of the signals were made.

TABLE I

SUMMARY OF RESULTS OF RECORDINGS
MADE AT FIXED MEASURING LOCATIONS

Location	Bearing	Distance	Number of Recording Periods	Average Ratio (DA/ND)
Bennington, N. H.	324.4^0	58 mi.	190	- 7.1 db
Montpelier, Vt.	334.2	151	27	-10.9
North Woodstock, N.H.	349.5	121	35	-14.7
Laconia, N.H.	350.4	84	175	-15.5
Mt. Washington, N.H.	358.6	135	67	-12.4
Biddeford, Me.	25.9	97	185	+ 0.2

The number of periods for which 15-minute records of both "non-directional" and directional signals were obtained is indicated for each location along with the average ratio of the signals. Comparison of the results as plotted in Figure 4 shows close agreement between the ratios obtained at the fixed locations and the ratios obtained from the radial and "cross minimum" measurements made at closer distances. It should be noted, however, that the results obtained at 121 miles (349.5^0 True) indicate one or two db less suppression than the measurements made at closer distances. This effect may be due to scatter propagation modes which tend to "fill in" the minimum of the pattern.

With the exception of the Mt. Washington and Montpelier locations the fixed locations were selected to represent typical rural receiving locations for the terrain involved. The Mt. Washington recordings were made at the site of Television Station WMTW-TV at an elevation of approximately 6300 feet above sea level. The Montpelier recordings were obtained at the Montpelier Community Television receiving site located on the southwest side of a mountain at an elevation of 1125 feet above sea level.

The equipment used at the fixed locations consisted of high gain fringe type antennas mounted at heights of 30 to 40 feet. Baluns and coaxial transmission lines were used to connect the antennas to crystal controlled receivers which were connected to the recording meters. The receivers were calibrated on a daily basis with laboratory type signal generators.

Figures 5 and 6 show the distributions of the medial signal levels for all fifteen-minute periods of "non-directional" and directional operation recorded at the two fixed recording locations in the direction of maximum suppression. Smooth lines were drawn through the measured points, and the ratios of the signals exceeded for 50% and 10% of the time are indicated. These data do not indicate any consistent trend between the 50% and 10% signal ratios.

MEASUREMENT OF THE PERFORMANCE OF THE ANTENNA AT TELEVISION STATION WKY-TV

An extensive program of measurements was undertaken to determine the performance of a special experimental directional antenna installed by Television Station WKY-TV at their transmitting site located 5 miles north of Oklahoma City, Oklahoma. Careful control of the antenna design was possible because the management of Station WKY-TV agreed to incorporate the directional antenna project into the installation of a new standby antenna system.

The directional antenna consisted of a modified RCA Type TF-3EM three-section superturnstile designed for operation on Television Channel 4. Figure 7 is a photograph showing the main antenna and the special reference antenna which is mounted some twenty feet above the upper superturnstile elements. The reference antenna consists of two folded half-wave dipoles mounted in the same horizontal plane with the spacing and phasing arranged to provide a "figure 8" type pattern and low coupling to the superturnstile antenna elements. Both the superturnstile antenna and the reference antenna were equipped with motor drive mechanisms and remote control and bearing indicator systems so that the antennas could be independently positioned to any desired orientations. Flexible RG-117/U coaxial transmission lines provided connections between the antenna elements and the rigid 3-1/8 inch transmission lines used to connect the antennas to the transmitter.

Three interchangeable power dividing tees provided power ratios of 0, 10, or 20 db between the two sets of superturnstile elements. Motor driven coaxial switches permitted switching the transmitter to either the superturnstile antenna or the reference antenna.

The special directional antenna and reference antenna were assembled by RCA and a complete set of pattern measurements was made at the Gibbsboro test site of RCA. Figure 8 shows measured horizontal patterns for the three modes of operation as made at Gibbsboro with the reference antenna removed. Similar pattern measurements were made at the aural carrier frequency, and pattern measurements were also made with the reference antenna in place. Analysis of these measurements showed that the reference antenna had only a small effect on the pattern of the main antenna.

The antenna was then shipped to Oklahoma City and installed on a 263-foot supporting tower located some 800 feet from the 969-foot main antenna tower of Station WKY-TV. The field measurements made after installation included measurement of pertinent details of the radiation patterns at the visual carrier frequency, aural carrier frequency and at side band frequencies 2.0 and 3.6 mc above the visual carrier frequency. All measurements were made during the early morning experimental hours following sign-off of the regular WKY-TV program. Three basic types of measurements were made. The first type employed the reference antenna method for which measurements were made of the signals received from the main antenna and the reference antenna, with the reference antenna oriented for maximum signal at the measuring location.

Measurements by the reference antenna method were made along four radial routes from the transmitter and along one cross minimum route as shown by Figure 9. These measurements were made with a half-wave dipole receiving antenna mounted at a height of 10 feet.

The second type of measurements utilized the rotation method. The signal received from the main antenna was observed as the main antenna was rotated. Measurements were made by this method at locations along the 90^0 radial route from the transmitter employing a receiving antenna height of 10 feet.

The third type of measurements consisted of recordings made for extended periods of time over two paths of 65 and 206 miles (see Figure 9). Measurements were made on the visual carrier frequency at Bristow, Oklahoma with the main antenna set at specific orientations for alternate ten-minute periods. Measurements were also made of the visual signal received from the KRLD transmitter located near Dallas, with the WKY-TV directional antenna used as a receiving antenna.

The portion of the pattern providing minimum radiation (maximum suppression) was considered to be the most important area for exploration, and the "90^0 minimum" portion of the pattern (see Figure 8) was selected for detailed study. The "0^0 maximum" was used as the reference for establishing suppression ratios.

Figure 10 shows the results of the measurements of the 20 db pattern made by the reference antenna method along four radial routes. At each location measurements were made of the signals from both the main antenna and the reference antenna at three cluster points spaced at 50-foot intervals along the road. The main antenna orientation remained fixed with the "north" elements aligned with True North, and the reference antenna was oriented for maximum received signal. The graphs show the minimum, average and maximum ratios for each measuring location.

Figure 11 shows the results of the cross minimum ratio measurements of the 20 db pattern made using the reference antenna method. Each point plotted on the graphs represents the ratio observed at a single measuring point along the cross minimum route. The average results of the radial measurements are also shown.

Figure 12 shows the results of measurements made at the aural and visual carrier frequencies and side band frequencies using the point-by-point rotation method. Measurements were made at 17 locations along the 90^0 radial route and the graphs of Figure 12 show the minimum, average and maximum values observed. At each location the received signal was measured as the antenna was rotated point-by-point over the sector required to provide details of the position and width of the "90^0 minimum" of the radiation pattern. The signal obtained from the "0^0 maximum" of the radiation pattern was also measured in order to obtain the ratio of minimum to maximum signal. Analysis of the data obtained by the rotation method indicates that the depth, orientation and width of the minimum of the radiation pattern vary as a function of both location and frequency. Substantial variations in the pattern parameters occurred at different locations in the same radial direction and even at locations spaced about 100 feet along the same road. These variations are believed to be due to scattering of the signal caused by terrain irregularities. The test data indicate that the results of a large number of measurements made at different locations must be averaged to obtain an accurate operational radiation pattern.

Measurements of the 20 db pattern were made at Bristow, Oklahoma during the early morning experimental hours for the period of October 7 through October 11, 1959. The measuring equipment was set up in a downtown hotel room and the signal was received by means of a fringe area type antenna mounted on the roof of the hotel. The visual signal was recorded for thirty-minute periods and the average results are given in Table II. During each period the signal was recorded both for the indicated orientation and with the "0^{0} maximum" towards Bristow, and the ratio of the median signals was established.

TABLE II

RESULTS OF BRISTOW MEASUREMENTS

(73.2^{0} True - 65 miles)

Orientation of Path Measured Clockwise from North Antenna Elements	No. of Recording Periods	Average Ratio of Signals Referred to "0^{0} Maximum"
80^{0}	12	-16.6 db
90^{0}	29	-20.6
100^{0}	10	-14.4

Table III shows the results of measurements of the 20 db pattern made by employing the WKY-TV directional antenna as a receiving antenna to pick up visual signals transmitted by Station KRLD-TV which operates in Dallas, Texas on Television Channel 4. The use of this reciprocal technique permitted obtaining data over a relatively long path (206 miles). The measurements were made between the hours of 1 A.M. and 5 A.M. from November 30 to December 12, 1959.

During the first ten minutes of each half-hour period the signal was recorded with the antenna oriented for maximum pickup from KRLD-TV (north superturnstile element towards KRLD-TV). During the next ten-minute period the signal was recorded with the indicated orientation. The remaining time of each half-hour period was used to calibrate the receiving equipment and to record the noise level and any other signals present with the KRLD-TV transmitter shut down. The analysis of these periods of noise recordings showed the absence of significant signals arriving from other sources.

The median signal values (db above 1 μv input to the receiver) for the ten-minute periods were determined and the average ratios for each day's recordings are given in Table III. The antenna orientations given are corrected for an error of 0.8^{0} in the bearing indicator system which was discovered after the measurements were made.

TABLE III

SUMMARY OF RESULTS
KRLD-TV MEASUREMENTS

Date	Number of Periods	Average Ratio of Signals Referred to 0^{0} Maximum		
		80.8^{0}	90.8^{0}	100.8^{0}
Nov. 30	8		-19.9 db	
Dec. 2	8			-12.5 db
Dec. 3	8	-15.8 db		
Dec. 4	8		-19.8	
Dec. 5	8		-19.3	
Dec. 7	7		-22.7	
Dec. 9	8			-15.3
Dec. 10	8	-19.3		
Dec. 11	8		-22.2	
Dec. 12	4			-15.1
	4	-18.5		
Weighted Average		-17.7 db	-20.7 db	-14.1 db

Figure 13 shows the results of the measurements of the "90^0 minimum" portion of the 20 db radiation pattern by the several methods employed. Data are shown for operation at both the visual and aural carrier frequencies, and the dashed lines provide a comparison with the pattern measurements made before installation. The results show close agreement for the pattern measurements made after installation by different methods and there is no great difference between the patterns measured before and after installation.

Figure 14 shows the results of measurements of the 10 db directional antenna pattern before and after installation. Measurements of the 10 db pattern were not made at the two distant recording locations, but the measurements made by the reference antenna method and the rotation method are in close agreement.

Figure 15 shows photographs of test patterns made at four locations between 4.9 and 6.7 miles from the transmitter with the 20 db antenna pattern employed. Photograph A shows the test pattern as received with the antenna oriented for maximum signal at the receiver. The remaining photographs show the signals received with the antenna oriented for either minimum signal at the receiver or 10^0 from the position of minimum signal, as indicated. These photographs were selected as typical of test pattern observations made at locations in all eight directions from the transmitter. In all cases, ghosts ranging from moderate to severe were evident when the antenna was oriented for minimum received signal. In some cases, ghosts were still quite noticeable with the antenna oriented 10^0 from the minimum position.

A limited number of test pattern observations made with the 10 db pattern indicated negligible to slight ghost problems in the directions of minimum radiation.

RECOMMENDED METHOD OF MEASURING THE OPERATIONAL ANTENNA PATTERN OF A TELEVISION ANTENNA

On the basis of the results obtained and described in this paper, it is considered that the most practical way of measuring the operational antenna pattern is the reference antenna method. The directional antenna should incorporate a rotatable reference antenna designed to operate on the visual, color sub-carrier and aural frequencies. The coupling between the reference antenna and the main antenna or other nearby objects must be low enough to minimize errors due to radiation effects. The test transmitter may be of lower power than the transmitter normally used, but should have sufficient power to provide signals of adequate strength at the required measuring locations. The power into the antennas must be accurately determined and maintained. Controls should be available at the transmitter for rotating the reference antenna.

Field strength measurements should be made along at least eight radial paths from the transmitting antenna. These paths should include the direction(s) of maximum radiation, the direction(s) toward stations requiring protection and at least two additional directions toward the service area of each station requiring appreciable protection. For each direction, measurements of the signals received from the main and reference antennas should be obtained in at least eight measuring locations at distances between 10 and 30 miles. The measuring locations should be selected so as to provide a clear unobstructed path to the transmitting antenna, and the reference antenna should be rotated for maximum received signal. The ratio of the signals from the reference and main antennas should be established either by means of short mobile runs made by the continuous recording technique, or on the basis of the average results of four cluster measurements at points located at least 50 feet apart.

Measurements should be made at the visual carrier frequency at each measuring location. At approximately half of the measuring locations, measurements should also be made at the color sub-carrier frequency and at the aural carrier frequency. Field strength measurements may be made with a receiving antenna height of approximately 10 feet.

Measurements should also be obtained at the visual carrier frequency along cross minimum routes through those arcs which include the service area(s) of other station(s) where suppression is required. These should be made at distances between 10 and 30 miles and point ratio measurements should be obtained at intervals ranging from three to four degrees in the case of suppressions on the order of 10 db to 1 or 2 degrees for suppression on the order of 17 db. At all measuring points, the reference antenna should be positioned for maximum received signal and measurements should be made of the signals from both the reference antenna and the main antenna.

The operational antenna pattern should be established by analysis of the ratio measurements using the average or median ratio obtained for each radial direction. The ratios for each radial direction should be plotted versus distance and the resulting graphs should show no significant correlation with distance, except as expected due to the difference in vertical patterns of the two antennas. The radiation determined for each direction should be referred to the radiation in the direction of maximum radiation.

The suppression obtained at visual carrier frequency should meet the requirements set forth under Conclusions. It is suggested that suppression at the color sub-carrier and aural frequencies be within $\pm$ 2 db of the suppression measured at the visual carrier frequency.

Monitoring points should be selected in each critical direction. These points should provide unobstructed paths to the transmitting antenna. If the cluster measuring method is employed, at least six points should be measured and the exact location of each of the cluster measuring points should be permanently established. Ratio measurements should be made at the monitoring points at monthly intervals to insure the operational pattern is properly maintained.

CONCLUSIONS

Factors beyond the control of TASO and the Directional Antenna Committee made it necessary to restrict the tests to measurements which were expected to provide an answer to the two problems set forth in the terms of reference of the Committee previously quoted. Tests were conducted at only two sites employing only one basic type of directional antenna and any conclusions which are drawn must be made with full appreciation of the limitations thus imposed. Measurements made upon directional antennas of other types or having a more complicated structure and/or located in rough terrain or large metropolitan centers might show greater deviation from the expected results. However, the uniformity of the results obtained in these tests would tend to indicate that if sufficient care is employed in using directional antennas as an instrument of allocation, the antennas can be depended upon to perform in the manner intended. From the experience gained from future operation of directional antennas by operating television stations, it is to be expected that the limited conclusions reported here can be expanded and augmented in the same fashion as this information was obtained by the operation of directional antennas in the standard broadcast band.

Based upon the results of the tests just described and keeping in mind the limitations thereon, the following conclusions have been reached.

1. The operational antenna pattern, that is to say, the pattern measured with the antenna installed on its supporting structure at the transmitter site, can be accurately established after installation by field measurements, using either the reference antenna or rotational techniques.

2. Measurement of the operational antenna pattern after final installation is considered essential to insure that the suppression intended is actually obtained. Such measurements will not only show the influence of nearby objects on the operational pattern, but will permit correcting any possible irregularities in the antenna pattern caused by damage during installation or improper connections and adjustments.

3. The reference antenna method is probably more practical and feasible than the rotational method in the case of actual operating antennas. For accurate results, the reference antenna must be designed to insure low coupling to the main antenna elements, tower structure and guy wires. Utilization of the rotational reference antenna eliminates the necessity for an accurate radiation pattern of this antenna.

4. The methods employed in these tests are not suitable for determining the vertical directivity of the operational antenna pattern, although a small but important sector thereof can be studied by an analysis of ratio measurements made over a limited range of distances by the reference antenna method. Because of this limitation, the antenna

manufacturer must be relied upon to provide information on the vertical pattern characteristics. In making measurements on antennas with unusual heights or large beam tilts, the effect of the vertical plane pattern on the measured ratios at various distances should be considered when selecting the range of distances over which the measurements are to be made.

The question of the amount of fill in the directions of maximum suppression is of course most important. This fill is not only a function of the depth of the suppression but also the steepness of the sides of the pattern. As applied to the Television Allocations problem, suppression will generally be required over a relatively wide arc. Consequently, the use of directional antennas with high degrees of suppression and steep sides is not likely.

The observations at WKY-TV showed that with suppression of 20 db in the operational pattern at considerable distances from the transmitter, measured suppression of 16 to 17 db could be counted upon, and the average over a long period of time approximated the calculated 20 db value. It would appear that for the present at least a suppression of 20 db is too great to be used with confidence that the intended suppression would be obtained in practice. On the other hand, suppressions on the order of 10 db appear to present no problem.

Until further experience is gained we believe that directional antennas should not be used to provide protections greater than 15 db (ratio of major lobe to minimum). To provide for possible propagation "fill in" effects, the operational pattern should indicate somewhat greater suppression than that required to meet the protection requirements. Until further knowledge is available, it is suggested that a "fill in factor" of 2 db be used for suppressions in the order of 15 db and that the factor be reduced to zero for suppressions less than 10 db. For example, if calculations indicate that a suppression of 15 db is required, the directional antenna should be designed for 17 db and this figure should be obtained in the operational pattern.

Distinct from this problem is the appearance of ghosts when the radiation is suppressed to the order of 20 db, as for example, in the WKY-TV case. Reflections of the main beam from nearby objects may reach a magnitude equal to, or greater than, the direct signal. In selecting a site for a television station which would require a directional antenna having a high degree of directivity, it would be desirable to locate the transmitter so that the suppressed direction is toward the area of lowest population density.

The conclusions expressed herein are those of the authors of this paper and they do not necessarily reflect the conclusions of the Directional Antenna Committee or of TASO.

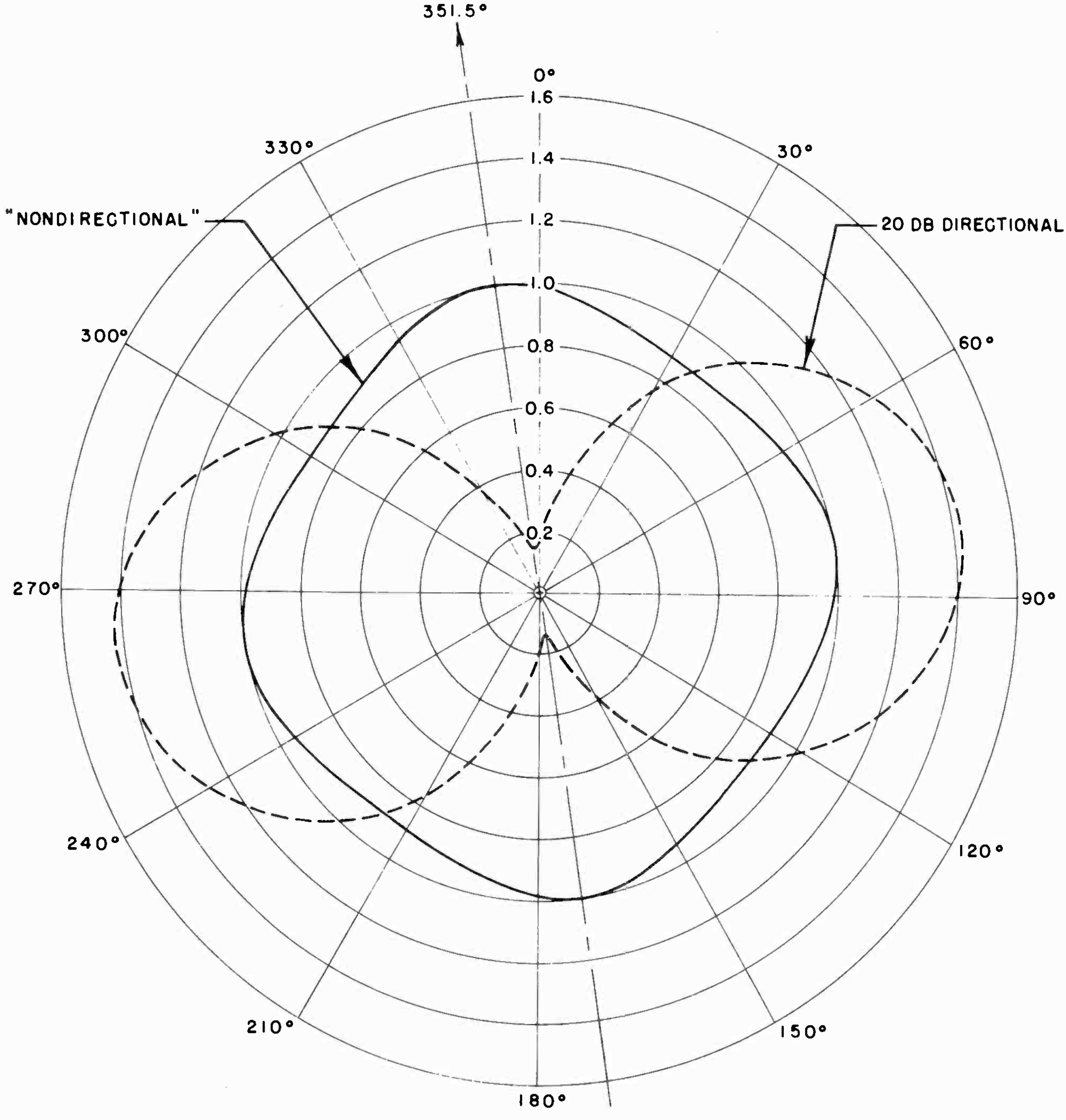


FIGURE I

COMPUTED HORIZONTAL RADIATION PATTERNS OF WBZ-TV ANTENNA

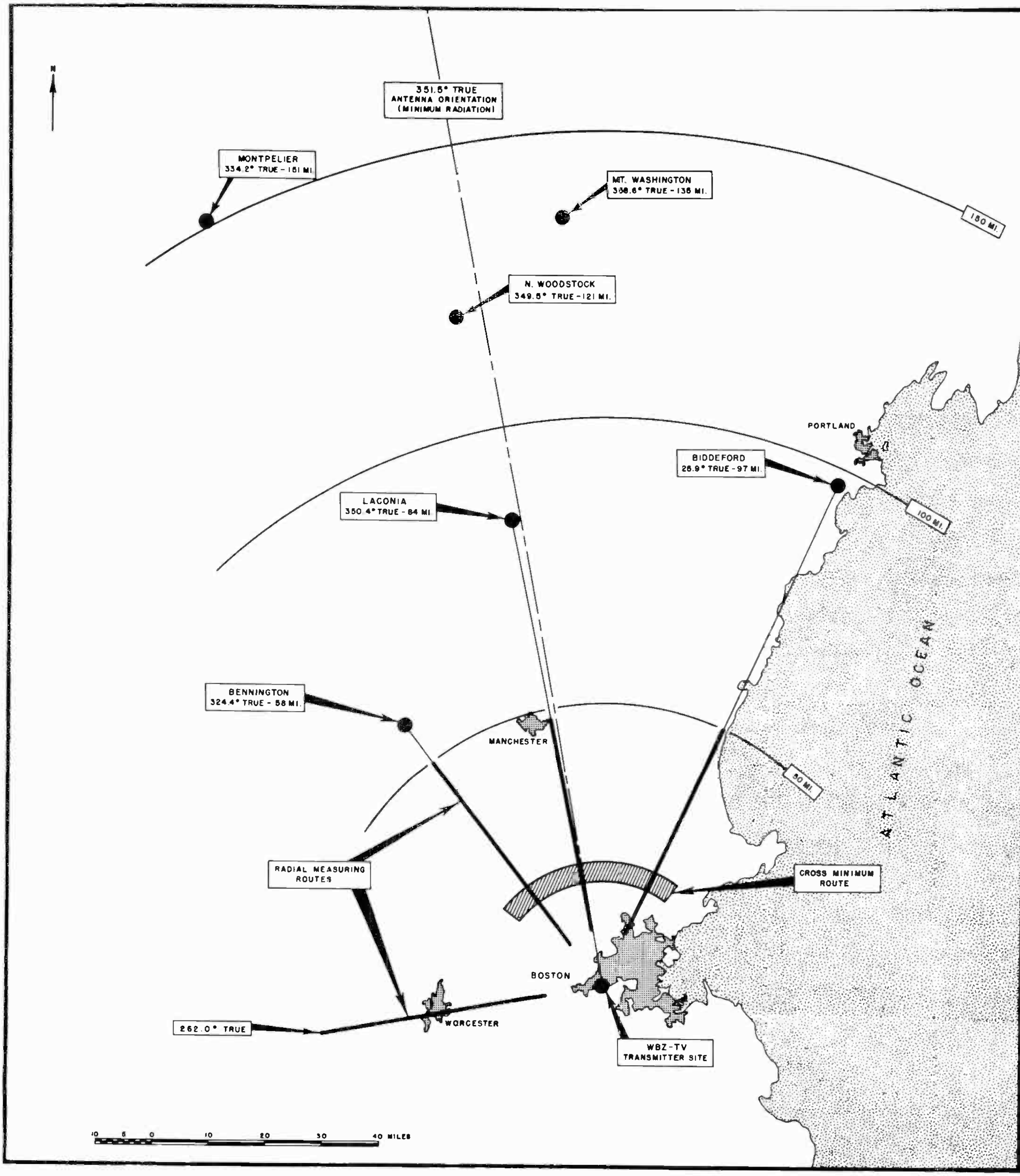


FIGURE 2

MAP SHOWING WBZ-TV TRANSMITTER SITE AND MEASURING LOCATIONS

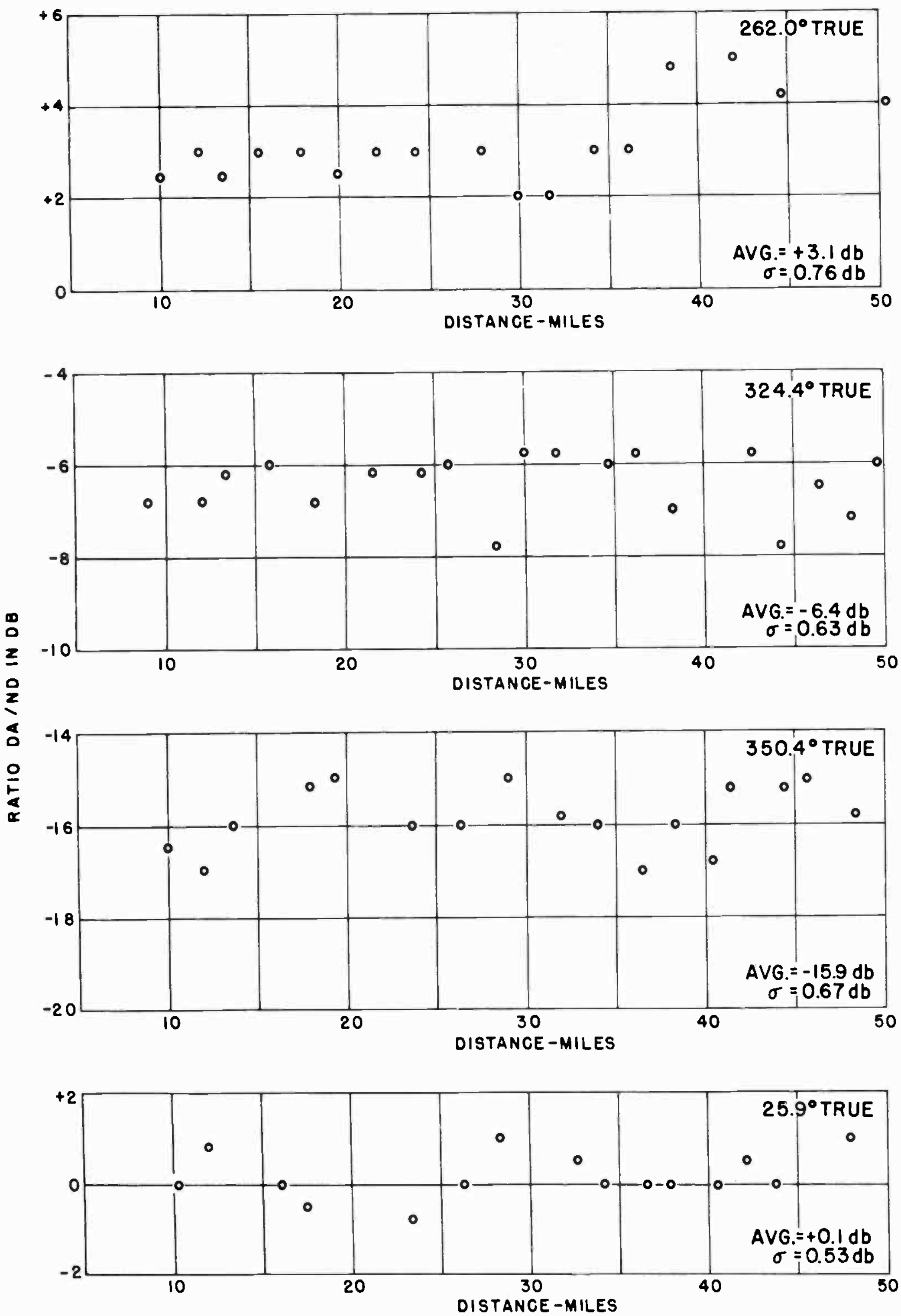


FIGURE 3

RADIAL RATIO MEASUREMENTS
(WBZ-TV)

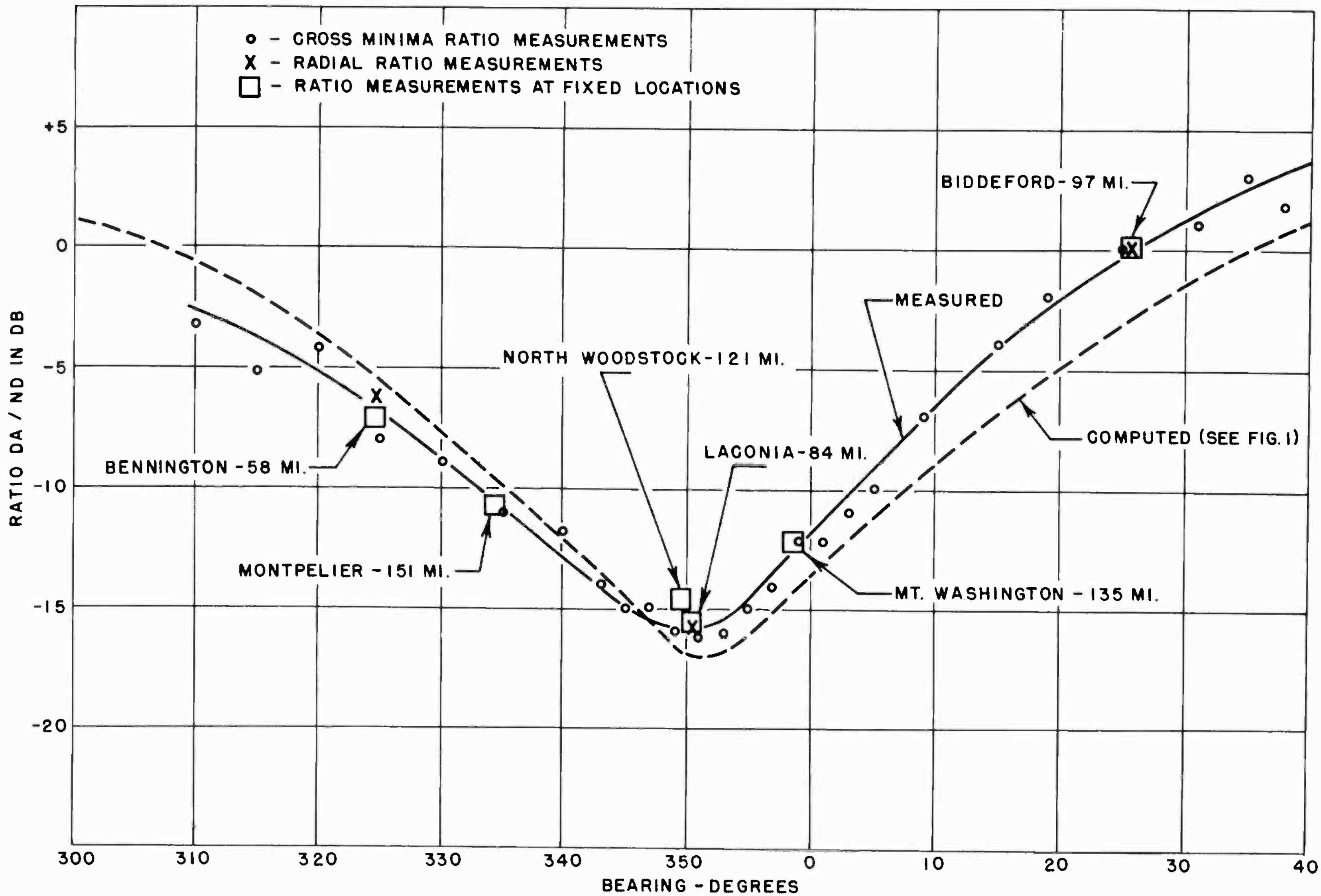


FIGURE 4
MEASURED AND COMPUTED RATIOS
(WBZ-TV)

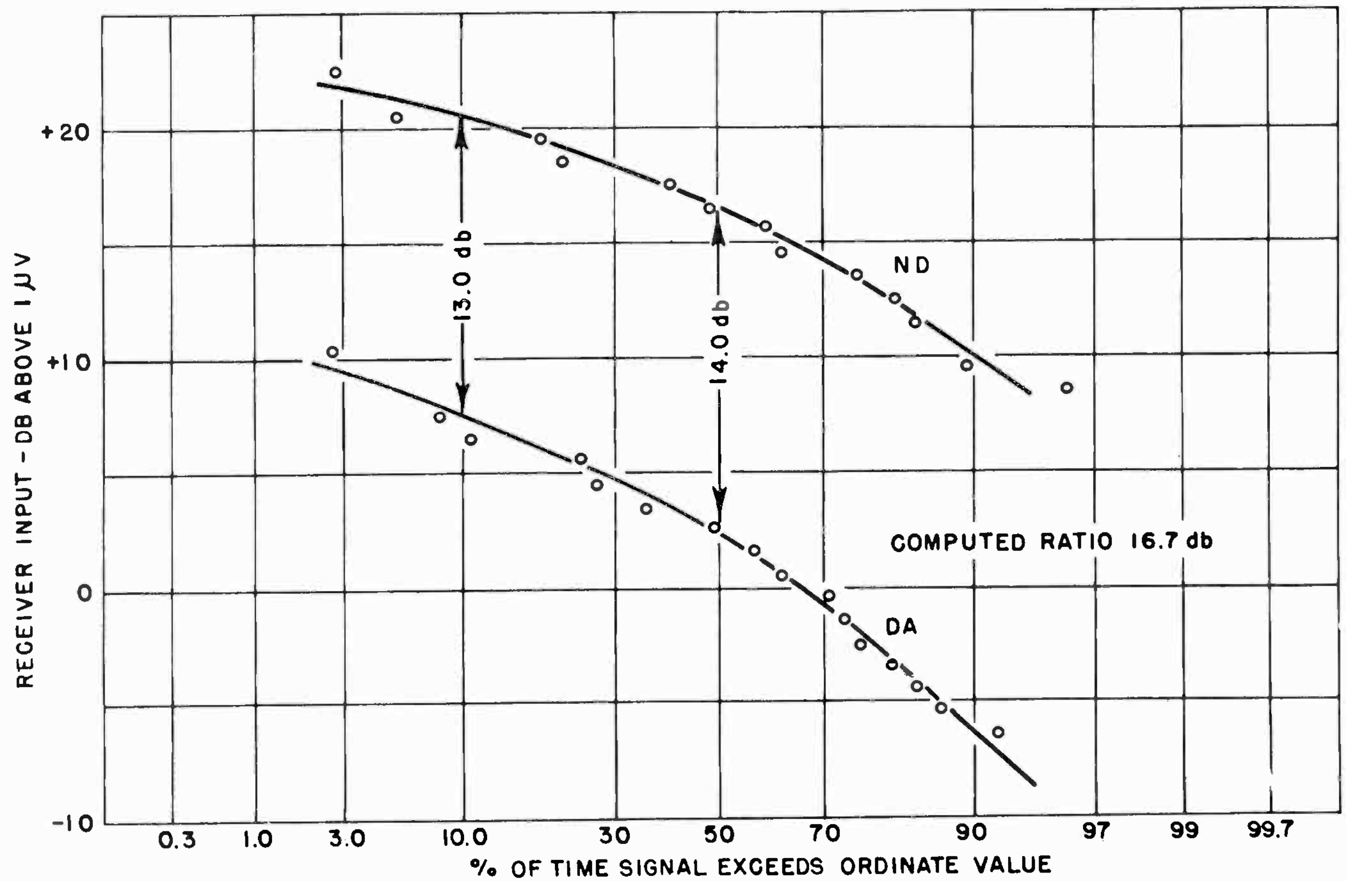


FIGURE 5

RESULTS OF RECORDINGS MADE AT
NORTH WOODSTOCK — 349.5° TRUE — 121 MILES

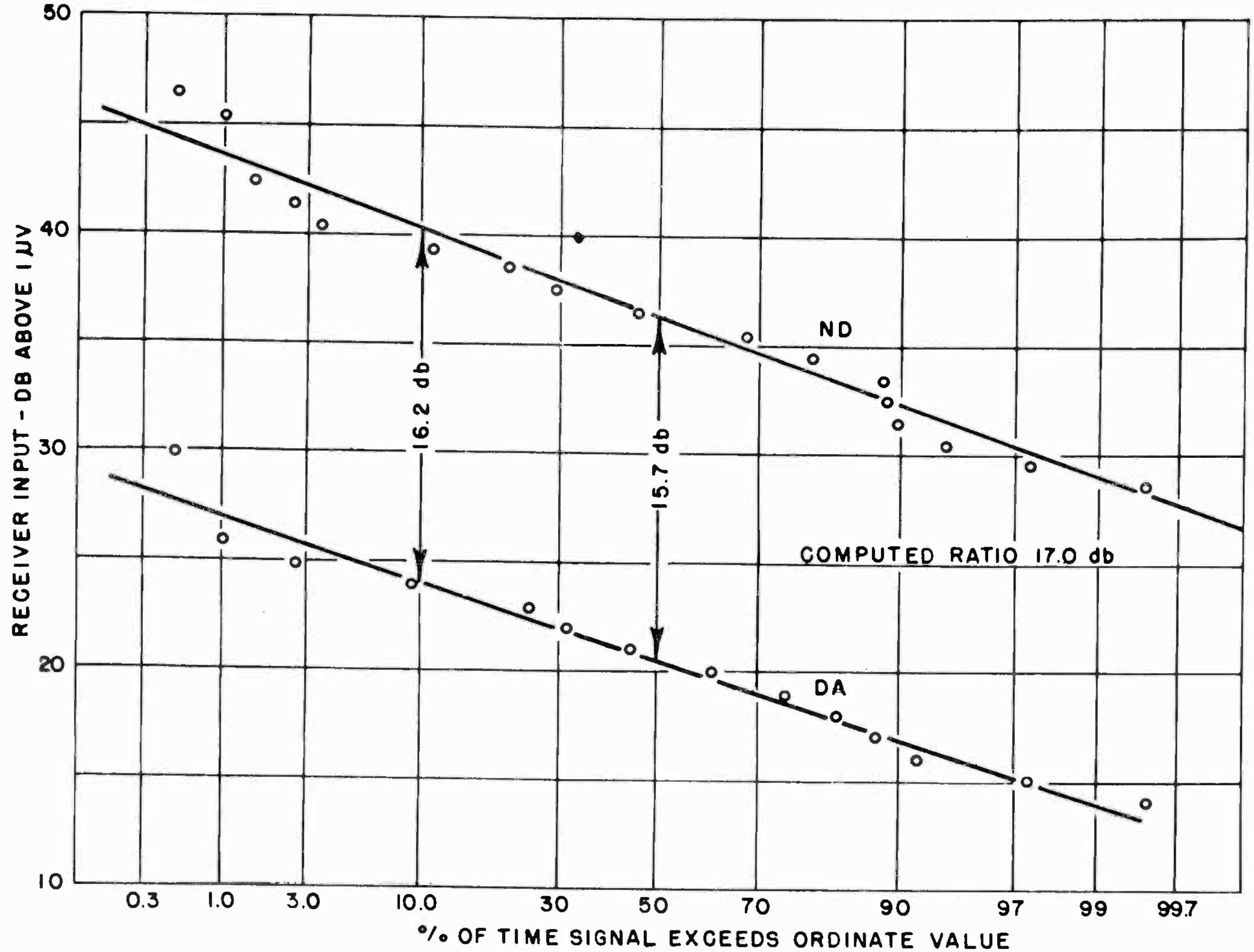


FIGURE 6

RESULTS OF RECORDINGS MADE AT
LACONIA - 350.4° TRUE - 84 MILES

FIGURE 7

PHOTOGRAPH OF WKY-TV DIRECTIONAL ANTENNA SYSTEM
SHOWING MAIN AND REFERENCE ANTENNAS

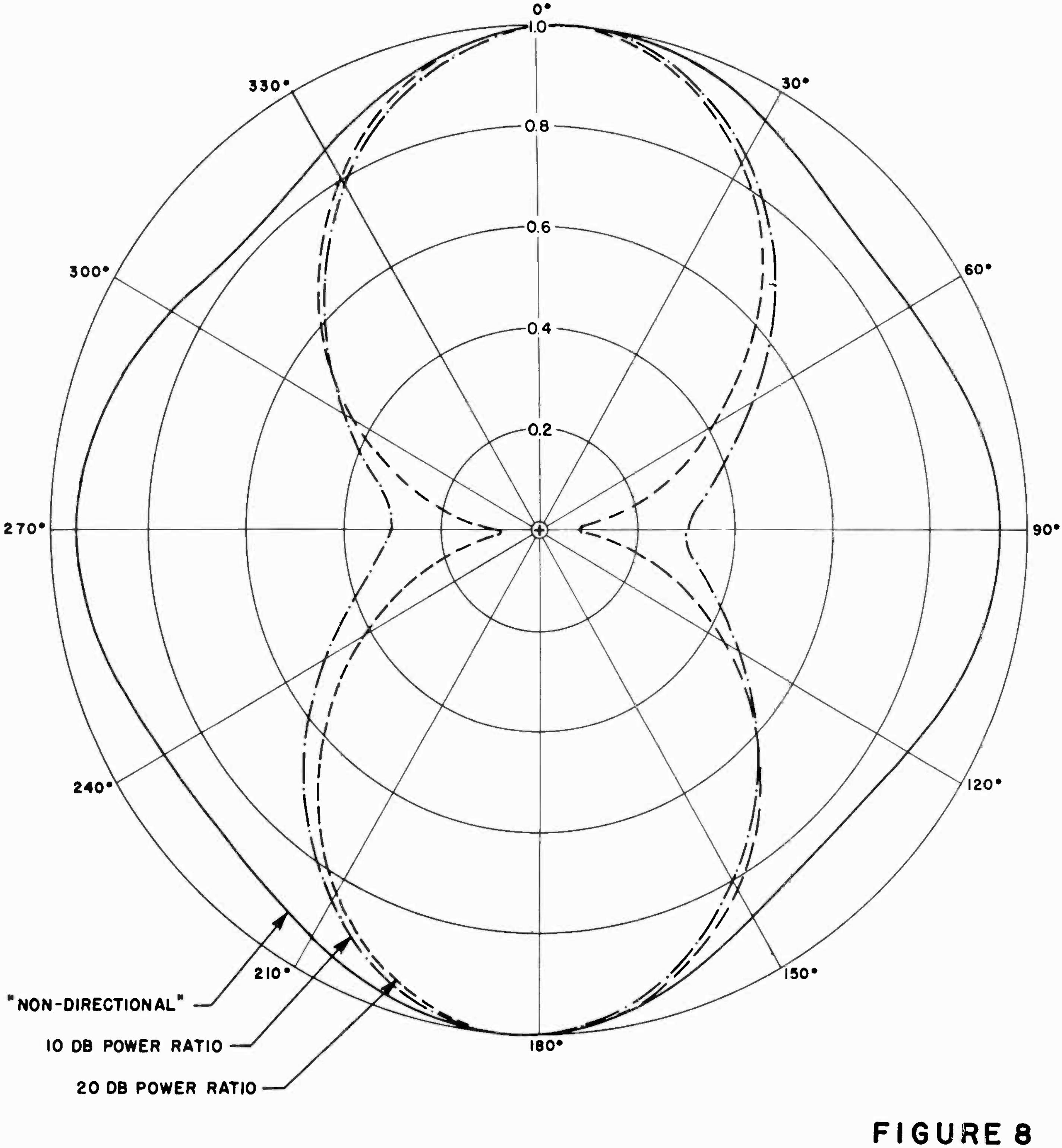


FIGURE 8

HORIZONTAL RADIATION PATTERNS MEASURED BY RCA
67.5 Mc. — REFERENCE ANTENNA REMOVED

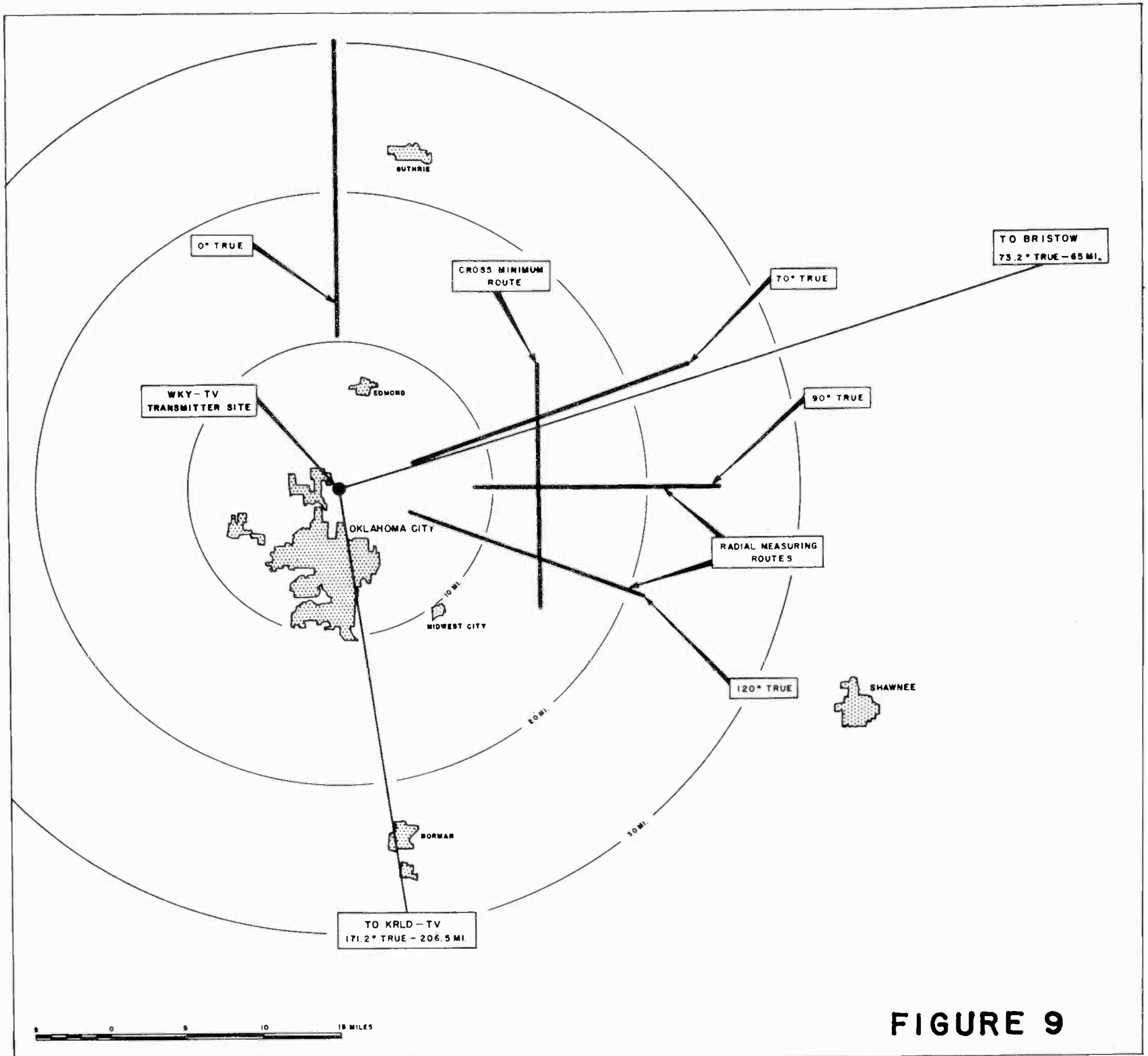


FIGURE 9

MAP SHOWING WKY-TV TRANSMITTER SITE AND MEASURING LOCATIONS

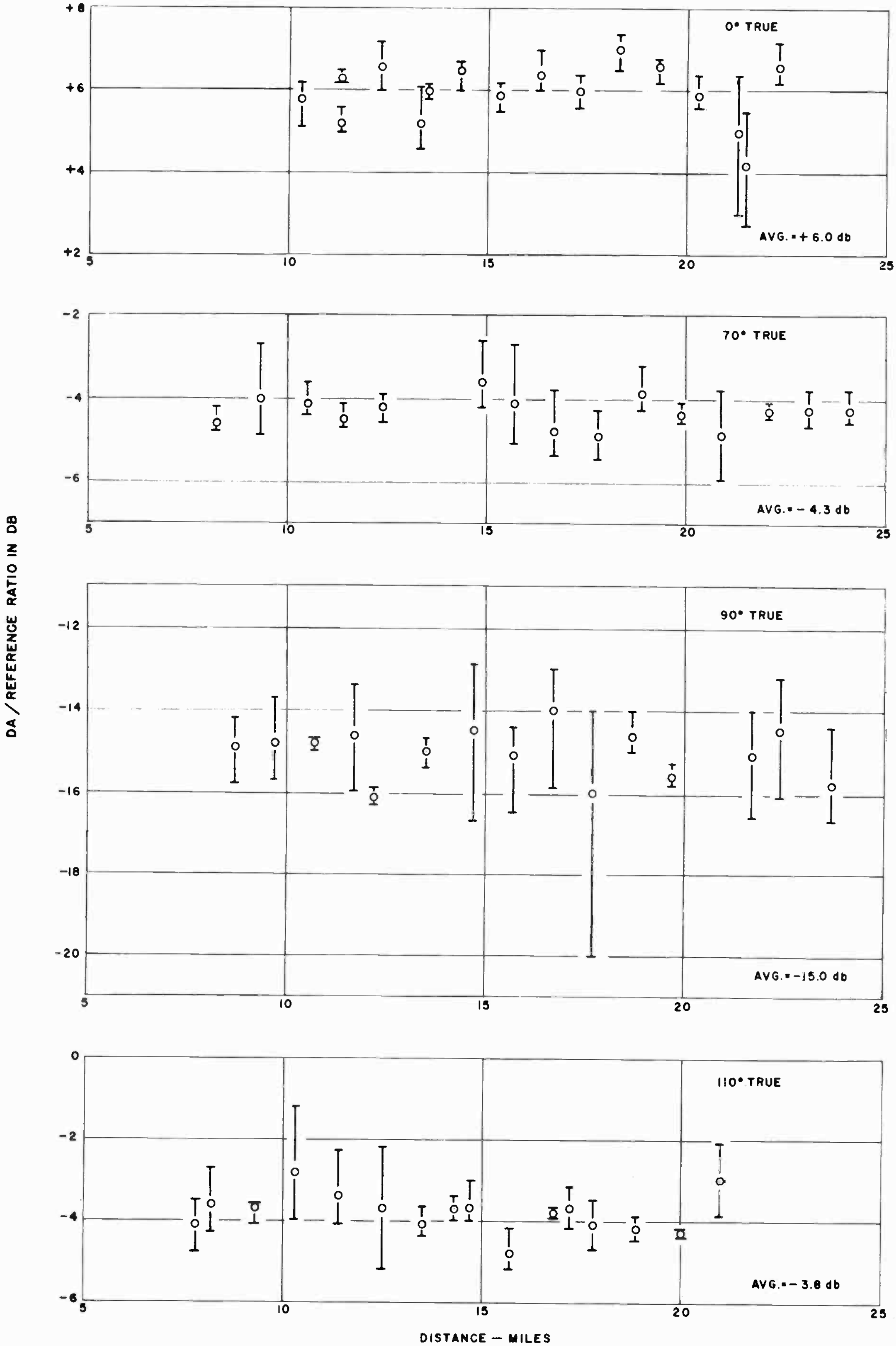


FIGURE 10

ESULTS OF REFERENCE ANTENNA RATIO MEASUREMENTS ADE ALONG RADIAL ROUTES - 20 DB POWER RATIO - ISUAL CARRIER.

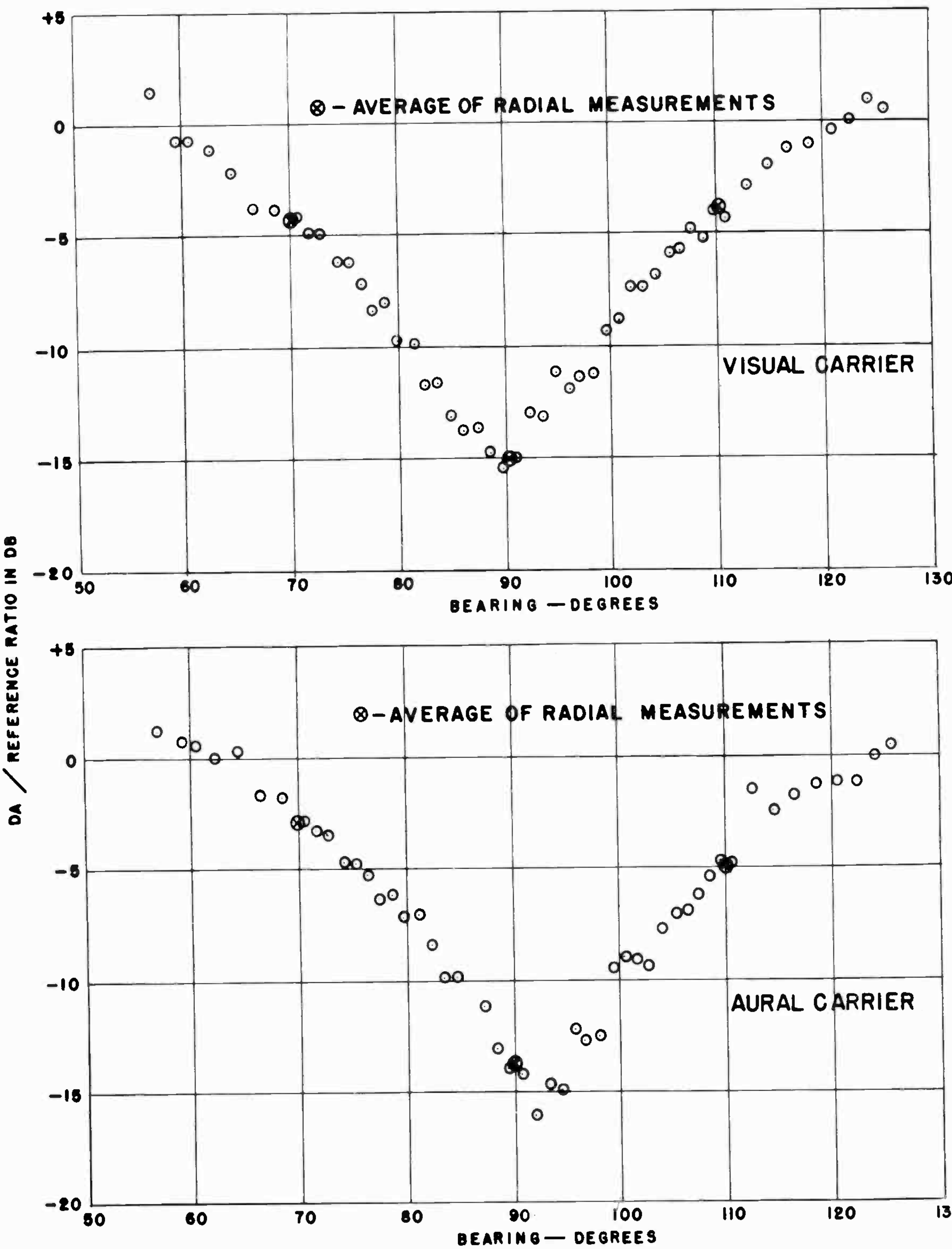


FIGURE 11

REFERENCE ANTENNA RATIO MEASUREMENTS ALONG "CROSS MINIMUM" ROUTE - 20 DB POWER RATIO

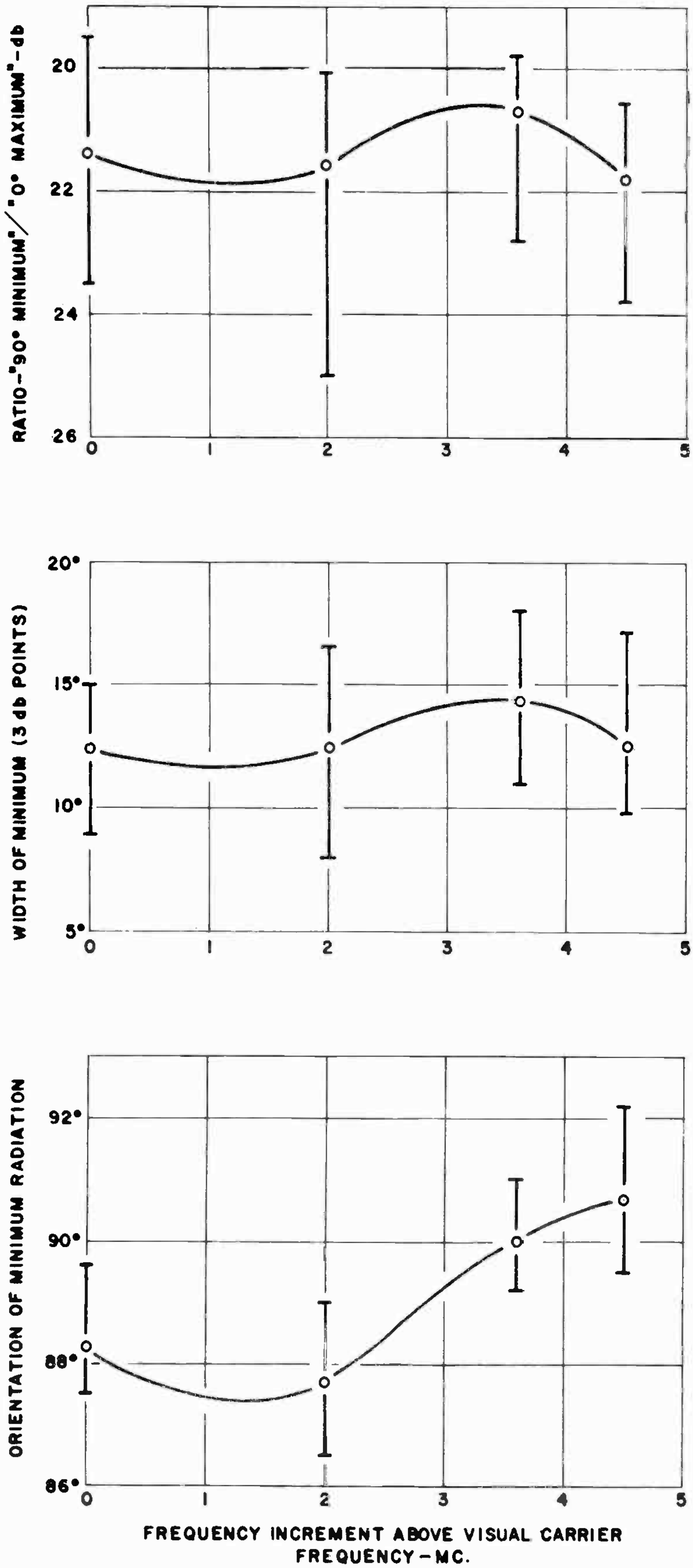


FIGURE 12

RESULTS OF MEASUREMENTS MADE USING POINT BY POINT ROTATION METHOD — 20 DB POWER RATIO.

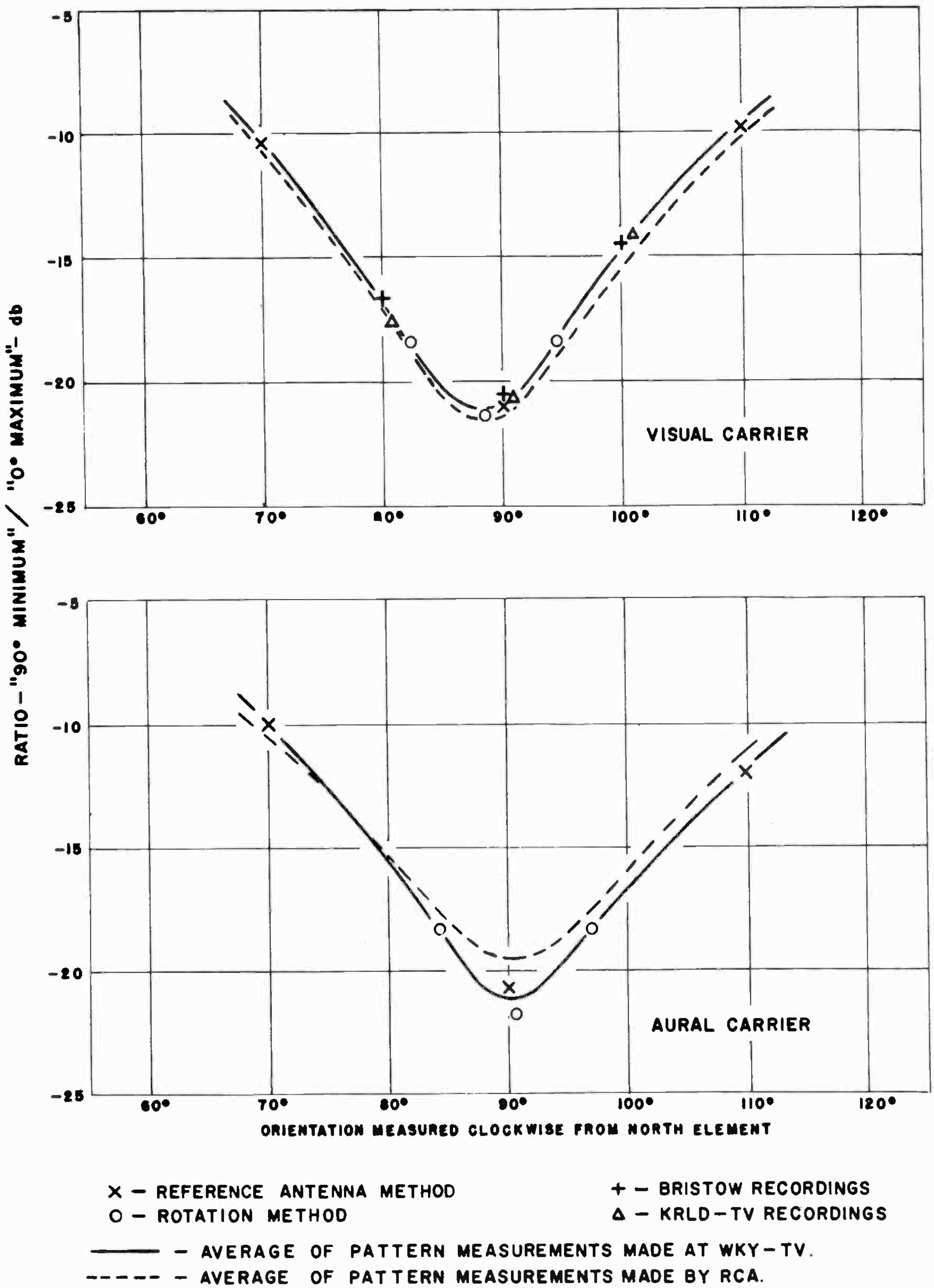
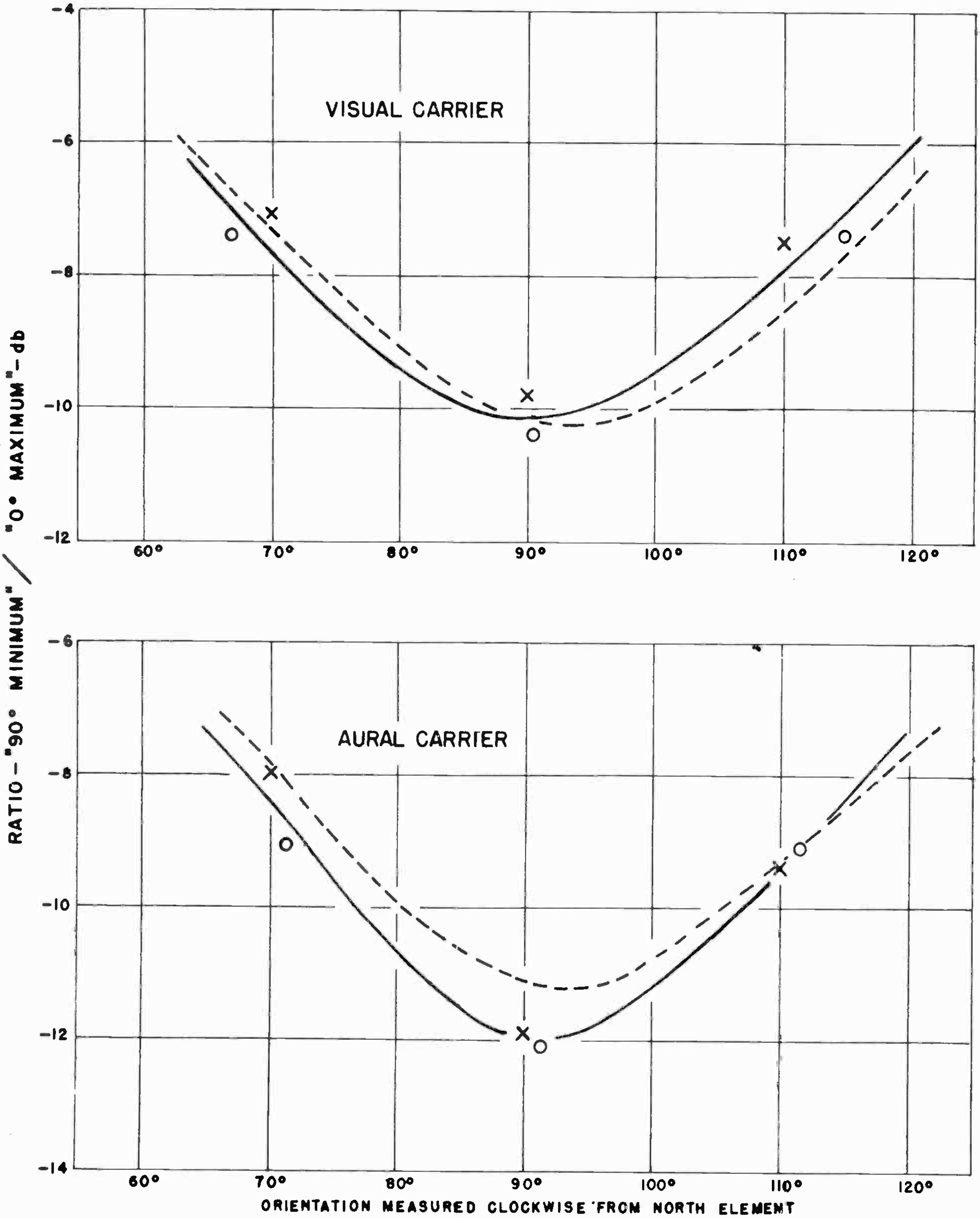


FIGURE 13

RESULTS OF MEASUREMENTS OF THE "90° MINIMUM" PORTION OF THE PATTERN — 10 DB POWER RATIO.



× — REFERENCE ANTENNA METHOD.

O — ROTATION METHOD.

——— — AVERAGE OF PATTERN MEASUREMENTS MADE AT WKY-TV.

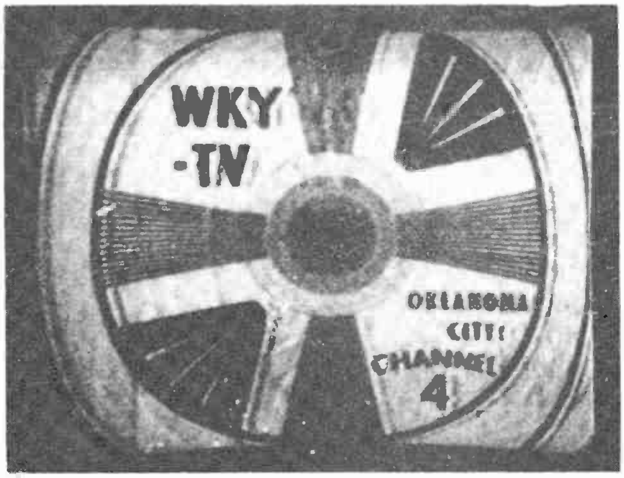
- - - - - — AVERAGE OF PATTERN MEASUREMENTS MADE BY RCA.

FIGURE 14

RESULTS OF MEASUREMENTS OF THE "90° MINIMUM" PORTION OF THE PATTERN - 20 DB POWER RATIO.

A. 6.2 MILES WEST—
ANTENNA ORIENTED
FOR MAXIMUM SIGNAL.

B. 6.2 MILES WEST—
ANTENNA ORIENTED
FOR MINIMUM SIGNAL.



C. 5.8 MILE SOUTHWEST—
ANTENNA ORIENTED
FOR MINIMUM SIGNAL.

D. 5.8 MILES SOUTHWEST—
ANTENNA ORIENTED 10°
FROM MINIMUM.

FIGURE 15

PHOTOGRAPHS OF TEST PATTERNS
20 DB POWER RATIO

A CONSTANT LEVEL PROGRAM AMPLIFIER

BY

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Almost all broadcasting stations utilize automatic gain control amplifiers in one form or another. Peak limiters are used universally with AM transmitters to prevent overmodulation and, as an extra bonus, to increase coverage by raising the average percentage of modulation. Peak limiters, as well as compressors, are also found in the disk recording industry, where they provide protection against over-cutting record grooves, and overloading tape recordings. In the motion picture industry, amplifiers of this type prevent overloading in variable-area optical recording systems. Compressors are becoming increasingly more valuable in radio stations in two areas: in automatic programming operation, where automatic control is required on the wide variation in output level of pop records; and in disk jockey operation, where accurate level control is usually considered haphazard, at best.

Improvements are constantly being made in limiting amplifiers to meet the rapidly changing needs of today's programming, and it is the purpose of this paper to describe a completely new development in this field, and to illustrate how it has overcome a disadvantage of previous types of limiters.

It would be helpful to begin by defining the differences between the various types of automatic-gain-control amplifiers. Generally, a compressor is an amplifier which, for a given change in input level, delivers a smaller change in output level. The Gates Sta-Level is an example of this type, with a compression ratio of 3.3 to 1. In one definition, a limiter delivers essentially no change for an input variation above a certain point. Another definition establishes a certain minimum compression ratio for a limiter, such as 5 or 6 to 1, for example.

Distinction is also made on the basis of attack time, with compressors ranging from 25 to 100 milliseconds, and limiters from 1 to 10 milliseconds. A peak limiter is obtained when the attack time is reduced to an extremely small value, such as 100 to 500 microseconds.

In practice, compressors are used to average out longer term variations in program level, and limiters are set above the compressor output level to catch instantaneous peaks, preventing overloading or overmodulation of the following equipment. All too often, the peak limiter at the transmitter is adjusted in an attempt to do both jobs, with compression running as high as 15 or 20 db. Its attack and release times make it completely unsuited for this job, and the result is a signal of poor quality, without the added increase in coverage that is expected with the additional compression.

The many advantages that limiter amplifiers offer are offset by one serious disadvantage - the reduction of signal-to-noise ratio in the system in which it is used. We have all heard this characteristic effect of the background noise level rising during pauses in the program material. It is especially apparent on broadcasts of sporting events, where the noise level is high; over studio applause; and on many pop records, where the bass end is overloaded for the benefit of the juke-box set.

The action involved is illustrated in Fig. 1. The upper curve is a typical plot of output vs. input for an amplifier having a compression ratio of 4 to 1. For input levels above the threshold of compression, the amplifier gain is automatically reduced to provide this ratio. When the program level is removed, the gain returns to normal, as indicated by the dashed line. Noise is shown as 20 db below the program level for the purpose of this example. When the threshold of compression is reached, amplifier gain reduces to level off further increase in input level, and noise output is reduced correspondingly. Thus, the signal to noise ratio will remain the same regardless of the amount of compression. However, when the program material is removed, amplifier gain returns to its uncompressed value, and the noise level increases by the amount shown. For our operating point of 10 db compression, the noise level will rise 10 db during pauses in the program.

This effect is not a problem when the background noise level is low, as with most records and studio shows. It grows increasingly important as background level increases, as mentioned previously, and becomes most acute where the noise holds at a constant value. Among the most common offenders in this respect are TV films.

The amplifier to be described has been designed to overcome this difficulty. It is a combination of limiter and expander, and it has been dubbed the "Level Devil". A graph of its characteristics is shown in Fig. 2. Two differences are apparent in this curve: the compression ratio is higher, and there is a sharp increase in gain just before compression threshold is reached. As the input signal is increased from its minimum value the output follows linearly, until the threshold of expansion is reached. At this point, the gain increases rapidly until 10 db of expansion has been obtained. The limiting circuit then takes over, and the amplifier behaves like a limiter for further increases in input, but with the important difference that there is now 10 db more gain than before.

To understand the effect that this amplifier has on the noise level of a system, refer to Fig. 3. In use, the amplifier is placed between the output of the studio console and the input to the peak limiting amplifier, and its internal attenuators are set for the correct operating levels. It should be stated here that this amplifier was not designed to replace the peak limiter, but to be used in conjunction with it. Signal-to-noise ratio for the program fed out of the console is assumed to be 20 db. With program levels out of the console below -10 on the VU meter, the amplifier has constant gain. When the program level reaches -10, or point A on the curve, the amplifier gain expands by 10 db, thus providing full program level to the transmitter. Noise is also expanded, so that the S/N ratio remains at 20 db.

As the level increases toward 0 VU out of the console, compression begins at point B. At the operating point, D, the amplifier has compressed 10 db. This is measured from the line BC. Line BC is the output curve that would be obtained if the compressor circuit were disabled; it is 10 db higher than the original line due to the expansion. Operating point for the noise is at J on line GH, and is 20 db below program.

During a pause in the program of several seconds duration, both the expander and compressor circuits will lose excitation. Amplifier gain will return to normal, and the noise operating point will fall on line EF, which is the normal output curve for the amplifier. Since the amount of expansion equalled the amount of compression at the operating point, it can be seen that there is no change in output noise level.

Fig. 3 also illustrates another interesting feature of this amplifier. For amounts of compression below 10 db, the noise level is actually reduced in the absence of program. If the operating point were moved down to point B, a 10 db reduction in noise would be possible. This action is shown for an extreme case in Fig. 4. Here, the signal-to-noise ratio is only 3 db, and operating points are at A and B for program and noise, respectively. During a pause in the program the expansion gate will close, amplifier gain will drop 10 db, and noise will reduce by 10 db, to point C. This is an extreme situation, of course, since it would be difficult to prevent the program from falling below point A, and dropping below the threshold of expansion. This operating condition could be approached, however, where the program material has already been compressed, and is mixed with an external source of noise. This would be the case with noisy records, and especially with some TV film programs. Short wave pickups can also be improved. The U.S. Information Agency has ordered a number of amplifiers very similar to this one for use in the outputs of short-wave receivers at their overseas relay bases. In this application, the compressor compensates for changes in level as receiver outputs are switched to provide optimum transmission paths, and the expander prevents the high noise level from rising during periods of silence.

To understand the circuit operation in the Level Devil, refer to the simplified schematic diagram, Fig. 6. The amplifier consists of four stages of audio amplification and a control section. By the use of pads in the 600 ohm input line, signal levels between -35 and +27 VU can be accepted. The first stage is a pair of 5749 tubes in push-pull. These are similar to the 6BA6 tube but are manufactured to closer tolerance. This is the variable gain stage - bias on the cathodes and grids of this stage control the overall amplifier gain. The push-pull signal is coupled to the grids of a differential amplifier, which amplifies the difference between the two input signals and tends to cancel any in-phase signal, such as bias thump or DC shift. This in-phase signal rejection is greatest when the gain of the two tubes is equal, and balance is obtained by varying the grid bias on the lower tube. The output of this differential stage is single ended and feeds a two stage line amplifier.

Let us examine the compressor control section first. The amplifier output signal is sampled at the plate of the last stage and fed to the grid of a split load phase inverter tube, V9A. A phase inverter is necessary at this point so that both positive and negative peaks will be compressed. This push-pull signal is then fed to two diodes connected in a full-wave rectifier circuit. A gating voltage of 39 V. biases the rectifiers so that no negative voltage is passed until the signal voltage overcomes this gate. Instantaneous signal voltages higher than this will cause the diodes to conduct, developing a negative voltage across a portion of the grid circuit of the first stage through its time constant network, C1, R3 and R40. The time constants of the compressor circuit have been chosen so that the effect is that of an average level amplifier rather than a peak limiter. The compressor attack time is 10 milliseconds and the release time is 1½ to 2 seconds. About 30 db of compression may be handled by the amplifier without serious distortion. Compression is achieved by varying the grid bias voltage on the first stage.

The expander is the novel portion of the amplifier and the noise reduction qualities of the amplifier depend upon this section. The signal voltage for the expander circuit is also sampled from the output stage. The first stage of the expander circuit, V7A, is a voltage amplifier which is biased so that at the time the expansion gate is overcome, this stage is saturated so that any further increase in signal level in the amplifier proper will produce no more signal voltage at the plate of this stage. This is done to reduce the capture effect, so that the expander will release at the proper signal level. The second stage of the expander circuit, V7B, is also a voltage amplifier, and a voltage dividing network between these two stages establishes the amplifier gain. This voltage is fed to a rectifier, V6A, whose bias gate is set at 64 V. This negative rectified voltage is then fed to a series resistance tube, V6B, whose cathode current flows through the common cathode resistor, R7, of the first amplifier stage. With no negative bias applied to this control tube, the circuit values are chosen so that the gain of the first amplifier stage is reduced by 10 db. This is accomplished by raising the voltage applied to the cathode, which is the same as applying a negative grid bias voltage. When negative bias is applied to this control tube, its plate current is cut off. This, in turn, results in a reduction of cathode voltage of the first amplifier stage, increasing the amplifier gain by 10 db. The time constants for this stage are adjusted for the optimum value for broadcast service. The attack time for this network is two seconds and the release time is about four seconds.

If the amplifier is limiting 10 or 15 db when the signal is removed, it is desirable that the amplifier gain not rise to maximum. If this occurred there would be a noticeable rise and then fall in the background noise level. To prevent this, another diode rectifier, V9B, which receives its signal from the compression section phase inverter is biased, or gated, so that when the amplifier limits more than 10 db a negative bias is applied to the second stage of amplification in the expander circuit. This serves to cut off the signal in this stage and allows the expander time constant network to discharge. This, in effect, disables the expander circuit, and the amplifier gain returns immediately to the no-signal condition when the signal is removed.

Two adjustments are provided for dynamically balancing the amplifier. To balance the differential amplifier, a 60 cycle signal is applied to points A, and R22 is adjusted for a null in the output. To balance the input stage, a 60 cycle signal is applied to point B, and R6 is adjusted for a null.

The amplifier is adjusted for optimum operating conditions, when placed in service, by the application of a complex wave signal. As described previously, the ideal operating point is at 10 db of compression. At this point the front panel meter, shown in Fig. 5, will read in the center position. This is considered the normal operating range of the amplifier. A higher than normal signal from the console will cause the pointer to move to the left, indicating a decrease in amplifier gain, or additional compression. A decrease in output level from the console will cause the pointer to move to the right, indicating an increase in amplifier gain. The peak limiter should be adjusted for only 1 or 2 db of limiting on program peaks, to take maximum advantage of the noise reducing feature of this system.

There are some types of programs, such as musical programs with a wide dynamic range, and with consistent low level portions, during which it would be desirable to disable the expanding circuit. With this type of program the abrupt change in amplifier gain possibly in the middle of a sustained note would be very undesirable. The expander may be disabled by closing switch S3.

To summarize, the amplifier just described offers several important advantages over average level amplifiers. First, it eliminates the fluctuation of background noise due to changes in program level. Second, it offers the convenience of an expander in providing even more completely automatic gain control. And, third, its fast attack time and high ratio of compression qualify it for use as a peak limiter in TV and FM application. These features are vitally important in today's quest for better sound on the air, coupled with more economy in station operation.

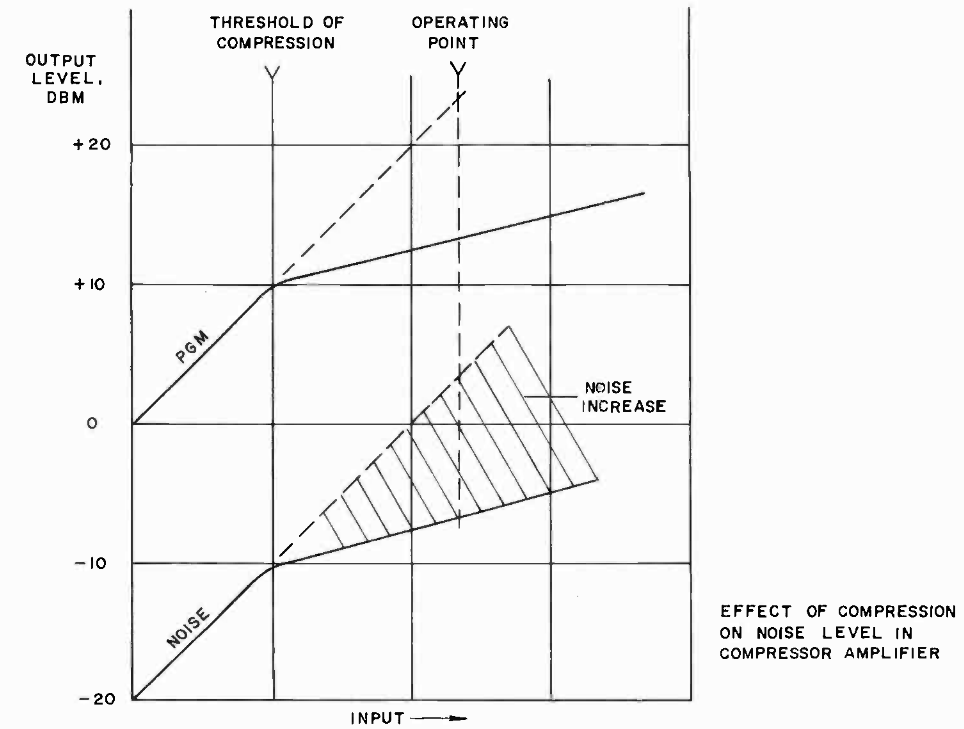

THRESHOLD OF COMPRESSION
OPERATING POINT
OUTPUT LEVEL, DBM
+20
+10
0
-10
-20
PGM
NOISE
NOISE INCREASE
INPUT
EFFECT OF COMPRESSION ON NOISE LEVEL IN COMPRESSOR AMPLIFIER

FIG. 1

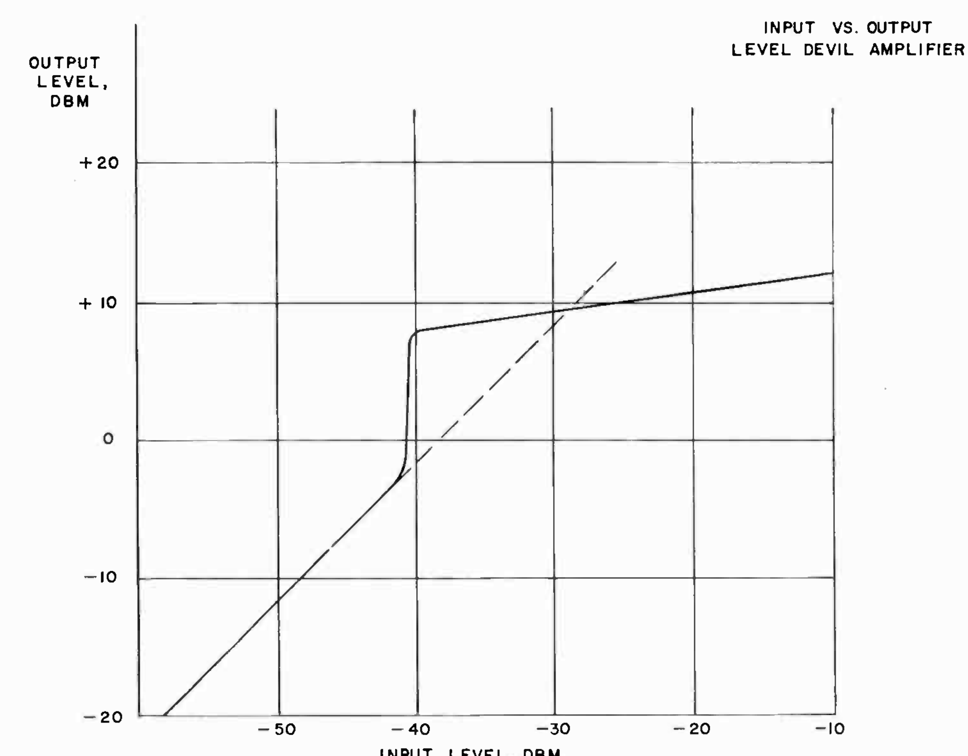

INPUT VS. OUTPUT LEVEL DEVIL AMPLIFIER
OUTPUT LEVEL, DBM
+20
+10
0
-10
-20
-50
-40
-30
-20
-10
INPUT LEVEL, DBM

FIG. 2

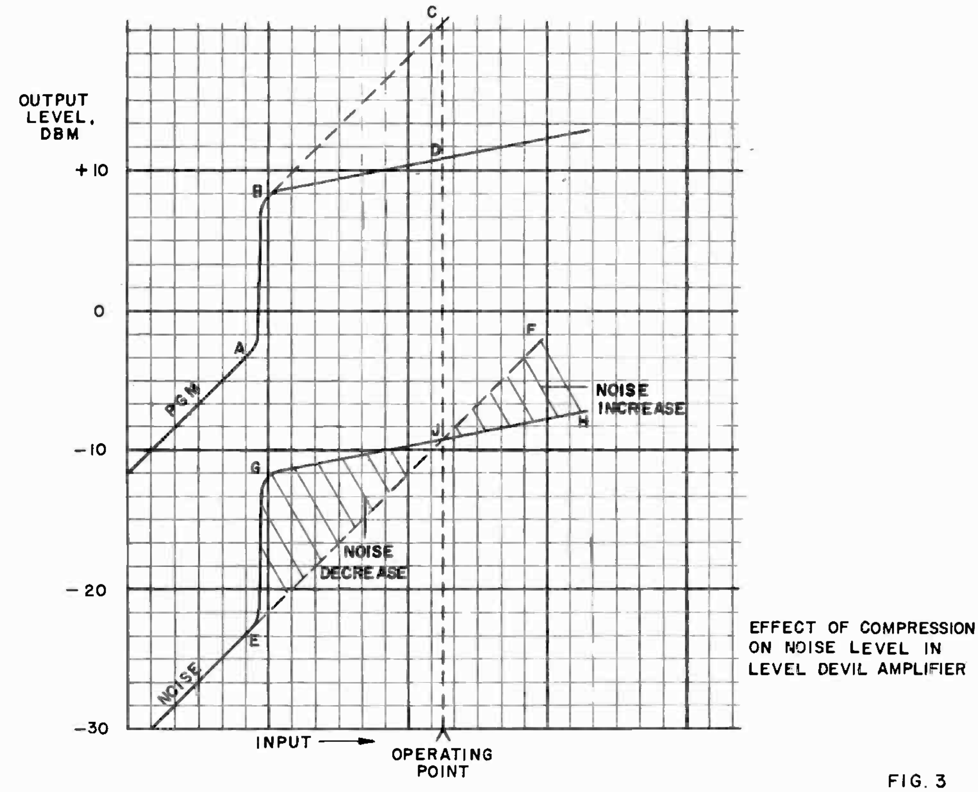

OUTPUT
LEVEL,
DBM
+10
0
−10
−20
−30
C
D
B
A
PGM
F
NOISE
INCREASE
H
J
G
NOISE
DECREASE
E
NOISE
INPUT
OPERATING
POINT
EFFECT OF COMPRESSION
ON NOISE LEVEL IN
LEVEL DEVIL AMPLIFIER

FIG. 3

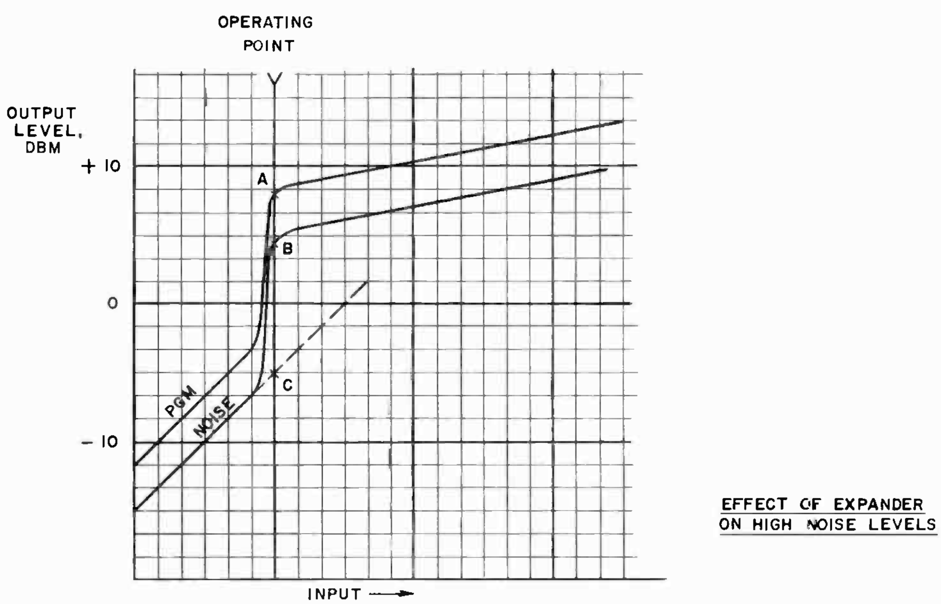
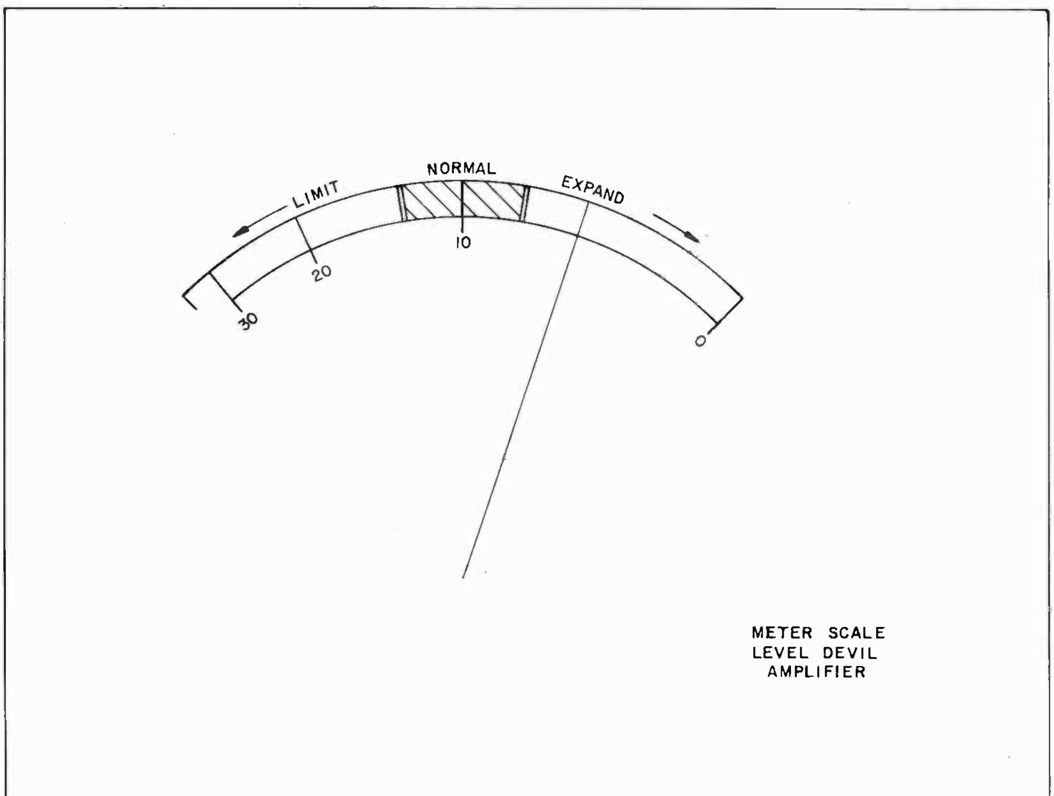
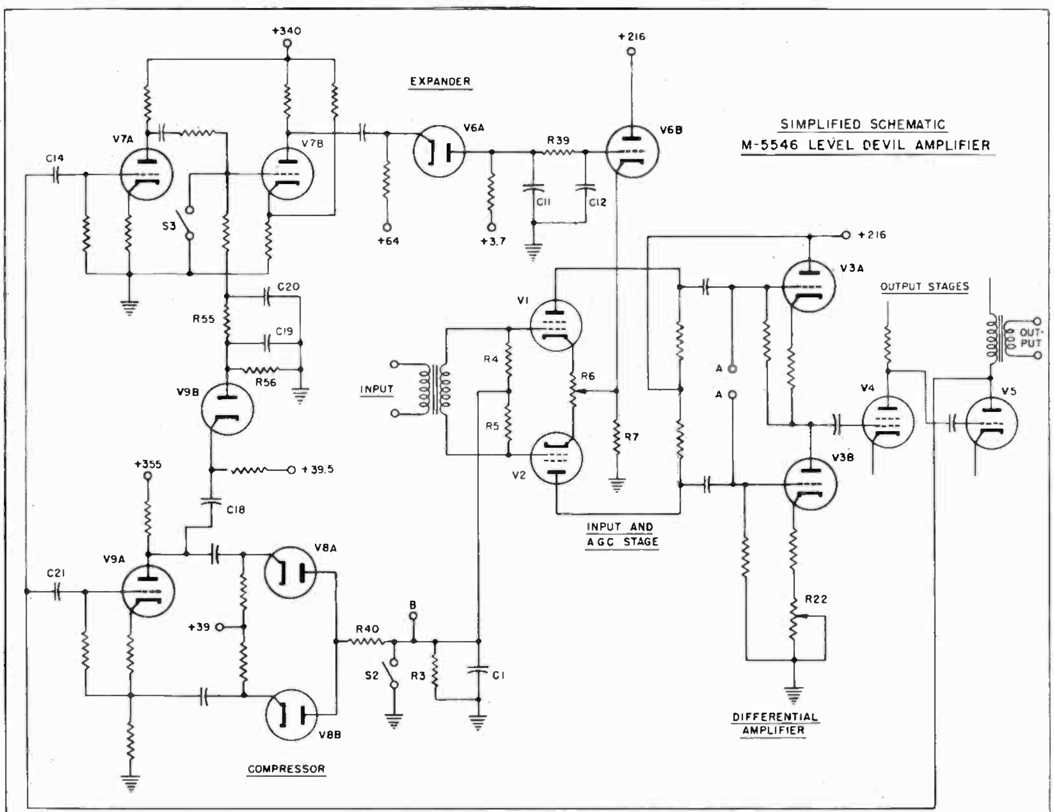

OPERATING
POINT
OUTPUT
LEVEL,
DBM
+10
0
−10
A
B
C
PGM
NOISE
INPUT
EFFECT OF EXPANDER
ON HIGH NOISE LEVELS

FIG. 4



NORMAL
LIMIT
EXPAND
10
20
30
0
METER SCALE
LEVEL DEVIL
AMPLIFIER

FIG. 5



SIMPLIFIED SCHEMATIC
M-5546 LEVEL DEVIL AMPLIFIER
EXPANDER
+340
+216
V7A
V7B
V6A
V6B
R39
C14
S3
C11
C12
+64
+3.7
C20
R55
C19
R56
V9B
V1
V2
R4
R5
R6
R7
INPUT
V3A
V3B
V4
V5
OUTPUT STAGES
OUT-
PUT
A
A
+39.5
+355
C18
C21
V9A
V8A
V8B
+39
R40
B
S2
R3
C1
R22
INPUT AND
AGC STAGE
DIFFERENTIAL
AMPLIFIER
COMPRESSOR

FIG 6


M5546 LEVEL DEVIL
MFD. BY
GATES RADIO COMPANY
SUBSIDIARY OF
HARRIS INTERTYPE CORPORATION
LEVEL DEVIL
GATES

The Folded Unipole Antenna for Broadcast

Presented by: John H. Mullaney

Consulting Radio Engineer

Washington, D. C.

Tuesday, April 5, 1960

14th Annual NAB Engineering Conference

Chicago, Illinois

THE FOLDED-UNIPOLE ANTENNA FOR BROADCAST

I - INTRODUCTION:

This paper will discuss a method for reducing the physical height of an antenna system without seriously impairing its electrical characteristics. This will be accomplished by use of folded-unipole antenna theory. Present day techniques dictate that in order to reduce the physical size of an antenna system and still obtain a reasonable efficiency, inductive or capacitive loading be utilized in order to change the current distribution of the array. It will be shown that by grounding a vertical structure and folding back one or more conductors parallel to the side of the structure, it is possible to obtain a wide range of resonant radiation resistances by varying the ratio of the diameter of the folded back conductor in relation to the tower. It will also be shown that a top-loaded folded-unipole antenna can obtain a wide range of resonant radiation resistances and at the same time obtain a band-width many times greater than the same antenna without loading and use of the folded-unipole method of feed.

Series-fed vertical antennas are commonly used in standard broadcast service today. Some stations use a shunt-fed antenna, but the great majority are series-fed. The folded-unipole antenna could be called a modification of the standard shunt-fed system. Instead of having a slant wire leaving the tower at an angle of approximately 45^{0} (as used for shunt-fed systems), the folded-unipole antenna has wires (one or more can be used) attached to the tower at a pre-determined height, supported by stand-off insulators, and run parallel to the sides of the tower to its base. The tower is grounded at its base--that is, no base insulator is used. These folds, or wires, are joined together at the base and driven at this point through an impedance matching network. Depending upon the type of folded-unipole antenna used, the wires may be connected to the tower at the top and/or at pre-determined levels along the tower (shorting stubs).

The folded-unipole antenna has the advantage of not requiring a base insulator, lighting chokes, or isolation transformers. It provides better protection against lightning, due to the fact that the antenna is grounded. In addition, the folded-unipole antenna, on a comparison basis, will develop a somewhat higher radiation efficiency, particularly for towers of the order of 45^{0} to 60^{0} high. The band-width for the folded-unipole antenna is also superior to that of a series or shunt-fed antenna system. The folded-unipole has an additional advantage over a series or a shunt-fed system in that it will operate with a much shorter ground system and still produce approximately the same effective field.

Basically speaking, a folded-unipole antenna can be visualized as a half-wave folded-dipole perpendicular to the ground and cut in half. The following discussion will briefly treat the theory of and results obtained from this type of antenna system.

II - THEORY OF FOLDED-UNIPOLE ANTENNA:

A - General:

To readily understand the folded-unipole antenna and its use in feeding a grounded tower, let's take a quick look at some basic transmission line

II - THEORY OF FOLDED-UNIPOLE ANTENNA (CONTINUED):

A - General (Continued):

theory. We know that a transmission line which is less than 90^0 in length and shorted at its far end will appear inductive at its input terminals. If this line is increased in length so that it equals a quarter wave, it will appear to be a parallel resonant circuit at its input. That is, it will appear to have very high impedance.

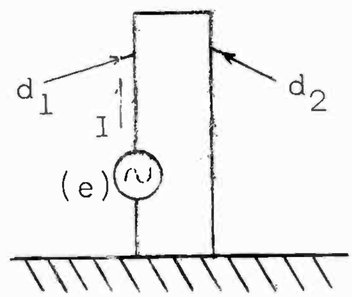


FIGURE 1

Figure 1 illustrates a one fold, folded-unipole antenna. In order to determine its input impedance, let us assume a generator voltage (e) and then find the current (I) flowing in the lower end of element d_1 as illustrated in Figure 1. Roberts (Input Impedance of a Folded Dipole, R.C.A. Review, Volume 8, No. 2, June, 1947, W. Van B. Roberts) has outlined a method for analysis of a folded-unipole antenna. Figure 1 then becomes:

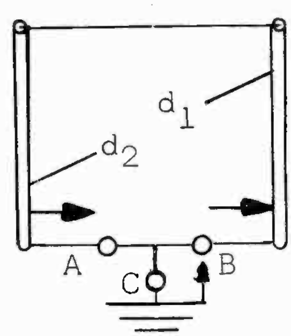


FIGURE 2

Referring to Figure 2, it should be noted that Generator A is opposing Generator C, with respect to the lower end of element d_2. Thus, element d_2 is grounded so far as any voltage is concerned.

II - THEORY OF FOLDED-UNIPOLE ANTENNA (CONTINUED):

A - General (Continued):

Generators B and C impress a voltage, 2E, on the lower end of element d_1; therefore, Figure 2 is equivalent to Figure 1. Our reason for using three generators is that it is fairly easy to determine the current developed by each generator and then by the principal of superposition, add these currents to obtain the actual current in the lower end of element d_1.

Let's go a little further and first assume that there is no voltage (for the moment) in the lower generator. There is then only the voltage 2E acting between the lower ends of d_1 and d_2. Inasmuch as elements d_1 and d_2 form a 90^o transmission line, shorted at the far end, their impedance is very high; consequently, only a small current will flow into element d_1. Next, assume there is voltage only in Generator C. Then, since the lower ends of d_1 and d_2 are shorted together (by the zero internal impedance of A and B), the two elements act as a simple 90^o radiator made up of two elements connected in parallel. If R is the radiation resistance of this radiator, Generator C will supply a total current equal to E/R to this composite antenna, but by symmetry, this current divides equally between d_1 and d_2, so that the current entering element d_1 is:

$$I_1 = \frac{1/2\ E}{R} \qquad (1)$$

Thus, if Generators A, B and C are well working at once, the voltage impressed on element d_1 is 2E, while the current entering it is 1/2 E/R plus a very small amount produced by Generators A and B working above. The input resistance of element d_1, being the ratio of voltage impressed to resulting current flow, is therefore approximately 4R. If the two elements are close together, the value of resistance will be different from that of a single radiator, and the impedance multiplication due to folding is approximately four.

The impedance transformation can be expressed as follows:

$$\text{The impedance transformation} = \frac{Z_1}{Z_o} = (1 + n)^2 \qquad (2)$$

Where:

Z_1 = input impedance of the folded-unipole antenna.

Z_0 = input impedance of a single antenna.

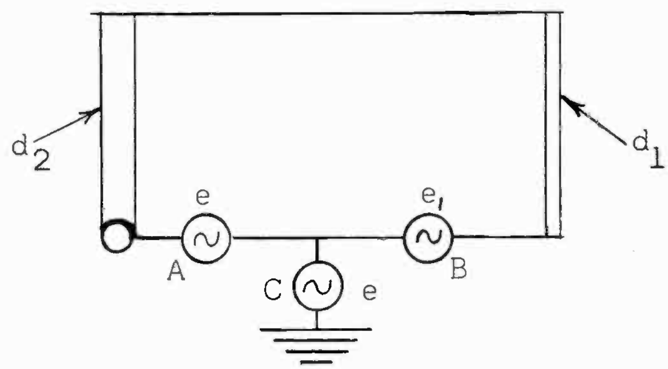
n = current ratio $\frac{I_2}{I_1} = 1$

Up to this point, we have discussed equal size conductors, that is the diameter of the tower and the fold is the same. However, with the introduction of the transformation ratio, as noted in (2) above, we are

II - THEORY OF FOLDED-UNIPOLE ANTENNA (CONTINUED):

A - General (Continued):

now prepared to discuss the operation of a folded-unipole antenna with unequal diameter conductors. Figure 3 illustrates the folded-unipole antenna with unequal size conductors.



F I G U R E 3

Generators A and C are alike in order to put zero voltage on element d_2, but Generator B must now be so chosen that no current will flow through Generator C when it is not producing voltage. The determination of this voltage (e_1) is one of the two essentials to the solution of the problem. The other is to determine how the current produced by Generator C, acting above, divides between elements d_1 and d_2. This problem becomes extremely complex because of the non-symmetry of the elements and there are several methods which can be used to solve the problem. "Guertler" (Impedance Transformation in Folded-dipole, Proceedings of the IRE, September 1950) demonstrates a method for determining this voltage. "Roberts" has also demonstrated methods for determining this voltage. We will use the electrostatic or capacitive method discussed by Roberts, since this method appears to offer the most promise for a simple solution. Briefly, this theory states that the current will divide directly as the ratio of the capacities of the elements, while the voltage ratio will be the inverse of the capacity ratio. To solve our problem then, we must assign undefined capacities, c_1 and c_2 to elements d_1 and d_2. Then:

$$\frac{e}{e_1} = \frac{c_1}{c_2} \qquad (3)$$

The current entering element d_1 is the total current produced by Generator C acting alone multiplied by:

$$c_1 \Big/ (c_1 + c_2) \qquad (4)$$

Neglecting the very small current produced by Generators A and B acting alone, as already discussed for equal elements, the total current due to Generator C alone is:

$$\frac{e}{R} \qquad (5)$$

II - THEORY OF FOLDED-UNIPOLE ANTENNA (CONTINUED):

A - General (Continued):

Where R = radiation resistance of the two elements connected in parallel.

The driving point impedance of the antenna is:

$$\frac{(e + e_1)}{\text{the current entering } d_1} \qquad (6)$$

Thus, it is readily proven that the driving point impedance is:

$$R\left(1 + \frac{c_2}{c_1}\right)^2 \qquad (7)$$

The above method of determination indicates that the impedance step up ratio depends upon the ratio of the elements' diameters, being inversely proportional to the diameter of the excited fold or element and directly proportional to the diameter of the grounded element. The spacing between the tower and fold is not extremely critical, but does determine, to some extent, the impedance transformation ratio. Although this type of antenna has good band-width, its band-width characteristics will be decreased if a transformation ratio of greater than approximately ten is attempted by means of the spacing ratio. It has been found that the best way to increase the band-width of the antenna is to increase the number of folds.

The electrostatic or capacitive method outlined by Roberts is primarily a physicist's approach to a solution of the folded-unipole antenna. It can be shown that the impedance transformation ratio for a folded-unipole antenna where unequal diameters are used is:

$$\text{Transformation ratio} = \left(1 + \frac{Z_1}{Z_2}\right)^2 \qquad (8)$$

Where:

Z_1 = the characteristic impedance of a transmission line made up of the smaller of the two conductor diameters spaced the center to center distance of the two conductors in the antenna.

Z_2 = the characteristic impedance of a transmission line made up of two conductors the size of the larger of the two.

The above equation assumes that the power will be fed to the smaller conductor (fold). That is, the feed line from the transmitter is connected in series with the fold (fold's diameter always assumed smaller than tower's) so that an impedance step-up of greater than four will be achieved.

The magnitudes for Z_1 and Z_2 of equation (8) for uniform cross-section conductors can be determined from standard transmission line formulas.

II - THEORY OF FOLDED-UNIPOLE ANTENNA (CONTINUED):

A - General (Continued):

During the last five years, numerous experimental measurements have been made on different types of folded-unipole antennas for broadcast use. Our experience indicates that the average height of a non-directional broadcast antenna will vary somewhere between 150 and 300'. Inasmuch as the change in frequency from the low end to the high end of the broadcast band is approximately three to one and if we assume that the height of the broadcast antenna is not higher than 90^{o} and six driven folds are used on the tower without any shorting stubs, the following empirical expression may be used to obtain the impedance of a folded-unipole antenna:

$$Z_{fu} = 3.6 \ (Z_{11}) \tag{9}$$

Where:

Z_{fu} = base impedance of the folded-unipole in ohms.

Z_{11} = base self-impedance in ohms for the tower height under consideration.

3.6 = empirical constant determined from measurements.

Equation (9) assumes that the folded-unipole antenna is approximately 90^{o} and has not been resonated by use of shorting stubs (that is, wires connected between each of the folds to the tower at pre-determined levels, based on impedance measurements at the base of the tower).

In normal practice, it is desirable to resonate the folded-unipole antenna by means of shorting stubs. These stubs are actually short circuits connected between each of the folds to the tower at some point below the top of the tower. The actual location for these shorting stubs must be determined experimentally. To do this, first measure the tower with the shorting stubs at the very top. Then have a tower rigger move the shorting stubs down until j0 is measured at the base. It should be noted that a folded-unipole antenna will initially measure +j. Consequently, if the shorting stubs are moved down the tower too far, the measured reactance sign will change to a minus, indicating that the antenna has gone through resonance. Hence, this means that the shorting stubs should be moved up until j0 is obtained. This condition is theoretically referred to as first resonance. At resonance, Z = R; hence, the following empirical expression may be used for obtaining the resistance of a folded-unipole antenna at first resonance:

$$Z_{fu} = 7.3 \ (R_{11}) \tag{10}$$

Where:

Z_{fu} = base impedance or resistance for folded-unipole at first resonance (ohms).

R_{11} = self-base resistance of tower (ohms)

7.3 = empirical constant determined from measurements.

III - PRACTICAL ASPECTS OF FOLDED-UNIPOLE ANTENNAS:

So far, we have discussed how to determine the impedance for a folded-unipole antenna, assuming it had six folds, but no information has been given with regard to the practical construction of this type of antenna. Equations (9) and (10) were developed from measurements of what we call our standard broadcast folded-unipole antenna.

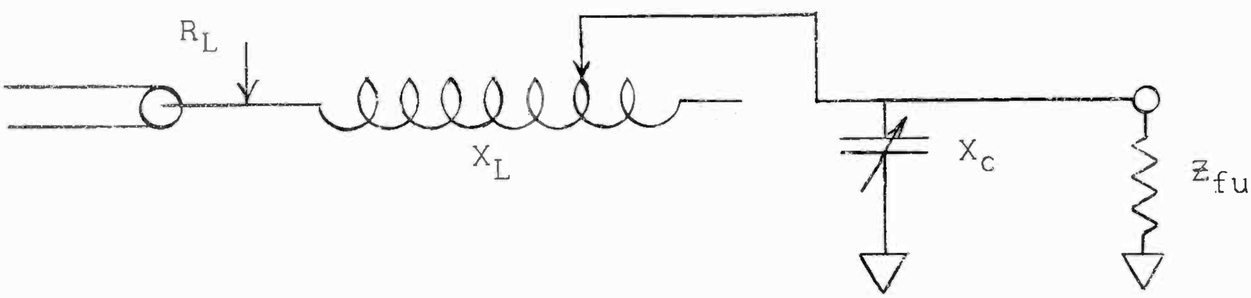
Figure 4 is a top view of a uniform cross-section, guyed tower rigged for a six wire folded-unipole antenna.

Figure 5 is a drawing indicating the details of the fold attachment at the tower's base.

Figure 6 is a detail drawing of the cross-arms or spider.

Figure 7 is a bill of materials for a typical folded-unipole antenna installation on a uniform cross-section guyed tower.

Figure 8 is a plot of impedance measurements obtained on a 200' tower with six folds at 1570 KC. This tower is 0.319 wave lengths or approximately 115^{0} high and would be expected to have a self-impedance (Z_{11}) of 155 j260; however, when it is converted to a folded-unipole antenna and the folded-unipole shorting stubs have been adjusted to obtain j0 or resonance at the base, the resistance is multiplied up to 1,170 ohms. This is a transformation ratio of 7.55. In order to transform this impedance to 50 ohms j0 (transmission line impedance), an "L" or "T" type of network may be used. We prefer to use a modified version of an "L" network (See Figure 10) and treat the transmission line resistance as a series resistance of a parallel network at resonance.



F I G U R E 10
(Schematic of "L" type impedance transforming network)

The following formulas may be used to determine X_1 and X_c for an "L" network:

$$Z_{fu} = \frac{X_1}{R_1} + R_1 \quad (11)$$

$$X_c = X_1 + \frac{R_1^{\,2}}{X_1} \quad (12)$$

$$X_1 = \sqrt{(R_1\ Z_{fu}) - (R_1)^2} \quad (13)$$

The following data furnishes complete information for the construction of a typical standard broadcast folded-unipole antenna.

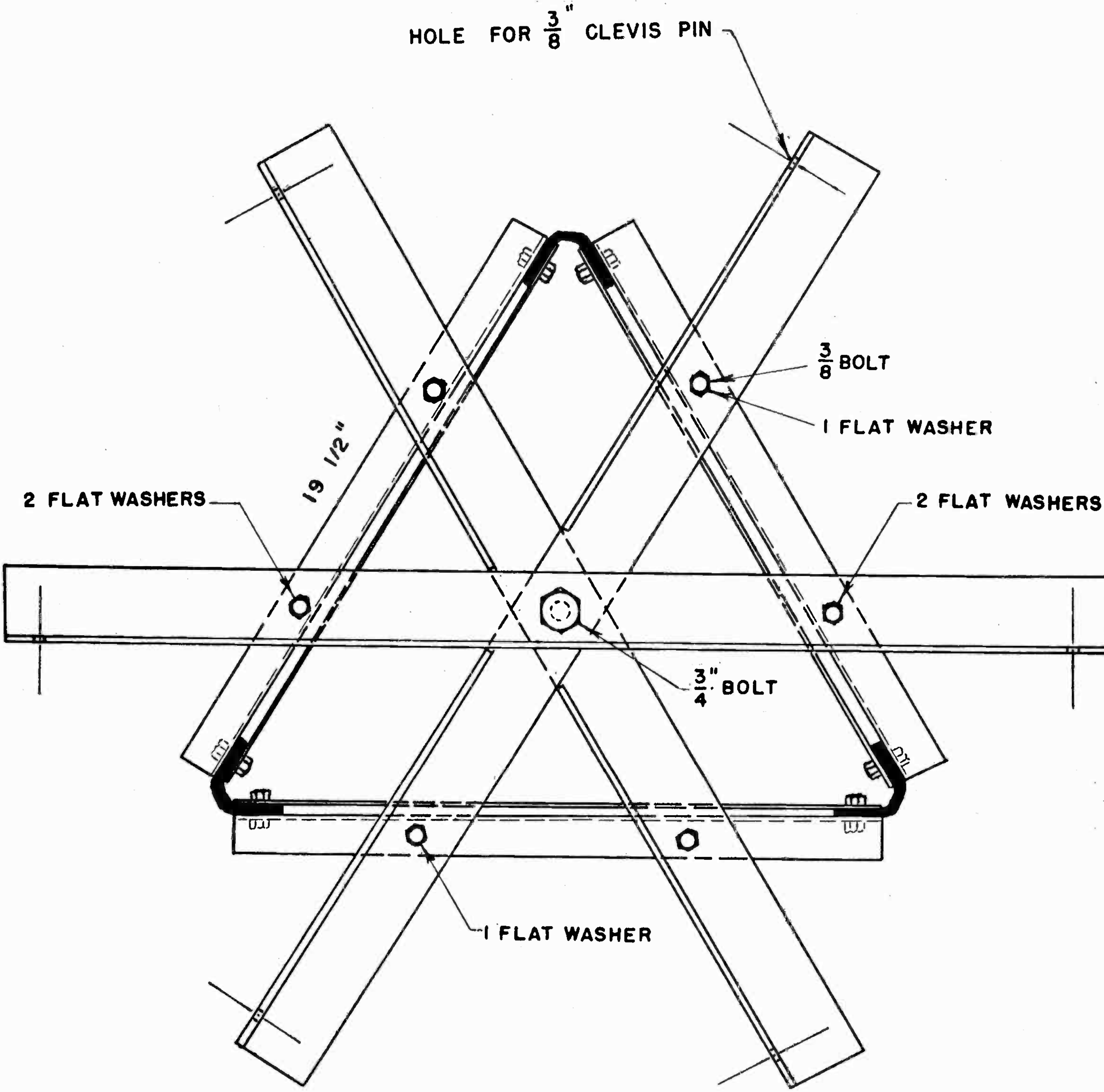

HOLE FOR $\frac{3}{8}$" CLEVIS PIN
$\frac{3}{8}$ BOLT
1 FLAT WASHER
19 1/2"
2 FLAT WASHERS
2 FLAT WASHERS
$\frac{3}{4}$" BOLT
1 FLAT WASHER

FIGURE 4

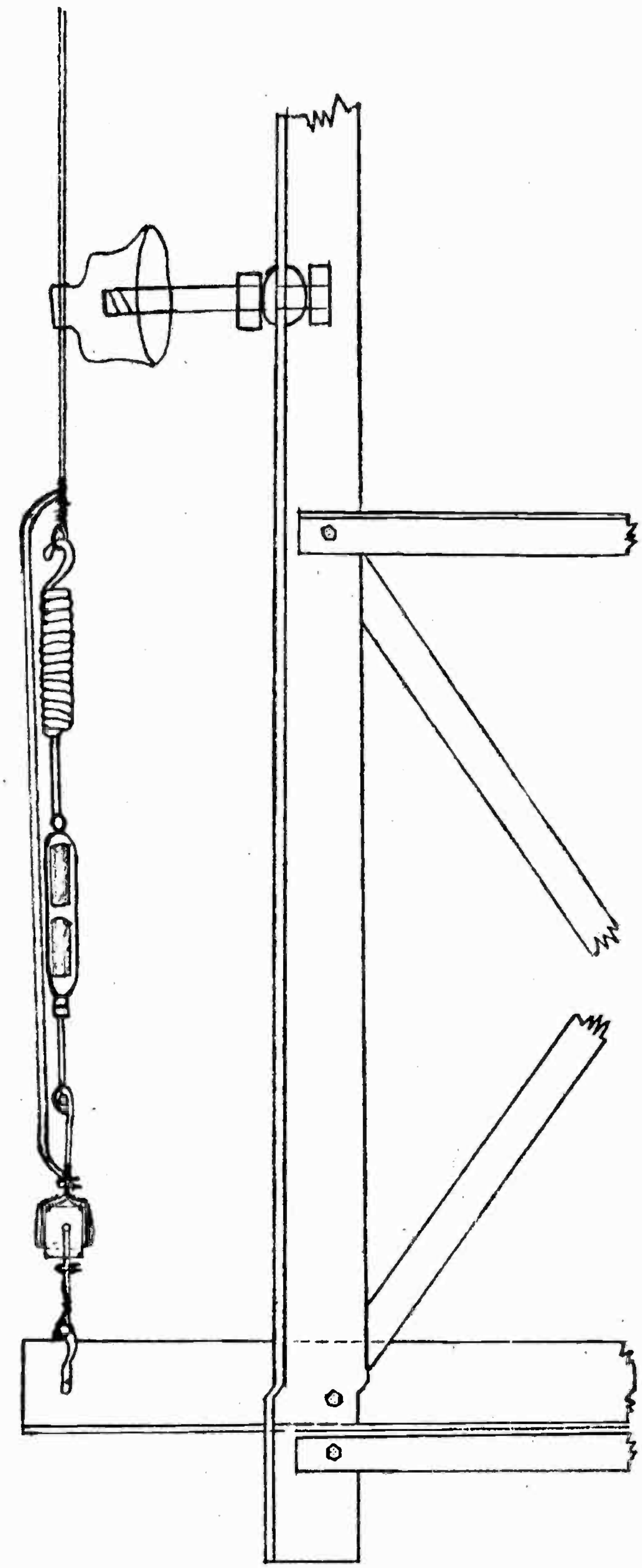
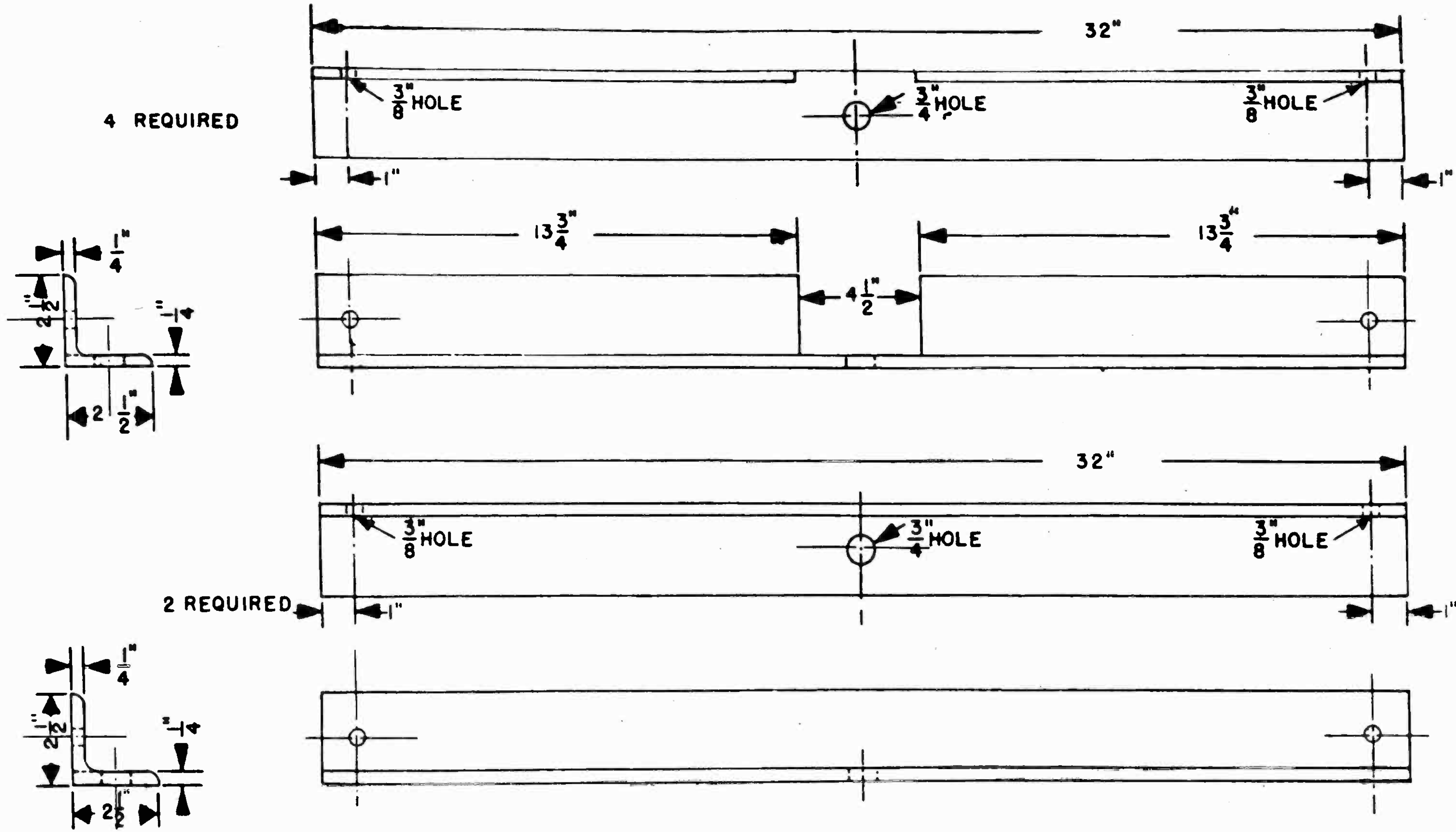


FIGURE 5
DETAILS OF FOLD
ATTACHMENT AT TOWER BASE



NOTE: OVERALL LENGTH IS FOR TYPICAL GUYED TOWER. LENGTH MAY VARY DUE TO CROSS SECTION. HOLE SIZES ARE STANDARD.

FIGURE 6

FIGURE 7

BILL OF MATERIALS FOR FOLDED-UNIPOLE ANTENNA INSTALLATION FOR UNIFORM CROSS-SECTION GUYED TOWER

1. 6 pieces of angle iron (Figure 6).
2. 2 each 3/4" x 1 3/4" bolts and 2 lock washers.
3. 12 each 3/8" x 1 1/2" bolts and 12 lock washers.
4. 12 flat washers 7/16" I.D. maximum O.D.
5. 12 each 3/8" Clevis Shackle.
6. 6 turnbuckles 1/2" bolts or larger.
7. 3 pieces of copper strap 6" wide (long enough to ground antenna at base).
8. 24 wire clamps suitable to attach shorting straps to antenna (aluminum deadend clamps).
9. 6 folds - #4 NCSR, stranded aluminum wire - total length equal to 6 times tower's height plus 25' additional.
10. 6 egg type strain insulators - to insulate folds at base of antenna 3" diameter or better.
11. 36 stand-off insulators (placed at 30' intervals on tower adjacent to folds) (Jocelyn Cross Arm Pin and 15 KV Insulator).
12. 1 variable vacuum capacitor 10/1000 uuF or equivalent 15 KV, 45 amperes (suggest Jennings type).
13. 1 variable inductor 0/60 microhenries - appropriate to handle 1 KW power (suggest Gates, Johnson, or Multronics type coil).
14. 6 springs 4" - 6" long.
15. 1 Weston or equivalent R.F. ammeter 0-6 amps (for 1 KW installations).
16. 1 remote antenna ammeter unit.
17. Tuning unit cabinet with bowl feed thru for output connection.
18. Miscellaneous:

    Solder, brazing rod and torches, flux, polyethelene tape, hand tools, and small parts to mount inductor and variable capacitor. Also needed to facilitate the measurements, adequate extension lights and a rough support for the measuring equipment to provide access to the antenna tuner unit.

Note: All hardware to be galvanized or painted with aluminum paint. Dissimilar metal clamps recommended for use between tower and aluminum wire.

III - PRACTICAL ASPECTS OF FOLDED-UNIPOLE ANTENNAS (CONTINUED):

Where:

Z_{fu} = measured base impedance of folded-unipole at resonance (ohms).

R_1 = transmission line impedance (ohms).

X_1 = reactance of series coil (ohms).

X_c - reactance of shunt condenser (ohms).

Using the above formulas, a modified L network was used to match the impedance shown in Figure 8. Figure 9 is a plot of coupling impedance obtained for this antenna system.

In order to determine the current in the antenna, an ammeter may be placed in either the transmission line output (input to modified L network) or the output of the network (input to the folded-unipole) or at both locations for determining power. The F.C.C. will allow the meter to be placed at either location and to be used for direct measurement of power. Where a folded-unipole antenna is operated at first resonance, it is recommended that the antenna ammeter be placed in the input to the network so that a larger scale ammeter can be used. It should be noted that inasmuch as the antenna is adjusted to j0, line current is a true indication of power.

Figure 11 is a plot of the measured resistance and reactance for a folded-unipole antenna (resonated) which is 70° in height at 800 KC. This antenna would be expected to have a base impedance (when measured without folded-unipole rigging) of 31 +j9. Examination of Figure 11 shows that this antenna (folded-unipole rigged and resonated) has a feed point impedance of 230 $\pm$j0. An impedance match from 50 ohm line to this impedance can be readily obtained by use of an "L" or "T" coupling network.

IV - CURRENT DISTRIBUTION ON A FOLDED-UNIPOLE ANTENNA:

During the writer's experiments with folded-unipole antennas in 1949 and 1950 for the United States Air Force, it was determined by measurement that the current distribution on a folded-unipole antenna is the same as that of a base insulated antenna of identical height. D. L. Waidelich has proven ("General Folded-dipole Antenna Design", Communications, April 1949) that the current distribution on a folded-dipole antenna is the same as that of a simple dipole antenna. Inasmuch as a folded-unipole is basically 1/2 of a folded-dipole antenna, it follows that the current distribution of a folded-unipole would be the same as that of a simple unipole. Further, Schelkunoff (Antennas "Theory and Practice", Wiley) has shown that the current distribution for a folded-dipole is the same as that of a simple dipole of similar length.

Numerous field intensity measurements have been made during the last five years on folded-unipole antennas to determine their current distribution and effective E_{rms}. Measurements have been made on series-fed antennas before converting to folded-unipole and then comparison measurements made to demonstrate that the current distribution and effective fields are similar for both antennas. It can therefore be concluded that the current distribution of a folded-unipole type of antenna will be the same as that of a simple base insulated series-fed antenna.

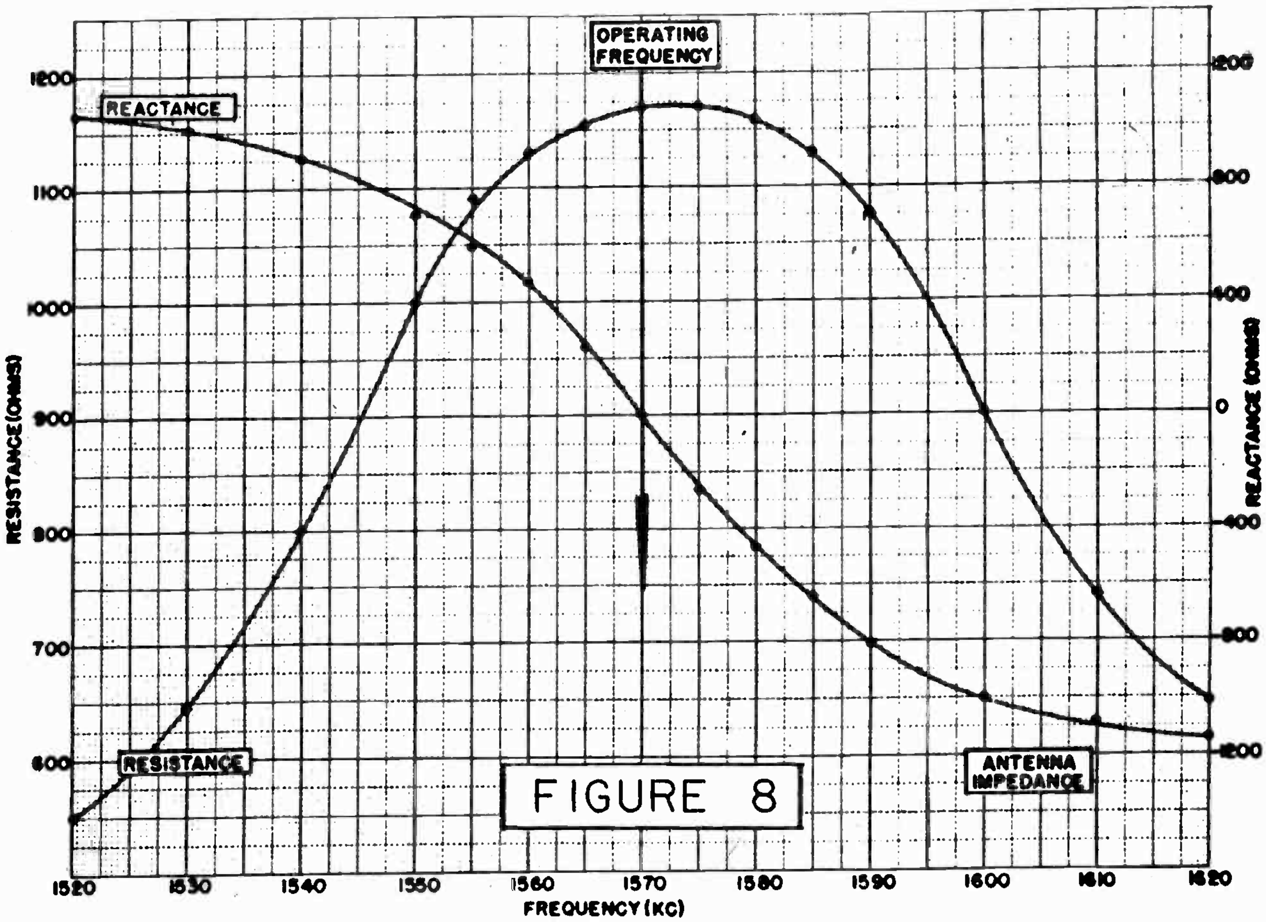


FIGURE 8

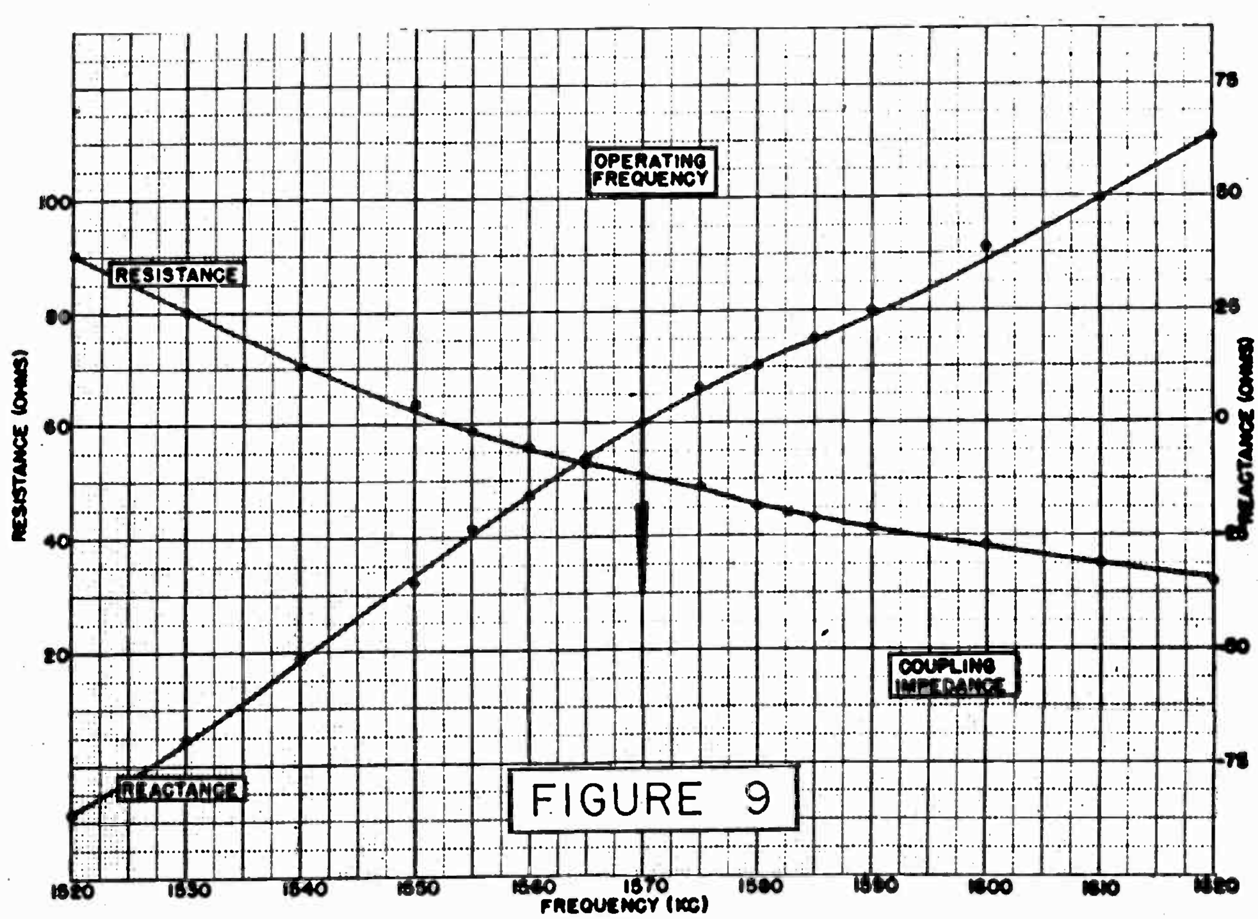


FIGURE 9

V - BAND-WIDTH CONSIDERATIONS:

The band-width of an antenna depends upon its base impedance and the rate with which its reactance changes with frequency. The band-width is considered to be the frequency band within which the power is equal to or greater than one-half the power at resonance. Expressed in equation form:

$$\Delta f = \frac{2R_a}{\frac{dx}{df}} \tag{14}$$

Where:

Δf = band-width in kilocycles between half-power points.

R_a = measured antenna resistance in ohms.

$\frac{dx}{df}$ = slope of reactance curve at resonant frequency.

The effective band-width will be doubled when the generator is matched to the antenna circuit. The Q of a folded-unipole antenna can be determined from the equation:

$$Q = \frac{f_o}{\Delta f} \tag{15}$$

Where:

f_o = operating frequency in kilocycles

Δf = band-width of antenna in kilocycles

Our experiments indicate that a folded-unipole antenna has a much more desirable band-width characteristic than an equal height series-fed antenna.

VI - TOP-LOADED FOLDED-UNIPOLE ANTENNAS:

For very short towers, advantage may be taken of top-loading to increase the effective height of a folded-unipole antenna.

Our experience indicates that the simplest and most effective means for top-loading a folded-unipole antenna is to connect the top three guy wires to the tower, adjust them to a given physical length and then inter-connecting them at the lower end to simulate a pyramid. Experimental data indicates that the following expression can be used to compute the length of guy wires necessary to obtain a given amount of top-loading:

$$G^o_{eff} = \frac{TL^o}{0.705} + G^o_{11} \tag{16}$$

Where:

G_{eff} = desired electrical tower height in degrees.

TL^o = desired top-loading in degrees

VI - TOP-LOADED FOLDED-UNIPOLE ANTENNAS (CONTINUED):

0.705 = empirical constant.

Figure 12 is a plot of the measured resistance and reactance for a folded-unipole antenna (resonated) which is 69.5^{0} in height at 1000 KC and has been top-loaded an additional 15.5^{0} to given an electrical height of 85^{0}. This antenna would be expected to have a base impedance of 39 +j40 (when measured without folded-unipole rigging but with top-loading). Figure 12 shows that this antenna (folded-unipole) rigged and resonated) has a feed point impedance of 350 $\pm$ j0. An appropriate impedance transformer should be used to match this antenna impedance to a transmission line.

VII - SECOND RESONANCE FOR FOLDED-UNIPOLE ANTENNAS:

A folded-unipole antenna can obtain a wide range of resonant radiation resistance by varying the ratio of the diameters of the folded conductors to the diameter of the tower. The radiation resistance varies as the square of the height and if the transformation ratio is raised enough, the height of the antenna can be reduced, the limit being the point where ground losses consume a prohibitive percentage of the power.

For practical operation a short antenna should have a resistance of at least 50 ohms. Unfortunately short series-fed antennas in the range of 45^{0} to 60^{0} do not approach this value; consequently, this type of antenna has excessive losses. In these ranges, the use of a top-loaded folded-unipole antenna is extremely desirable, inasmuch as these antennas can be operated at first or second resonance. For second resonance, a top-loaded folded-unipole has a length of approximately one-half that of a folded-unipole at first resonance. This is the same as saying that if a folded-unipole antenna had a length of approximately 90^{0} (electrical), we would expect second resonance to occur at approximately one-half this length or 45^{0}. The base impedance for a top-loaded folded-unipole antenna at second resonance can be expressed as:

$$R_{2r} = 1580 \left[\frac{h_{2r}}{2r} \times \frac{\log 4S^2/d_1 \, d_2}{\log 2S/d_2} \right]^2 \qquad (17)$$

Where:

R_{2r} = resistance of folded-unipole at second resonance (ohms).

h_{2r} = height at second resonance.

$2r$ = wavelength at second resonance (same units as h_{2r}).

S = spacing, center to center, of tower to fold.

d_1 = fold diameter.

d_2 = tower diameter.

S, d_1 and d_2 should be expressed in the same units.

It should be noted that "$\log_{10}$" or "$\log_e$" can be used, inasmuch as a ratio is expressed in equation (17).

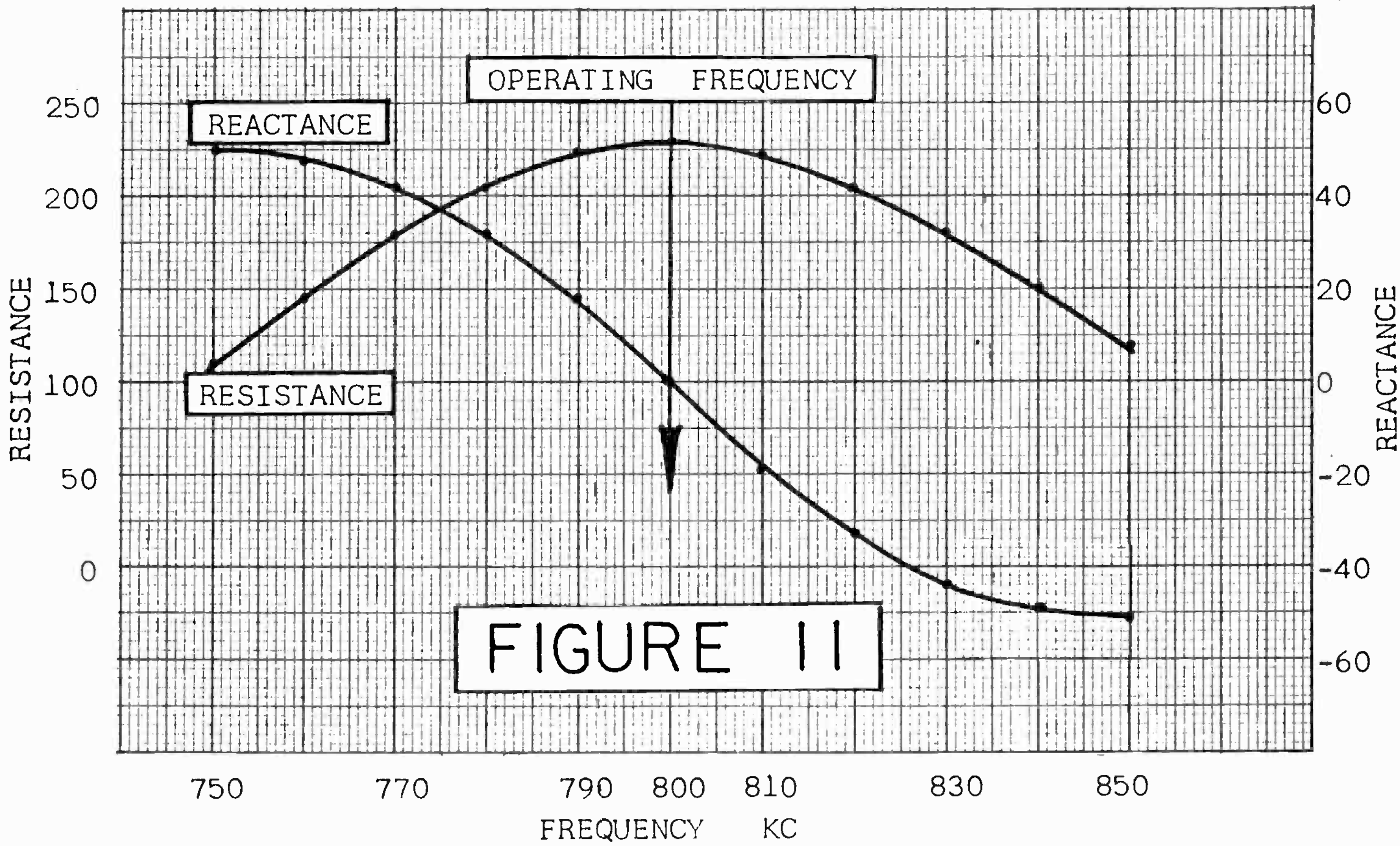


FIGURE 11

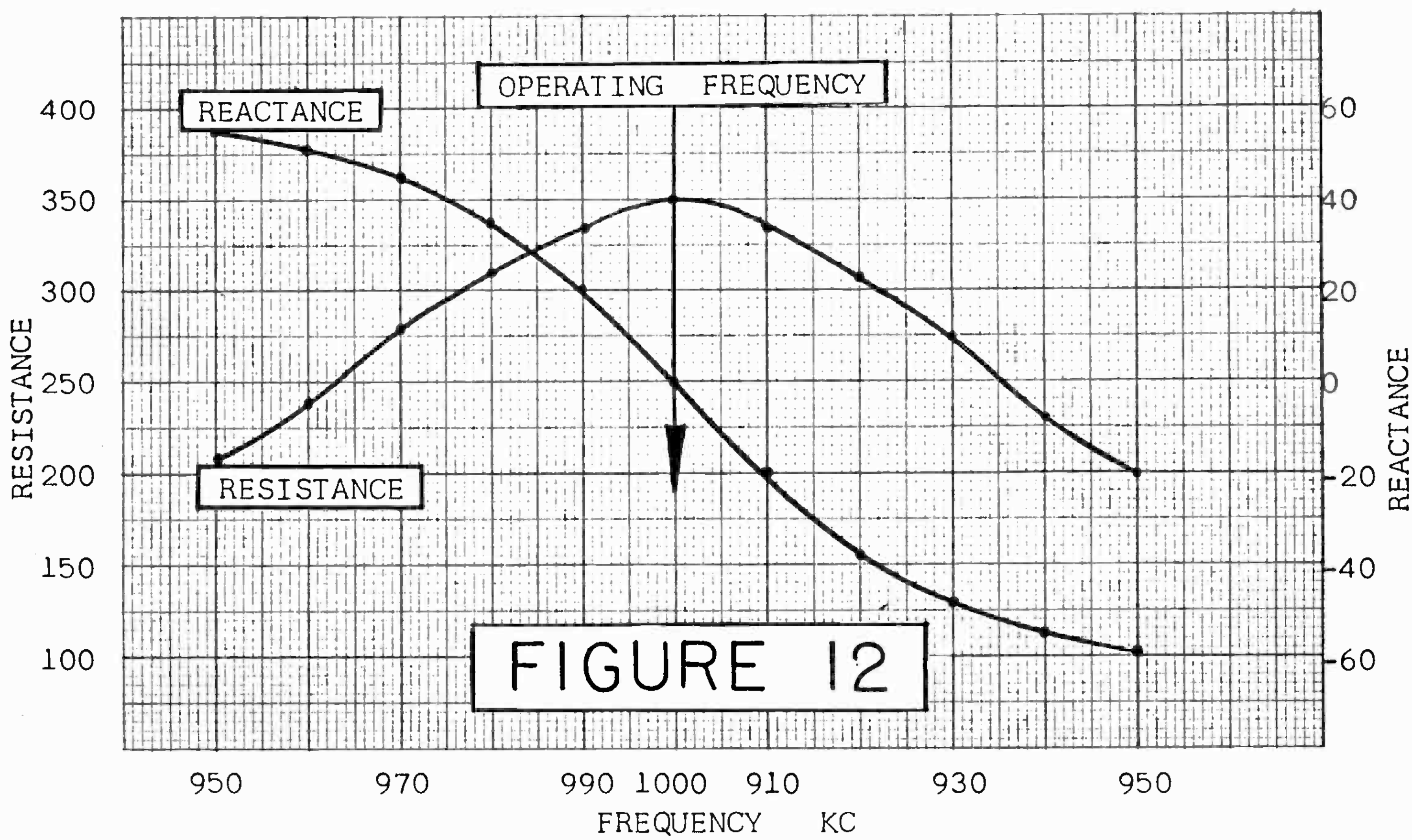


FIGURE 12

VII - SECOND RESONANCE FOR FOLDED-UNIPOLE ANTENNAS (CONTINUED):

It should be noted that the operation of a folded-unipole at second resonance is similar to that at first resonance; however, the ratio of the diameter of the folds to the tower's diameter and the spacing is much more critical.

VIII - UNATTENUATED FIELD INTENSITY:

It has been observed experimentally that a folded-unipole antenna will develop a higher unattenuated field intensity than the same equivalent height series-fed antenna system. The increase in field intensity varies between approximately two to ten percent. The greatest increase in field intensity is experienced on short antennas in the range 45^{o} to 75^{o}.

IX - ACKNOWLEDGMENT:

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Engineering Department Publications

CBS TELEVISION NETWORK

Video Tape Recording Interchangeability Requirements

K. B. Benson

(Presented at NAB Engineering Conference, April 6, 1960) E2238-D

VIDEO TAPE RECORDING INTERCHANGEABILITY REQUIREMENTS

by K. B. Benson

INTRODUCTION

The use of video tape in broadcasting service often requires that recordings be played back with a different head assembly than was employed for the original recording. If such interchangeability of head assemblies is to provide optimum quality, it is essential that close control of many manufacturing parameters and operating standards be maintained. In present-day multiple head equipment, mechanical dimensions of particular importance include those relating to the video track azimuth, pitch, and width as well as the angular placement of the four rotating heads. Essential electrical parameters include the value of carrier frequency corresponding to reference video levels. In addition, response-frequency characteristics of audio, video, and carrier frequency channels must be standardized. The significant factors are discussed relative to proposed Industry Standards and current CBS Television Network practices.

BACKGROUND

The first use of video tape by CBS in November 1956, and shortly thereafter by other networks, was for the regional delay of program transmission in order to accommodate time-zone differences across the United States. This service merely requires an elementary type of performance consisting of record, rewind, and playback operations. In fact, normally the tape does not leave the recorder between the times of recording and playback. Therefore, the electrical and mechanical characteristics of the equipment may be entirely nonstandard as long as they result in acceptable playback performance. Set-up adjustments can be made to correct shortcomings of a particular head assembly or recording equipment even though the recorded magnetic characteristics may be completely incompatible with the requirements of other heads or recorders.

Thus, with the broadcasting operation limited to recording and almost immediate playback of long, uninterrupted program segments, the need for playback interchangeability among recorders was not particularly urgent.

However, before long, realization by production personnel of the potentialities of video tape created a demand for greater operational flexibility. Initially the first expanded usage was for the recording of complete programs or inserts for live programs at times when talent or studio facilities were more conveniently available than at the scheduled air-time. The requirements for this type of operation are similar to those for time-zone delay transmission with one important exception - in many cases the playback of the tape is scheduled for a time well after the head used for the recording may become worn out from other programming use. Because the uniformity of head manufacture at the time did not assure acceptable playback on heads other than the one used for recording, it was necessary to hold the recording head assembly in storage with the tape until time of air playback.

At the present time design improvements and production control have developed to the degree where it now is practical to playback on any normally adjusted head assembly. Furthermore, the more rigorous production demands for the facility to playback taped program material made up by splicing together tape segments recorded on different heads can be accommodated. In other words, complete interchangeability of head assemblies exists. As a result, techniques which are common in the motion picture business have been adopted for many of the more involved television productions. For example, many shows are no longer recorded in a straight run-through. Instead, where production problems dictate, scenes or even portions of scenes may be recorded out of time sequence. Thus, in many cases, the transition between tapes recorded on different heads may occur instantaneously in the midst of a scene.

SURVEY OF INTERCHANGEABILITY FACTORS

It is apparent from the foregoing that interchangeable performance has had to be developed to the level where not a single operating adjustment is required in order to accommodate tapes made on different recorders or head assemblies. To achieve such highly desirable flexibility of video tape operation rigid control must be exercised over many parameters. The magnitude of the problem is indicated by the following tabulation of the most significant factors to be considered:

Video Head:	Quadrature alignment
	Gap azimuth alignment
	Vacuum guide position
	Recorded track dimensions
Control Track:	Control signal phasing
	Edit pulse phasing
	Recording signal levels
	Track width and placement
Video Signal:	Carrier frequency for blanking level
	Carrier frequency for white level
	Preemphasis
	Postemphasis
	Video bandwidth
Audio Head and Track:	Track width and placement
	Gap azimuth alignment
Audio Signal:	Recorded signal level
	Preemphasis
	Postemphasis
	Audio bandwidth
Magnetic Tape:	Physical dimensions and properties
	Magnetic properties
	Reel dimensions

As will be evident in the subsequent discussion, several of the items listed cannot be adjusted or corrected except during manufacture. In these cases, the tape equipment user's control is limited to a periodic check in order to determine if the equipment remains within the permissible limits of tolerance. However, the majority of the factors are subject to set-up or operating adjustment and must be held under careful control if interchangeable performance is to be comparable to that achieved in noninterchangeable operation.

VIDEO HEAD

One of the most objectionable degradations encountered in video tape reproduction is the geometric distortion resulting from timing errors in the operation of the head assembly. Although the effect upon the picture always is evident as a horizontal displacement of one or more scanning lines, the cause may be attributed to three fundamental variations from optimum performance, viz. (1) a uniform time displacement resulting from an error in the quadrature placement of one or more pairs of pole-tips around the rotating head drum, (2) incorrect velocity of the pole-tips relative to the tape because of a difference between the horizontal* positioning of the vacuum guide relative to the axis of head rotation used during recording and that used during playback, (3) non-uniform velocity of pole-tips relative to tape because of an incorrect vertical* positioning of the vacuum guide.

In order to avoid noticeable horizontal displacements in the playback picture an exceptionally high degree of accuracy in head assembly and adjustment must be achieved in manufacture and maintained in operation. For example, a timing error in the order of 0.05 microseconds in a first generation playback is discernible at normal viewing distance on a picture monitor. This is equivalent to a linear deviation on the tape of 0.0001 inch or an angular error in head rotation of roughly 0.005 degrees. In the case of second or third generation playbacks the possibility of errors being cumulative necessitates that variations be limited to a figure appreciably less than 0.05 microseconds. In current CBS practice the maximum error permitted in any single head assembly is 0.02 microseconds. This requires routine measurement of quadrature alignment, vacuum guide position, and gap azimuth.

**Horizontal and vertical in reference to the vacuum guide positioning relate to a horizontally mounted tape transport system as is employed in the current Ampex designs. The nomenclature must be modified in order to be applied to a vertically mounted tape transport such as used by RCA.*

In addition to the distortions in geometry of the playback picture, errors in head dimensions or mechanical alignment can cause other picture degradations, most noticeable of which are an increase in noise level or poor amplitude-frequency response. Checks of gap azimuth and recorded track dimensions are required in order to determine if such faults are attributable to the video head assembly.

Quadrature Alignment: Fig. 1 illustrates a 0.12 microsecond error in timing of picture elements produced by an error in the quadrature placement of one gap. In addition to the uniform displacement of the scanning lines picked up by the one head which is out of quadrature, a smoothly varying displacement of all lines is introduced because of the slow recovery of the horizontal locking circuits in the picture monitor to the abrupt timing changes.

It is important to check periodically for any shift in quadrature in the event that (a) any slippage or damage has occurred in the quadrature adjustment screws or (b) the pole-piece gaps are not coincident with radii of the drum. The latter will produce a shift in the effective angular position of the gap as the pole-tips wear during normal use.

Quadrature errors unacceptable for interchangeable operation can be detected easily and with sufficient accuracy very simply by a recording and playback on the head assembly in question. During playback, an adjustment in capstan tracking so that each of the four heads picks up the track recorded by the adjacent head will cause the quadrature error between any two heads to appear as a horizontal displacement in the playback signal. Insertion of appropriate calibrated delay correction between the preamplifiers and switcher will provide a quantitative measure of error.

The Ampex Corporation has developed a sophisticated pulse technique for this measurement which has the distinct advantage of eliminating any errors that can enter into the measurement because of variations in recording drive adjustments or electrical delays. In addition, where several readjustments of quadrature are to be made, the pulse system will permit a very rapid alignment. This system has been described in a recent Ampex Service Bulletin.

Horizontal Positioning of Vacuum Guide: The timing of the playback signal is dependent upon the velocity of the rotating pole-tips of the video head relative to the particles of oxide on the tape surface. This

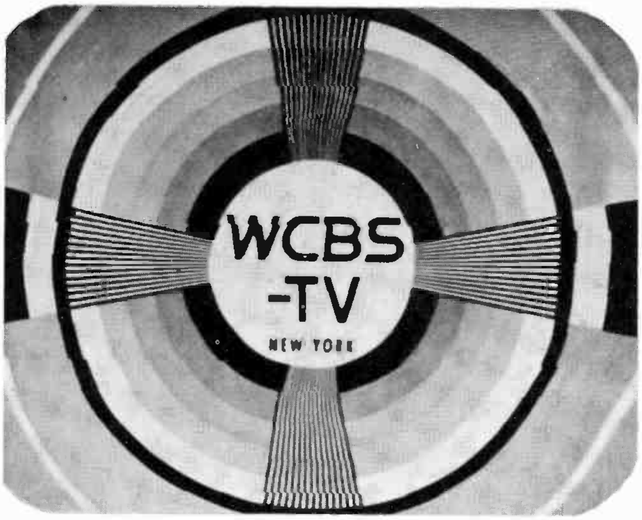


FIG. 1 - QUADRATURE ERROR: A timing error of 0.12 microseconds is evident as a horizontal displacement of the band of picture lines corresponding to the head in error.

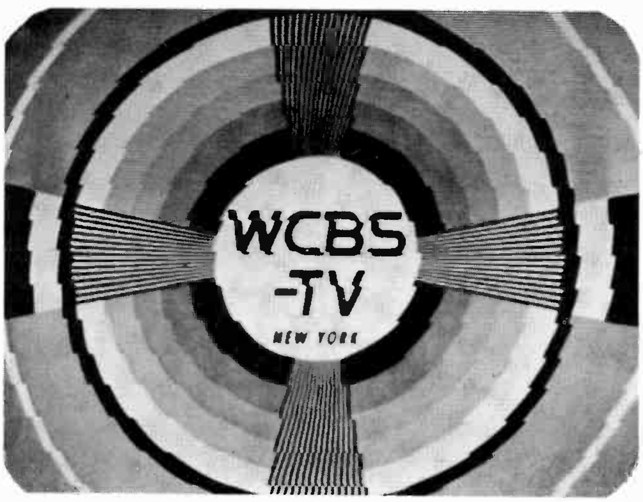


FIG. 2 - INCORRECT HORIZONTAL POSITIONING OF VACUUM GUIDE: A difference between recording and playback velocities of the pole-tips relative to the tape surface causes a timing error which is evident as a sawtooth serration of vertical lines.

factor can be controlled by a change in pole-tip penetration into the tape resulting from a change in position of the vacuum guide relative to the axis of head rotation. If the vacuum guide horizontal position during playback differs from that used for recording, displacements are produced in the playback picture similar to those illustrated in fig. 2. The diagrams in fig. 3 represent schematically the head and tape relationships for two positions of the vacuum guide. For example, in fig. 3 (a) the pole-tips are shown barely in contact with the tape surface. In other words the tip penetration is nil. Fig. 3 (b) illustrates the effect of a repositioning of the vacuum guide in relation to the heads to the extent that the pole-tip penetration of the tape equals the pole-tip projection above the drum surface. This movement of the vacuum guide and the accompanying increase in tip penetration into the tape causes an elongation or stretch of the tape at, and immediately adjacent to the point of contact with the pole-tips. The result is an effective decrease in velocity of the pole-tips relative to the oxide surface. In other words, particles of oxide are moved further apart by the stretching process and, assuming the velocity of head rotation is constant, a longer time is required for the pole-tips to traverse the same particles than in the case of lesser penetration. Conversely, if the vacuum guide is moved away from the pole-tips, the tape shrinks toward its normal unstretched dimensions and the effective velocity of pole-tips relative to tape oxide surface increases. Fortunately, the characteristic of tape stretch varying with pole-tip penetration provides an automatic correction for the reduction in peripheral velocity of the pole-tips as their projection above the drum surface is reduced by normal wear. Over the normal range of pole-tip projection encountered over the life of a head, the necessary compensating distortion of the tape surface is provided when the position of the vacuum guide relative to the pole-tip axis of rotation is fixed. In terms of practical operating adjustments this indicates that the correct value of tip penetration, under any condition of tip projection, is equal to the tip projection plus or minus some arbitrary constant. This has been demonstrated dramatically by John King of the Ampex Corporation wherein he has shown that acceptable playback timing performance from tape made on a normally adjusted head can be achieved using a head assembly wherein one pair of pole-tips differs from the other three in projection above the drum by more than 1 mil.

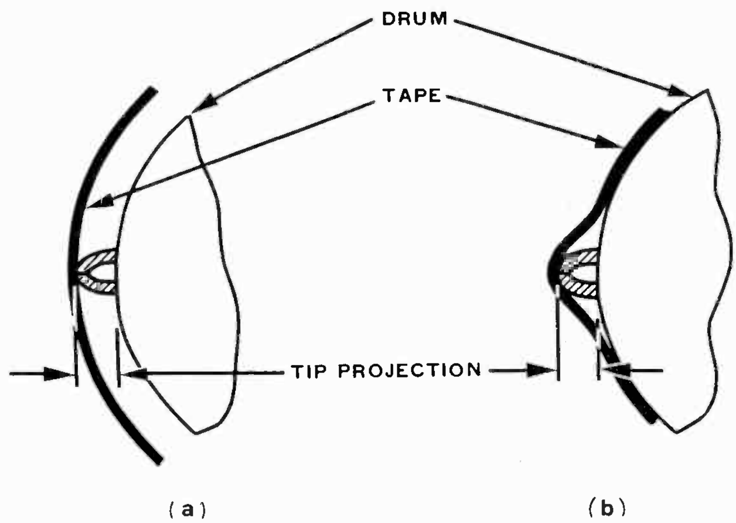


FIG. 3 - RELATIONSHIP BETWEEN TAPE AND POLE-TIPS: (a) Pole-tips are barely making contact with the tape surface. (b) Pole-tip penetration into tape causes stretch of tape. As shown pole-tip penetration is equal to pole-tip projection.

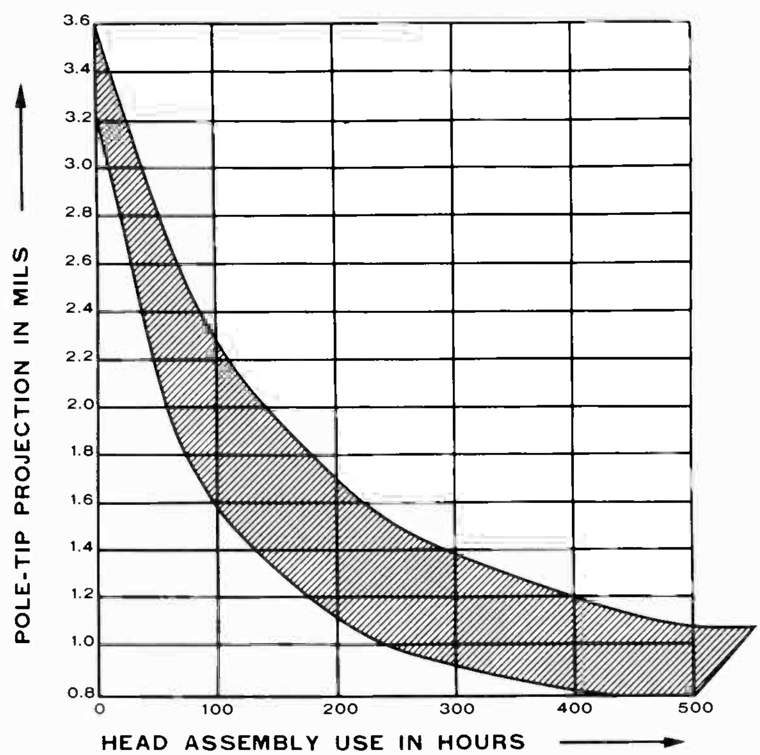


FIG. 4 - POLE-TIP WEAR VS. USE: Curve summarizes data from the operation of 24 heads over a period from September 1959 to January 1960. 5,700 hours of head life are represented.

It is apparent that this flexibility of self-compensation brings with it the need for standardization. It is essential that all tapes are made with the same relative velocity between the pole-tips and the tape surface. This condition can be met for all values of tip projection if the position of vacuum guide relative to the axis of head rotation is fixed.

Standard Horizontal Position of Vacuum Guide: The choice of a standard value for the horizontal position of the vacuum guide is influenced by two primary considerations of conflicting significance:

(a) The vacuum block must be positioned close enough to the head axis to provide adequate magnetic contact between the tape and pole-tips at the low values of tip projection encountered near the end of the life of a head. Since the vacuum block position relative to the head axis is constant, this will result in a comparatively high value of penetration for new heads which have a high tip projection above the drum.

(b) A high value of tip penetration accompanying a close positioning of the vacuum guide to the heads produces excessive head and tape wear. Warranting secondary attention is the lesser but not insignificant effect of high penetration upon head servo stability, particularly during the passage of splices.

With these factors in mind, in July 1959, CBS undertook an extensive investigation into video head operation in an attempt to determine whether the standard of tip penetration in use at that time was optimum or whether a change to some other value was justified. The equipment manufacturers concurrently began a parallel investigation.

Laboratory measurements revealed that the then-current standard placed the tape under tension across the drum as well as at the pole-tips. The advantages claimed for this method of operation were: (a) The burnishing action of the pole-tips and the drum reduces dropouts on many new tapes after a few passes. (b) Long life and high signal output are achieved because the high value of tip penetration permits the use of heads on which wear has reduced the tip projection to as low as 0.6 mil above the drum. These factors were discounted because: (a) The use of expensive tape recorders and highly skilled technicians to perform a final burnishing operation on tape is not economical. This rightfully is a manufacturing operation which ultimately can be performed more economically by the tape supplier. (b) The maximum manufacturing tolerance for the dimension from the bottom of the head gap to the drum surface is approximately 1 mil. Consequently, use of heads after the tip projection is reduced to under 1 mil may result at any time in an enlargement of the gap and unusable performance. Of course, the apparent disadvantages of heavy loading of the head motor drive system as well as the head and tape wear accompanying high tip penetration during the early portion of the head life span are worthy of consideration.

A further investigation was conducted to determine at what point the friction between the tape and drum is eliminated. At a tip penetration equal to the tip projection the contact was found to be very slight. At a tip penetration of 0.5 mil less than tip projection, no contact was found to exist between the tape and drum at any point. These results hold true for new as well as old heads because for interchangeable operation the vacuum guide position relative to the drum is not changed as pole-tip projection decreases with wear.

In an attempt to obtain a meaningful operational evaluation, all of the CBS-New York and Hollywood video tape facilities were run at the latter value of tip penetration for a period of ten weeks. Although head life was found to be very high, it was noted that frequently heads were retired from service because of loss in contact between the pole-tips and the tape. The condition occurred when the pole-tip projection above the drum was in the order of 1.2 mils. Since this figure is appreciably above the 1.0 mil limit for the bottom of the gap, several hours of head life were being lost because of the necessary premature retirement. The use of a higher, intermediate value of penetration was indicated as more nearly optimum.

Accordingly, it was decided in September 1959 to change over to a compromise value of tip penetration equal to the tip projection. This value appeared to be the maximum which could be employed without incurring appreciable friction between the tape and drum. In addition, since it results in near coincidence of the centers of the vacuum guide curvature and head rotation, a more uniform deformation of the tape due to the tip penetration may be expected. Data representing the performance under this condition of operation is shown on fig. 4. The broad-brush curve encompasses data taken on 24 heads at CBS-Hollywood over a period from September 21, 1959 to January 7, 1960. 5,700 hours of head life are represented. A possible life of several hundred hours with good head to tape contact was found to be normal. The average curve approaches as an asymtote the value of tip projection approximately equal to the maximum tolerance for the bottom of the gap above the drum. Thus, a large percentage of the life span is under conditions where the usuable gap height is small and a high level of playback signal output is produced.

Vertical Positioning of Vacuum Guide: A non-symmetrical positioning of the vacuum guide about the circle of pole-tip rotation will produce non-uniform stretch of the tape throughout the scan of the video heads. Even though the absolute peripheral velocity of the pole-tips is constant, their velocity relative to the recorded tracks will vary in accordance with the non-uniform tape stretch. In other words, the velocity at the start of a scan across the tape will differ from that at the end of the scan. The effect upon the picture is a scalloping of vertical lines shown in fig. 5.

The criterion for proper vertical positioning of the vacuum guide is a value of tip penetration and accompanying tape stretch at the top edge of the tape equal to that at the bottom edge. This characteristic provides a very accurate and simple alignment test. By reversing a tape upon playback, any differences in stretch will produce double amplitude indication of the timing error. If the guide was set correctly for both recording and playback, no scalloping should be observed in either the normal or reverse playback. Of course, in order to maintain servo control for this test, it is necessary to have recorded the 240 cps control signal on the audio track as well as on the control track. This provides a control track on both edges of the tape.

Where a rapid operational check of the vertical positioning of the vacuum guide is required, this can be accomplished by backing the guide away from the head to the point where almost all contact between the tape and heads is lost. If the vertical position is symmetrical with respect to the circle of head rotation, the playback signals at the start and finish of head travel across the tape will be equal. The waveform as observed at the preamplifier output will appear as pulses of equal amplitude as shown in fig. 6 (a). If the position is non-symmetrical, the output will be unequal. The unequal waveform shown in fig. 6 (b) illustrates the case where the vacuum guide is positioned too high.

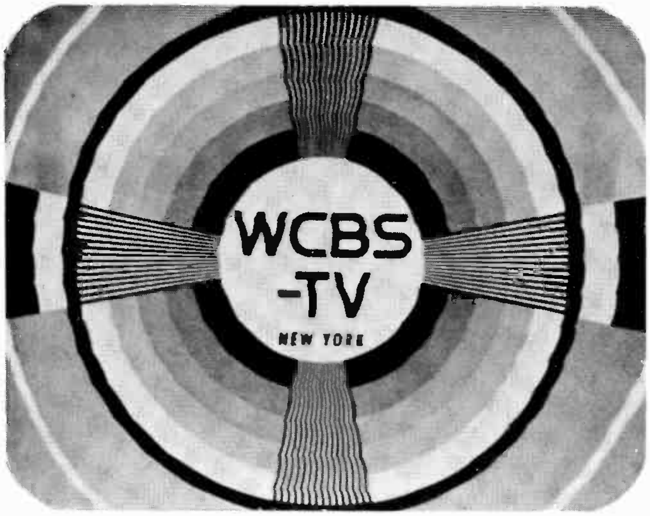
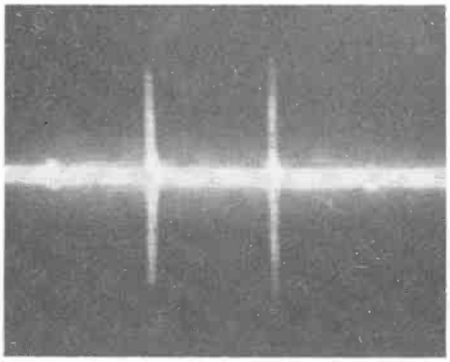
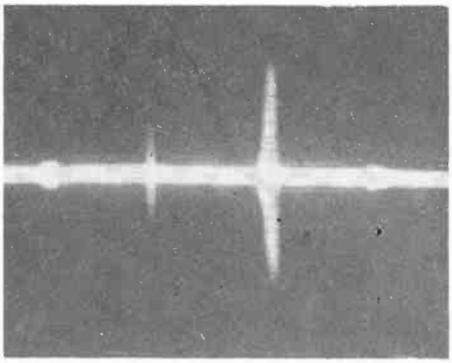


FIG. 5 - INCORRECT VERTICAL POSITIONING OF VACUUM GUIDE: A variation in the velocity of pole-tips relative to the tape surface during the traverse of the pole-tips across the tape causes a timing error evident as a scalloping of vertical lines.



(a)



(b)

FIG. 6 - INDICATION OF VACUUM GUIDE VERTICAL POSITION: Output signal wave-forms from a preamplifier under conditions wherein the pole-tips are barely in contact with the tape show in (a) equal signal outputs at the start and finish of a head traverse across the tape indicating correct symmetrical positioning of the guide relative to the circle of head rotation and in (b) low output at the start of the head traverse indicating the guide is positioned too high.

Azimuth: It is essential that the gap between the pole-tips of the recording and playback heads fall on the same line if maximum signal-to-noise ratio and high-frequency response are to be obtained. Any angular difference between the two is equivalent to a widening of the playback head gap and results in a loss in signal output and bandwidth. In addition, if the gaps are not parallel to the movement of the tape past the head assembly, an error in quadrature can occur. This last effect is not limited to interchangeable playback. It can be demonstrated on a head playing back its own recorded track by shifting capstan phase so as to cause slight mistracking. This effect serves as a convenient check for azimuth error. The diagram in fig. 7 indicates in an exaggerated manner, how by a shift in tracking of the head from the right in (a) to the left in (b), pickup of same signal can be retarded in time.

Recorded Track Dimensions: In addition to azimuth errors, loss in signal-to-noise ratio with interchangeable operation can be attributed to non-uniformity in width or position of the magnetic tracks laid down by the recording head or of the paths traversed by the playback head. A uniformly high noise level throughout a band corresponding to one head indicates that that head is not in the same vertical plane as the other three and the pitch of the tracks is not uniform. A variation in noise level throughout each band can result from the plane of head rotation not being perpendicular to the tape and producing curved tracks. Lastly, a reduction in widths of the heads from standard can produce an increase in noise level.

Although these effects often can be detected by a careful examination of a magnetic development of the recorded tracks, this method is recommended only as a secondary check. The primary evaluation should consist of a measurement of playback performance using a tape made on a standard head, the critical dimensions of which fall close to the manufacturer's design center.

The signal output of each of the heads should be of uniform level and adequate to override preamplifier noise level. With present-day cascode input circuits, this dictates a peak-to-peak signal level of at least 2 millivolts. In lieu of more detailed specifications at this time the evaluation, for the most part, must be limited to qualitative observations of picture quality. However, it is expected that in the near future developments now under way will yield more precise techniques.

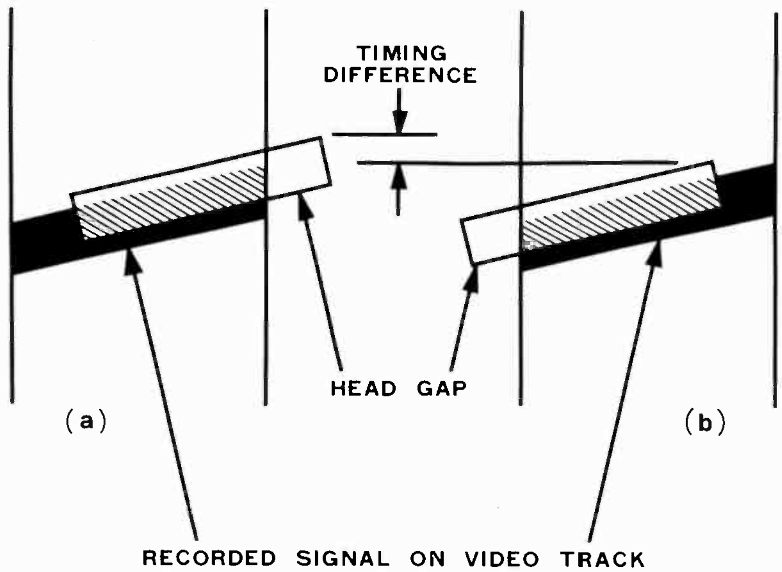


FIG. 7 - RELATIONSHIP BETWEEN AZIMUTH ERROR AND PLAYBACK TIMING: When the gap of the head is not in line with the direction of tape travel, a mistracking of the playback head can cause a change in timing of the playback signal. Two cases of mistracking are shown. The playback signal in (a) will be advanced in time compared to that in (b).

CONTROL TRACK

The primary requirement for the recorded control track signals other than the obvious ones of adequate level and track width, is a uniform phase relationship to the video tracks. This characteristic is important in order to avoid the need for readjustment of capstan phasing when playing back recordings made on different head assemblies. In addition, the phase of the edit pulse must be fixed in relation to specific video tracks so as to indicate the optimum location for a splice. To further facilitate splicing, the phase relationship between edit pulse and control signals must be such that the former can be easily distinguished by magnetic detection systems.

Edit Pulse: The purpose of the edit pulse is to indicate the proper video guard band for a splicing cut. Since some minor disturbance very often occurs during passage of a splice, it is essential that splicing cuts are made after the vertical synchronization signal in order to avoid spurious triggering of receiver vertical scanning circuits. The reason for this can be seen from the waveforms in fig. 8. The solid lines indicate the normal grid voltage characteristics of the usual vertical scanning oscillator in a receiver. The vertical synchronizing pulse drives the grid into conduction and thus triggers the oscillator cycle at the appropriate time for start of vertical scanning. Any small disturbance prior to the synchronizing pulse also can drive the grid into conduction and cause a premature start of vertical scan. This is shown by the dashed curve. However, a similar spurious pulse after the synchronizing pulse has no effect upon the oscillator operation. Therefore, the splice line as indicated by the edit pulse should be located after the vertical synchronizing signal interval. Current practice records the edit pulse in line with the second video track guard band after the vertical synchronizing interval. This is shown in fig. 9.

The majority of the video tape equipment in use at this time records the edit pulse at field rate. The CBS equipment currently is being modified to record the pulse at frame rate so as to minimize the possibility of a half line shift during passage of a splice. Use of the frame pulse in conjunction with more precise head servo equipment recently developed will eliminate significant shifts in horizontal

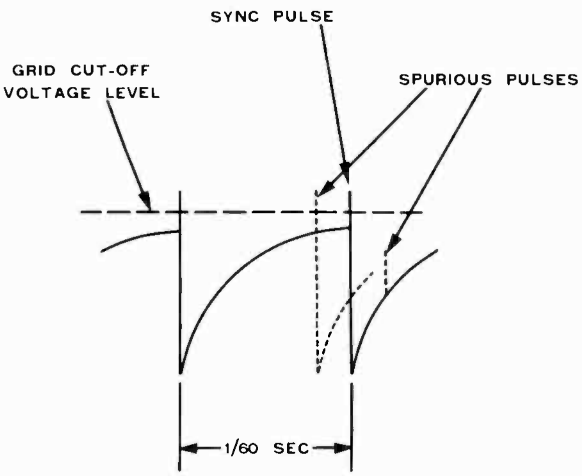


FIG. 8 - EFFECT OF SPURIOUS SIGNALS UPON RECEIVER VERTICAL SCANNING SYNCHRONIZATION: Loss of synchronization is more likely to result from a spurious signal occurring before rather than immediately after the vertical synchronizing pulse.

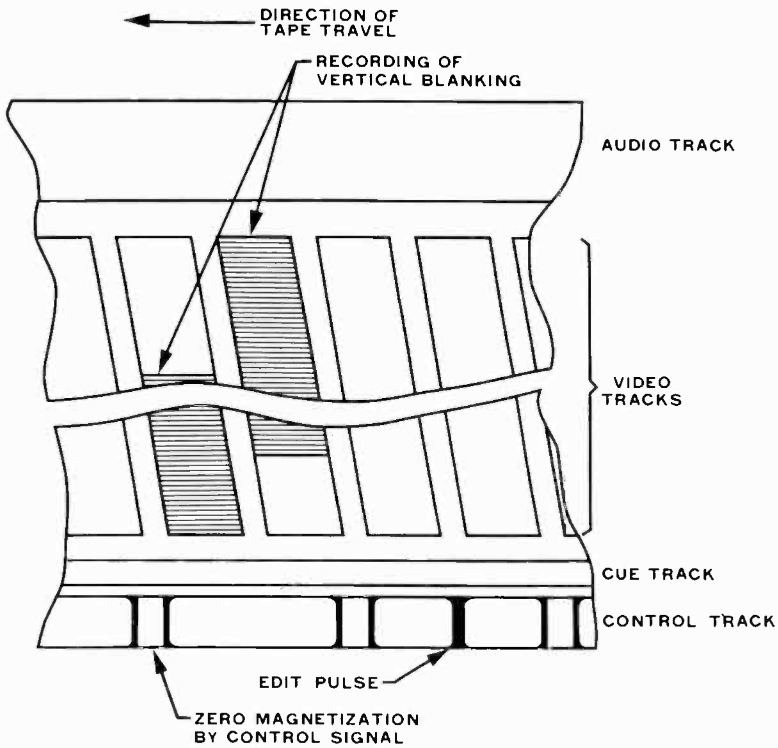


FIG. 9 - PROPOSED RELATIONSHIP BETWEEN CONTROL TRACK AND VIDEO TRACKS: The area of minimum magnetization of the oxide by the control signal is in phase with every other video guard band. The edit pulse is recorded in phase with the video guard band between the areas of zero control signal magnetization. The control track recording is portrayed as it would appear from a magnetic development of the tape.

phasing. The frame pulse is timed to identify the recorded vertical blanking interval which is preceded by a full rather than half horizontal picture line.

Control Track Signal Phasing: The purpose of the control track signal is to provide a timing reference during playback for the capstan servo system. The capstan with its accompanying control system maintains the velocity of tape travel relative to the video head so that during playback, the pole-tips trace precisely the magnetized track record laid down during recording. The degree of accuracy required for acceptable playback performance is impressive. An error of a few degrees at the control track frequency of 240 cps can produce a visible reduction in signal-to-noise ratio.

The problem is most acute in the case of interspliced tapes. If two spliced tapes have not been made with an identical value for phasing between the control track and video tracks, it is necessary to correct for the difference by manual adjustment of the capstan phasing control. Any such manual operation following a splice is undesirable since it results in a momentary increase in noise level because of the mistracking during the time of readjustment. The other apparent disadvantage is the need for the close attention of an operator to note the passage of a splice and to perform the correction adjustment.

Therefore, the phase of the control track relative to the video tracks is a parameter of major significance for the success of interchangeability. At present the control track is placed so that the point of zero magnetization occurs near the edit pulse. To facilitate locating the edit pulse by magnetic development or magnetic sensing, it has been proposed in the SMPTE Video Tape Recording Committee to shift the control track phasing in order to place the edit pulse at the point of peak magnetization as shown in fig. 9. The matter currently is under active consideration by the Committee.

THE VIDEO SIGNAL

One of the major problems in any phase of television program transmission is the consistent maintenance of uniform video signal levels. In video tape recording and playback these parameters are dependent not

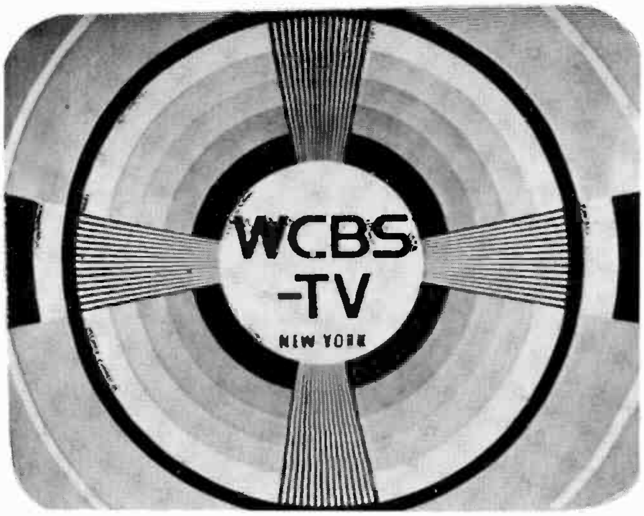


FIG. 10 - OVERDEVIATION: The carrier deviation produced by the leading transient overshoot of the white level signals are beyond the bandpass of the system and result in a streaked interference pattern following the transition from black to white.

only upon the gain of the various video amplifiers, but also upon the deviation employed for the frequency modulation of the carrier signal applied to the recording heads. Second in importance to level control is the choice of pre and post emphasis for optimum compromise between video bandwidth and signal-to-noise ratio.

Carrier Deviation: The choice of deviation frequencies is dependent upon two opposing factors, viz. (a) the band-pass limitation of the tape and head combination, and (b) the need for a maximum value of signal-to-noise ratio. The signal-to-noise ratio will vary directly with the peak-to-peak magnitude of the deviation. Therefore, it is desirable to modulate the carrier over as wide a band as the system elements will permit. However, if the high-frequency cut-off of the head and tape is exceeded, the limiting action in playback amplifiers prior to demodulation ceases because of the loss in carrier. This permits the random noise from the tape and preamplifier to be amplified to full signal level by the high-gain amplifiers. The resultant noise and streaking in peak white is very objectionable in appearance as can be seen in fig. 10. It is apparent that the maximum frequency deviation must be limited to that which can be accommodated by any or all heads. A thorough investigation was conducted over a period of several months by the equipment manufacturers and the broadcasters in order to determine a suitable figure for the deviation corresponding to modulation by reference white level. The minimum cut-off encountered with production head assemblies indicated 6.8 Mc as a safe operating value.

The lower limit of frequency modulation swing for monochrome recording must be above the 4.5 Mc video channel normally employed for television transmission in order to avoid undue interference between the carrier and video signals. Practical low-pass filter circuits for this video bandwidth dictate the use of a compromise value of 5 Mc for blanking level modulation. These modulation frequencies are being recommended as a Standard Practice by the SMPTE Video Tape Recording Committee.

In the case of color television recording, in order to avoid spurious beat signals between the color sub-carrier and the tape system carrier, a slightly higher frequency generally is used for blanking level.

Preemphasis: Current monochrome practice provides an amplitude characteristic rising with frequency wherein the 4 megacycle response is 10 to 12 db above the low frequency response. In order to avoid overdeviation from the higher frequency components, CBS equipment normally is adjusted to restrict the rise in response to frequencies under 4 megacycles. It should be noted that a significant portion of the preemphasis in the case of the multivibrator oscillator is necessary to overcome loss in response in the circuit and does not contribute to an increase in high-frequency sideband energy.

The question of optimum preemphasis, in itself, is a suitable subject for a paper. Considerable investigation already under way must be completed before optimum performance is achieved and industry agreement is reached on these characteristics.

AUDIO SIGNAL

The practices currently in use for the recording and playback of the audio signal in video tape recording are essentially the same as those employed for audio-only equipment. The pre and post emphasis characteristics are those determined by the standard magnetic tape reproducing characteristic specified by the NAB. As for standard program level, in CBS operation this is set at 10 db below the level of a 400 cps signal at which distortion is 3%. Because of the narrower track and the cross-orientation of the magnetic particles, performance is slightly degraded from that of high-quality audio-only equipment. However, providing it is not necessary to resort to third or higher generation rerecordings, the performance is adequate for broadcast transmission.

MAGNETIC TAPE

Until very recently there has been only one commercial source for video magnetic tape. Consequently, the problems of uniformity of performance have been relatively few. As more manufacturers enter the field, however, it will be necessary to develop standards in regard to the tape oxide characteristics in addition to the dimensional standards for tape and reels currently being adopted by the SMPTE Video Tape Recording Committee.

CONCLUSION

Full interchangeability of video tape recordings among different playback equipments is a necessary practice in present-day television broadcasting. This mode of operation is being put to daily wide-scale use by a large number of video tape users. For example, the CBS Television Network currently is running a combined load in New York and Hollywood of well over 1,000 machine hours a week, almost all of which relies upon the ability of being able to provide acceptable playback performance on a head assembly or video tape equipment other than that used for recording. However, this cannot be accomplished without an intensive program of operating checks and routine maintenance. It is hoped that the foregoing discussion has made it clear that practical means exist for the measurement and control of the critical factors necessary for the achievement of a high level of interchangeable performance on a day-to-day basis.

ACKNOWLEDGEMENT

A valuable contribution to the preparation of this paper has been the encouragement and assistance of Howard Chinn, Richard O'Brien, and Price Fish of the CBS Television Network Engineering Department. In addition, the operational data furnished by Mr. Andersen and by Messrs. Sedia and Schwartz of the CBS Video Tape Operations in Hollywood and New York, respectively, provided a sound basis for the conclusions reached.

NEW IRE ROLL OFF

AS RELATED TO THE BROADCASTER

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NAB - April, 1960

During the past ten years there have been two IRE standards established for the measurement of video levels. The first was reported in the May 1950 IRE Proceedings and was developed in the interest of providing a measurement tool whose response characteristics were fixed. Standardizing the response characteristics of video wave form oscilloscopes minimizes differences in interpretation of signal levels. The advent of color television brought into focus, the need for a measuring tool which would evaluate the luminance component of the signal.

Revision of the 1950 standard was announced in the February 1958 IRE Proceedings wherein it is stated that ". . .the need for revision of the previous standard stems from the standardization of color television signals in the U.S.A., and the inadequacy of the earlier standard in providing methods of measuring the luminance component of the new signal. The revision consists primarily of a change in the roll off characteristic to insure adequate suppression of the color sub-carrier." It is further stated, "For the purpose of this standard, the levels which are significant are the levels of the monochrome signal or the levels of the luminance portion of the color signal. The peak amplitude excursion of a color signal may exceed, by substantial amounts, the peak amplitude excursions of the luminance portion of the signal but since the subjective brightness of a color signal is more nearly proportional to the luminance level than to any other quantity, it is more desirable, from the operating standpoint to control and adjust levels using the luminance signal as a guage."

When this is done, monochrome and color signals interspersed in a given program sequence will appear to have approximately the same brightness and contrast when viewed on color or monochrome monitors without supplementary adjustments. The revision of 1958 was made to insure adequate suppression of the chromenance components, thus permitting its use for either color or black and white signals.

Whereas the IRE standards serve as an industry guide, the use of these standards is, of course, voluntary. Where techniques have been in use over long periods of time, there is sometimes reluctance to institute new practices of operation. So has it been in the case of initiating the use of the new IRE roll off standards. Perhaps the industry area most concerned with this matter is that pertaining to the broadcaster and the inter-connecting telephone services. Standardized measurements are vitally important where distances intervene between engineers involved in the overall operation of a facility. In a system complicated by distance and two possible measurement standards, misunderstanding and confusion is almost assured.

The VITEAC Committee, representing both the television broadcaster and the telephone company organizations set about bringing order out of the confusion. VITEAC (Video Transmission Engineering Advisory Committee) is an industry group composed of television network engineers and local and long line telephone company engineers. This group meets on a monthly basis in New York to discuss engineering problems which pertain to all broadcasting interests. As a work committee, the National Transmission Committee (N.T.C.) has been established reporting to the parent VITEAC group. Membership in the N.T.C. is composed of operating engineers from each of the three networks and engineers from the operating branch of the telephone company. This committee works directly with affiliate broadcast stations to effect corrective measures where required and to improve overall station-network liaison. Through the combined efforts of these two groups, much has been accomplished over the years in terms of bringing a better network service to all areas.

Attempts at application of the IRE level measurement techniques revealed a degree of confusion in the following areas: (1) measurement of levels involving pre-emphasized modulation processes i.e., video tape; and (2) apparent non-uniformity of level indication between oscilloscopes. Subsequent to the release of the 1958 roll off characteristic, the VITEAC Committee assigned to N.T.C. the responsibility of implementing the new standard.

In regard to video tape, it is considered desirable and perhaps necessary in some cases to be able to monitor waveform applied to the recorder in terms of uniform wide band response as well as with standard roll off. This will help to determine the relationship which must exist to avoid overmodulation in cases where pre-emphasis is employed in the recording process. Overmodulation is evidenced by the appearance of black areas where normally white highlights should appear. Other degradations such as excessive noise and scintillation may also be noted. This same practice (the use of both flat and roll off scopes) is, of course, desirable in setting level at a transmitter especially where color is transmitted. It should be borne in mind that the IRE roll off is a standard for measurement of video luminance levels and its use does not preclude the need for occasional reference to a flat scope for video adjustment. It is essential that basic performance checks and initial adjustments to any system be made on instruments which give the total picture.

With respect to ambiguity of level measurement (as noted on oscilloscopes adjusted within the '58 standard IRE roll off), differences in the order of 8 to 10 IRE divisions were noted. This discrepancy of indication resulted from two oscilloscopes having been adjusted for upper and lower IRE limits. Figure 1 shows the two IRE roll off characteristics. The top curve shows the 1950 standard and the bottom curve shows the most recent 1958 standard IRE roll off.

It will be noted that a tolerance of about 8 db exists on the '58 curve at the color sub-carrier frequency (3.58 Mc). This represents a voltage ratio of 2.5 to 1. In order to improve measurement correlation, it is currently being recommended to the IRE that the new IRE roll off characteristic remain fixed in its center position but that the tolerance limits be halved. Figure 2 shows the recommended tolerance. It will be noted that at 3.58 Mc a variance of 4 db is evident. Application of the new IRE standard has indicated the desirability of its use by all concerned with video transmission; however, reduction in tolerance to approximately the values shown will provide a more uniform system of measurement of video levels and the best industry standard for this purpose.

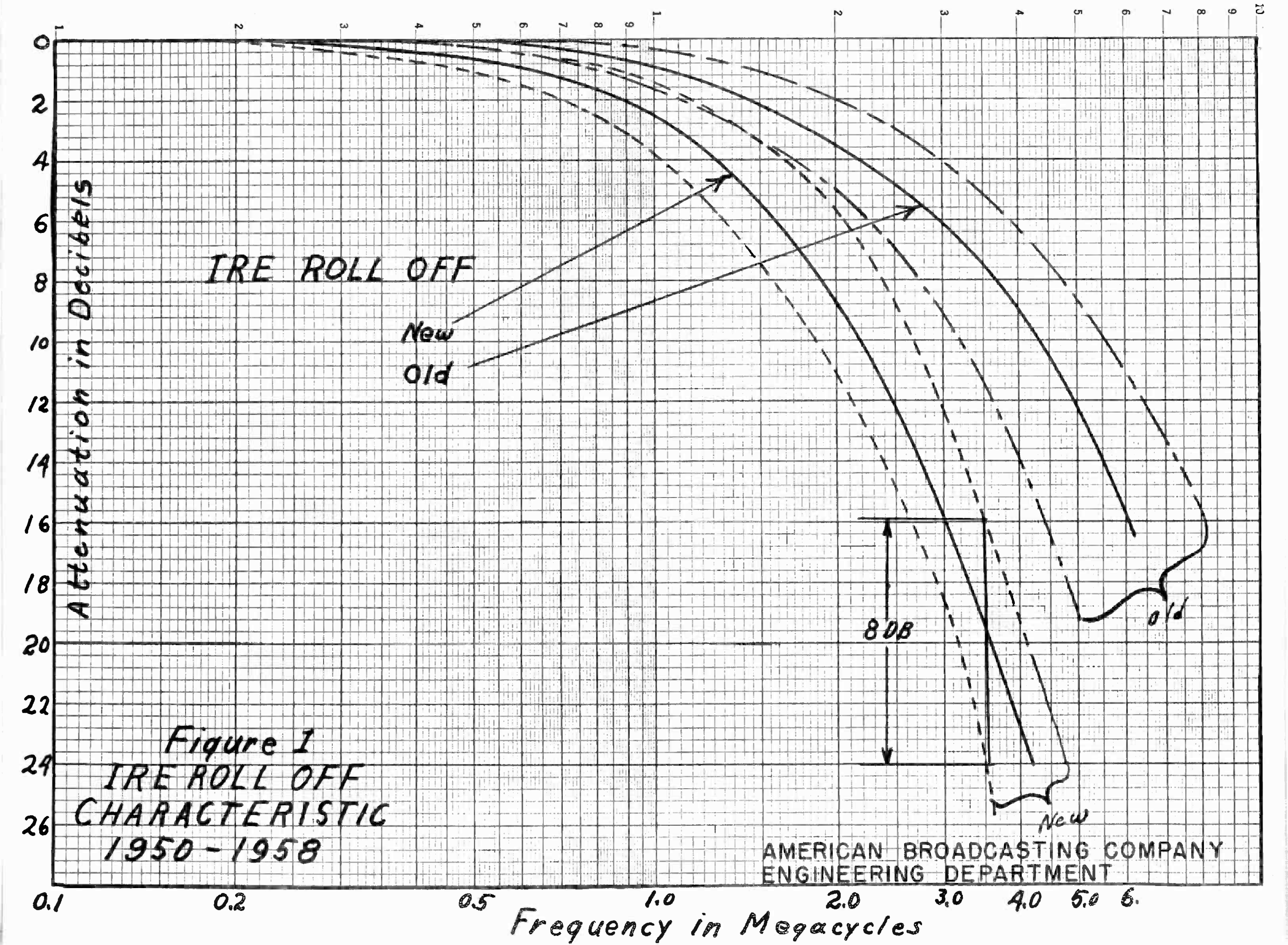

Figure I
IRE ROLL OFF
CHARACTERISTIC
1950 - 1958