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EXPERIMENTAL STUDIO FACILITIES FOR TELEVISION

By

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Introduction

In May 1935, David Sarnoff, President of the Radio Corporation of America, announced extremely significant television plans. Mr. Sarnoff reported to the stockholders that television had advanced to a point where a conclusive field test was both necessary and expedient. A $1,000,000 expenditure was recommended to construct and install a complete operating plant for experimental television. The plan included a three point schedule:

1. The existing audio and video transmitters in the Empire State Tower were to be remodeled.
2. A number of experimental receivers were to be manufactured and distributed to engineers for test purposes.
3. Studio facilities—the subject of this discussion—were to be designed and provided for experimenting with the actual production of programs, both direct pickup and film.

Since this field test was to approximate actual operating conditions, the problem of providing adequate studio facilities became more complex. The requirements for producing interesting television programs were known to be exacting, for television programs, like radio programs, must be continuous. It is not possible to shoot each scene individually and later combine a number of scenes into a prolonged sequence as is now common motion picture practice. Each television program involves instantaneous switching from long shots to closeups with no break in the continuity. Or, as is often the case, there may be switching from one studio to another, all in a split second. In order to achieve the desired flexibility, the utmost care was required in planning the design of the television studios and associated apparatus. It was necessary to provide sufficient space for a direct pickup studio, as well as a studio for televising motion picture film, which is also an important element in television programming.

One of the first considerations in planning the studios was the matter of a suitable location. It was decided that Radio City offered several distinct advantages. Here were the most modern broadcasting studios in the world, some of which were of sufficient size to serve as a proving ground for a television service. Moreover, the selection of one of these would immediately eliminate the need for extensive sound proofing and acoustical alteration inasmuch as the treatment applied to these radio studios is also peculiarly adapted to the needs of television sound pickup, at the present stage of the development.

Radio City offered other advantages no less important. The severe air conditioning load, contributed by lighting in a direct pickup studio, could be carried by the existing NBC conditioning system. Furthermore, by locating television studios in the same building with the NBC and RCA executive offices, television experimentation would be under closer supervision by executives. Programming, also, would be simplified through the use of NBC artists, conveniently available through routine programs and the NBC Artists Service.

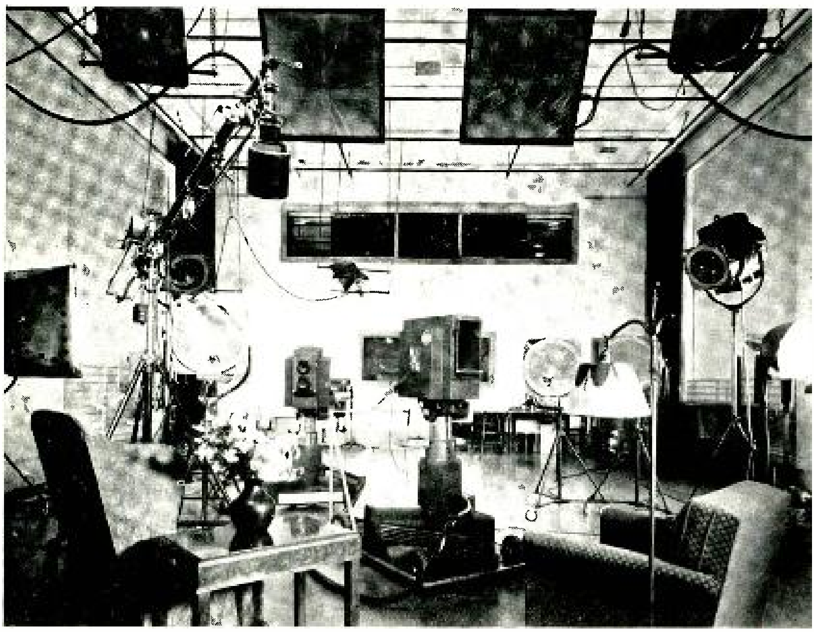

Fig. 1—Direct pickup studio.

These advantages far outweighed possible difficulties, the principal limitation being the lack of convenient outdoor facilities suitable for program settings. Other limitations were minor and consequently a direct pickup studio was selected on the third floor of the NBC quarters. A film studio had already been anticipated when Radio City was planned, and base facilities were thus available on the fifth floor.

Factors Influencing the Design of a Direct Pickup Studio

There are a number of factors concerning the operation of apparatus in a television studio which must be carefully considered in planning

Direct Pickup Studio

The direct pickup studio at Radio City is 50 feet long and 30 feet wide with a ceiling height of about 18 feet, a size which conforms, to a large extent, with the requirements just mentioned. Figure 1 shows a view of this studio looking toward the control booth from the approximate location of the main studio set. Two of the studio cameras and several of the lighting units are clearly visible. The camera at the left utilizes a narrow angle lens system with a focal length of eighteen inches for televising closeups, whereas, the camera in the foreground is used

Fig. 2—Television control booth.

for semi-closeups and long shots. Sound is picked up by a standard velocity microphone equipped with a wind shield and attached to the familiar boom, seen at the left of the picture.

Studio walls and ceiling are surfaced with perforated transite backed with rock wool, to eliminate discrete sound reflections and generally, to provide the studio with acceptable acoustical conditions. Three of the studio walls are coated with aluminum paint. The fourth wall is painted black to increase light absorption and thereby eliminate interference with the operation of background projection apparatus which is located in a booth at this end of the studio. A network of pipe is hung from the ceiling for use in suspending key lighting units and stage backdrops.

adequate studios. For example the "Iconoscope"* pickup tube in the television camera is one of the determining elements in studio length. This tube is a gourd-shaped glass envelope enclosing, at the enlarged spherical end, a photosensitive mosaic plate which is so placed within the glass envelope that an electron beam, generated in the elongated section of the tube, is free to sweep across the plate. The distance between this plate and the glass envelope enclosing it is about 4½ inches, at present at a minimum consistent with the structural strength of the tube and the proper physical relationship of component parts. This distance, then, constitutes the absolute minimum focal length for any lens system used in connection with the Iconoscope cameras. In practice, lenses with a focal length of approximately 6½ inches and an angle of 37 degrees are found to be best suited to requirements just mentioned. However cameras equipped with lenses with this rather narrow viewing angle must be operated at a considerable distance from the wider studio sets if complete accommodation is desired. Studio length must be sufficient to permit such camera technique.

The studio length should also allow for ample distance between the back of the studio set and any projection apparatus used for producing background effects. Here again lenses are a controlling factor. The narrow angle lenses (not more than 30 degrees) are vastly more efficient in light transmission than wider angle lenses, but require longer projection distances which in turn increase the necessary length of the television studio. Studio width is of course determined by the width of the largest scenes desired, with allowance for passageway on either side.

Studio height is influenced by several other elements. In order to relieve congestion on the floor, key lighting units for set illumination are better suspended from a ceiling of considerable height and structural strength. Control booth facilities should be elevated also to permit engineers and production men to have an unobstructed view of the entire studio floor area. Furthermore, the use of scenic backdrops and the familiar scenery flats require a rather high ceiling.

The overall cubic volume of the studio, as governed by the area and height, is an equally important factor. The acoustics of a studio have an important relationship to the cubic volume enclosed. The sound pickup associated with television transmission serves to complete the illusion created by the image and must be faithfully reproduced. Studio volume is also closely related to air conditioning problems which will be discussed in more detail later. All these considerations are vital to the operating success of a studio installation for television.

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* Reg. trade mark, R C A Mfg. Co., Inc.

Automatic sprinklers and a special rate of temperature rise fire alarm device are also installed on the ceiling of the studio as are the air conditioning ducts. For a floor surface, a light gray linoleum was chosen.

The studio is arranged to accommodate one large scene and at least one additional smaller one. There is no fixed size of set, the arrangement purposely being flexible to fit the varied requirements of experimental television programs. Thus far, the largest set used was about 22 feet in width and included a section of a fully equipped kitchen plus a complete dining room with tables, chairs and the usual accessories.

Control Booth and Equipment

The control equipment for the direct pickup studio, both audio and video, is located in a booth on the second floor level at one end of the studio. (See Figure 1.) This elevated position permits a clear view of all action on any of the studio sets. The main set is placed at the opposite end of the studio about 15 feet from the back wall in such a way that control room occupants and the men operating the Iconoscope cameras view the action from the same direction. This arrangement is most desirable because stage illumination is then directed away from the control booth and does not produce a direct glare which would interfere with monitoring the televised images.

A soundproof glass partition separates the control booth from the studio proper, extending practically the full width of the studio, and is of such height that seated control booth occupants may comfortably view nearly the entire studio floor area. This window is partially covered with a dark green transparent cellulose material which effectively attenuates reflected light from the studio, further aiding video monitoring.

Those operating controls which require more or less constant attention are centrally located on a long console in the control booth as shown in Figure 2. Audio controls, including the volume indicator meter and gain adjustors are clearly visible in the foreground. The engineer at this control position also has the responsibility for switching from one studio to another.

All scenes televised by the Iconoscope cameras appear on two image tubes known as "Kinescopes"*. These are located just above the window partition in front of the video engineer and the production man who sits between video and audio control. The video control setup is shown clearly in Figure 3. Brightness and video gain controls for the three studio camera chains are grouped on the panel directly in front of the operator. The operator is shown adjusting these dials for the best relationship between contrast and brightness in the image. Elec-

* Reg. trade mark, R C A Mfg. Co., Inc.

trical focusing of the Iconoscopes in the studio cameras is controlled by the three dials at the left of the operator's hands. Pushbuttons for controlling camera switching relays are visible on the console immediately under the associated signal lights. The group of dials at the right is used to vary "shading" of the transmitted image. By regulating these controls, voltages having special wave forms are added to the video impulses in the amplifiers for balancing out unwanted dark or light areas in the image. Note the Kinescope monitors and the associated cathode ray oscilloscopes. These latter provide a wave picture of

Fig. 3—Video control setup.

the television image and are to television what the volume indicator meter is to sound broadcasting.

Amplifying equipment for video signals and for the horizontal and vertical deflection potentials, together with rectifiers for supplying the Iconoscope beam potentials, are mounted on several equipment racks easily accessible for repair and maintenance. Since video circuits are required to pass a wide band of frequency extending from 60 cycles per second to extremely high frequencies of the order of 4 million cycles per second, it was necessary to wire these equipment racks with coaxial cable. Special shielded blocks were designed to terminate such cables and to act as distribution centers to other remotely located equipment (See Figure 4). Several types of coaxial cable were used in this installation, the type being selected according to circuit requirements. Special care was exercised to avoid cross-talk between circuits in the band passed by the equipment.

Power requirements for operating the television system include both alternating and direct current supplies. Video amplifiers operate on direct current supplied from a central battery source on the fifth floor of the NBC plant. Alternating current is distributed from a circuit breaker panel in the control room, such circuits being isolated from the remainder of the wiring and routed through separate conduits. High potential circuits are protected by sheet steel boxes with interlock switches which automatically turn off the power when the covers are removed.

STUDIO LIGHTING

Television at present requires somewhat more light than is needed for motion picture production. The present limits of sensitivity of the Iconoscope tube necessitates an incident light intensity on a set of about 1000 to 2000 foot candles. To provide this illumination, the studio is equipped with incandescent lamps of various types, having a total power consumption of over 50 kw, the amount in use at any one time depending upon the size of the set. Rifles, floods, and focusing spots with ratings of between 2 and 5 kw each, are most numerous, although there are several larger units of special design. Key lighting and back lighting units are suspended from the ceiling; modeling lights are operated on the studio floor. These latter are mounted on mobile standards which require considerable floor area for effective operation. At present, studio lighting is operated on direct current obtained from the generators at Radio City. Alternating current is also available for use when desired.

The selection of incandescent illumination represents months of experimenting with practically every known source of high intensity light which would meet the requirements of quiet operation and dependability. Measurements were made of the spectral characteristics, lumen output per watt, useful life, and changes in color temperature. These tests indicated incandescent lamps, with high lumen output, to be the most satisfactory of any light source commercially available at this time. Some small scale experiments have been conducted using high pressure mercury vapor lamps which indicated promise for the future.

Incandescent lamps, like most other types, radiate a considerable amount of heat. When a battery of such lights is focused on a relatively small set, a serious heat problem is created. This difficulty was partially alleviated by placing heat filters in front of the various light units to reduce the radiant heat in the beam. Here again many types were tested before serviceable filters were found which would absorb a large part of this heat energy without undue reduction in the amount of incident light. Those now in use are a special glass, cut in strips to relieve internal stresses in the glass caused by the high temperature. Their performance is quite satisfactory; the actual reduction in effective heat is of the order of 2 to 1.

In addition to the heat filters, diffusing screens are used on several light units for reducing the glare and equalizing light distribution. By this method the intrinsic brilliance of the incident light is considerably reduced without subtracting materially from the net illumination on the set. This method has the effect of making the high intensity light flux less apparent to performers whose comfort must be considered if a satisfactory performance is expected. For further comfort it is also

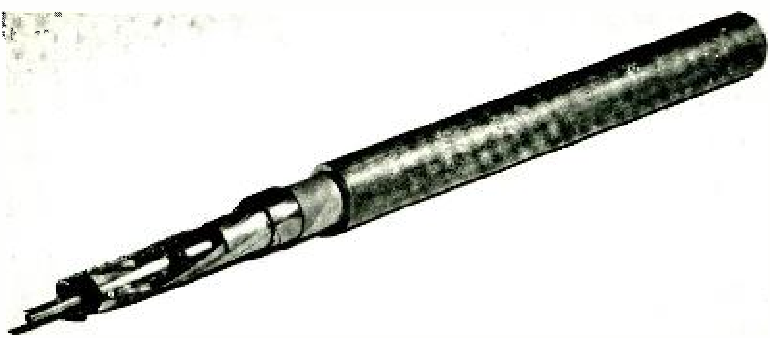

Fig. 4—Coaxial cable.

desirable to cool the sets by concentrating freshly conditioned air into the action areas.

Radiant heat absorbed by the filters is of course eliminated from the light beam and hence from the set, but is necessarily redistributed by the filter to the surrounding atmosphere. Thus there is no change in the overall heat load which must be carried by the air conditioning system. In this respect, extensive tests were conducted to determine means for eliminating not only the heat concentration on the set, but also means for maintaining comfortable effective temperatures throughout the studio. At the outset, the handling of an internal sensible heat load so great in proportion to the volume of the studio requires a combination of high cooling-temperature differentials and rapid air change. Extremes of either of these factors must, of course, be avoided. In the present system, refrigerated supply air in large volumes is handled at temperature differentials approximating 30 degrees. In this manner, the heavy internal heat load is absorbed at reasonable room temperature.

Acoustics

The sound accompanying the television program is a necessary complement to the video signal to complete the illusion of the transmission of the performance taking place in the studio. The acoustical design of the studio and the microphone technique employed are important considerations and supplementary problems in the television project.

The present television studio was previously used for sound broadcasting and has a volume of about 25,000 cubic feet. The adapting of this studio to television requirements necessitated structural modifications, but the acoustical changes were relatively small because of the provision for adjustment of acoustical conditions in the original design. The ceiling and end walls (except for the wainscot) are treated entirely over the available area with rock wool covered with perforated transite. The side walls are equipped with sliding panels which are acoustically treated with rock wool covered by perforated metal. These panels are arranged in pairs, three pairs on each side wall. Each pair of panels is approximately 10 feet wide and 15 feet high. Sheet metal pilasters, backed by cork to avoid resonance, are so arranged that when the panels are opened they slide behind these pilasters and their acoustic absorption is effectively removed from the room. It is possible by opening all of the panels to effect an increase in reverberation time of almost 100 per cent over a greater part of the frequency spectrum. The pilaster wall surfaces exposed and those of the pilasters (which are not acoustically treated) are "Vee'd" to avoid discrete reflections or "flutter" and effectively disperse incident sound. The reverberation time at 1000 cycles with the panels exposed is about .4 seconds.

The change in reverberation time can be varied continuously over the available range as the remote-control hydraulically-operated panels may be opened any desired amount. In certain cases where the acoustical effect of very reverberant spaces must be simulated the "echo" chambers developed for and used so successfully in radio broadcasting may be used when the required change is greater than can be accommodated by the panels.

The microphone technique employed in television differs from that in radio mainly with regard to the respective locations of the microphone and performers. In radio the performers may change their location to suit the one chosen for the microphone while in television the microphone must be moved to the location of the performer. It is further desirable to correlate the acoustical "pick-up" with the video—that is, a "close-up" should sound like a "close-up" and a distant "shot" should sound distant. It is the change in ratio of reflected to direct sound that creates this impression of proximity of distance.

A majority of the "pick-ups" have been made with the velocity microphone, equipped with wind shield, and suspended from a boom which traverses the scene of action. Provision has been made for the use of parabolic reflector microphones which will be suitable for many types of pickup and will not require the careful manipulation necessary with the "boom microphone".

It is apparent thus far, that the studios should be less reverberant than those of equivalent size used for broadcasting, but that the fundamental principle of the provision of uniform acoustical conditions throughout the studio should be retained.

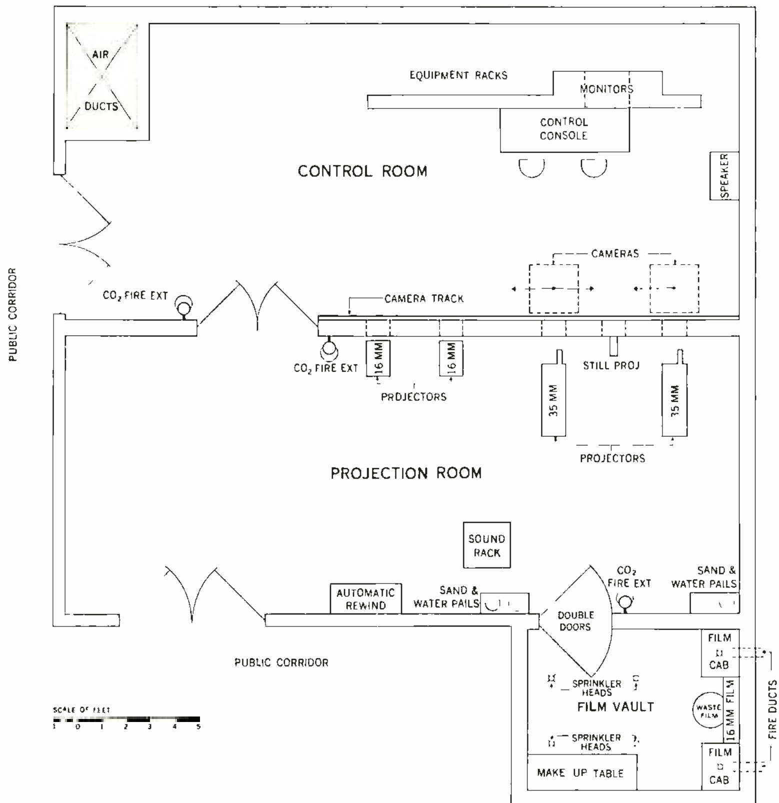

Fig. 5—Film studio layout.

The Film Scanning Room

The transmission of motion picture film used in the project is handled in a specially designed film scanning room on the fifth floor of the NBC Radio City plant. Any standard 35mm or 16mm motion picture film can be used and many of these films provide interesting entertainment. Such features as comedies, topical films, and news reels have already proved to be extremely valuable as program material.

Structurally, any television film studio must comply with municipal building and fire regulations prescribed for rooms where nitrate film is handled. Basic construction for this studio was provided for in the original plans for Radio City. Of particular interest is the film storage vault, constructed of heavy masonry walls, and provided with fireproof doors. The vault is equipped with sprinklers and drains, and ventilated directly out of doors in compliance with City regulations. Film storage cabinets are themselves fireproof and internally sprinkled, with connecting ducts to the outside atmosphere. At various points in the studio there are fire extinguishers and sand pails conveniently located for emergency use (See Figure 5).

Although adherence to the building and fire codes is compulsory, compliance with these provisions must be accomplished without impairing operating efficiency. The continuous nature of a television transmission requires that equipment be flexible in use. Instantaneous switching from one film projector to another without interruption is necessary, and was so arranged in this installation. The layout also was designed to facilitate rapid substitution or replacement of various units.

The actual layout of the film studio is shown in Figure 5. There are two adjacent rooms and a film vault. One room houses all projection apparatus and supplementary equipment, the other being reserved for the video apparatus and control facilities. In the projection room are four motion picture projectors, two 35mm projectors with sound heads and two 16mm machines without sound. There are also two small still projectors for test patterns and film slides. The 35mm projectors operate at the regular rate of 24 frames per second and are provided with a high-speed shutter and a modified intermittent system. This ingenious arrangement makes it possible to use standard motion picture film, operating at the normal projection rate, with a television pickup at a higher picture frequency. If such a device were not used the wealth of film entertainment already available on standard film could not be used in television since operation of standard film at 30 frames per second would obviously distort the action and sound far beyond reasonable tolerance. The 16mm machines are also provided with a high speed shutter, but in this case film is projected at a rate of 30 frames per second. This higher rate is taken into account in the making of the films.

The power requirements of this projection equipment make the use of oversize driving motors necessary. These must be of the synchronous type in order that they remain in step with the video system. This is accomplished by supplying these motors from the same alternating current supply which feeds the video synchronizing apparatus about which more will be mentioned later.

All projection machines operate through standard glass ports, focusing images directly on the plates of Iconoscope tubes encased in two cameras mounted on the opposite side of the wall in the control room. These cameras are so mounted on a track that they can be moved into place in front of any projector quickly and accurately.

The video apparatus for film television is centralized on a group of equipment racks in the control room as shown in Figure 5. Operating

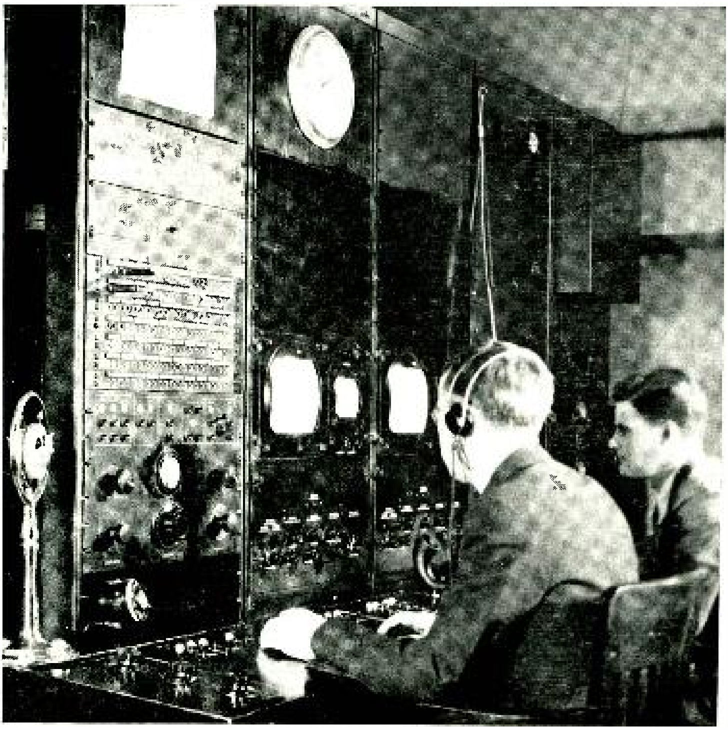

Fig. 6—Control console and equipment racks with audio controls, interstudio switching, Kinescopes and associated cathode-ray oscilloscopes.

controls are grouped on a control console that is affixed to the equipment racks on which are mounted the two Kinescope monitoring screens. The arrangement of controls is quite similar to the installation in the direct pickup studio. In Figure 6, the control console and three of the equipment racks are shown. Audio controls and inter-studio switching arrangements are mounted on the panel in the foreground. To the right are the Kinescopes and associated cathode ray oscilloscopes; controls for these are immediately below. The console controls include Iconoscope electrical focusing, camera switching relay push-buttons, motor and framing controls for the projectors, video gain and brightness, and shading. The microphone in the foreground is used to communicate instructions to the projectionist in the next room. An observation port is also provided for this purpose.

To the left of the operating position, not visible in the picture are two equipment racks on which are mounted video amplifiers and horizontal and vertical deflection amplifiers, as well as the beam power supply for the Iconoscopes. High potential circuits and switches are centralized on the miscellaneous equipment rack to the right of the installation. There is sufficient room in back of all equipment racks to permit easy maintenance and repair.

Main Equipment Room

Iconoscopes and Kinescopes are dependent for their operation upon deflection and blanking impulses which are generated by special equipment installed in the Main Equipment Room. Figure 7 shows this installation. The equipments mounted on the first and third panels from the left are the synchronizing generators, complete electrical units which produce all blanking and deflection impulses for the apparatus in the Film Scanning Room and the Direct Pickup Studio. These signals are amplified by the apparatus on the rack between the generators and are then distributed by coaxial cable to the television studio equipment. To guarantee maximum stability, these generators are operated continuously twenty-four hours a day, and either one may be instantaneously switched into service, the other acting as a standby. These generators also produce a fifth impulse known as the locking frequency, so named because it synchronizes receivers with the transmitter. This latter impulse is added to the video signal at the input to the line amplifiers, which are mounted on a rack at the right in the photograph. Here the studio signals are given a final boost before distribution to the television transmitters in the Empire State Tower, or to remote monitoring points in the NBC headquarters. Again there is a provision against failure. Three line amplifiers are available, any one of which may be selected for use. Video signals from either the film studio or the direct pickup studio feed inputs of these amplifiers through remotely controlled switching relays. The channel method of distribution such as is used for sound broadcasting, has been followed in the video switching arrangements. Present interlocking relays allow instantaneous switching from either originating studio to the input of the line amplifiers. Audio and video channels are switched simultaneously by one operation.

Two methods have been provided to transmit the picture signals to the transmitter on the Empire State Tower:

1—By coaxial cable.

2—By ultra high frequency radio circuit.

A special experimental coaxial cable is provided for conducting signals directly from the main equipment room to the Empire State transmitter, or the signal may be routed to a special ultra high frequency transmitter on the 10th floor of the NBC plant (See Figure 8).

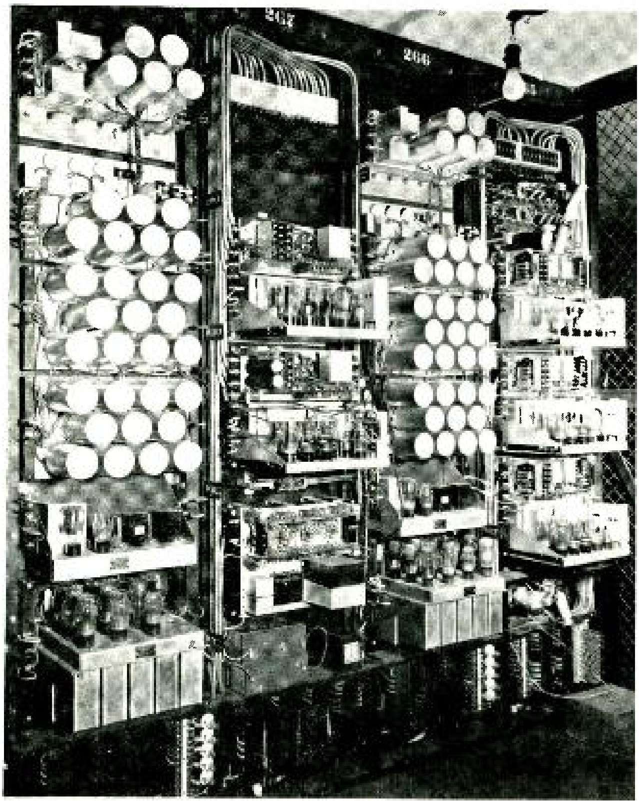

Fig. 7—Synchronizing generators and associated equipment.

This link transmitter operates on a frequency of 177 megacycles. The antenna of this transmitter is aimed at a similar array on the 85th Floor of the Empire State Tower where the signals are received for retransmission. The equipment at the left in Figure 8 is a radio frequency monitor which operates directly from the antenna circuit of this transmitter, thus providing a final check as the picture leaves the link transmitter. This equipment is provided with the usual Kinescope monitoring screen and associated apparatus.

Conclusions

From the above discussion it may be readily appreciated that the ramifications of studio planning for television are many. Numerous fields of scientific endeavor contribute to the general technology of television. To mention but a few it would be necessary to include optics, electronics, lighting, motion pictures, radio engineering, acoustics, air conditioning and photography, etc. The coordination of these sciences and the development of techniques which are applicable to television is a continuing process. The television field can only be briefly surveyed at this time, but from present knowledge there is ample reason to an-

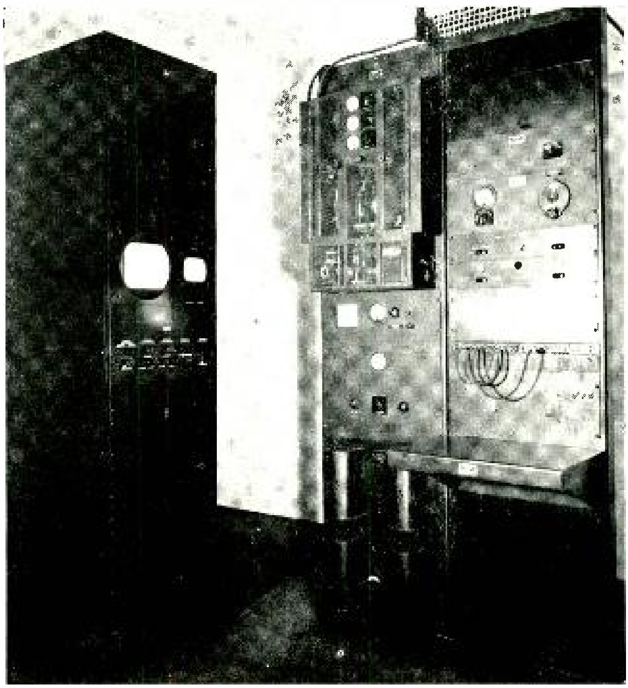

Fig. 8—Special ultra-high frequency link transmitter.

ticipate a public service of stupendous proportions, a medium with new engineering techniques, new program ideas, new talent and new commercial application. Experience will undoubtedly result in changes and improvements in existing apparatus as the progress of television is advanced toward the ultimate goal of a comprehensive program service.

Television covers a vast field of various subjects too numerous to consider in a single article such as this, however succeeding issues of the RCA Review will contain one or more papers dealing with other aspects of the problem of Television.

A NEW FORM OF INTERFERENCE — EXTERNAL CROSS MODULATION

By

DUDLEY E. FOSTER

RCA License Division Laboratory

Digest—*This paper describes a new form of interference first noticed during the past year and which has mysterious manifestations. The causes and remedies are described.*

Also it is pointed out that the "Luxembourg Effect", which has not been explained previously, may be due to this same phenomenon.

SOMEWHAT over a year ago reports began to be heard concerning a type of interference with broadcast reception which had never before been noticed. The interference occurred only in localities having high field strength from one or more local stations, and its new characteristic was that the program of the strong local station was heard when the receiver was tuned to one particular other station, but not to still others. The effect was not due to lack of selectivity because, when tuning the receiver, the local station could be tuned out and then would reappear when a certain other station was tuned in. Occasionally two local stations would be heard together on a frequency which was quite different from that of either one of them.

This type of interference also had other peculiarities. In the area in which it occurred, it would be found in one house whereas the house next door would be free from interference even when the same set was used. In those houses where it occurred, any make or model of receiver, including battery sets, experienced it. Still another puzzling factor was that the interference was not constant, being much more severe at some times than at others, and occasionally disappearing entirely for a period. In one case the interference was eliminated by opening the window through which the antenna lead-in passed, and in another case the interference was heard only when a certain bedroom light was turned on.

These characteristics led to the deduction that the interference was not caused in the radio receiver, but by some agency external to the receiver itself. This was further proven by laboratory experiments with two signal generators simulating the desired and interfering stations. In the laboratory inputs of three or four volts applied to the receiver did not cause interference, whereas, in the field at those locations having this type of interference, field strengths causing less than half a volt signal to be impressed on the receiver were present. Furthermore, decreasing the length of antenna did not eliminate the interference.

A survey was made to determine whether interference of this nature had been noticed in other parts of the country. Reports as a result of this survey showed it to be present in certain areas in or near the following cities: Cincinnati, Chicago, New York, San Francisco, Seattle and Washington.

Since by this time it was evident that the trouble was some form of cross modulation, and since it was exterior to the receiver, this type of interference was designated "external cross modulation".

A location was found where the cross modulation existed consistently and a study was made to determine the fundamental cause and a remedy. In this location, a battery receiver with a short antenna exhibited cross modulation inside the house, but when the receiver was a few feet outside the house, cross modulation ceased. A trap circuit in the antenna was of no benefit, which was further proof that the difficulty was external to the receiver. It was observed that at this location, as well as at others where the effect was serious, that the house wiring was of the knob and tube type and the service mains from the distribution transformer were overhead. A filter near the receiver, consisting of two 0.1-μf. condensers across the line with the center point grounded had only a slight effect on the interference, but an additional condenser across the line where it entered the house greatly decreased the cross modulation. It was further found that by placing the antenna at a distance from the power lines and using a shielded lead-in, the external cross modulation disappeared.

This experience showed that the cross modulation was due to rectification of radio frequencies in the power wiring, with resultant new, spurious frequencies being induced in the antenna or lead-in. Radio signals were picked up by the power wiring or other metallic conductors near the receiving antenna and at some point along the conductor were impressed on a rectifier or non-linear circuit element. The characteristic giving the output current of a rectifying element is commonly expressed as a series expansion in ascending powers of the applied voltage, the applied voltage in this case being the radio-frequency signals present on the power wiring or other conductor. The power-series representation of the rectifier characteristic discloses the new harmonic and combination frequencies which result from the rectification process. A simple laboratory test confirmed the observations. Two antennas were placed a few feet apart and to one of them a radio receiver was connected. An impedance was connected between the other antenna and ground, and when a simple diode was connected across this impedance, cross modulation of the signals in the first antenna occurred.

The question arises as to where the rectifier may exist in the field. Wherever there is a poor connection between any two metallic bodies, especially if oxidation is present, rectification can take place. The poor contact may be in the lighting lines, in piping, or even in the antenna itself. In one case the trouble was located at a point where a pipe passed through metal wall lathing. Bonding the pipe and lath together eliminated the interference. In another case two pipes were found to be touching and insertion of a block of wood between them cleared up the cross modulation. When such a rectifier exists and one or more powerful signals are present, new frequencies are generated by the rectifier. Where only one powerful signal is present, the only

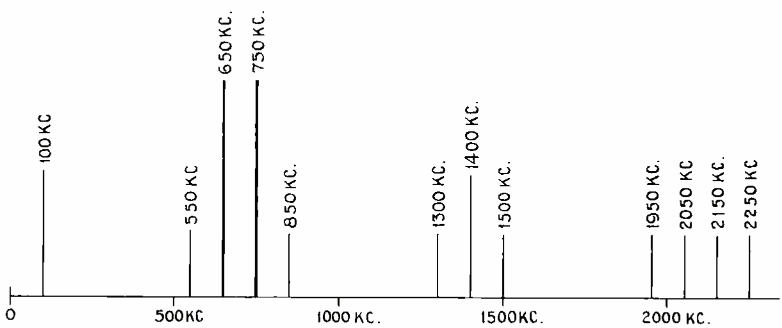

Figure 1.

new frequencies made by the rectifier are multiples of the fundamental, that is the second harmonic, third harmonic, etc. of the signal frequency. Where two strong signals exist, a number of cross modulation combinations take place. Let us call the frequency of one of the strong stations a, and that of the other b, then the rectifier generates the following frequencies:

$a + b$	$2a - b$
$a - b$	$2b + a$
$2a$	$2b - a$
$2b$	$3a$
$2a + b$	$3b$

An effect also takes place whereby the modulation of station with frequency a is heard on station b, and the modulation of station b is heard on a.

It should be noted that these spurious frequencies do not depend upon the presence of a second harmonic from either of the stations. If both stations are entirely free from harmonic radiation these same frequencies are generated if a rectifier is present.

Let us suppose that two stations are so located that in the region between them signal strengths of 0.1 volt per meter occur from both, and that one station is on 650 kc. and the other on 750 kc. Then the following table shows the frequencies produced.

$a = 650$ kc.	$2a + b = 2050$ kc.
$b = 750$ kc.	$2a - b = 550$ kc.
$a + b = 1400$ kc.	$2b + a = 2150$ kc.
$a - b = 100$ kc.	$2b - a = 850$ kc.
$2a = 1300$ kc.	$3a = 1950$ kc.
$2b = 1500$ kc.	$3b = 2250$ kc.

These same frequencies are shown diagrammatically in Figure 1. In this example these two stations would produce five new frequencies in the broadcast band and five new frequencies outside the broadcast band where one or both the stations together would be heard. It can be appreciated readily that a large amount of interference will be produced in this manner. The interference produced by station of frequency a on frequency b and vice versa has been found to be serious only when the rectifying action is particularly severe, because the modulation of the strong desired station usually masks the interfering modulation.

It may be seen also that there is a possibility of hum modulation being introduced when a rectifying condition exists in the power wiring. In this case, one of the frequencies is that of the signal carrier and the other that of the lighting system, which is usually 60 cycles. The rectifying action then imposes a 60-cycle modulation on the carrier. Some instances of modulation hum in receivers at certain locations have been traced to this source. *Hum of this type would be present in a battery receiver at the same location.* The remedy is the same as for interference between stations, namely elimination of the rectifying condition or changed installation of the antenna to avoid pickup of resultant spurious frequencies.

Knowledge of the frequencies produced is helpful in determining whether a case of interference is due to external cross modulation or not. Most of the combination frequencies are readily calculated when the frequencies of the two stations having high field strength are known. The combinations $2a - b$ and $2b - a$ are usually in the broadcast band and for that reason are troublesome. Figure 2 is a chart for reading the spurious frequency $2a - b$ for any value of a and b. By reversing the designation of a and b the chart can be used for finding $2b - a$ also.

In investigating a situation where interference exists, the first step should be to determine whether or not it is due to external cross modulation by observing the frequencies at which interference exists.

For example, with the two strong signals at 650 kc. and 750 kc., if the program from both is heard at 550 kc., 850 kc. and 1400 kc., it may be safely assumed that the trouble is due to external cross modulation. If the interference is not due to external cross modulation, shortening the antenna or installation of a wave trap tuned to the interfering signal, or both, will remedy the situation.

Cross modulation may, of course, be produced in the radio-frequency or first-detector stage of the receiver if the tubes are not of the remote cut-off or variable-mu type or if the operating bias is, for any reason, incorrect.[1] Cross modulation occurring in the receiver

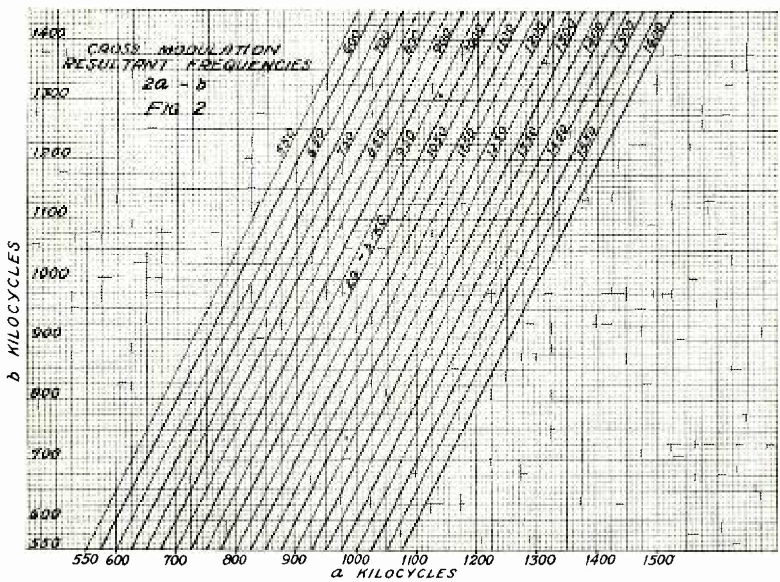

Fig. 2.

can be differentiated from that due to external causes by use of a short antenna, a wave trap tuned to the strongest interfering station, or by substituting another receiver. These expedients will eliminate, or greatly reduce, cross modulation which takes place in the receiver, but will not affect external cross modulation.

As seen from some of the cases, the rectifying element may be in the power wiring, piping, or in the antenna itself. Therefore, the first step in eliminating the trouble should be to make sure that the antenna and ground connections to the receiver have secure, tight joints

[1] "Reduction of Distortion and Cross-Talk in Radio Receivers by Means of Variable-Mu Tetrodes". Stuart Ballantine and H. A. Snow. *Proceedings of the Institute of Radio Engineers*, December 1930.

throughout, soldered joints in the antenna being preferable. If this does not cure the interference, the next step is to endeavor to find the rectifying element elsewhere. If the rectifier is in the power wiring, connection of two 0.1 μf. condensers across the lighting lines, with the center point going as directly as possible to a good ground, should produce at least some decrease in the cross modulation. In this connection it should be remembered that steam or gas piping, and in some cases water piping, may have joints which are electrical rectifiers, and in this event use of such piping as a ground for the receiver will intensify cross modulation. The house should be examined for indications of pipes or electrical conduits which touch each other. If such points are found they should be separated by a block of wood or else bonded together securely.

If the source of rectification cannot be located, it still is usually possible to secure interference-free reception by the proper type of antenna installation. The location for an antenna which is free from cross modulation can be readily found by the use of a portable battery receiver equipped with a short antenna. It will be found that the cross modulation occurs in the battery receiver when it is within the house, but disappears a few feet outside the house. By this exploration means, a location for the antenna is to be found where cross modulation does not exist. The spurious frequencies will, however, be picked up on the lead-in unless it is thoroughly shielded. In some cases metallic braid shielding may not be good enough and concentric transmission line cable, which is now available in small sizes, must be used. Since the shielded cable is low in impedance, it is necessary to use matching transformers at the antenna and at the receiver to obtain maximum efficiency. If such transformers are used, they should be examined for possibility of poor connections which will cause rectification and resultant cross-modulation interference. It must be remembered also that the ground lead of the receiver is capable of picking up radio-frequency energy so that it should be as short and direct as possible. The receiver should be re-located to accomplish this if necessary.

SUMMARY

The steps involved in eliminating cross-modulation interference are:

1—Calculate the frequency combination values to make sure the interference is cross modulation.
2—Examine antenna and ground for poor connections.
3—Try capacity filter across light lines.
4—Look for and eliminate rectifying contacts in piping or wiring.
5—Find antenna location free from cross modulation and install antenna there with shielded lead-in to set.

By following this procedure it should be possible to clear up even stubborn cases of interference due to external cross modulation.

The discovery of the source of the external cross modulation phenomenon has led to proper analysis and elimination of many cases of interference which formerly were mysterious in origin and therefore difficult or impossible to remedy.

Theoretical Discussion

A rectifier or non-linear element has a characteristic which may be expressed by a power series expansion:

$$\frac{i}{k} = m_o + m_1 e + m_2 e^2 + m_3 e^3 + \ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

Where i is output current of rectifier
k is rectification constant
e is applied voltage
m_o, m_1, etc. are coefficients of the rectification characteristic.

$$e = E_1 \cos a + E_2 \cos b \quad (2)$$

Where E_1 is amplitude of signal with frequency a.
E_2 is amplitude of signal with frequency b.
E_1 and E_2 vary at modulation frequency if signals are modulated.

Substituting (2) in (1) the resultant output of the rectifier becomes:

$$\frac{i}{k} = m_0 + m_1 E_1 \cos a + m_1 E_2 \cos b + \frac{m_2}{2} E_1^2 + \frac{m_2}{2} E_1^2 \cos 2a + \quad (3)$$

$$\frac{m_2}{2} E_2^2 + \frac{m_2}{2} E_2^2 \cos 2b + m_2 E_1 E_2 \cos (a + b) + m_2 E_1 E_2 \cos (a - b) +$$

$$\frac{3m_3}{4} E_1^3 \cos a + \frac{m_3}{4} E_1^3 \cos 3a + \frac{3m_3}{4} E_2^3 \cos b + \frac{m_3}{4} E_2^3 \cos 3b +$$

$$\frac{3m_3}{2} E_1 E_2^2 \cos a + \frac{3m_3}{4} E_1 E_2^2 \cos (2b + a) + \frac{3m_3}{4} E_1 E_2^2 \cos (2b - a) +$$

$$\frac{3m_3}{2} E_1^2 E_2 \cos b + \frac{3m_3}{4} E_1^2 E_2 \cos (2a + b) + \frac{3m_3}{4} E_1^2 E_2 \cos (2a - b).$$

From this expression may be seen the large number of resultant frequencies and their relative magnitudes. The second order term results in new frequencies carrying the modulation of one or both of the signals. The third order term shows that rectification increases the modulation depth of the signal and also that the modulation of one signal becomes impressed on the frequency of the other signal. The third order term produces additional new frequencies carrying the modulation of one or both of the signals.

The Luxembourg Effect

About three years ago an effect was noticed in Europe whereby the modulation of the Luxembourg station, which is a high-powered long-wave station, was noticed in Holland on the frequencies of stations in the broadcast band, and caused interference with those stations.[2] This phenomenon was called the "Luxembourg effect" and was ascribed to a possible non-linearity of the transmission medium. Later this phenomenon of interference from the Luxembourg station was noticed in several other European countries. It is entirely possible that the effect was due to some non-linear element in the neighborhood of the receiving location and was therefore what we have called external cross modulation, especially since the Luxembourg effect is the first phenomenon which would indicate the possibility of a non-linear medium of propagation. Examples have been found in this country of external cross modulation at distances from the interfering station of over 100 miles, which are similar to the observations of Luxembourg effect. In general, when the interfering station is at such a distance, it has been found that the interfering station has high power and that there are high-tension lines extending in the direction where the interference was found, so that field intensity of the interfering signal was high at those points.

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[2] "Interaction of Radio Waves" by Balth. van der Pol and J. van der Mark. Publications of N. V. Philips Gloeilampenfabrieken, Nos. 964 and 1036.

A. G. Butt, *Radio World*, April 28th, 1933.

B. D. H. Tellegen, *Nature*, June 10th, 1933.

Hochfrequenz Technik und Electro Akustik 46:181-186 1935.

Onde Electrique 14 No. 168 80-808 1935.

Wireless World, February 26th, 1937.

CHARACTERISTICS OF AMPLITUDE MODULATED WAVES

BY

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INTRODUCTION

PURE amplitude modulation is intuitively comprehended in the form of a periodic wave function with varying amplitude, but it is somewhat more difficult to comprehend it as a synthesis of three components, all in a precise relationship of amplitudes, frequencies and phases. One must revert to the latter conception, however, to be able to cope with the many problems involved in the transmission of intelligence by means of amplitude modulation, phase modulation, frequency modulation, or combinations of these three fundamental processes. Unfortunately, intuition is of little assistance even in the broader aspects of amplitude modulation, wherein are concealed some of the problems of communication.

A simple aid to the treatment of amplitude modulation, and capable of extension to the other processes, is the method using stroboscopic vectors. This method deals with relative motions in a system of vectors representing the same or different frequencies, as if all were viewed in their periodic rotations by means of stroboscopic light synchronized with one of them. Any rotating vector representation is really a stroboscopic image of the vector. In a vector diagram representing currents and potentials of the same frequency, the relationships are fixed. When, instead, the various vectors are of different frequencies, the relationships are varying in time, and the vector diagram is animated. Facility in the use of stroboscopic vector diagrams in connection with modulation studies brings the complexities of carrier and side-frequency synthesis into intimate acquaintance.

When employing amplitude modulation we are particularly interested in the shape of the envelope of the wave which arrives at the receiver, for it is this envelope which yields the desired intelligence. Most detectors are devices responsive to variations in the amplitude of the input potentials, and it is the envelope of the incoming signal which is reproduced in the low-frequency output circuit of a linear detector. The reproduction of the envelope may be with or without distortion, and the characteristics of the detector are of primary importance in determining the final result.

A wave which was originally the result of pure amplitude modulation may be slightly or greatly modified in passing through amplifiers, filters, transmission lines, antennas and through the transmission medium in space. The original carrier and its two symmetrical side-frequencies, or sidebands, may be reduced, eliminated or shifted in relative phase, in any combination, by the above influences. All such changes affect the envelope of the ultimately received wave, and the detector output. In assymmetric sideband and single sideband suppressed carrier systems of transmission, certain modifications are

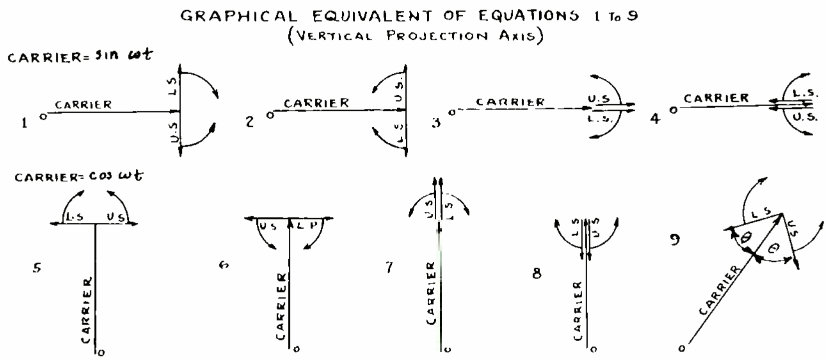


Fig. 1

willfully imposed on what is at the start, an essentially pure amplitude modulated wave. However, it matters little whether the disintegration of the original wave is deliberate or random so far as the analysis is concerned; but since all the various combinations of effects occur in suppressed carrier single sideband transmission, with local replacement carrier at the receiver, we shall discuss later the prevalent conditions in such a system by way of illustration.

Pure Amplitude Modulation

There are listed eight equations for a periodic function having a slow periodic variation in amplitude, corresponding to pure amplitude modulation under conditions where there are sine or cosine carriers, and plus or minus sine or cosine modulating potentials. These are in envelope and sideband forms. In addition, a more general equation (9) for pure amplitude modulation is included.

$$\sin \omega t\ (1 + m \sin \Omega t) \equiv \sin \omega t + \frac{m}{2} \cos\ (\omega - \Omega)\ t - \frac{m}{2} \cos\ (\omega + \Omega)\ t \ldots. (1)$$

$$\sin \omega t\ (1 - m \sin \Omega t) \equiv \sin \omega t - \frac{m}{2} \cos\ (\omega - \Omega)\ t + \frac{m}{2} \cos\ (\omega + \Omega)\ t \ldots. (2)$$

$$\sin \omega t\ (1 + m \cos \Omega t) \equiv \sin \omega t + \frac{m}{2} \sin\ (\omega - \Omega)\ t + \frac{m}{2} \sin\ (\omega + \Omega)\ t \ldots. (3)$$

$$\sin \omega t\ (1 - m \cos \Omega t) \equiv \sin \omega t - \frac{m}{2}\ \text{in}\ (\omega - \Omega)\ t - \frac{m}{2} \sin\ (\omega + \Omega)\ t \ldots. (4)$$

$$\cos \omega t\ (1 + m \sin \Omega t) \equiv \cos \omega t - \frac{m}{2} \sin\ (\omega - \Omega)\ t + \frac{m}{2} \sin\ (\omega + \Omega)\ t \ldots. (5)$$

$$\cos \omega t\ (1 - m \sin \Omega t) \equiv \cos \omega t + \frac{m}{2} \sin\ (\omega - \Omega)\ t - \frac{m}{2} \sin\ (\omega + \Omega)\ t \ldots. (6)$$

$$\cos \omega t\ (1 + m \cos \Omega t) \equiv \cos \omega t + \frac{m}{2} \cos\ (\omega - \Omega)\ t + \frac{m}{2} \cos\ (\omega + \Omega)\ t \ldots. (7)$$

$$\cos \omega t\ (1 - m \cos \Omega t) \equiv \cos \omega t - \frac{m}{2} \cos\ (\omega - \Omega)\ t - \frac{m}{2} \cos\ (\omega + \Omega)\ t \ldots. (8)$$

$$[\sin\ (\omega t + \Phi)]\ [1 + m \sin\ (\Omega t + \Psi)] \equiv \sin\ (\omega t + \Phi) +$$
$$\frac{m}{2} \cos\ [(\omega t + \Phi) - (\Omega t + \Psi)] - \frac{m}{2} \cos\ [(\omega t + \Phi) + (\Omega t + \Psi)] \ldots. (9)$$

These equations are represented vectorially in Figure 1 at the instant of zero time. They all have the common characteristic of an envelope which is identical in shape with the modulating potential. They also have in common

1—The original carrier unmodified

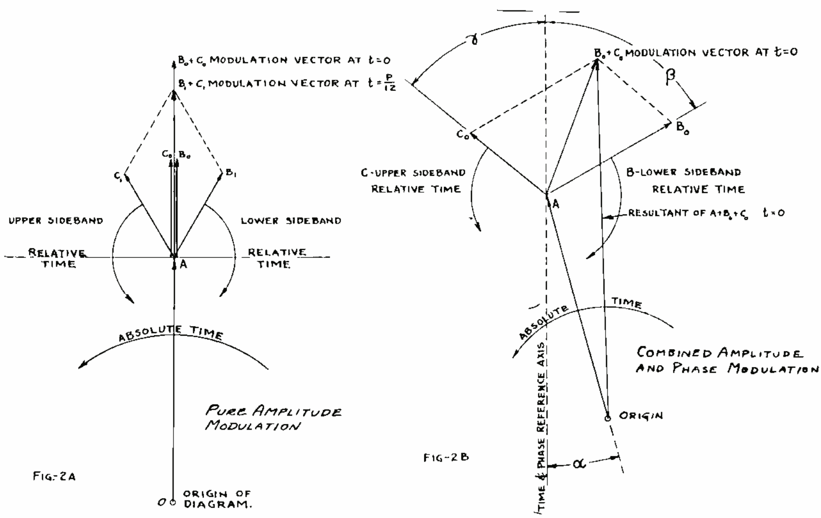
2—Two side-frequencies of equal amplitude, one of higher and one of lower frequency than that of the carrier, but each separated from the latter by a frequency difference equal to that of the modulating frequency. Thus, modulation by this process is the addition of side-frequency energy to that of the original carrier, in a precise frequency, amplitude and phase relationship.

These equations differ only in the positions of the original carrier component and the modulating function at the instant of zero time reference.

In pure amplitude modulation, the side-frequency vectors add to give a "modulation" vector which is always in phase with the carrier vector. The addition of the modulation vector with that for the carrier gives a final resultant vector which has the same angular velocity as the carrier alone, but varying in length periodically to describe the well-known envelope which is a reproduction of the form of the original modulating function. The uniform angular velocity of the resultant of carrier and modulation vectors is a unique result of pure amplitude modulation, and does, in fact, define it. Figure 2a demonstrates this.

Combined Phase and Amplitude Modulation*

Equation 9 is a general expression for the products of pure amplitude modulation. However, this wave function, once produced, is not necessarily retained in the translation of it through active, passive and radiation circuits employed in communication. The amplitude and



Figs. 2A, 2B.

phase relationships specified may be modified in any degree, but the only relations that are inviolate are those between the frequencies of the components.

To determine the function for the carrier and its original side frequencies after having been subjected to random influences which modify the amplitude and phase relationships, one writes

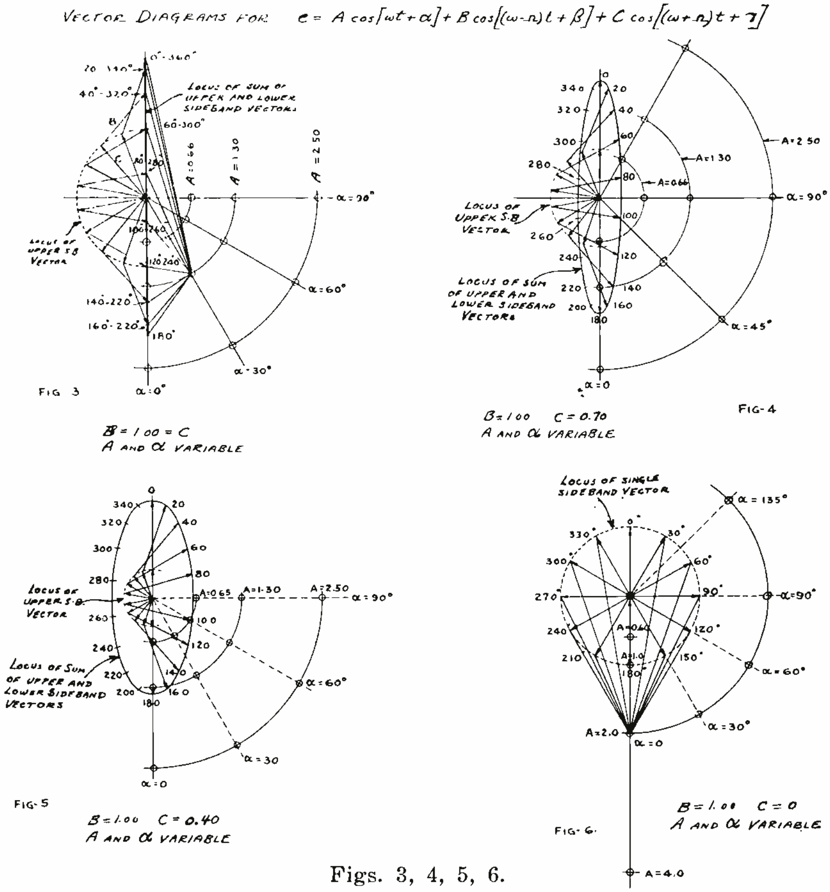
$$e = A \sin(\omega t + \alpha) + B \sin[(\omega - \Omega) t + \beta] + C \sin[(\omega + \Omega) t + \gamma] \quad (10)$$

The synthesis of the components of this function is easily performed graphically by stroboscopic vector diagrams, an example of which is shown in Figure 2b at the instant of zero time. The development of such diagrams through a complete modulation cycle will follow.

One notes immediately that the resultant of the two side-frequencies with the carrier may no longer be in phase with the carrier during

* Sometimes called pseudo-phase modulation.

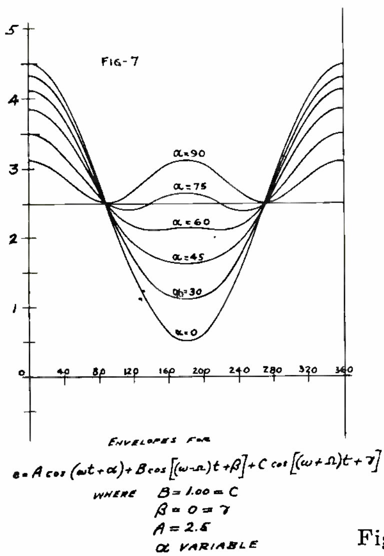
the modulation cycle, but may oscillate symmetrically or eccentrically about the carrier vector, depending upon the coefficients for the components of Equation 10. At the same time, there are variations in the amplitude of the resultant which appear as the envelope for the function. The vector diagram discloses a combination of phase and amplitude modulation.

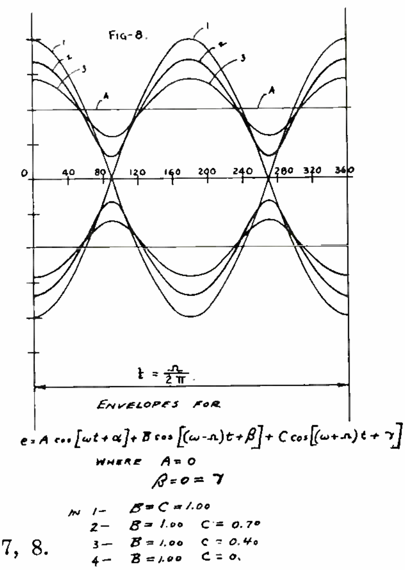


Figs. 3, 4, 5, 6.

In pure amplitude modulation, the sum of the two symmetrical sideband vectors (modulation vector) is in phase with the carrier vector at all times, so that the resultant vector is always in phase with the carrier also. Since the carrier vector has uniform angular velocity of rotation, the resultant vector must also. If we plotted out in rectangular coordinates the entire wave function for a pure amplitude modulated wave, one of its characteristics would be found to be that there were equal time intervals between successive crossings of the zero axis.

If, on the other hand, we find that the resultant of the carrier and sideband vectors not only changes in its amplitude, but also in its position with respect to the carrier vector during the modulating cycle, which is a periodic deviation in relative phases between these vectors, we have combined amplitude and phase modulation. While pure phase modulation is not included in the scope of the title of this paper, we must at least identify it as this point. Pure phase modulation is the process of imparting the influence of the modulating source to the position of the carrier vector instead of to its length. In this system, the vector which is the resultant of the carrier and sideband vectors is always equal in amplitude to that of the unmodulated-carrier vector,

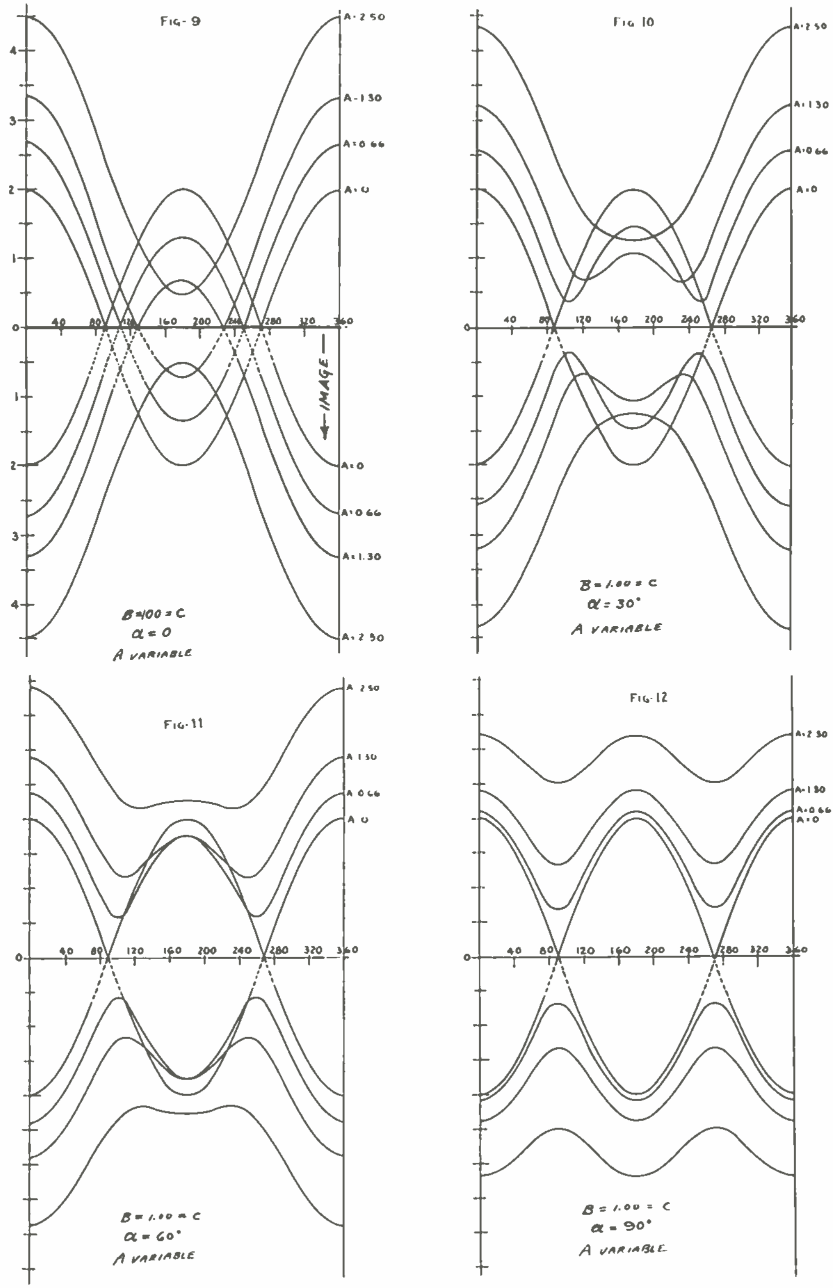




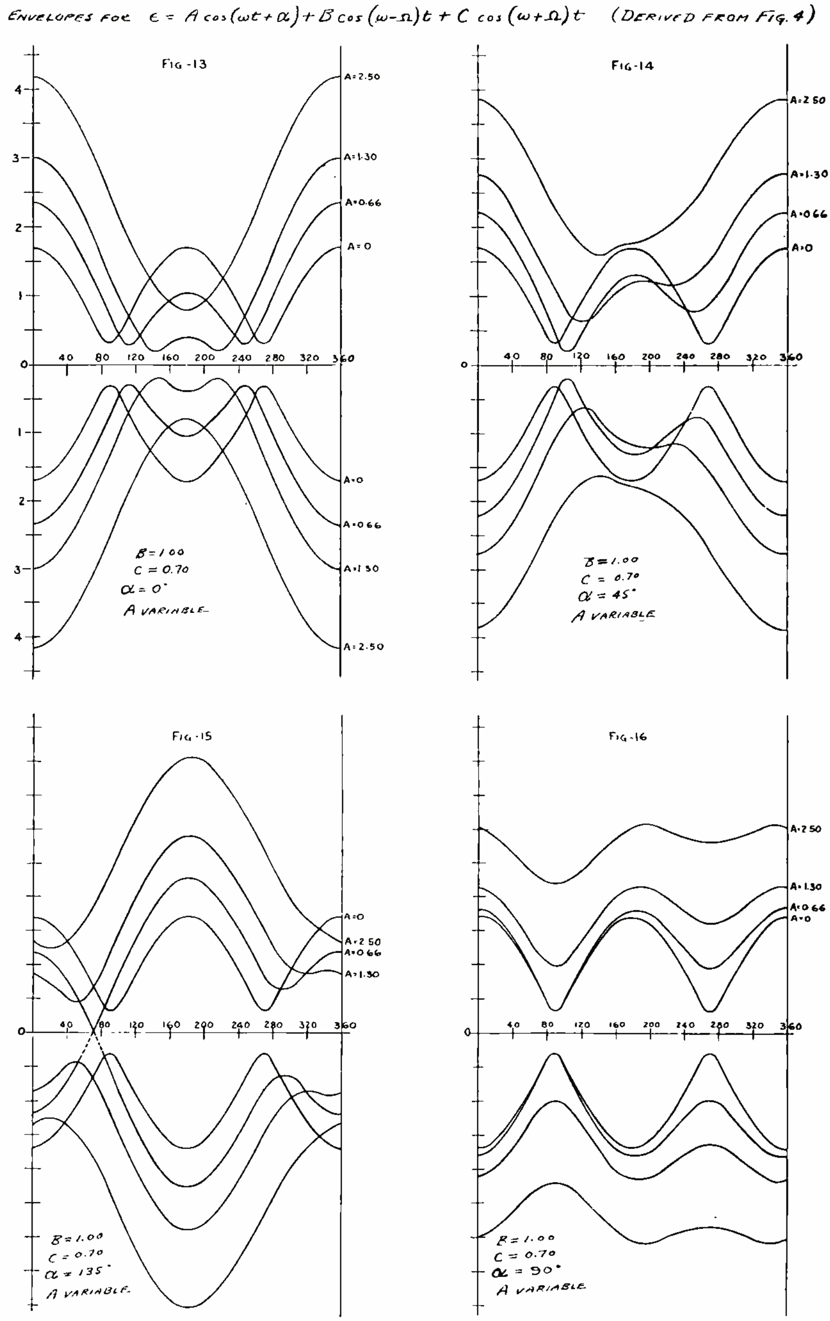
Figs. 7, 8.

but has a relative phase with respect to the latter which, being oscillatory, causes it to fall behind it during one portion of the modulating cycle, and in advance of it during another portion. A rectangular plot of this complete wave function would therefore display unequal time intervals between successive crossings of the zero axis. It is this generic feature of phase modulation which we recognize in the movements of the vector resultant under the general conditions represented by Equation 10. Not only does the amplitude of this vector change throughout the modulating cycle to describe the wave envelope, but its phase with respect to the carrier vector changes. This can be seen in Figure 2b. The latter represents the vectors at some instant, say at the start of the modulating cycle. The direction and length of the resultant vector will change as the sideband vectors rotate in relation to the carrier vector through one period of the modulating frequency.

ENVELOPES FOR $e = A\cos(\omega t + \alpha) + B\cos(\omega - \Omega)t + C\cos(\omega + \Omega)t$ (DERIVED FROM FIG. 3)



Figs. 9, 10, 11, 12.



Figs. 13, 14, 15, 16.

The segregation of the two types of modulation coexistent in a combined phase and amplitude modulation problem of this character can be accomplished. In fact, the most satisfactory methods for producing phase or frequency modulation are those obtained by first utilizing pure amplitude modulation and then rearranging the components so as to obtain combined amplitude and phase modulation. When the amplitude variations are eliminated by passing the wave through a saturated device which acts as a demodulator, the amplitude variations are removed and only the phase variations are retained. To remove the phase modulation and retain the amplitude modulation, one utilizes a linear detector.

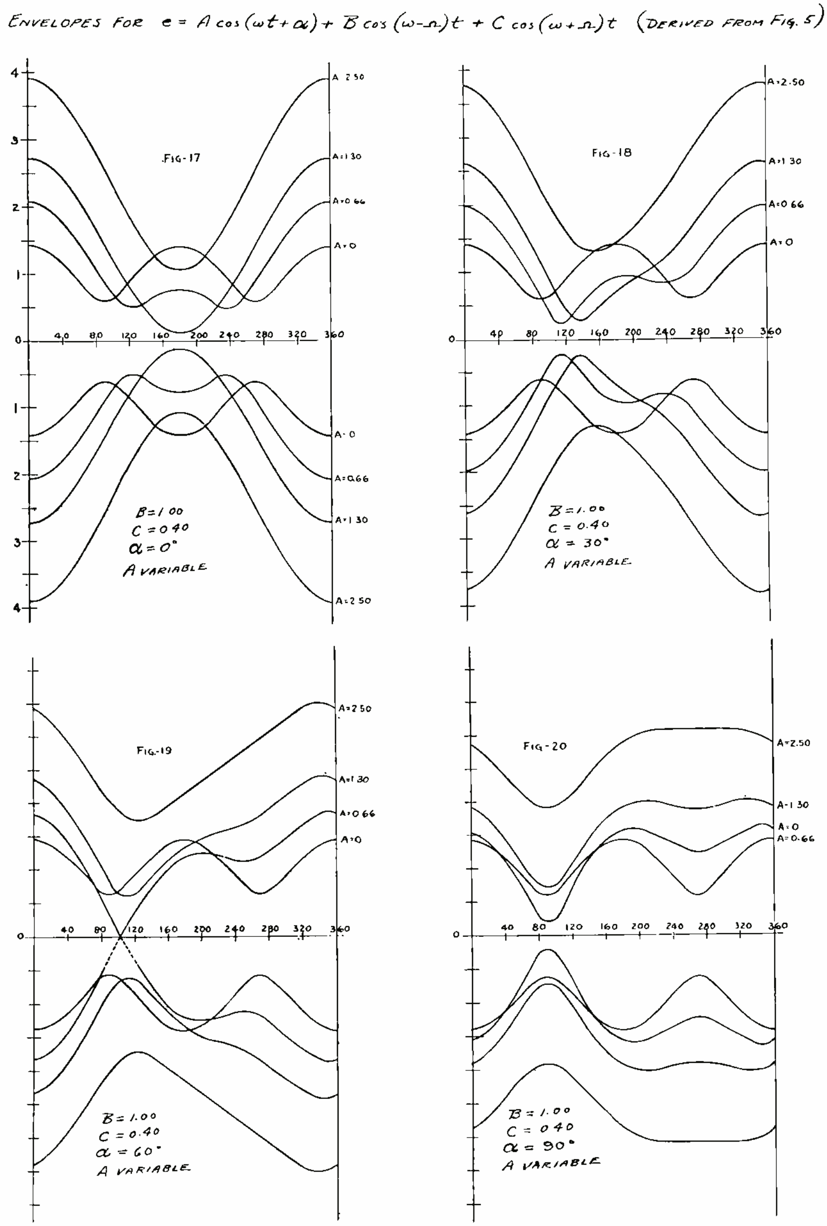
Envelopes for Several Conditions of Equation 10

By means of the construction of composite vector diagrams in Figures 3 to 6, a series of envelopes for the function (Equation 10) with arbitrary coefficients and phase angles is compiled in the regions of greatest practical interest. Starting with two normal symmetrical primary sidebands, the effect of the phase of the carrier is shown in Figure 7. The envelope for the two sidebands without the carrier component is shown in Figure 8, Curve 1. When the sideband amplitudes are not equal, the envelope varies between this and a straight line, as indicated for a succession of ratios in the same figure.

With two equal sidebands, the envelopes produced by the variations in the amplitude and relative phase of the carrier are diagrammed accurately in Figures 9 to 12. On the same basis, the envelopes for the same carrier conditions, but for two cases of unequal sideband amplitudes and one when one sideband is eliminated, are shown in Figures 13 to 21. Figure 22 shows the effect of varying the phase of the carrier with respect to a single sideband component, such as is done at the receiver in a single sideband suppressed carrier system. The distortion in the envelope for various sideband-carrier amplitude ratios for single sideband system (or any two frequencies) are plotted in Figure 23.

Discussion of Figures

In selective fading, any of the conditions represented by the envelope curves may occur at random. Any of the conditions may also occur in a suppressed carrier single sideband transmission system, with the replacement carrier introduced at the receiver. Figure 24 represents the typical action of a band-pass filter on the normal sideband spectra obtained by amplitude modulation. The carrier A has been suppressed. The dominant (lower) sideband is transmitted together with vestiges of the upper. Modulating with a frequency Z pure single sideband is obtained, but with frequencies, W, X and Y there are two sidebands



Figs. 17, 18, 19, 20.

of unequal amplitude. For W, very close to the carrier, Figure 3 is nearly a correct vector representation, while X, Y and Z are represented by Figures 4, 5 and 6 respectively. The synthesis of local replacement carrier and the incoming sidebands at the receiver produces envelopes of the nature depicted, depending upon the amplitude and phase of the carrier.

In the examples worked out, the angles β and γ were made zero in all cases. From the vector diagrams it is seen that the locus of the modulation vector, which is the resultant of the side-frequency vectors, is an ellipse when the two side-frequency vectors are of unequal amplitude. When β and γ are zero, the major axis of the ellipse is vertical,

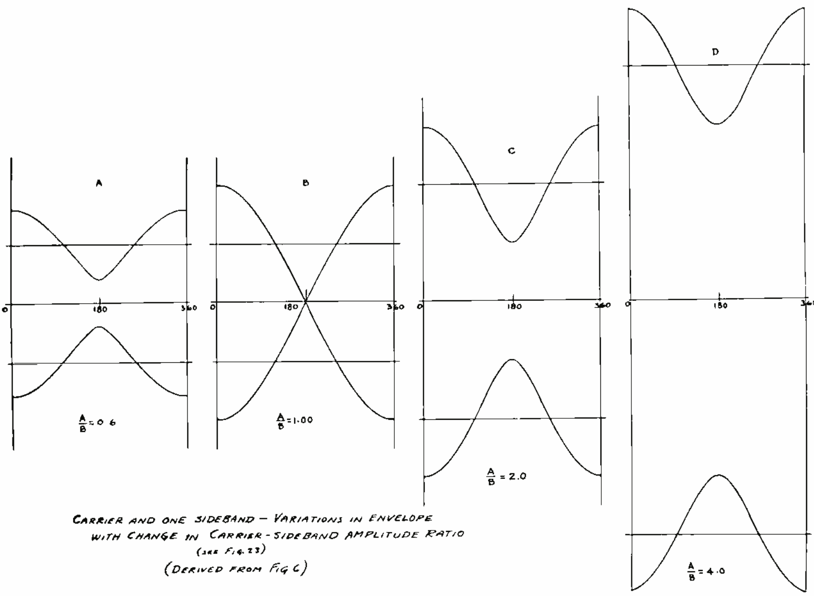


Figure 21.

but when β and γ are other than 0, the orientation of the major axis is other than vertical, but has the same shape. So far as envelope shapes are concerned, no new ones are introduced by this effect, since it is equivalent to shifting the phase of the carrier in the manner previously described.

A major effect of definite values of β and γ other than 0 is to translate the envelope in the time scale, which amounts to merely changing the phase of the envelope function.*

In suppressed carrier transmission, the employment of a non-synchronous replacement carrier produces effects equivalent to that of a synchronous carrier of uniform and continuous phase rotation.

* This effect is produced by selective circuits.

For pure single sideband signals, this phase rotation produces an envelope which, viewed in an oscilloscope, is constantly travelling with time or against time, depending upon whether the frequency of the replaced carrier is lower or higher than that of the true carrier. The tone heard, however, is low or high by the amount of this frequency discrepancy. See Figure 22.

When there are vestigial and dominant side frequencies received, the envelope changes in its form as well as moves along the time scale. Assume the condition of Y in Figure 24, and a non-synchronous replace-

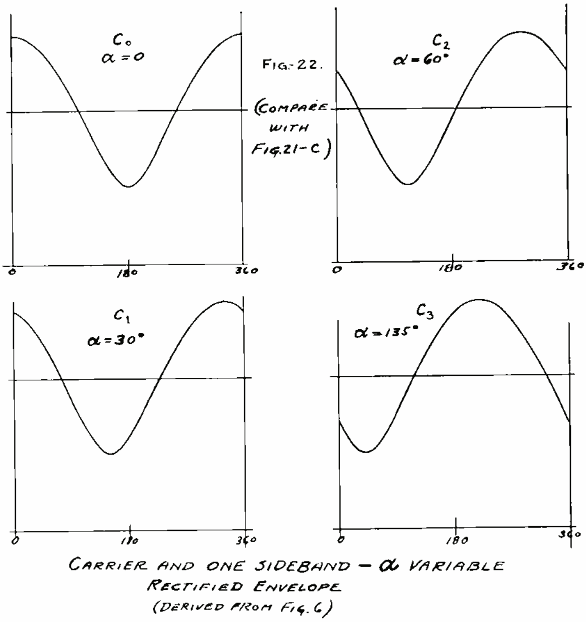


Figure 22.

ment carrier amplitude of 2.5 units. Following the curves for 2.5 through Figures 17 to 20, we see the evolution of the envelope for 90° of carrier phase change. Listening, we hear a tone of variable quality which passes through two cycles of variation for each 360° of phase change of the carrier. Now, modulating at frequency W (Figure 24) and listening under the same conditions, we hear a pure tone which is off in pitch by an amount equal to the frequency difference between the original and the false carriers at times when the carrier is at positions of 0° and 180°. When the carrier phase is 90° and 270°, only second harmonic is heard at 16.5 *db* lower volume. (See Figure 7.) At the lowest modulating frequencies, where this effect is most pronounced, the permissible vestigial side-frequency amplitude is readily determined from the envelope curves and the sharpness of cut-off for a filter specified, to allow the use of a non-synchronous carrier. So far as tolerance for carrier deviation is concerned, the opinion of six mod-

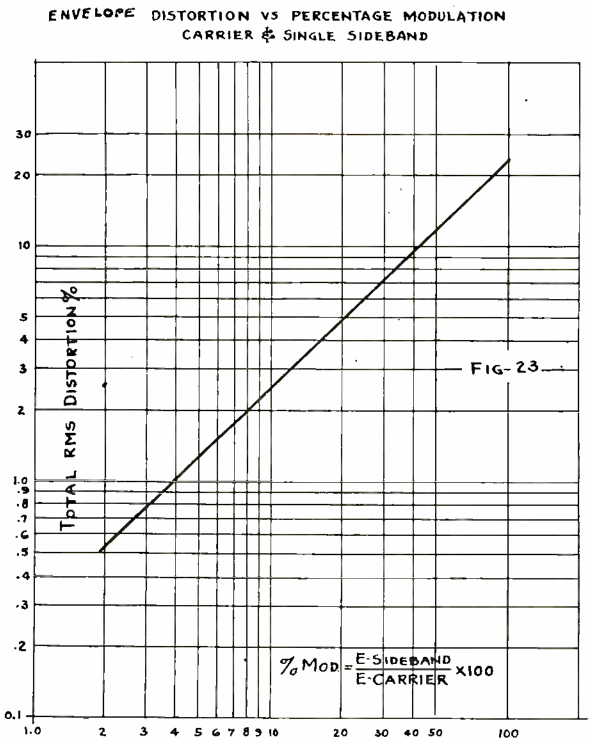


Figure 23.

erately critical observers is that 5 cycles deviation is the maximum allowable before the departure from true chromatic scale intervals

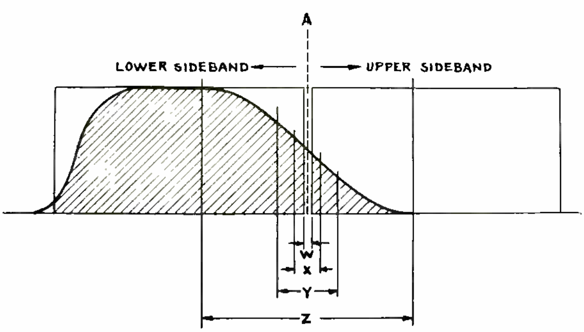


Figure 24.

is noticeable in music. The error is, of course, most noticeable at the low audio frequencies.

NOTES ON BROADCAST ANTENNA DEVELOPMENTS

BY

RAYMOND F. GUY

Radio Facilities Engineer, National Broadcasting Company

ONE of the first important contributions to the knowledge of antennas was the discovery by Marconi in 1895 of the effect of raised aerial wires or antennas, when used in conjunction with radio transmitting and receiving apparatus. This discovery marked the beginning of the development of our modern antenna systems.

To generalize a bit, the main improvement of the modern antennas for broadcasting has not been a large increase in the amount of wave energy radiated, but has been the "compressing" of the same amount of energy down close to the earth where the receiving antennas are located. The poorest transmitting antenna may be very efficient at radiating power, but at the same time be very ineffective in serving its purpose by diverting energy high into the air, utterly wasting much of it. It costs approximately $5.00 per watt to install a 50,000 watt station and approximately $15.00 per watt to install a 5 kilowatt station. It is not good economics to waste 25 or 50 per cent of this costly power by directing it toward the upper atmosphere where it is either dissipated or reflected to cause fading.

MEASUREMENT OF NETWORK COVERAGE

Broadcast coverage, or "circulation", is the main commodity which a network or station has to sell. It is of primary importance to the National Broadcasting Company, and the coverage of its own and associated stations has been carefully evaluated and used in the formula for determining station rates.

The need for specific "circulation" data on its own and associated stations led the NBC in 1933 to undertake to measure and evaluate the coverage given by each of the then 90 odd NBC network stations. There followed the most comprehensive and thorough coast-to-coast study of field intensity coverage ever undertaken, and, simultaneously, there were sorted, analyzed and tabulated, the contents of five million individual audience-mail letters. Statisticians counted and tabulated

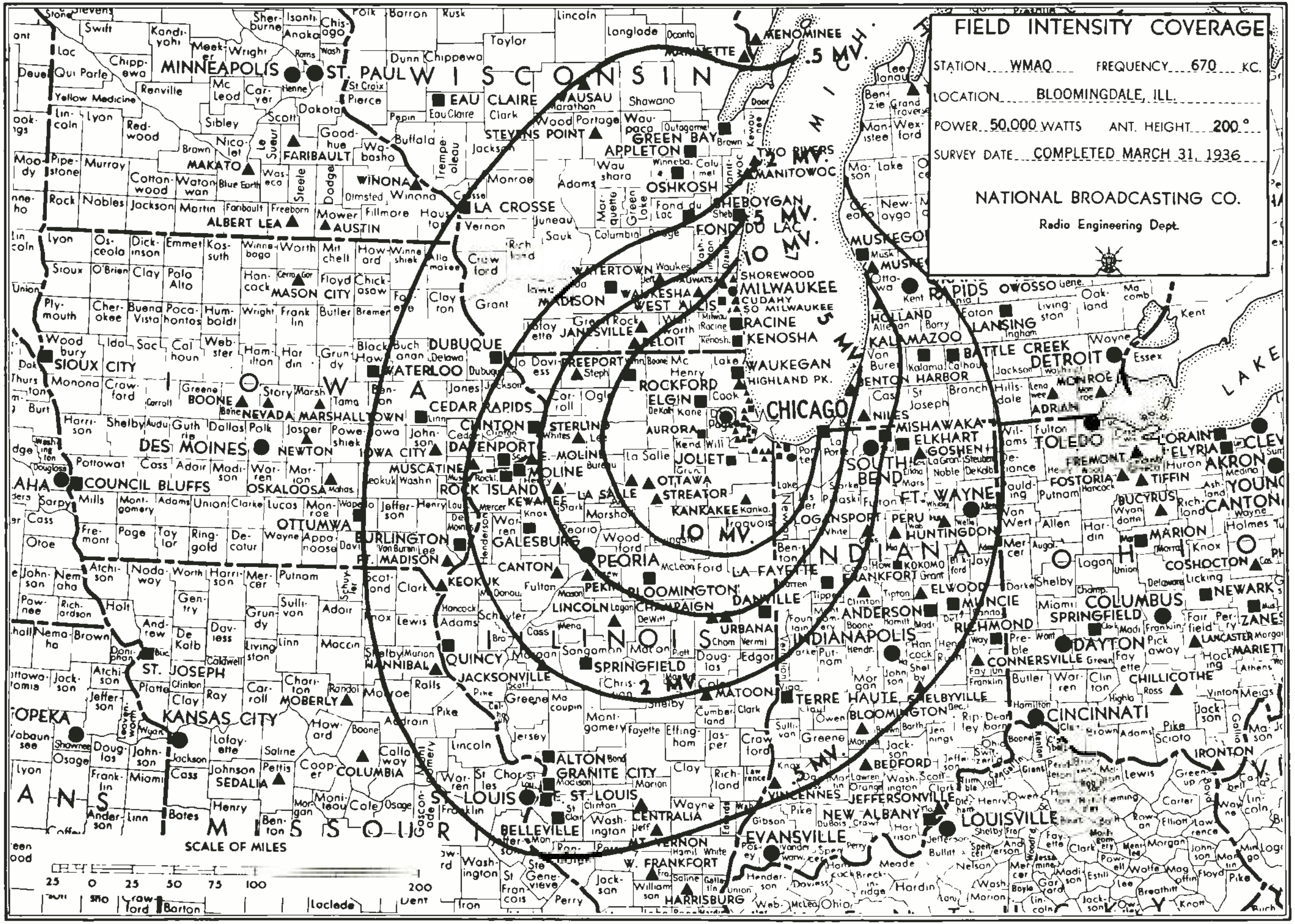


Fig. 1—A representative coverage map of WMAQ.

these letters station by station and by individual counties. Five million letters, stacked, would stand one and one-half miles high and end to end would reach from New York to Cleveland. During the field intensity survey of each of these 90 odd stations, 18 measuring cars were driven 232,218 miles throughout 1,250,000 square miles (40 per cent of the area of the United States), to make 21,316 individual field intensity measurements, not counting repeats or checks, in four months consecutively elapsed time. The field intensity contours for each station measured were carefully plotted and correlated with the mail analysis, and counted heavily in the evaluation of the coverage. Figure 1 shows a representative coverage map which, in this case, is WMAQ, Chicago. In making the WMAQ survey, an NBC Radio Engineer drove a radio engineering car, equipped with suitable measuring instruments, over 4,000 miles during a period of four weeks.

Factors Which Effect Coverage

The coverage of a station is effected by a number of factors, some of which can be controlled and some of which cannot. They are:

1—Power.
2—Antenna design.
3—Soil conditions as they determine the rate of decay of waves over the earth.
4—Interference from other stations.
5—Local noise levels.
6—Frequency assignment.

The field intensity of a station varies as the square root of the ratio of one power to another. The frequency assignment has a considerable effect upon the coverage obtainable. Ordinarily changes of power and frequency may be made only with consent of the Federal Communications Commission and consequently are not under direct control of the broadcaster. Figure 2 shows a comparison of the areas which can be served by a 50,000-watt station over average soil when operating on approximately the highest broadcast frequency in one case, and approximately the lowest broadcast frequency in the other case. Figure 3 shows the difference in area which exists with a station of 50,000 watts on 1000 kilocycles, when transmitting over the two extremes of soil conditions which might be encountered in actual practice. Soil conditions obviously play an important part in determining coverage. Figure 4 shows a comparison of the areas when operating with 50,000 watts, using in one case approximately the lowest broadcast frequency and the best soil conditions encountered in practice, and in the other case approximately the highest broadcast frequency and the worst soil encountered in practice. This is a combination of Figures 2 and 3.

Other factors which affect coverage are interference and local noise levels, but these are partly a function of field intensity received.

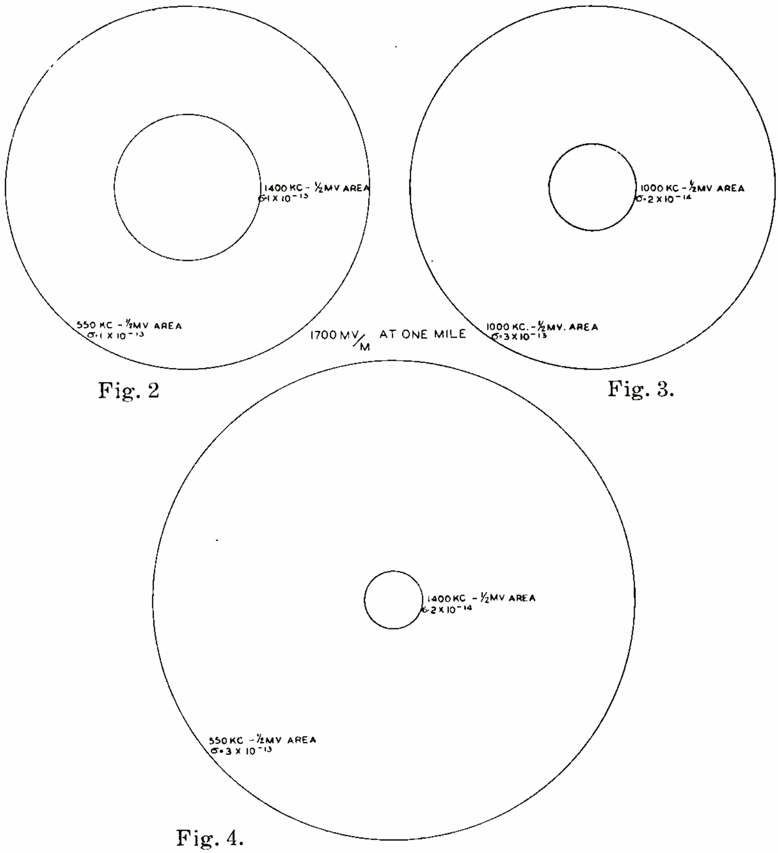


Fig. 2

Fig. 3.

Fig. 4.

Coverage factors.

The remaining factor is the antenna and it is to this that the rest of the paper is devoted.

EVALUATION OF ANTENNA EFFECTIVENESS

Because the amount of energy radiated by an antenna does not express its effectiveness in giving service along the surface of the earth, a ready means of evaluating antenna effectiveness other than power output divided by power input is required. There is another reason. There has been no suitable means available for measuring the power output of an antenna.

Measurement of average field intensity at one mile, provides this method of evaluation quite satisfactorily. (In some cases attenuation within one mile makes a small correction desirable.) The type "T"

Fig. 5—WMAQ antenna.

antennas produced, with 50 kilowatts power, approximately 1200 millivolts at one mile. Guyed towers with narrow bases and tops and large center sections appear to produce 1600 millivolts at one mile or slightly more. The uniform cross section towers of about 195 degrees electrical height, such as the new WJZ anti-fading antenna, produce slightly over 1800 millivolts at one mile. If each of these quantities is corrected for attenuation within one mile, they would become about 1300, 1700 and 1900.

The one-mile field intensity indicates the distribution of the radiated field directly. A low field intensity at one mile ordinarily indicates that much of the energy from the antenna goes skyward. A high

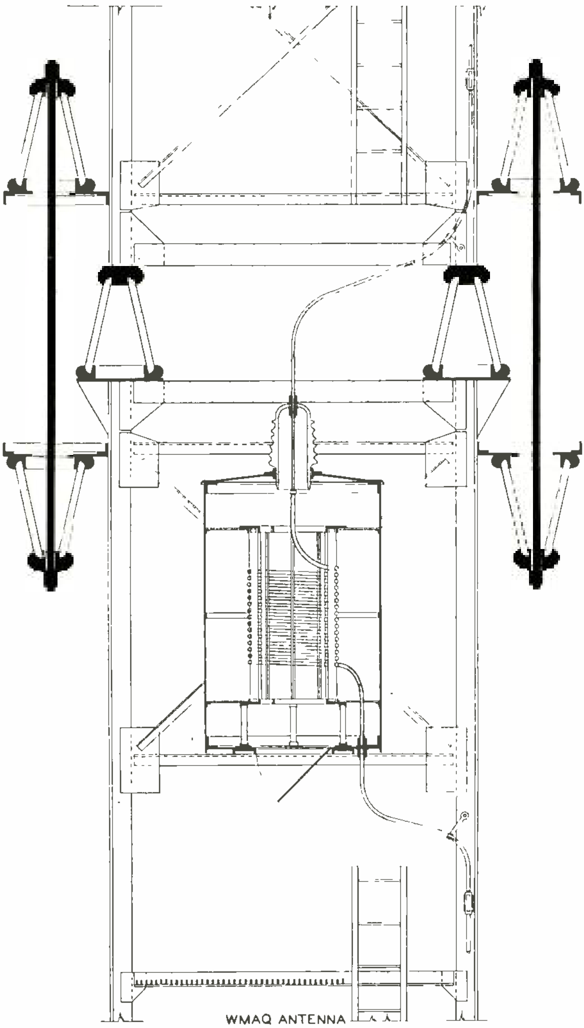


Fig. 6—Details of sectionalizing system.

field intensity indicates that the energy is "squashed" or compressed close to the earth where it is most useful.

Broadcast antennas may be improved in effectiveness by going to great heights, but economic factors usually make it impractical to do so. For the lower broadcast frequencies a height of about 190 electrical degrees will usually serve to prevent serious fading, within those areas receiving serviceable field intensities, with powers up to at least 50 kilowatts.

Top Tuned Antennas

Due to the proximity of airlines with heavy traffic, it is sometimes necessary to build an antenna to less than 190°. If the restrictions are not too rigid, it is possible to approach the performance of an ideal antenna by using a lumped loading system at the top of the tower. This expedient is a modern and tremendously improved version of the old familiar flat top. The improvement consists of adding a

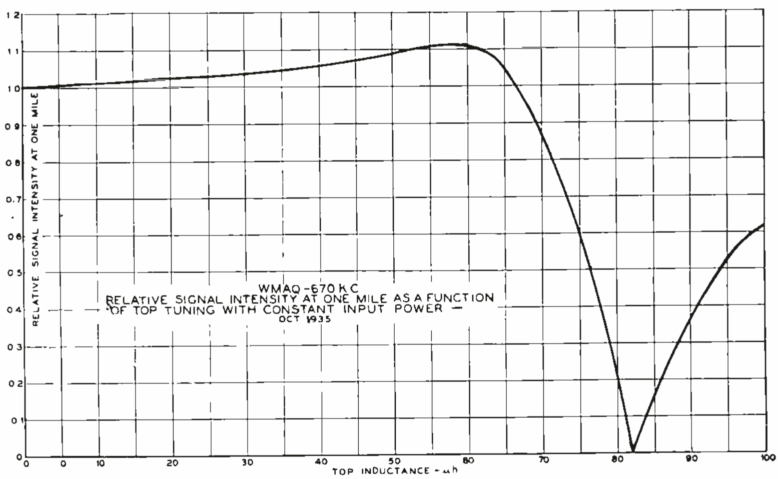


Fig. 7—Graph of one-mile signal intensity.

lumped capacity flat top with lumped series inductance, if necessary, to raise the current loop to the optimum point on the tower. If the tuning coil is used and it is large enough, the tower characteristics and current distribution may be varied at will over a tremendous range.

The WMAQ antenna, Figure 5, was built with top loading because of the proximity of commercial air lines. It is 490 feet high, operates on 670 kilocycles with 50,000 watts and has a 60-foot steel saucer outrigger at the top. Eighty feet below the top there is a sectionalizing system containing insulators and a tuning coil. Figure 6 shows the details of the sectionalizing system.

This tuning coil and the weather proof copper housing weigh over 1500 pounds and cost approximately $1500. The assembly is practically air tight and is insulated for the 70,000-volt peaks which are often obtained during modulating conditions. The reactance required in this tuning coil to obtain the desired current distribution is approximately 400 ohms for this antenna height. The current in the coil under the optimum conditions of adjustment is over 50 amperes. The insulators not only have to be adequate for the high voltages developed, but also must support the upper 80 feet of the tower and the 60-foot outrigger, up to a 100-mile wind velocity, with a suitable factor of safety. Several preliminary mechanical designs for the sectionalizing structure were discarded before a final satisfactory design was evolved. In addition to the other problems, the lighting circuits for the tower had to be carried through and beyond this point. This was accomplished by making the coil large, of one inch IPS copper tubing, and running the circuits through the tubing.

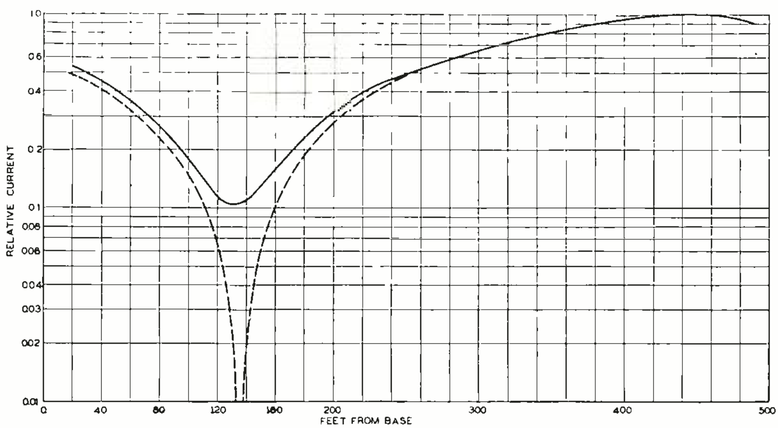


Fig. 8—Graph of measured current distribution.

The manufacture of this coil was quite a problem in that short lengths had to be brazed together and then formed into a coil. It could not be made in one piece. The lighting wires had to be installed in the tubing before it was formed. All of the supporting insulation is built of micalex with sufficient insulation to carry the design up to the corona point. Special clamps and other parts had to be built to make the corona point as high as reasonably possible. The entire coil assembly is inside a copper can approximately six feet in diameter and six feet high with only one door, in the bottom.

Figure 7 shows the one mile signal intensity as a function of the amount of inductance used in the top tuning coil. Figure 8 shows that the measured current distribution obtained with the top tuned was sinusoidal, and it may be compared with the theoretical ideal distribution which is shown on the same curve. Full advantage was taken of the opportunity to study thoroughly this first ideal design of a top tuned antenna system, but lack of space prevents showing all of the many other measurements made. One of the most important things that these measurements showed was that there were no factors in the design of such a tower that could not be satisfactorily evaluated by the design engineer.

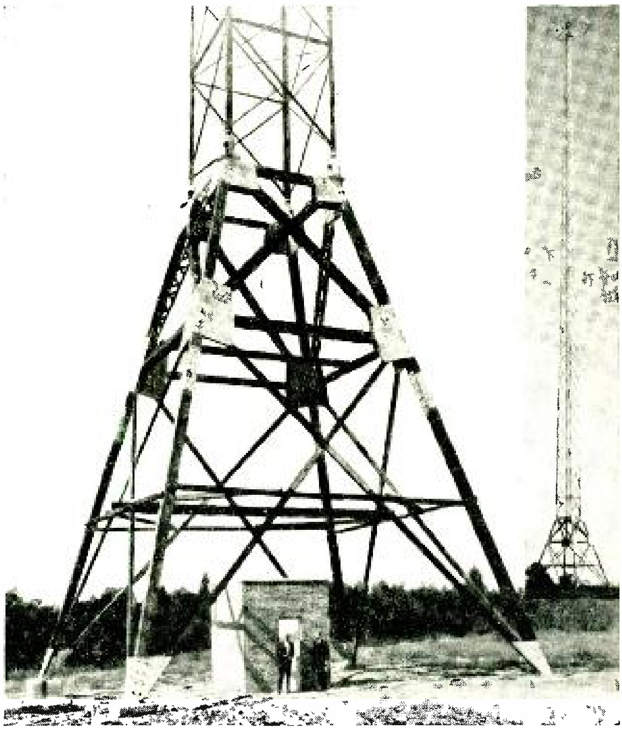


Fig. 9—WPTF antenna system.

A Study of the Effect, on Distant Transmissions, of the Vertical Pattern of a Broadcast Antenna

It is established that the "squashing" of the vertical field of an antenna increases the primary service area. However, how does this effect the transmission to distant points?

Various theories had been advanced as to exactly what happens to a broadcast wave in its path from a transmitting antenna to a receiver at a distant point. No very exact measurements were available to show how the energy from the transmitting antenna should be concentrated to obtain the most favorable distant transmission. For instance, does a wave, bounce several times between the heaviside layer and the earth? In 1934 the opportunity presented itself to make such observations and measurements in connection with some other research on directive broadcast transmission.

NBC designed a directional antenna for station WPTF, Raleigh, N. C., and in 1934 had adjusted it and placed it in operation. There were two identical antennas with 50-foot wooden bases and 320 feet of steel above them, tapering from an 11-foot square at the steel base to a 3-foot square at the top. These antennas had 30-foot steel saucer outriggers and associated tuning apparatus at the tops which were

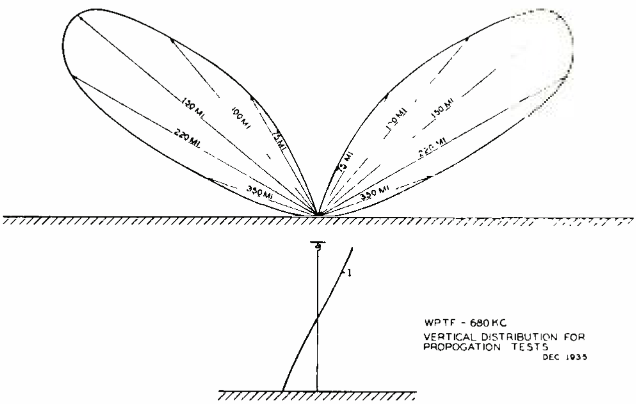


Fig. 10—Vertical distribution pattern for propagation tests

used for adjusting the effective electrical height and current distribution. These are "tuned top" antennas.

Figure 9 shows the antenna system. For the purposes of the experiments to be described, these antennas were operated independently of each other under different adjustments to obtain a quick means of switching from one condition of vertical field distribution to another. Relays were available for switching purposes at each tower and these relays were controlled remotely by push buttons in the transmitter building. The original purpose of the relays was to change from directive to non-directive transmission at sunset, but for the purposes of this experiment they were used to disconnect and suitably detune one antenna while the other one was being used and vice versa.

One antenna was adjusted for normal current distribution. The other antenna was adjusted by means of the top tuning system to produce a minimum signal intensity at the surface of the earth. The latter adjustment gives a vertical distribution pattern as shown in Figure 10. With the facilities provided, these conditions could be alternated practically instantaneously. By means of field intensity measurements on the ground and in an airplane, the vertical patterns of these two antennas were measured and checked against the calculated patterns. Figure 11 shows the field intensity measuring equipment set up in the airplane. Figure 12 shows a recording station established four miles from the station to keep a continuous check

Fig. 11—Field intensity measuring equipment.

upon the adjustments during the transmission. Previously established recording stations made continuous recordings of field intensity at Corbin, Kentucky; Marion, Illinois; Emporia, Kansas; Albuquerque, New Mexico; Oklahoma City, Oklahoma; Duluth, Minnesota; Urbana, Illinois; Columbus, Ohio; and Boulder, Colorado. Figure 13 shows the location of these recording stations.

The transmitting conditions were alternated at twenty-minute intervals between the hours of 12 midnight to 6 A.M., of which the hours of 3 to 6 A.M. are shown in the figures. KPO operated on the same frequency until 3 A.M. after which the channel was clear for this experiment. Only a few of the many recordings are shown, for lack of space, although the experiment continued over a period of approximately two weeks to evaluate properly temporary changes in long distance transmitting conditions. Figure 14 shows some of these recordings. With the exception of Corbin, Kentucky, which was within the sky wave range of the transmissions from WPTF, no recording stations received any signal during transmissions with zero ground signal intensity. The recordings did not indicate zero because of the static level, but no signal was heard. The measured intensity at the surface of the earth under this condition was .2 of 1 per cent of normal. The experiment shows many interesting points, the most important of which is that the transmission which provides coverage to distant

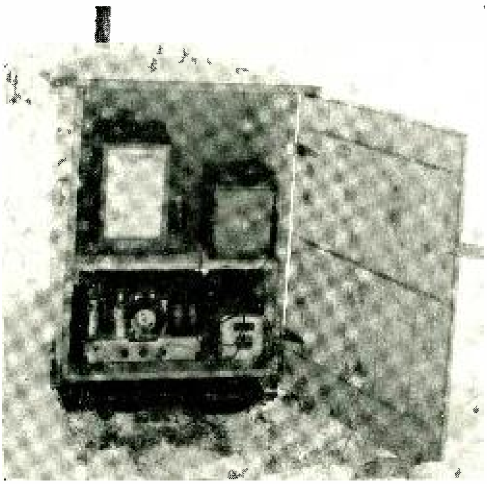


Fig. 12—A recording station.

points is confined to angles less than 10 degrees above the surface of the earth. This establishes clearly that the ideal broadcast antenna should concentrate all of the radiation as low as possible. In these tests there were no evidences of multiple reflections. It is not possible under practical conditions to build antennas high enough to obtain the indicated ideal distribution because they would in some cases be 3,000 feet in height. Other mechanical complications, in addition to the height, present difficulties which make such a radiator impracticable.

Effect of Current Distribution on Fading

Early in 1934, NBC designed a directional antenna for Station WHIO, Dayton, Ohio. One of these towers was utilized in an interesting experiment that showed the reduction of fading which can be

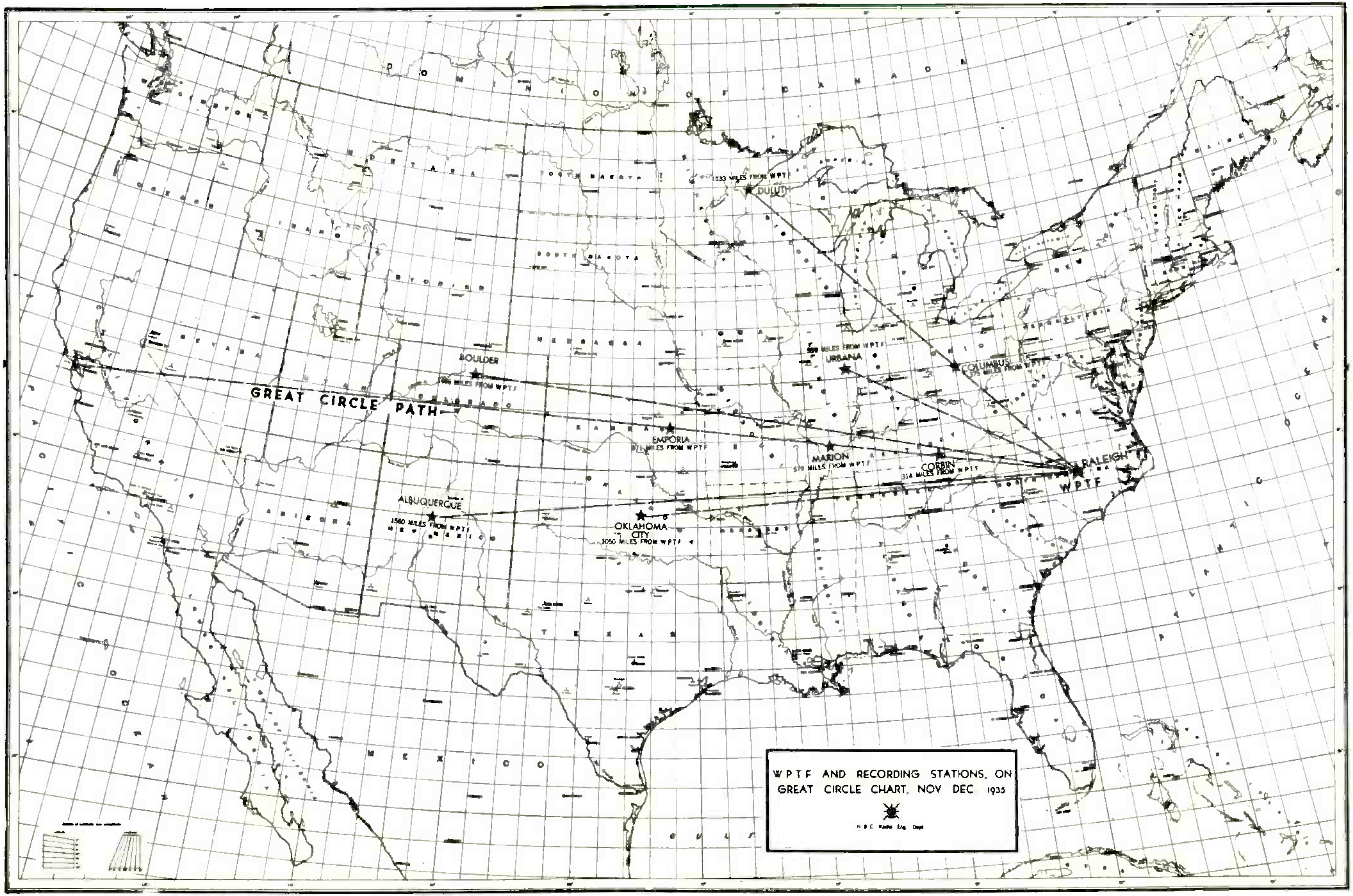


Fig. 13—Map showing location of recording stations.

accomplished by controlling the current distribution. The WHIO antennas have an electrical height of approximately 135 degrees and have at the tops steel saucer outriggers with tuning coils which make possible a wide variation in the effective electrical height. Upon the completion of one tower and before the second one was erected, recordings of fading were made to show the effectiveness of the tuned top in reducing high angle radiation and fading. Figure 15 shows a typical change in fading at 60 miles. It compares recordings made during consecutive periods when the vertical distribution of field was varied by changing from a top tuned ideal condition to an untuned condition at the top. These conditions produce the effect of a substantially ideal antenna in one case compared with a short antenna in the other case. The fading with the top tuned was unnoticeable with automatic volume controlled receivers whereas the fading with the top untuned was distorted and unusable.

In 1935 a tuned top antenna was built at Station WMAQ, Chicago, Ill. This was 490 feet high, top tuned to raise the effective electrical height from 130 degrees to 190 degrees. Figure 16 shows the comparison of the fading at 60, 85, and 125 miles when the transmitting conditions were alternated between the old ineffective WMAQ antenna, the new antenna with the top tuned and the new antenna with the top untuned. Comparisons were also made of the fading from this station, operating normally, and other Chicago stations also operating normally. Space does not permit showing all of these recordings, although they demonstrate effectively the superiority of an antenna of the ideal or approximately ideal characteristics compared with the obsolete "T" types supported between 300-foot towers.

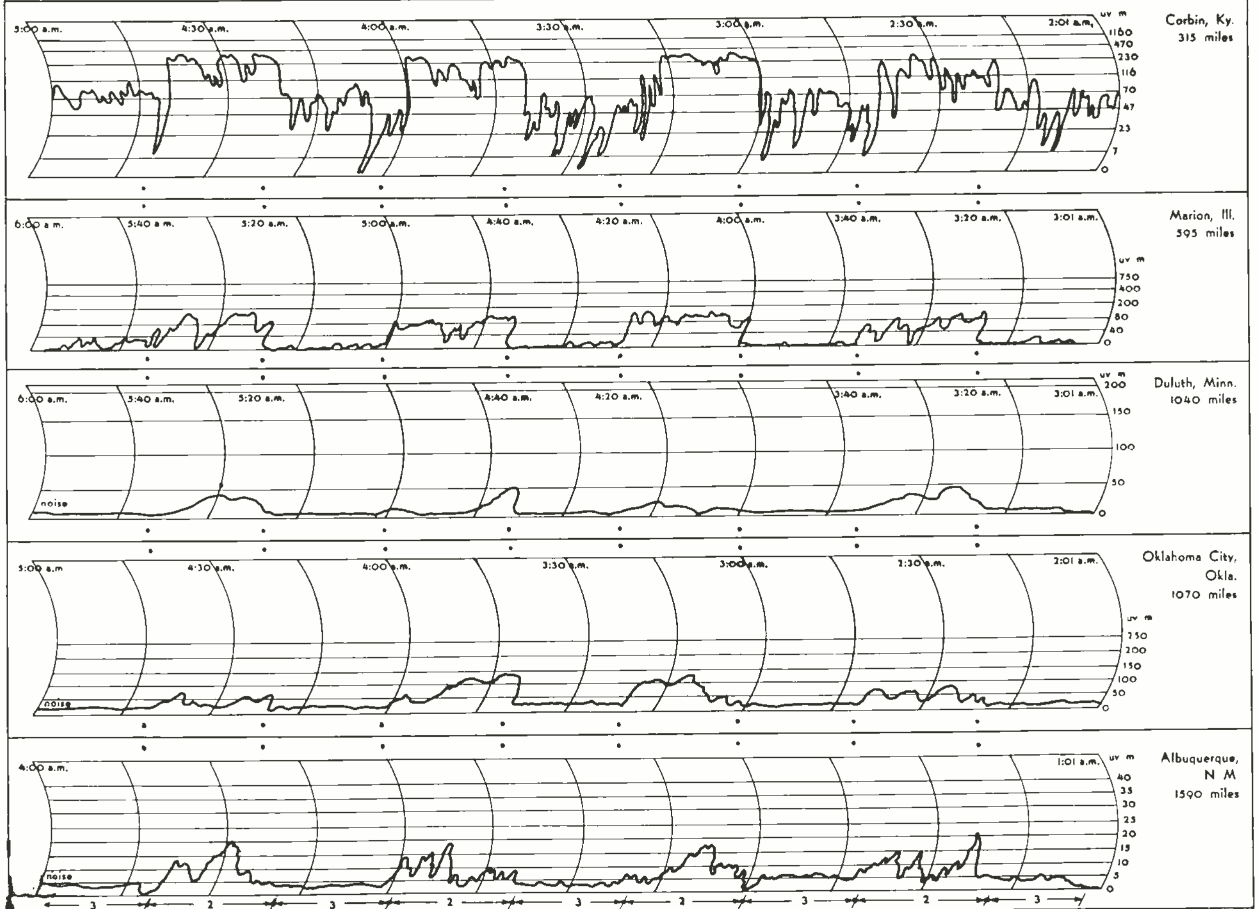
Mechanical Design of Antenna Towers

Much thought has been given by the NBC to the mechanical specifications for radio towers. It is rather common practice to design broadcast antennas for an indicated wind velocity of 90 miles per hour, corresponding to an actual wind velocity of 68 miles per hour. A search of recorded wind velocity over periods of approximately 50 years, in many localities, indicates that a tower designed for 90 miles indicated velocity is safe, although the figure could not be reduced much before it became unsafe. Cost estimates covering a 500-foot guyed antenna of uniform cross section designed for different wind velocities were, for a 90-mile indicated wind design $16,969, a 100-mile design $18,260, a 120-mile design $19,621, and 140-mile design $22,207. Figure 17 shows the difference between actual and indicated wind velocities for the three-cup and the four-cup annomometers.

Test No. 2: Normal 90° Antenna
Test No. 3: Top tuned for minimum ground signal

W P T F
RALEIGH, N. C.
680 KC.

National Broadcasting Co., Inc.
Radio Engineering Dept.
Dec. 17, 1935



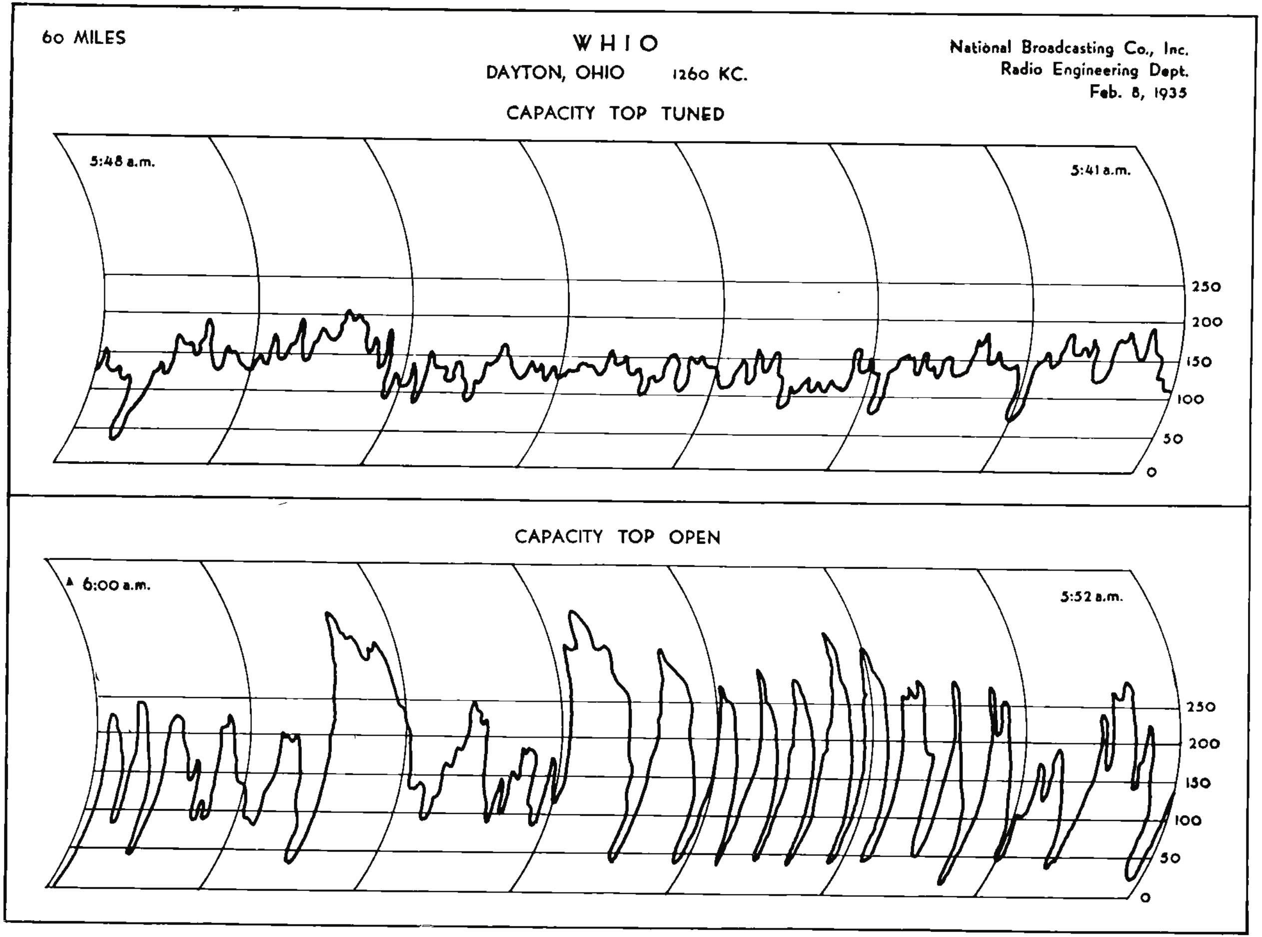


Fig. 15—Typical change in fading at 60 miles.

A factor of considerable importance which is often overlooked is the difficulty in determining the wind conditions which cause the failure of a radio tower. The government maintains wind reporting stations at many locations, but they record only average conditions in the immediate vicinity and these would not necessarily hold true for an antenna located several miles away, or even several hundred feet away. The literature was searched to find all of the data published concerning the variation of wind velocity over various sections of a tower at given instants.

There is comparatively little information available on this subject. The wind velocity is higher at the top of a high tower than it is at the base by a rather considerable amount although tower designers ordinarily do not design antennas for such a condition. In mechanical specifications for NBC's radio towers full allowance is made for these conditions and in the case of the WJZ antenna it was specified that the top section should be designed for a wind load of 35 lbs. per square foot and the lower section for a wind load of 25 lbs. per square foot, from any angle. Thirty-five lbs. per square foot is equivalent to an indicated wind velocity of 125 miles per hour or an actual wind velocity of approximately 95 miles per hour. The steel specifications were as follows:

All members shall be designed for the maximum stresses, and the unit stresses in pounds per square inch shall not exceed the following:

Axial tension (net section)	18,000 lbs./sq. in.
Axial compression (net section)	
20,000 — 85 L/R for L/R 150	
15,500 — 55 L/R for L/R 150	
Maximum compression stress	15,000 lbs./sq. in.
Bending (extreme fibre)	20,000 lbs./sq. in.
Shear, bolts	10,500
Bearing—bolts	21,000

Where L is the unsupported length of the member and R the least radius of gyration, both in inches, the ratio L/R shall not exceed the following:

Main legs	120
Other compression members	180
Redundant members	200

Specifications covering guy wires require individual treatment. Generally speaking, a guy wire, with full wind loading on the tower, should not be required to carry more tension than one-third of its ultimate strength. In addition the guy wires should be initially stressed to not less than one-half of the stresses they will be subjected

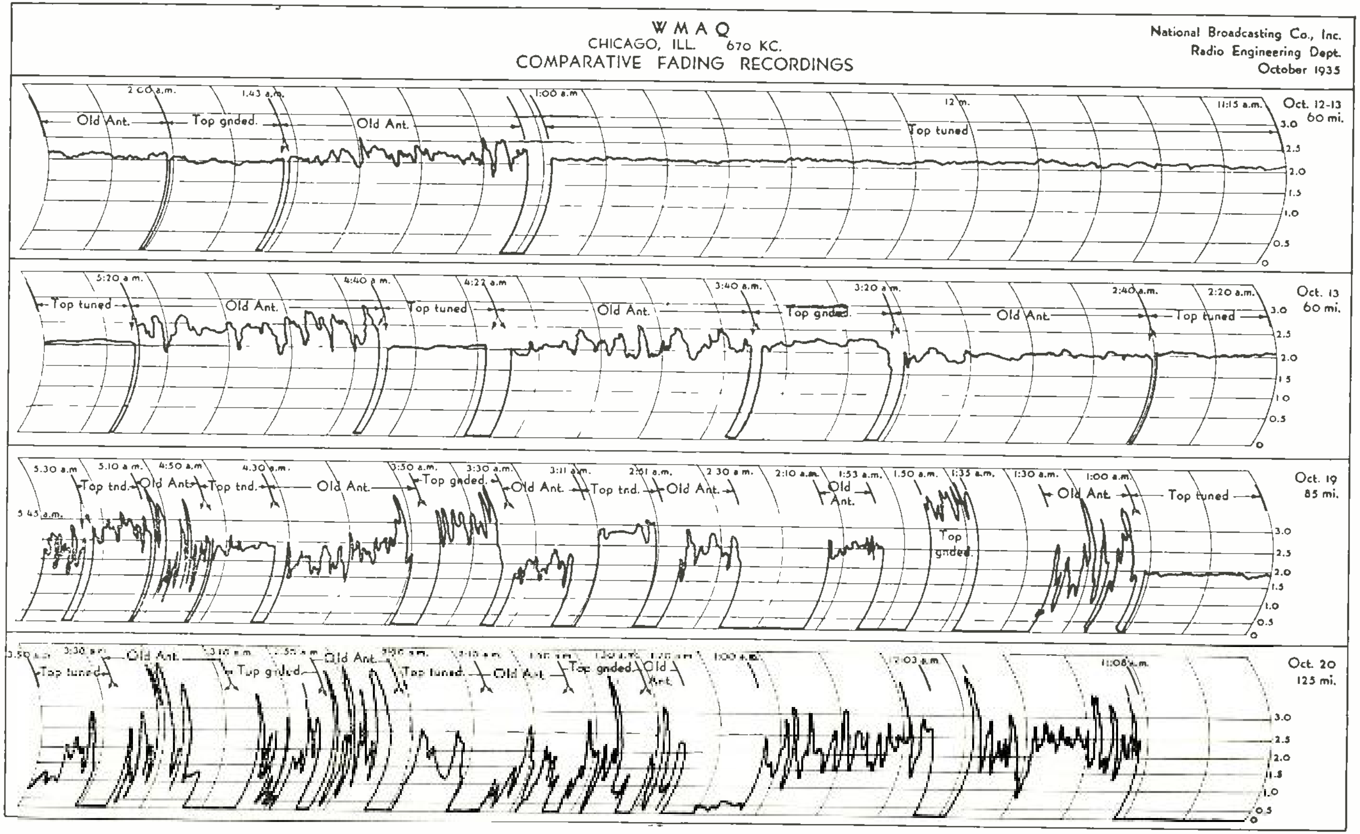


Fig. 16—Comparison of fading at 60, 85 and 125 miles.

to under full wind loading conditions. The object of this specification is to reduce the slack in the guys and so minimize whipping of the tower which would introduce extremely high transient stresses in the guys during gusts of wind. It is not believed that the scope of this article is wide enough to warrant going further into this particular phase of the subject.

Ground Screens

Where there is high base voltage on a tower the reduction of dielectric losses in the earth merits careful consideration. These losses are the result of heating of the earth between the lower part of the antenna and the actual ground wires which customarily are buried.

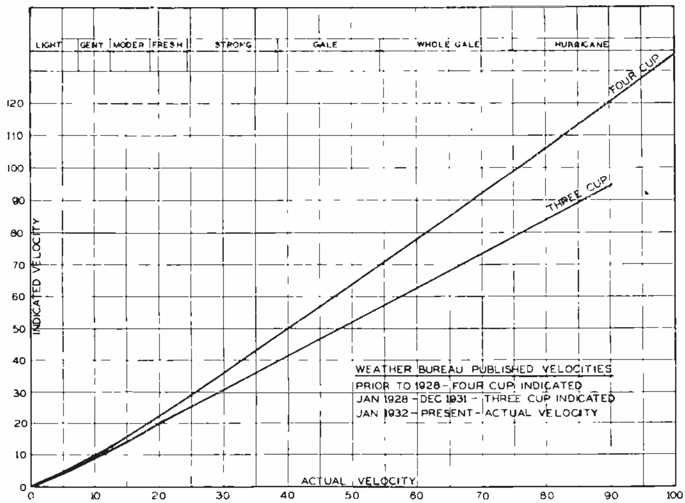


Fig. 17—Difference between actual and indicated wind velocities.

High base capacity should introduce very little loss, but interposition of the earth may introduce considerable which, fortunately, can be rather easily reduced. The first application of the ground screen and the quantitative measurements of the reduction of losses on broadcast frequencies was at station KOA, Denver, Colorado, 1934. These tests consisted of making measurements of field intensity at one-mile distance with constant power input, over the broadcast spectrum, without a ground screen. The entire performance was then repeated with a ground screen in position. This entailed making painstaking measurements of antenna resistance and reactance over the broadcast spectrum under each condition since the antenna input power could not have been determined without them. The screen consisted of galvanized iron fencing of approximately ¾-inch mesh, 50 feet square. Figure 18 shows the improvement in average one-mile field strength over the broadcast spectrum obtained by the use of this ground screen. An equal improvement obtained by increasing the power of this station would have cost over $30,000 whereas the ground screen cost approximately $300.

New WJZ Antenna

Over ten years ago, Stuart Ballantine* pointed the way to the modern broadcast antenna, but the high cost and mechanical problems proved to be a deterring influence on rapid development. Several years

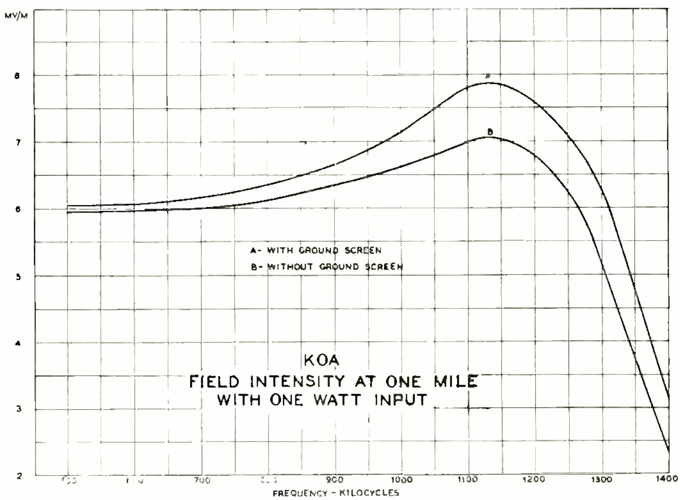


Fig. 18—Improvement obtained by use of ground screen.

ago high steel radiating towers made their appearances. The first designs were less than ideal in that they had wide bases or wide midsections producing variations in inductance and capacity, which in turn produced current distributions quite different from the sinusoidal distribution desired.

Brown and Gehring† recently demonstrated in model experiments an effect which had been anticipated mathematically. Briefly, the benefits expected from antennas built with slightly greater than one-half wavelength were only partly obtained because of the cross sectional variation throughout the length. This produced nonsinusoidal current

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* *Proc. IRE*—Vol. 12, 833-839, 1924.

† *Proc. IRE*, Vol. 23, 311-355, 1935.

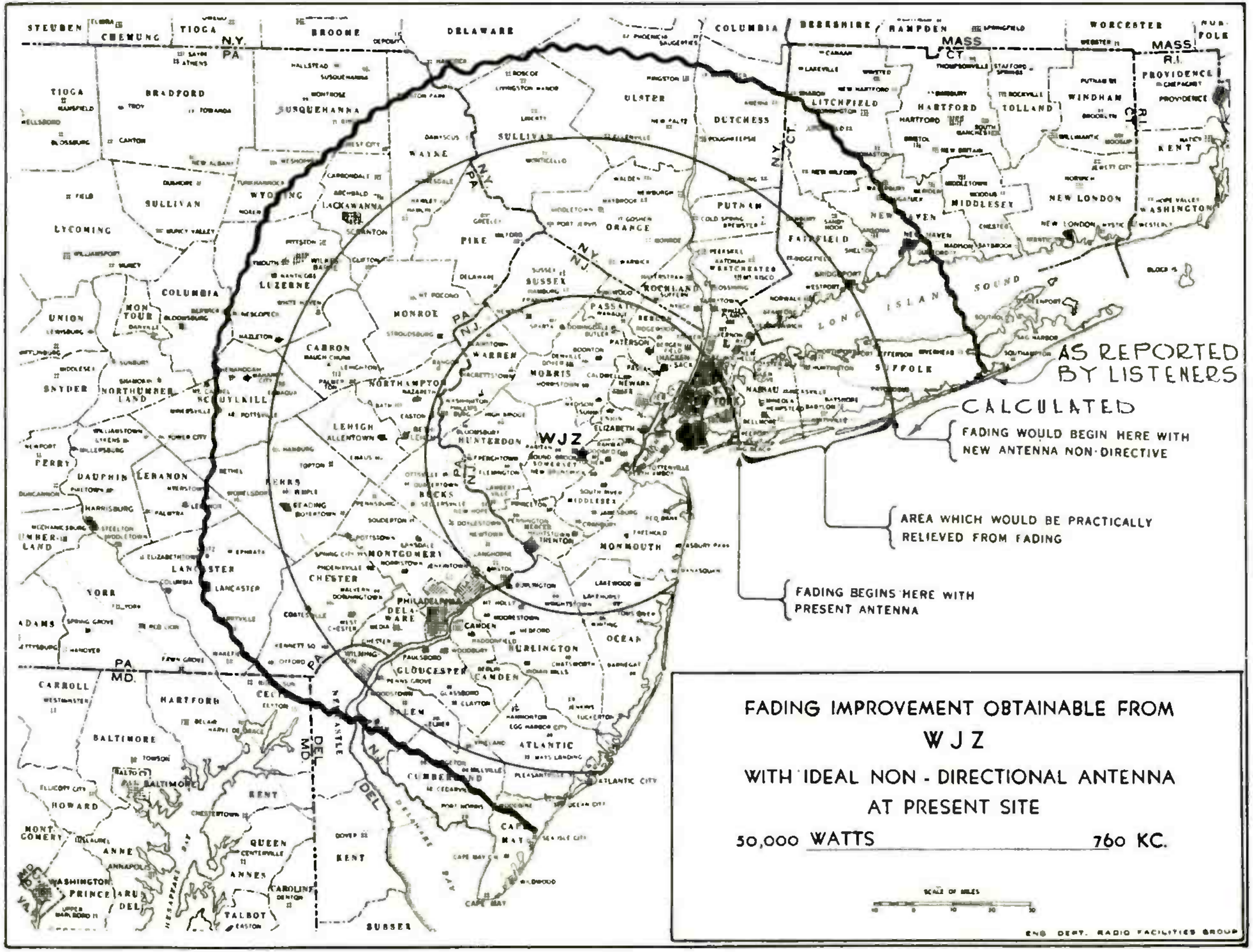


Fig. 19—Anticipated and realized reduction of fadings.

distribution which led to the distortion of the vertical field pattern. Some concentration of the vertical field at low angles above the earth was obtained, but not to the extent anticipated. The diameter or cross section of an antenna is not important within sensible limits so long as it is substantially uniform throughout its length.

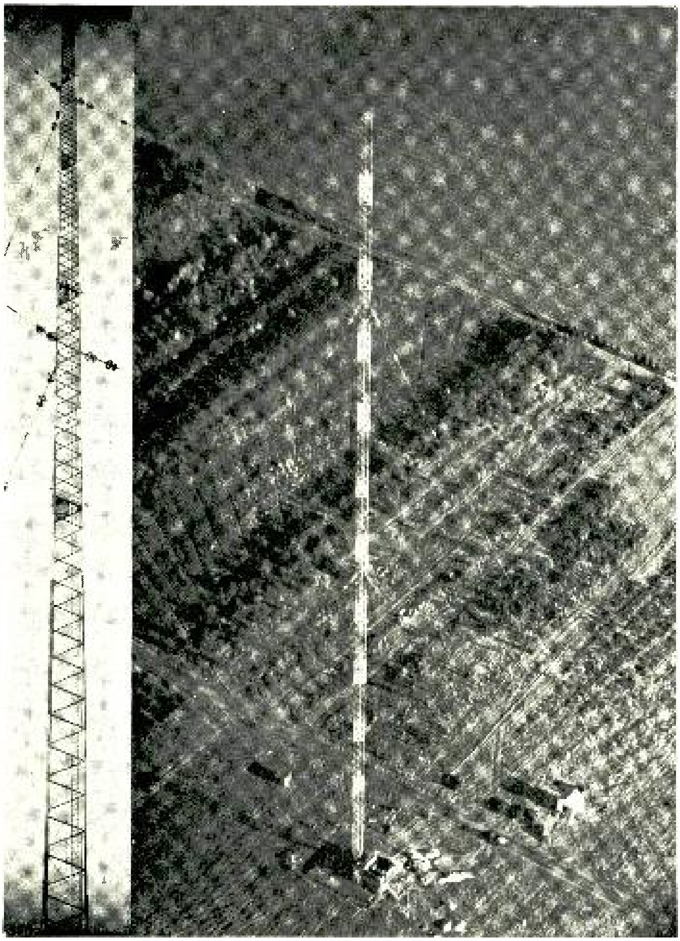


Fig. 20—WJZ antenna system.

Variations result in reducing the radiation at low angles and increasing it at high angles. Brown and Gehring showed conclusively that this is true. It has been proven to be true in measurements of actual antennas, but not quite as conveniently as can be shown with model experiments in which changes in shape can be readily made, other conditions remaining unchanged. The measured 1800 millivolts at one mile obtained at WJZ, Bound Brook, N. J., near New York City, represents about the maximum that can be obtained, at present at least, with antennas built to about one-half wavelength height. The 1800 millivolts recorded includes no corrections upward for ground loss within one mile, or other factors which represent the last unavoidable losses in any man-made instrument. When correction is made for earth loss within one mile, which in this case is 6 per cent, the WJZ field becomes 1910 millivolts per meter. NBC, in its studies of antennas, coverage, etc., has measured the one mile field intensities of many

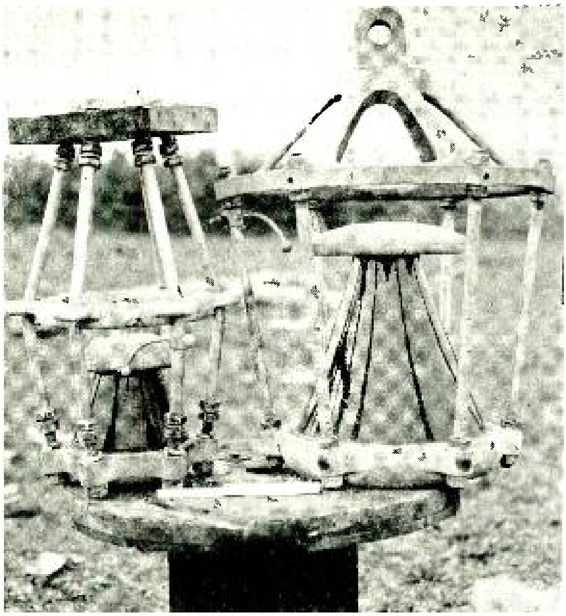


Fig. 21—Two types of insulators used in guy wires of WJZ antenna.

radio stations. On an equal power basis, WJZ has the highest field ever measured, as it should have.

Prior to approval of the WJZ project careful calculations were made of the improvement which could be obtained by the construction of a new tower, including the population which would be added to the service area, those who would be relieved of fading, etc. After the antenna was placed in service on November 15 the letters from the listening audience were carefully tabulated on maps to show where fading had been eliminated, where it was just noticeable and where it still existed and these maps were then compared with the engineering estimates of improvement which had been made prior to construction. Figure 19 shows the anticipated and the realized reduction of fading. Figure 20 shows a picture of the antenna system. This new antenna is 640 feet high, is triangular in shape, and has 6½-foot faces. It is so tall with respect to its width that it was very difficult to obtain a picture which could be satisfactorily reproduced. The best picture obtainable from 30 attempts was from an airplane and it is reproduced herewith. This tower is built to withstand an actual wind velocity at the top of 95 miles per hour and at the bottom of approximately 70 miles per hour.

Particular attention was given in this design to reducing or eliminating arc-overs of the insulators due to high static charges. A study was made of the potential gradient of the tower and also an estimate was made of the static potentials which might be developed across the guy-wire sections. As a result the insulators are very close together near the tower and are separated increasingly towards the bottom of the guys. Figure 21 shows the two types of insulators used in the guy wires of this antenna. These insulators are built in such a manner that the failure of the porcelain will not permit them to pull apart. The porcelain at all times is under compression. The large insulator has a flashover rating of 100,000 volts when dry and 85,000 volts when wet. These insulators are capable of resisting a mechanical tension of 200,000 pounds. The normal load due to the weight of the towers, guy wires, etc., is 230,000 pounds. The guy wires for the tower contain 12 of the large insulators and 33 of the small ones. The upper guys consist of 1¼-inch stranded cable with an ultimate strength of 162,000 pounds. The static stress without wind loading on these guys is 24,000 pounds and under full wind loading conditions is 48,000 pounds. The bottom guys consist of 1-inch stranded cable with an ultimate strength of 103,000 pounds, a static stress without wind loading of 15,400 pounds, and a full wind loading stress of 30,000 pounds.

Directly beneath the base of the antenna is a copper ground screen 48 feet square and radiating from the ends of this copper screen are 120 radials of buried copper ribbon each 600 feet long. Altogether there are over 90,000 feet of buried copper ribbon in the ground system of WJZ.

The antenna is connected to the transmitter through a coaxial tube transmission line of greatly improved design. It has a dry flashover rating of 95,000 volts and a wet flashover rating of 85,000 volts. Although the line is not the largest coaxial type ever built it has, so far as is known, the highest voltage rating of any ever built.

The transmission line is designed to operate with 500 kw. carrier and 2,000 kw. peak modulation power. It is of coaxial tube aluminum alloy construction with an outer tube inner diameter of 10 inches, and an inner tube outer diameter of 2¾ inches.

The line is 500 feet long, is built in 22-foot sections, and has provision for the 10-inch longitudinal expansion which would develop between a $-40°$ and $+120°$ range of temperatures. The line is supported above ground at 22-foot intervals. At each support a small trolley on ball bearings is free to move on a weather enclosed track. The inner conductor is free to move independently of the outer one as it will to a minor extent. The slenderness ratio of the inner tube is so low, and the resistance to movement so low, that buckling and short circuit could not occur. The clear air sparkover voltage in "coax" lines usually is considerably greater than can be obtained because of the necessity of imperfect insulating supports between tubes. A new type of conical porcelain insulator is used in the line which makes possible a design in this case with only 15 per cent difference between an ideal line without insulators and the actual line. The heat loss per insulator is only 3.8 watts on 500 kw.

The tower lighting consists of 100-watt lamps on each corner at the 105, 210, 315, 420, and 535-foot levels and a 1,000-watt Fresnel lens aviation beacon at the top, flashing red at 40 cycles per minute. The lighting is controlled by a Weston light meter which automatically operates at a pre-determined value of light intensity.

Judging by the response from listeners, which was immediate and enthusiastic, the severe selective fading along Long Island Sound, in Westchester County, New York, and other important areas, has been eliminated. The signal was at the same time increased five decibels. If the increase obtained with the new antenna were to be obtained, instead, by increasing power, 115 kw. would be required. Sixteen thousand square miles have been added to the WJZ primary service area. This is equivalent to an area 126 miles square.

The writer wishes to take this opportunity to gratefully acknowledge the efficient and untiring work of Mr. Lester Looney, Mr. Carl Dietsch and Mr. William Duttera, Engineers of the NBC Radio Facilities Group. These men have taken a very prominent part in building up the Radio Facilities of NBC over a period of many years. The antennas described in this paper were largely engineered by Mr. Duttera.

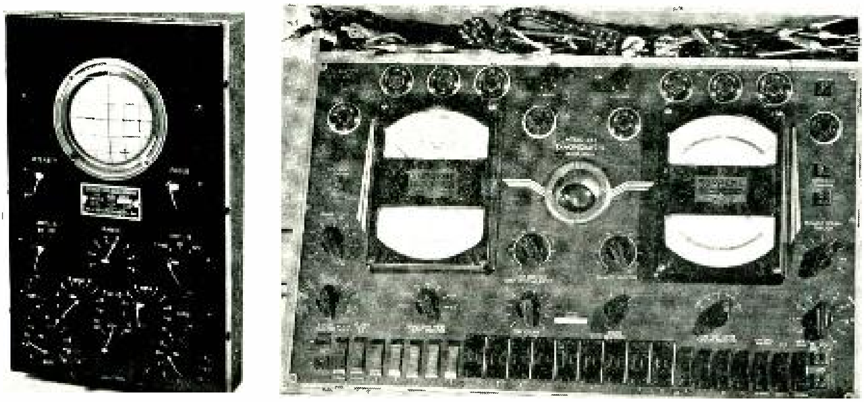
TECHNICAL EDUCATIONAL REQUIREMENTS OF THE MODERN RADIO INDUSTRY

By

W. F. Aufenanger

Superintendent, R.C.A. Institutes

THE rapid growth of radio, attaining the proportions of a major industry in the relatively short period of little more than one decade, has had no parallel in the annals of American business. Technical progress, sponsored and nourished by commercial

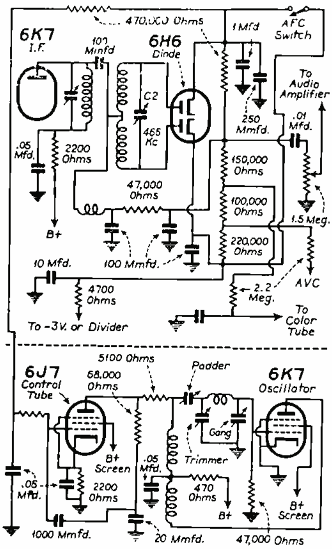


Typical modern servicing equipment. The cathode-ray oscilloscope is also invaluable as a visual aid in school laboratories.

opportunity, is swiftly advancing and widening in scope and is further accelerated by the lash of competition. Research and engineering skill of the highest order are today bringing forth instruments and equipment and producing radio services so superior to those available a few short years ago that even the layman marvels at the rapidity of radio's development.

A moment's reflection brings to mind many evidences of the progress resulting from this intensive technical activity, which is not confined to one specialized field, but is definitely evident throughout the entire radio industry of today. Witness the feverish intensity of aviation radio development, with new organizations entering the race almost daily; the marked improvement in short-wave and ultra-short-wave communications, both broadcast and telegraphic; volume range expansion, automatic frequency control, and other heretofore unknown innovations to broadcast receivers; the commercial introduction of facsimile, with one communications company transmitting actual weather maps of the entire North Atlantic Ocean almost instantaneously to any and every vessel on the high seas equipped to receive them; the widening field of application of electronic devices; advances in sound recording and reproduction technique, and many other improvements.

With this onward march, however, comes inevitably an increasing

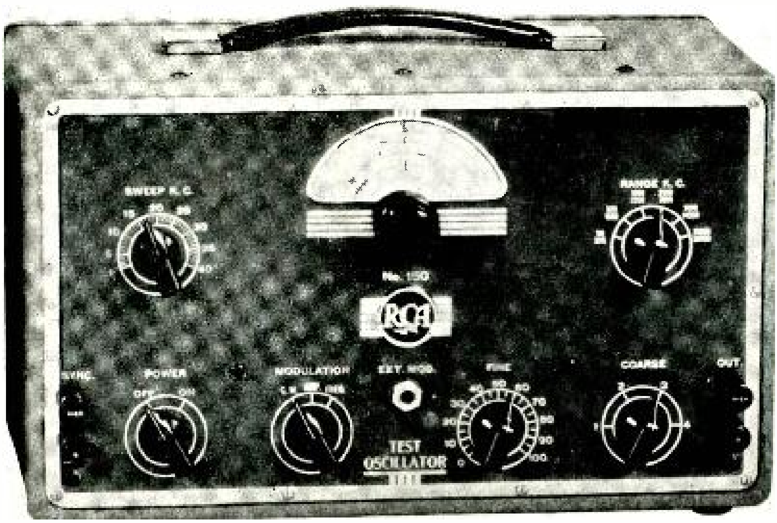


A type of circuit which service men are called upon to maintain and adjust today.

complexity of circuit design and function in equipment. Unless the field technicians of the industry keep in step with the advance of the designing and producing vanguard, the attainments of the latter group may be in vain.

If a fine receiver, functioning perfectly when shipped from the factory, requires adjustment or possible repair, or requires intelligent treatment of installation problems in order to bring out its finest performance, the best in engineering design and production skill will be brought to naught unless the technician in the field is also fully competent to render proper service.

At no previous time in the history of the radio art, has the need for thorough technical knowledge on the part of the great army of field technicians required by the industry to carry on its daily work, been so pressing a problem as at the present time. It is becoming increasingly evident that the radio technician in the field, while no doubt competent to satisfactorily service the relatively simple sets of the past, has not, in many cases, the depth of exact technical knowledge necessary to understand the intricacies of the complex radio and audio circuits contained in the extremely sensitive, higher-fidelity receivers of today. Many of the larger manufacturers have become aware of this situation and have been forced to regard it with growing apprehension. Some of them have taken action to disseminate technical infor-



The electronic sweep test oscillator is another instrument used in servicing modern broadcast radio receivers.

mation to the field by means of lecture meetings in various cities; the wide distribution of printed technical data; the issuance of free periodicals, and the formation of leagues and associations of service technicians. All of these measures have helped to supply and spread considerable information of much definite value.

The real root of the problem, however, is more fundamental. By reason of technical advancement, a higher level of technical ability in the field is absolutely necessary. The field technician who lacks a sound understanding of basic theory cannot possibly comprehend the complex circuits employed in recent receivers. The printed data freely furnished by the manufacturer is largely lost to him because he can but vaguely understand it. For such a man, there is but one solution, and it is mandatory. He must acquire the necessary knowledge, both fundamental and advanced. If he fails to do so, he will inevitably be replaced by the skilled specialist who is now being educated through the medium of carefully planned technical courses to meet the higher standards of today's requirements.

The problem is one clearly within the province of the educational field, and it is fortunate that there are specialized facilities in existence to meet it.

The need for a technical educational service of the highest type is evident, and the primary purpose of this article is to impress forcibly upon the average "man-in-the-field" that he faces the urgent necessity of meeting the challenge of rapid technical progress being made by the manufacturers of the instruments and services upon which he depends for his living. If he does not meet it, he will be replaced eventually by someone who has acquired the ability to do so.

The next article of this series will discuss a few of the more involved problems encountered in the field of receiver servicing.

HORN LOUD SPEAKERS

By

Harry F. Olson
RCA Manufacturing Co., Camden, N. J.

Part I. Impedance and Directional Characteristics

Introduction

HORNS have been widely used for centuries for increasing the radiation from a sound source. The principal virtue of a horn resides in the possibility of presenting practically any value of acoustic impedance to the sound generator. This feature is extremely valuable for obtaining maximum overall efficiency in the design of an acoustic system. As an example, in a horn loud speaker high efficiency is obtained by designing the system so that the driving force works against resistance instead of inertia of the diaphragm. Employing suitable combination of horns, directional characteristics which are independent of frequency, as well as practically any type of directional pattern, may be obtained. The combination of high efficiency and the possibility of any directional pattern makes the horn loud speaker particularly suitable for large scale sound reproduction. It is the purpose of these papers to consider some of the factors which influence the performance and characteristics of horn loud speakers.

Horn Throat Impedance Characteristics

The horn throat acoustic impedance characteristic is of paramount importance in designing a horn loud speaker because the dissipation or radiation of energy may be considered to take place in the resistive or real part of the throat acoustic impedance. The throat impedance characteristic[1, 2, 3, 4, 5] depends upon the length, throat and mouth dimensions and the shape of the horn. It is the purpose of this section to consider the factors which determine the impedance characteristics

[1] Webster, A. G. *Jour. Nat. Acad. Sci.*, Vol. 5, P. 275, 1919.
[2] Stewart, G. W. *Phys. Rev.*, Vol. 16, P. 313, 1920.
[3] Goldsmith and Minton, *Proc. Inst. Rad. Eng.*, Vol. 12, P. 423, 1924.
[4] Slepian and Hanna, *Jour. Amer. Inst. Elect. Eng.*, Vol. 43, P. 393, 1924.
[5] Ballantine, S. *Jour. Franklin Inst.*, Vol. 203, P. 85, 1927.

of a horn and the relation between the impedance and response characteristics.

The horns most commonly used for sound reproduction are the conical and the exponential. Consequently the following discussion will be confined to these two types.

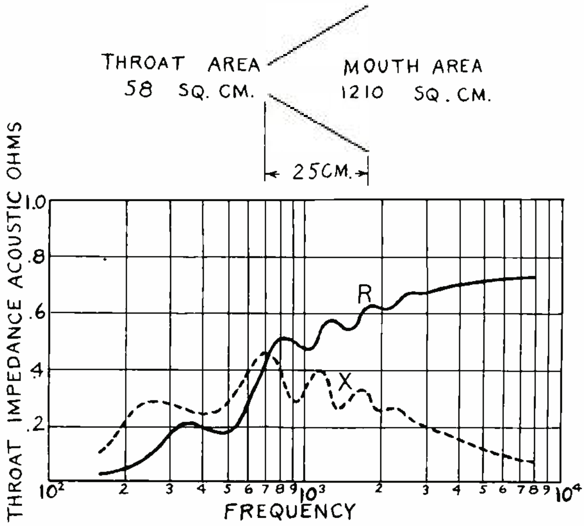


Fig. 1—Acoustic impedance characteristic, at the throat of a conical horn of the dimensions shown for comparison with the exponential horn of Fig. 2. *R*, resistive component. *X*, reactive component.

In the case of the conical horn the area at any point x along the axis is,

$$S = S_1 \; x^2 \qquad (1)$$

where $S_1 =$ area at $x = 1$,
$S_1 =$ throat area

In the case of the exponential horn the area at any point x along the axis is,

$$S = S_1 \; \varepsilon^{mx} \qquad (2)$$

where $S_1 =$ area at $x = 0$,
$S_1 =$ throat area,
and $m =$ flaring constant.

The expression for the throat acoustic impedance of the conical horn is,

$$Z_1 = \frac{j\rho\omega}{S_1}\left[\frac{Z_2 S_2 khl\cos[k(l-h)] + (j\rho\omega hl - Z_2 S_2 h)\sin[k(l-h)]}{j\rho\omega l - Z_2 S_2(1+k^2 lh)\sin[k(l-h)] + j\rho\omega klh + Z_2 S_2 k(l-h)\cos[k(l-h)]}\right] \qquad (3)$$

where S_1 = area of the throat, square centimeters,
S_2 = area of the mouth, square centimeters,
$k = \frac{2\pi}{\lambda}$
λ = wavelength, centimeters,
l = distance from the apex to the mouth, centimeters,
$\omega = 2\pi f$
f = frequency, cycles per second,
h = distance from the apex to the throat, centimeters,
ρ = density of air, grams per cubic centimeter,
Z_2 = acoustic impedance of the mouth, acoustic ohms.

The expression for the throat acoustic impedance of the exponential horn is,

$$Z_1 = \frac{\rho c}{S_1}\left[\frac{S_2 Z_2 [\cos(bl - \theta)] + j\rho c [\cos(bl)]}{jS_2 Z_2 \sin(bl) + \rho c [\cos(bl + \theta)]}\right] \quad (4)$$

where S_1 = area of the throat, square centimeters,
S_2 = area of the mouth, square centimeters,
l = length of the horn, centimeters,
Z_2 = acoustic impedance of the mouth, acoustic ohms,
$\theta = \tan^{-1} \frac{a}{b}$
$a = \frac{m}{2}$
and $b = \frac{1}{2}\sqrt{4k^2 - m^2}$

Throat impedance frequency characteristics of a conical and exponential horn of the same mouth and throat area and length computed from equations 3 and 4 are shown in Figures 1 and 2.

These characteristics show that the exponential horn has a definite low-frequency cut-off above which the throat resistance increases rapidly and becomes a constant. On the other hand, the throat resistance of the conical horn increases slowly with frequency and shows no definite low-frequency cut-off. Furthermore, the impedance frequency characteristics of the exponential horn show a larger ratio of resistance to reactance. For these reasons the exponential horn is more desirable and accounts for its almost universal use in horn loud speakers. In view of its wide-spread use it is interesting to examine some of the other characteristics of exponential horns.

The throat acoustic impedance characteristic as a function of the mouth, with the flare and throat kept constant, is of interest in determining the optimum dimensions for a particular application. The impedance characteristics of four finite horns having a cut-off of 100 cycles, throat diameter of one inch and mouth diameters of 10, 20, 30, and 40 inches and the corresponding infinite horn are shown in Fig. 3. These results may be applied to horns of a different flare by multiplying all the dimensions by the ratio of 100 to the new cut-off frequency. The cut-off frequency of an exponential horn is given by,

$$2\omega = mc \qquad (5)$$

where $\omega = 2\pi f$, $f =$ frequency,
and $c =$ velocity of sound.

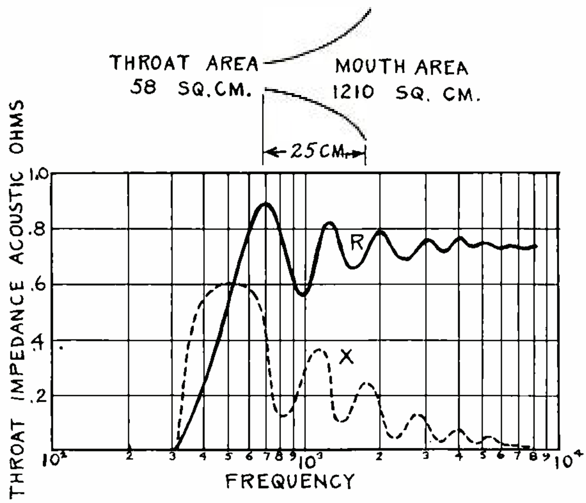


Fig. 2—Acoustic impedance characteristic, at the throat of an exponential horn of the dimensions shown and cut-off due to flare of 320 cycles, for comparison with the conical horn of Fig. 1. *R*, resistive component. *X*, reactive component.

The radiation resistance of a mouth 10 inches in diameter is relatively small below 500 cycles. The large change in impedance in passing from the mouth to the free atmosphere introduces reflections at the mouth and as a result wide variations in the impedance characteristic as shown in Figure 3A. For example, the first maximum in the resistance characteristic is 150 times the resistance of the succeeding minimum.

By doubling the diameter of the mouth the maximum variation in the resistance characteristic is 7.5, Figure 3B.

Figure 3C shows the impedance characteristic of a horn with a mouth diameter of 30 inches. The maximum variation in the resistance characteristic of this horn is 2.

The impedance characteristic of a horn with a mouth diameter of 40 inches, Figure 3D, shows a deviation in resistance of only a few per cent from that of the infinite horn of Fig. 3E.

These results show that as the change in impedance in passing from the mouth to the free atmosphere becomes smaller by employing a mouth diameter comparable to the wavelength, the reflection becomes correspondingly less and the variations in the impedance characteristic are reduced.

Due to the impracticability of a horn mouth diameter comparable to the wavelength for low-frequency loud speakers, it is interesting to note that a relatively smooth response characteristic can be obtained from a horn having an impedance characteristic varying over wide limits. For example, consider a moving-coil mechanism coupled to the throat of a horn and fed by a vacuum-tube amplifier, the sound power output is the real part of

$$\text{Power} = \left(\frac{e}{|z_T|} \right)^2 z_m \qquad (6)$$

$$\text{where } z_m = \left\{ \frac{(Bl)^2}{A^2 (R + jX) + jx} \right\} 10^{-9}$$

B = air gap flux density, gausses,

l = length of wire in the voice coil, centimeters,

A = area of the diaphragm, square centimeters

R = acoustic resistance at the throat, acoustic ohms,

X = acoustic reactance at the throat, acoustic ohms,

x = mechanical reactance of diaphragm and coil system, mechanical ohms,

$z_T = r_d + r_t + z_m$

r_d = voice coil resistance, ohms,

r_t = amplifier output resistance, ohms,

and e = amplifier open-circuit voltage, volts.

Equation 6 shows, providing suitable constants may be chosen for the driving mechanism, that the throat resistance R may vary over wide limits without introducing large variations in the power output. As a specific example, Figure 4 shows the power output as a function of the frequency for a horn, having all dimensions 2½ times that of Figure 5B and driven by a mechanism and vacuum tube having the constants indicated by the caption of Figure 4. Although the impedance variation is 6 to 1, the variation in power output is only 2 *db*.

The throat acoustic impedance characteristic as a function of the throat size with the mouth and flare held constant is of interest in

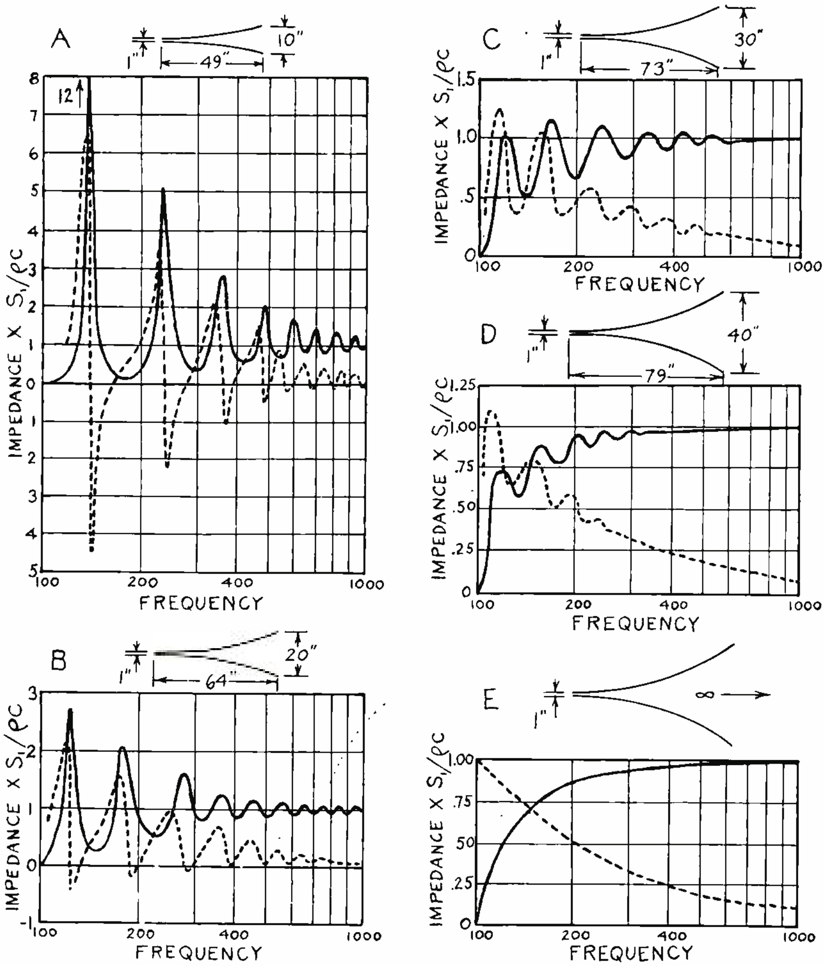


Fig. 3—The throat impedance characteristics of a group of exponential horns, with a flare cut-off of 100 cycles and a throat diameter of 1 inch, as a function of the mouth diameter, ρ density of air, grams per cubic centimeter. C velocity of sound, centimeters per second, and S_1 area of the throat, square centimeters.

determining the optimum length and a suitable matching impedance for the driving mechanism. The impedance characteristics of 4 horns having a cut-off of 100 cycles, mouth diameter of 20 inches and throat diameter of 1, 2, 4 and 8 inches are shown in Figure 5. A consideration of these characteristics shows that the throat size has no appreciable effect upon the amplitude of the variations in the impedance characteristics. However, the separation in frequency between successive maxima is increased, as the throat becomes larger, due to the decreased length of the horn. The frequency at which the first maximum in the resistance characteristic occurs becomes progressively higher as the length is decreased.

Directional Characteristics

The directional characteristic of a loud speaker is the response as a function of the angle with respect to some axis of the system.

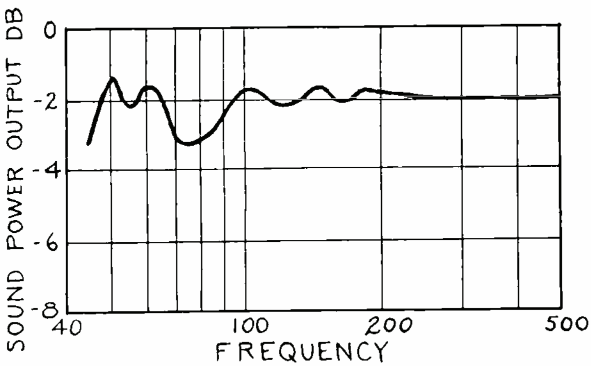


Fig. 4—Power output characteristic of a horn (horn of Fig. 5B. with all dimensions multiplied by 2½) coupled to a 10½ inch, 10 gram, diaphragm driven by a 5 gram aluminum voice coil in a field of 20000 gausses. Damped resistance of voice coil 20 ohms. Impedance of vacuum tube 35 ohms.

These may be plotted as a system of polar curves for various frequencies or as response-frequency curves for various angles with respect to the axis.

The directional characteristic of a horn depends upon the shape, mouth opening, and the frequency. It is the purpose of this section to examine and consider some of the factors which influence the directional characteristics of a horn.

The phase and particle velocity of the various incremental areas which may be considered to constitute the mouth determines the directional characteristics of the horn. The particular complexion of the velocities and phase of these areas is governed by the flare and dimensions and shape of the mouth. In these considerations the mouth will be of circular cross section and mounted in a large flat baffle. The mouth of the horn plays a major role in determining the directional characteristics in the range where the wavelength is greater than the mouth diameter. The flare is the major factor in determining the directional characteristics in the range where the wavelength is less than the mouth diameter.

Figure 6 shows the effect of the diameter of the mouth for a constant flare, upon the directional characteristics[6] of an exponential horn. At the side of each polar diagram is the diameter of a vibrating piston

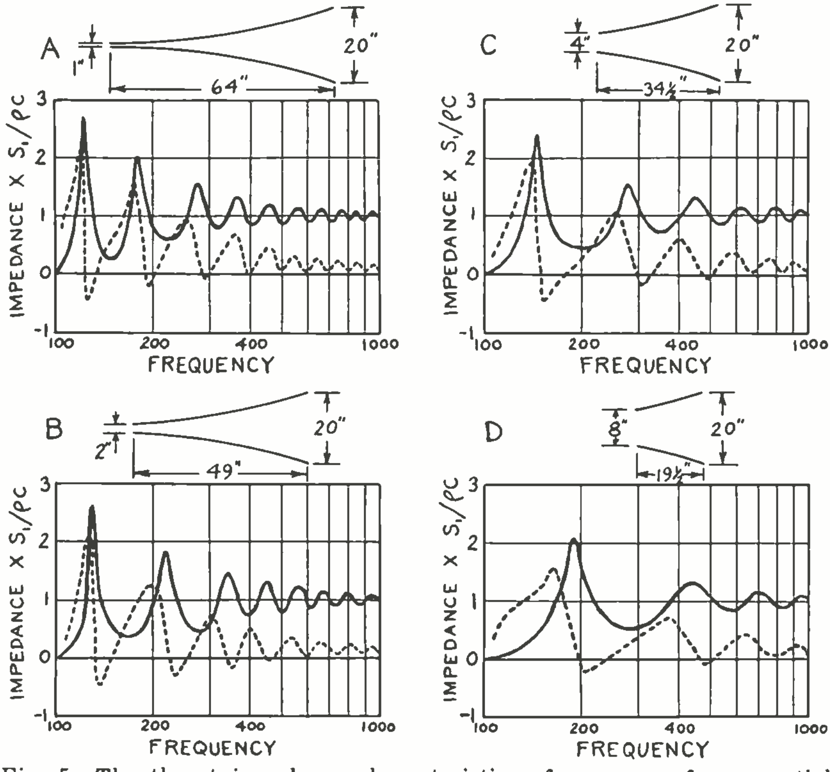


Fig. 5—The throat impedance characteristics of a group of exponential horns, with a flare cut-off of 100 cycles and a mouth diameter of 20 inches, as a function of the throat diameter. ρ density of air, grams per cubic centimeter, C velocity of sound, centimeters per second, S_1 area of the throat, square centimeters.

which will yield approximately the same directional characteristic. It will be seen that up to the frequency at which the wavelength becomes comparable to the mouth diameter, the directional characteristics are practically the same as those of a piston of the size of the mouth.

[6] Goldman, S. *Jour. Acous. Soc. Amer.*, Vol. 5, P. 181, 1934, reports the results of an investigation upon the directional characteristics of exponential horns at 15000 and 25000 cycles. A comparison can be made with the results shown in Figures 6 and 7 by increasing the dimensions of the horns used by him to conform with those shown here and decreasing the frequency by the factor of increase in dimensions. Such a comparison shows remarkable agreement between the two sets of data.

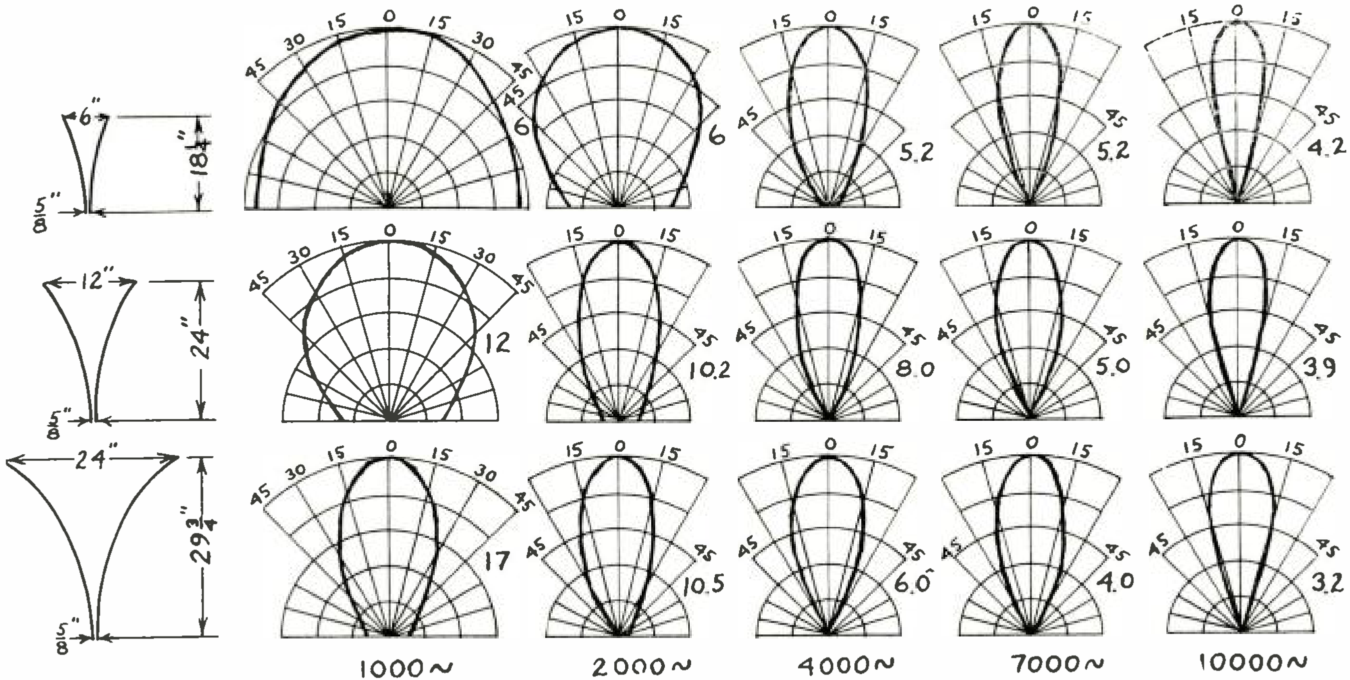


Fig. 6—The directional characteristics of a group of exponential horns, with a constant flare and throat diameter of ⅝ inch, as a function of the mouth diameter. The number at the right of each polar diagram indicates the diameter of a circular piston which will approximately yield the same directional characteristic. The length of the radius vector to a point on the curve is proportional to the sound pressure in the direction of the angular coordinate.

Above this frequency the directional characteristics are practically independent of the mouth size and appear to be governed primarily by the flare.

To further illustrate the relative effects of the mouth and flare, Figure 7 shows the effect of different rates of flare, for a constant mouth diameter, upon the directional characteristics of an exponential horn. These results also show that for the wavelengths larger than the mouth diameter the directional characteristics are approximately the same as those of a vibrating piston of the same size as the mouth. Above this frequency the directional characteristics are broader than that obtained from a piston the size of the mouth. From another point of view, the diameter of the piston which will yield the same directional characteristic is smaller than the mouth. These results also show that the directional characteristics vary very slowly with frequency at these smaller wavelengths. Referring to Figure 7 it will be seen that for any particular high frequency, 4,000, 7,000 or 10,000 cycles per second, the directional characteristics become progressively sharper as the rate of flare decreases.

The above results show that practically any directional characteristic can be obtained over a certain range of frequencies. In some cases, as for example, high-power announce over large distances, it is desirable to confine the radiation to a very small solid angle. To do this requires a very large mouth and a slow rate of expansion. Such a horn is very cumbersome and difficult to handle. A sharp directional characteristic may be obtained by employing a ring-type mouth which, in effect, increases the diameter. Providing the width of the ring shaped mouth is small, compared to the wavelength, the directional characteristics for a ring may be used to predict the performance.

The expression for the directional characteristics[7] of a circular ring is given by,

$$R = J_o\left(\frac{kd}{2}\sin\theta\right) \tag{7}$$

where R = ratio of the sound pressure at an angle θ off the normal speaker axis to that on the axis.

$k = \frac{2\pi}{\lambda}$ λ = wavelength,

d = diameter of the ring,

J_o = Bessel function of zero order.

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[7] Stenzel, H. *Elek. Nach. Tech.*, Vol. 4, No. 6, P. 1, 1927.

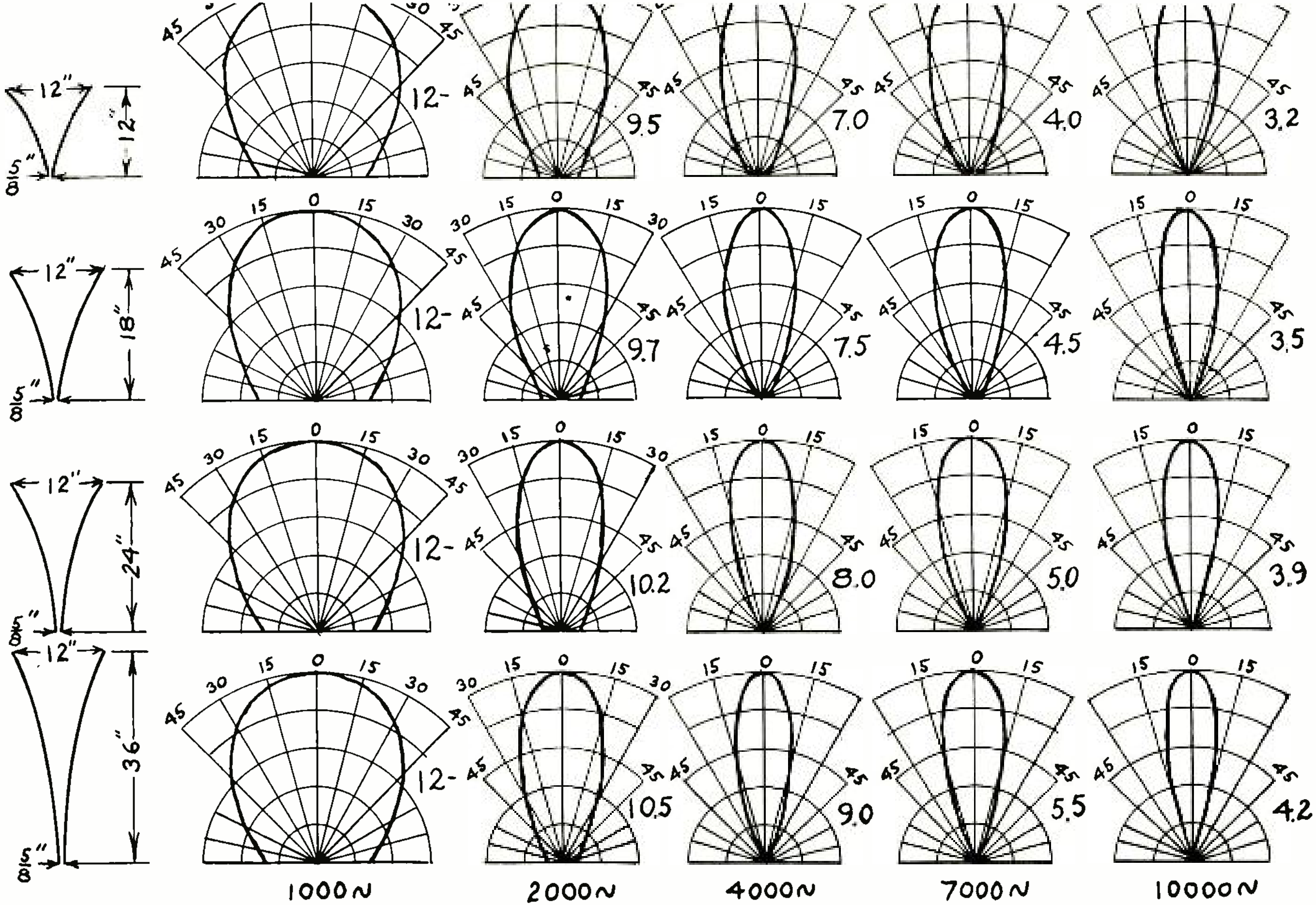

Fig. 7—The directional characteristics of a group of exponential horns, with a mouth diameter of 12 inches and a throat diameter of ⅝ inch, as a function of the flare. The number at the right of each polar diagram indicates the diameter of a circular piston which will yield approximately the same directional characteristic. The length of the radius vector to a point on the curve is proportional to the sound pressure in the direction of the angular coordinate.

This equation shows that for a particular frequency the directional characteristics are only a function of the diameter of the ring.

An example of how the directional characteristics may be sharpened by employing a ring-shaped mouth compared to the conventional mouth is depicted in Figure 8. This method is particularly adapted to loud speakers designed to cover a small frequency band, such as high-power announce, in which the response is confined to 2 or 3 octaves. When the frequency range is wide, considerable variation in the directional characteristics occurs together with additional lobes at the higher frequencies.

The exponential horns shown in Figs. 6 and 7 have directional characteristics which vary with frequency. The lower frequencies are projected through a relatively large angle, and as the frequency increases, the sound distribution angle decreases and becomes quite small for wavelengths small compared with the diameter of the mouth. This kind of directional pattern introduces frequency discrimination for points removed from the axis and is not suitable for high fidelity reproduction of sound. A sphere vibrating radially radiates sound uniformly outward in all directions. A portion of a spherical surface, large compared to the wavelength and vibrating radially, emits uniform sound radiation over a solid angle subtended by the surface at the center of curvature. Therefore, to obtain uniform sound distribution over a certain solid angle, the radial air motion must have the same phase and amplitude over the spherical surface intercepted by the angle having its center of curvature at the vertex and the dimensions of the surface large compared with the wavelength. When these conditions are satisfied for all frequencies, the response characteristic will be independent of the position within the solid angle.

A loud speaker[8, 9, 10, 11, 12] consisting of a large number of small horns with the axis passing through a common point will satisfy, for all practical purposes, the requirements of uniform phase and amplitude over the spherical surface formed by the mouths of the horns. A cellular or multi-horn of this type is shown in Figure 9. This particular horn system consists of 15 horns arranged in 5 vertical rows and 3 horizontal rows. The mouth opening of each individual horn is 8″ x 8″. The horizontal and vertical angle between the axis of the individual horns is approximately 17°.

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8 Slepian, J., U. S. Patent 1684975.
9 Hanna, C. R., U. S. Patent 1715703.
10 Wente, E. C., U. S. Patent 1992268.
11 Wente and Thuras, *Jour. A.I.E.E.*, Jan. 1934.
12 Hilliard, J. K., *Tech. Bul. Acad. Res. Coun.*, Mar. 1936.

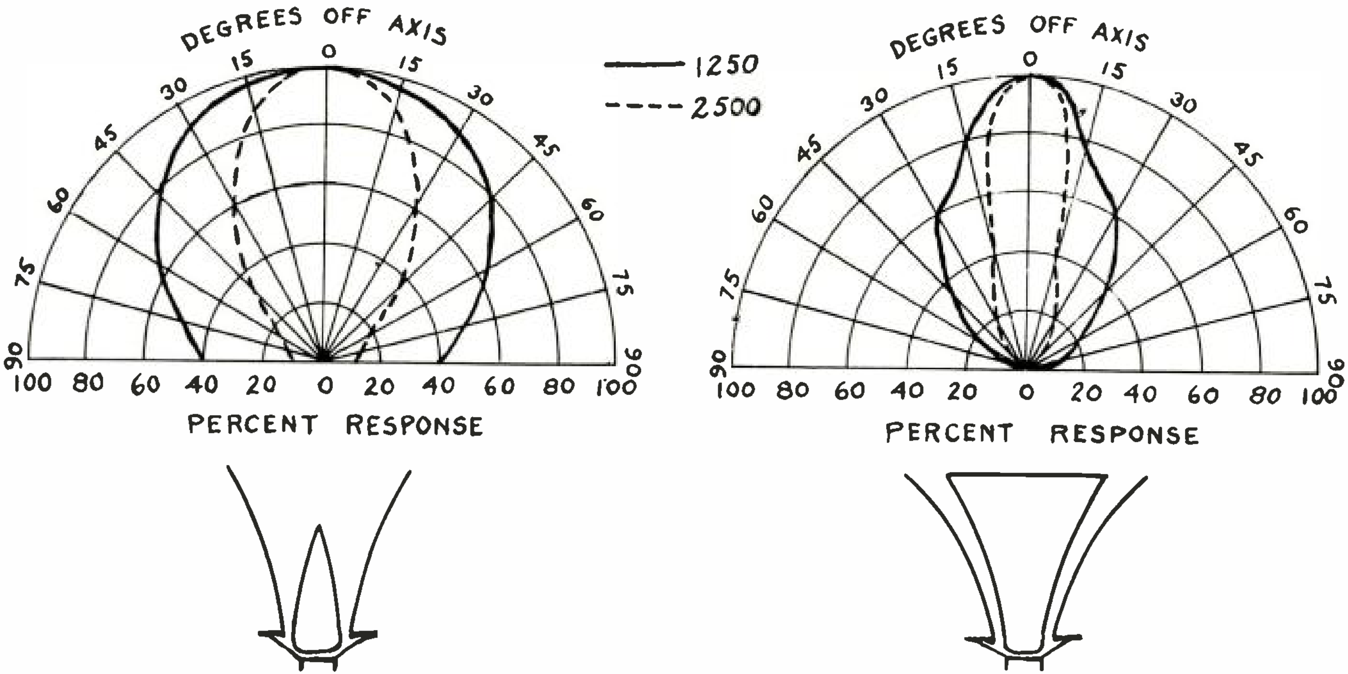

Fig. 8—Comparison of the directional characteristics of a ring-shaped mouth horn with that of a conventional horn having the same rate of flare and mouth area.

The directional characteristics of the cellular horn shown in Figure 9 are shown in Figure 10. Above 2,000 cycles the dimensions of the total mouth surface are several wavelengths and the directional characteristics are uniform and defined by the total angular spread. Where the dimensions are comparable to the wavelength, the directional characteristics become very sharp, as shown by the polar curves for 500 and 1,000 cycles. Then as the dimensions of the surface become smaller than the wavelength (250 cycles) the angular spread broadens, as is illustrated by the larger spread for the smaller vertical dimension when compared to the smaller spread for the larger horizontal dimension.

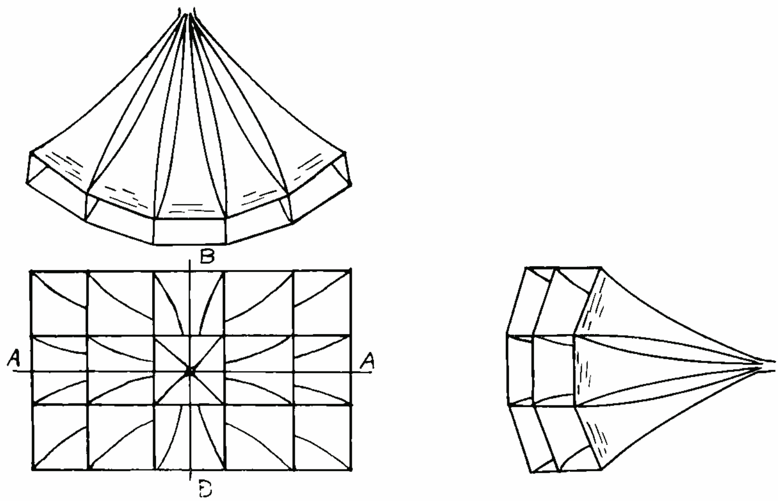

Fig. 9—Multi-horn loud speaker consisting of 15 individual exponential horns.

The directional characteristics of a multi-horn loud speaker may be predicted theoretically from the directional characteristics of an individual horn and the geometrical configuration of the assembly of horns. Assume that the point of observation is located on the *OY* axis, Figure 11, at a distance several times the length of the horn. The amplitude of the vector contributed by an individual horn for the angle ϕ can be determined from its individual directional characteristic. In this illustration, the plane X' O' Z' is chosen as reference plane for the phase of the vector. The phase angle of the vector associated with an individual horn is

$$\theta = \frac{d}{\lambda} \; 360° \qquad (8)$$

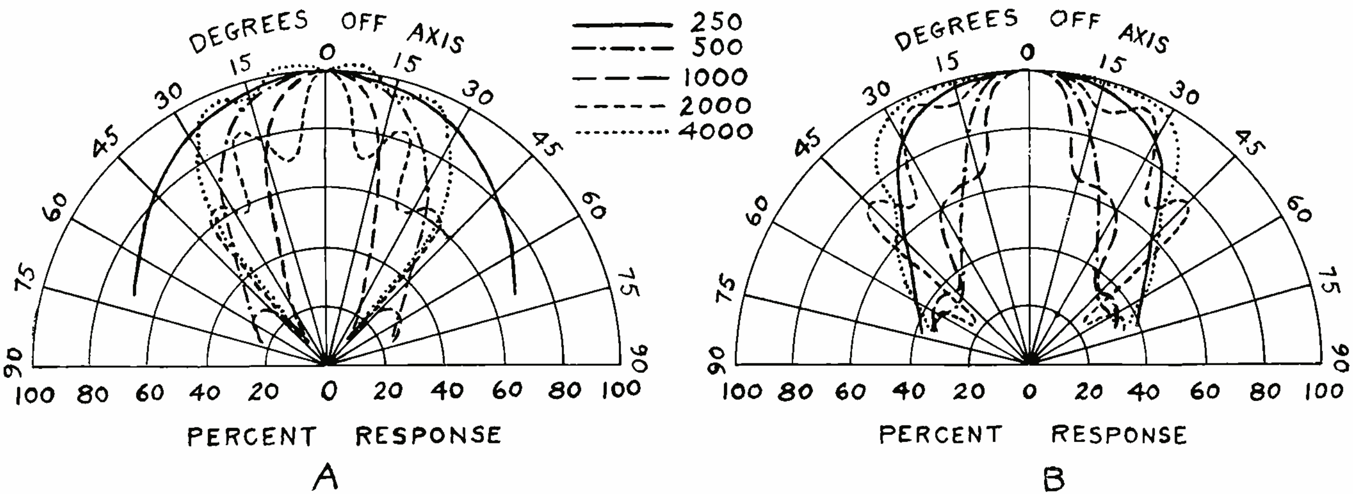

Fig. 10—Directional characteristics of the multi-horn loud speaker of Figure 9. *A* — vertical plane *B-B*. *B* — horizontal plane, *A-A*, of Figure 9.

where d = the distance between the center of the mouth of the horn and the reference plane $X' O' Z'$,

λ = wavelength.

The vectors, having amplitudes A_1, A_2, A_3, A_4, etc., determined from the directional characteristics and having phase angles θ_1, θ_2, θ_3, θ_4, etc., determined from Equation 8, are added vectorially as shown in Figure 11. This method of predicting the directional characteristics assumes that there is no interaction between individual horns which

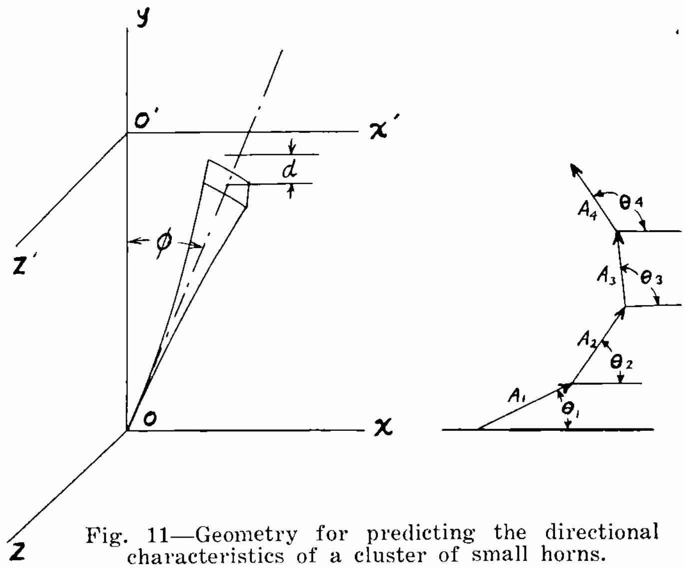

Fig. 11—Geometry for predicting the directional characteristics of a cluster of small horns.

changes the complexion of the velocities at the mouth from that which obtains when operating as an individual horn. Obviously, this condition is not absolutely satisfied. Apparently, the discrepancy has no practical significance because it has been found that this method of analysis agrees quite well with experimental results.

Analysis of this type shows that a combined mouth surface large compared to the wavelength is required to obtain uniform directional characteristics. It also shows that when the dimensions of the surface are comparable to the wavelength the directional pattern is relatively narrow. Furthermore, as would be expected, the directional characteristics are comparatively broad when the dimensions of the surface are small compared to the wavelength.

BROADCAST OF PRESIDENT ROOSEVELT'S SECOND INAUGURATION

By

George McElrath

Operating Engineer, National Broadcasting Company

THE varied nature of the broadcast programs associated with the second inauguration of President Roosevelt, including descriptions from air and ground, required the concentration of more personnel and equipment in one city than any other previous program.

Prior to Christmas Mr. A. A. Schechter, Director of Special Events for the National Broadcasting Company, completed preliminary plans for the broadcast of the inauguration. The diagram of the parade route (Figure 1) shows the program pickup locations decided upon as a result of these plans. It was clearly evident that our Washington office did not have sufficient personnel and equipment to handle the job. Mr. G. O. Milne, Eastern Division Engineer at New York, and Mr. A. E. Johnson, Engineer in Charge at Washington, coordinated and assigned sufficient personnel—also equipment—to cover all points.

Arrangements were made with the Inaugural Committee and the contractors who were building the reviewing stand in front of the White House and the public stands at 15th Street and Pennsylvania Avenue, to erect broadcast booths at both locations to house our equipment and personnel. Booths 6 x 6 x 7 feet high were provided at 2nd Street and Constitution Avenue; 7th Street and Pennsylvania Avenue; and at 15th Street and New York Avenue. Announcers in these booths described the President's trip from the White House to the Capitol to take the oath of office, and the inaugural parade one and one-half hours later.

Five separate 80-watt public address amplifying systems were installed, one at each of the following locations: East Capitol Plaza, White House reviewing stand, public stands at 14th Street and Pennsylvania Avenue, and stands at the north and south ends of the Treasury Building. They were connected to WRC's control room by wire lines. The President's inaugural address and NBC programs were reproduced over these systems all day for the information of the public in the stands and along the parade route.

Work was started early in December to modify the Special Events switching panel (used during the 1933 inauguration), incorporating improvements which experience had indicated would be needed to

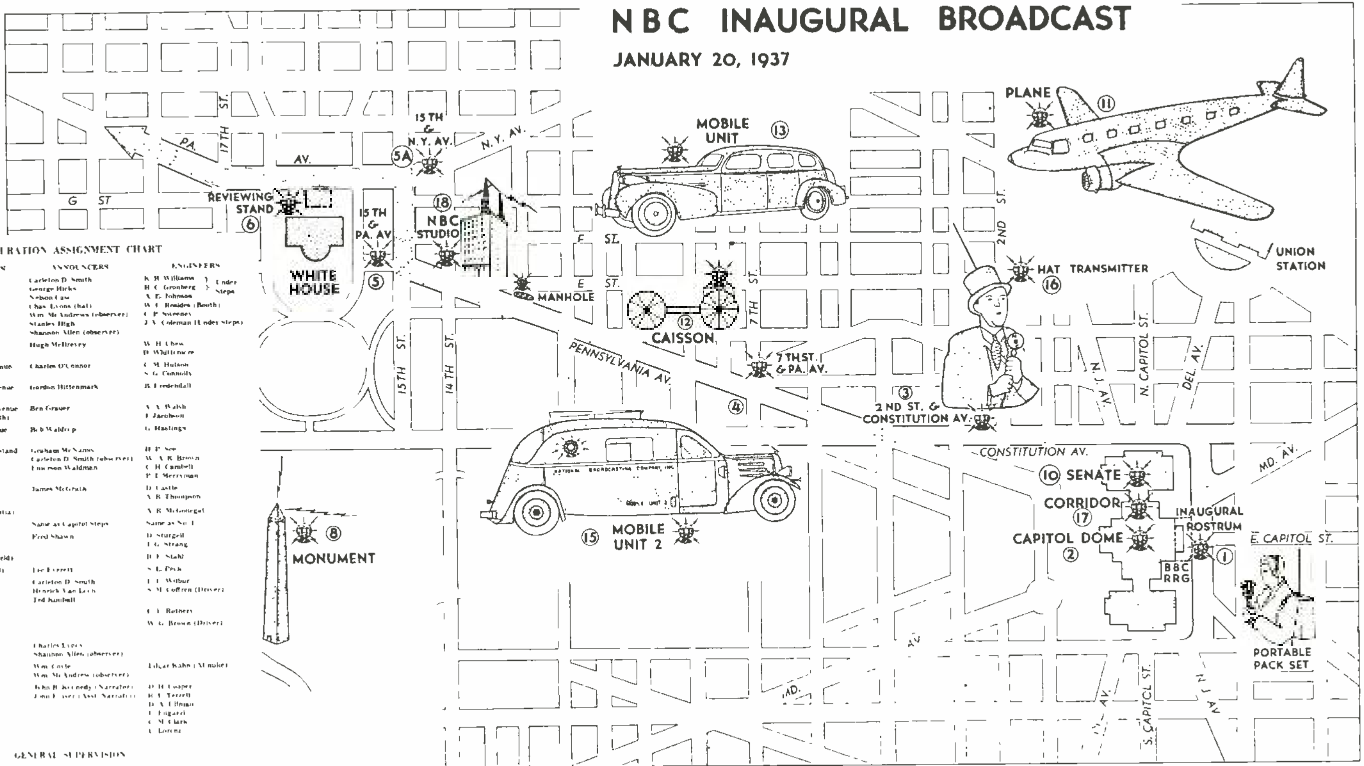

Fig. 1—Diagram of the parade route.

INAUGURATION ASSIGNMENT CHART

PICKUP POSITION	ANNOUNCERS	ENGINEERS
Capitol Building	Carleton D. Smith George Hicks Nelson Case Chas. Lyons (hat) Wm. McAndrews (observer) Stanley High Shannon Allen (observer)	R. H. Williams } Under H. C. Gronberg } Steps A. E. Johnson W. C. Resides (Booth) C. P. Sweeney J. A. Coleman (Under Steps)
Capitol Dome	Hugh McIlrevey	W. H. Chew D. Whittemore
2nd and Constitution Avenue (NBC Booth)	Charles O'Connor	C. M. Hutson S. G. Connolly
7th and Pennsylvania Avenue (Traffic Tower)	Gordon Hittenmark	R. Fredendall
15th and Pennsylvania Avenue (Atop Grandstand Booth)	Ben Grauer	A. A. Walsh F. Jacobson
15th and New York Avenue (Traffic Tower)	Bob Waldrop	G. Hastings
White House Reviewing Stand	Graham McNamee Carleton D. Smith (observer) Emerson Waldman	H. P. See W. A. R. Brown C. H. Cambell F. E. Merryman
Monument	James McGrath	D. Castle A. R. Thompson
Dupont Park (Anacostia)		A. R. McGonegal
Senate	Same as Capitol Steps	Same as No. 1
Eastern Airlines Plane	Fred Shawn	D. Sturgell L. G. Strang
Army Planes (Bolling Field)		R. F. Stahl
Caisson (Start at Capitol)	Lee Everett	S. L. Peck
Mobile Unit	Carleton D. Smith Henrick Van Loon Ted Kimball	F. E. Wilbur S. M. Coffren (Driver)
Police Car		C. E. Rothery
Mobile Unit No. 2 (Loud Speaker only)		W. G. Brown (Driver)
Hat Transmitter	Charles Lyons Shannon Allen (observer)	
Capitol Corridor	Wm. Coyle Wm. McAndrews (observer)	Edgar Kahn (Monitor)
Studio	John B. Kennedy (Narrator) [illegible] (Asst. Narrator)	D. H. Cooper R. A. Terrell D. A. Ullman F. Fugazzi C. M. Clark C. Lorenz
BBC Felix Greene RRG Kurt Sell		

GENERAL SUPERVISION

EXECUTIVE	PROGRAM	SPECIAL MASTER CONTROL
Royal Program Russell Washington Div. Hanson Engineering Morton M & O Stations PHOTO Pickard (Television) Hausler	A. A. Schechter R. H. Berkeley Don Goddard Tom McFadden Hazel Smith (Monitor) Gladys Murphy (Monitor) PRESS J. N. Babb H. Doherty Miss P. Gale	George Milne D. C. Shultis W. Baston F. Wankel W. L. Simmons (Standby) George McElrath (Supervision)

rapidly switch circuits in accordance with program plans. Four years ago the switching, equalizer, private line exchange, and amplifier panels were mounted permanently on two six-foot relay racks. All this equipment was dismantled and installed in four separate boxes built with a view to portability. The photograph, Portable "Special Events" Switching Panel, shows this apparatus set up for operation. The switching panel with keys, faders, mixer, volume indicator, and gain control is in the right foreground, the equalizer panel next to the left, followed by the feedback and program amplifier panels. The private line exchange is at the extreme left. Only the essential switching and amplifying equipment was provided to keep the weight down to a minimum. This apparatus was designed to be used with standard portable field amplifiers and battery power supply. Thus operations can be carried on at all times, without interruption, regardless of the availability

Portable "Special Events" switching panel.

of a public service power supply. If the switching equipment is required at other offices for a special purpose, only the important light items would be shipped and the remaining necessary apparatus could be made available from standard parts in use in all divisions.

On January 16 at 6:30 P.M., twenty-eight engineers with 122 pieces of equipment left New York by a special railroad car for Washington to coordinate with our Washington, D. C., staff. They arrived at 10:53 P.M. and transferred the equipment to the NBC studio headquarters in the National Press Building. Each pickup was given a job number, and the senior engineer assigned to a location was responsible for assembling in New York the apparatus he would need during the broadcast, and each item was tagged with that job number. Thus it was an easy matter to keep the apparatus for each program location together.

During the morning of the 17th the engineers assigned to the various locations installed the audio and radio equipment, including antennas for transmission and reception. The installation of the portable special events switching panel, which is in effect, a master control room in itself, was completed by noon in the office of the Engineer in Charge. The function of this panel is to instantaneously switch the program from one point to another, or combine one or more points to permit two-way conversation on the air and provide behind-the-scenes communication facilities. During the afternoon the program circuits to each stationary pickup point were equalized.

On the 18th the 25-watt ultra-high frequency radio transmitter and receiver were installed in the mobile unit, and the automobile traveled between Hyattsville and Alexandria, testing with the receivers installed in the Capitol Dome and Washington Monument and the 100-watt UHF cue transmitter on the roof of the National Press Building. Reception was perfect at both locations over the entire area. This successful transmission was due in great part to the latest type UHF superheterodyne receivers recently developed by the Laboratory group. These receivers have increased the range of all UHF transmitters by at least 100 per cent. and the greater selectivity has reduced extraneous noises.

The Army caisson was not available until the 19th and the one-watt UHF transmitter was installed on that date. The hat and hand transmitters on the east Capitol Plaza, and the pack transmitter at the White House portico were also successfully tested. UHF receivers were installed at 15th Street and Pennsylvania Avenue and the White House reviewing stand, in addition to those in the Capitol Dome and the Washington Monument, to receive the pack transmitters installed on the caisson and at the White House portico.

The 100-watt cue transmitter W10XR was shipped from New York to Washington several weeks prior to the inauguration and the staff there had it installed on the roof of the National Press Building on the 16th. On the 17th a frequency monitor was installed in the Capitol Dome and a signal generator was placed in the White House reviewing stand to measure the frequencies of all the transmitters in accordance with F.C.C. regulations.

The Eastern Air Lines plane was not available until the evening of the 19th, and the 50-watt intermediate frequency transmitter and cue receivers were installed during the night and were ready for service at dawn on Inauguration Day. On the 19th at 1:00 P.M., a full dress rehearsal was held with all engineering and program personnel at their designated posts, excepting the airplane. This rehearsal was for the purpose of assuring the staff that each piece of audio and radio apparatus was functioning properly and to familiarize the engineering and program personnel with their duties. In order that one may better understand the rehearsal procedure and how the inaugural proceedings were broadcast, a description of the technical facilities is in order.

Figure 2 illustrates the schematic technical layout. Let us now separate the audio and radio program originating points. Two wire program circuits (regular and emergency) connect each ground location, including the radio receiving stations in the Capitol Dome and Washington Monument, with the equalizer panel of the special events switching panel. The output of receivers and portable field amplifiers at the outside points are connected to the regular program circuit.

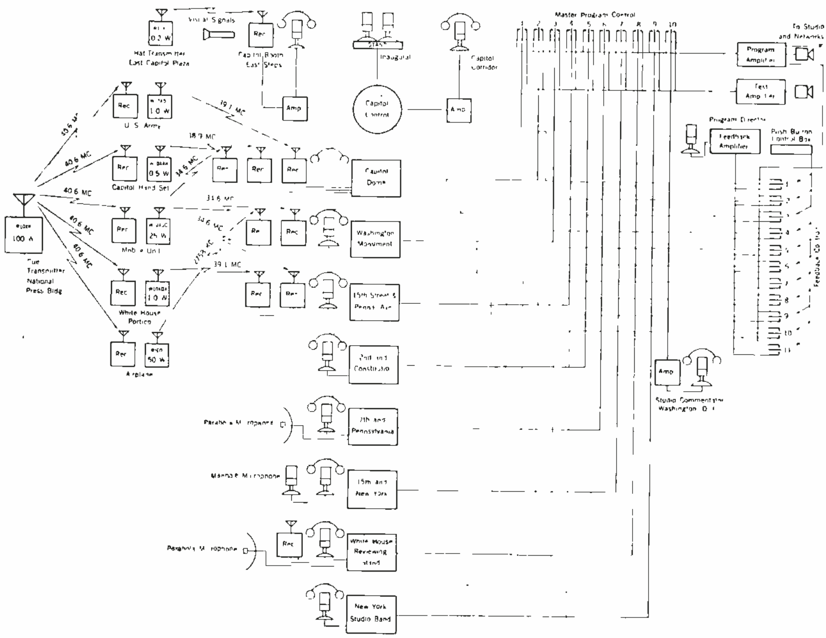

Fig. 2—Schematic of the "Special Events" switching equipment connected to radio and audio pickup points.

The program circuits pass through repeat coils, equalizers, and variable artificial lines, and connect to keys and faders on the program switching panel. The transmission level on each program circuit is predetermined on test and the engineer can mix two or more program locations together or rapidly connect each program circuit separately to the studio amplifier. The output of this amplifier can be routed through one of our regular studios, which was done during the inauguration broadcast, or connected directly to a circuit feeding the network.

A feedback circuit with two or more headphones at the outside point, one for the announcer or commentator, and the other for the engineer, is connected to the output of the feedback amplifier. A button controlled relay transfers the input of this feedback amplifier across the program, or is connected to the program director's microphone. Thus the cue from the program channel or instructions from the director are sent to the announcers.

Let us next consider the control box furnished for the program director and its application to the broadcast. It is a box approximately fourteen inches long, eight inches wide, and six inches high. In the front are imbedded ten push buttons and thirty lights—10 white, 10 green, and 10 red. Two microphones are connected to this feedback system, one for the program director, and the other for the engineering

President Roosevelt delivering his second inaugural address.

supervisor. When either desires to talk to any particular location, he presses the button associated with that position and a glowing white light indicates he is connected to that point. In the meantime the engineer at the program switching controls has all program circuits on the test position (green lights) except the one or more points on the air. Green lights mean it is safe to talk to those pickup points, and red infers danger—do not talk to this point—it is on the air. Thus the announcer hears the director through an earphone on his end of the feedback circuit and can answer over his program microphone which connects to a loudspeaker at the director's side through the test position on the program switching board. Thus the director can talk to each program point separately or collectively and those program points not on the air can talk to the director. This permits observers at the outside points to keep the director advised of interesting program material which may occur unexpectedly and enables the director to change his plans and transfer immediately the program to any one of the many originating points involved. He endeavors to keep the feedback circuit to the originating point or points clear of backstage conversation so as not to disconcert the announcer giving a description of events to the radio audience. However, at the time the program switch occurs the controls are placed so the announcer relinquishing control receives a cue from the program circuit or instruction from the director.

The output of the feedback amplifier also feeds the input of the 100-watt cue transmitter W10XR on 40.6 megacycles. Therefore, all audio signals sent over the wire feedback circuits are transmitted over the cue station to all mobile points. A UHF receiver capable of intercepting signals from the radio cue channel was part of the installation aboard the plane, the mobile unit, the caisson and at the portable pack, hat, and hand transmitter locations. Program signals from the transmitters listed above were received at the Capitol Dome, Washington Monument, or the receivers installed along the parade route, and transmitted by wire line to the control point. The engineer on the program switching controls had two phones, one attached to the output of the feedback amplifier and the other to the program circuit, and by following the cues and Program Director's instructions, also by exercising an unusual amount of perception, he could throw the keys and manipulate the faders and thus keep the program passing through the apparatus to the network stations and the radio audience.

BBC Announcer Felix Greene and Engineer Carl Lorenz.

Facilities were also provided to patch out any one audio or radio point for test purposes while other program points were on the air.

This setup allowed the transmission engineer to clear trouble between any program point and the control room without interfering with program transmission.

On January 20, at 8:30 A.M., E.S.T., the inaugural program opened with band music from the New York studios. A special program circuit between New York and Washington was connected to the switching panel and could be cut in anytime during the day. A feedback circuit to the band placed the New York studios on the same operating basis as at any other local point in Washington. The program continued with a roll call from all points which ended at 9:00 A.M. The entire program, excepting portions originating in Seattle and Honolulu, was transmitted through the special events switching panel

Engineer P. I. Merryman carrying receiving equipment to top of Washington Monument.

through WRC's control room in Washington to NBC New York where it was distributed to associate stations over existing network circuits.

Inaugural proceedings were again brought to the radio audience at 11:30 A.M. through a description by George Hicks from the Hill Capitol. The control was shifted from one point to another in Washington, including a description of the Presidential party leaving the White House through short wave facilities at the portico and on the mobile unit which accompanied the entourage to the Capitol where President Roosevelt took the oath of office for the second time. The inaugural ceremonies including President Roosevelt's Second Inaugural address started at 12:20 and ended at 12:48 P.M.

At 11:47 A.M., while the American audience was hearing these proceedings, Felix Greene in a British Broadcasting Corporation booth at the Inaugural Stand was sending a description of preliminary activities on Capitol Hill to his listening audience in England. Separate audio amplifiers in Washington, D. C., and line facilities to New York were provided to connect with RCA transoceanic radio facilities to the British Post Office in London. This circuit was discontinued at the end of President Roosevelt's speech.

Between 12:15 and 1:00 P.M., Max Jordan, NBC's European representative, described the ceremonies and summarized the President's

Announcer George Hicks in NBC booth
erected on the inaugural platform.

address in French, Italian, and Spanish over transoceanic channels to Europe where it was distributed to France, Switzerland, Austria, and Italy. Jose Tercero of the Pan-American Union in Washington, D. C., gave a summary in Spanish over special radio facilities to South American audiences via Buenos Aires.

Kurt G. Sell, representative of the Reichs Rundfunk Gesellschaft, gave a summary of President Roosevelt's speech between 1:00 and 1:30 P.M., which was rebroadcast in Germany. All these special programs were sent to New York over separate wire facilities and transmitted over transoceanic radio channels to foreign countries.

Anna Roosevelt Boettinger spoke to the radio audience from the studios of KOMO in Seattle, Washington, between 1:00 and 1:05 P.M., This talk was sent over a special line to NBC's Chicago control room where the network circuits were opened and the talk was connected to the network. The program from Honolulu between 2:25 and 2:30 P.M., was handled in the same manner with the exception that it was received by RCA Communications at Point Reyes, California, and routed through NBC, San Francisco, where it was connected to the same pair of wires that carried Mrs. Boettinger's talk eastward.

Programs from the American Clubs in London and Paris between 1:15 and 1:25 P.M., and from the S.S. Rex, between 1:50 and 1:55 P.M., were received by RCA Communications at Riverhead, L. I., and connected to the same circuit which carried the band music from the New York studios. In effect these extended locations were connected to the special events switching panel and could be handled from an operating standpoint the same as any one of the numerous local pickup points in Washington, D. C.

A smooth flowing word picture of Washington events was presented to the listening audience in America between the above-mentioned highlights of the program. These descriptions continued from stationary audio and mobile radio locations throughout the city.

Unfortunately, weather conditions grounded all planes and the flying observer never left Mother Earth. A heavy rainfall occurred during the President's address. The rain drops falling on a protective covering over the microphones installed on the speakers' stand produced sound effects not unlike dry beans hitting a drum head. You may have heard it during the broadcast. Excess moisture caused the microphone installed in a man-hole to become inoperative.

The following international short wave stations gave this program world wide coverage:

Station	*Location*	*Power*	*Frequency*
W3XAL	Bound Brook	20 KW	17,780 KC
W2XAF	Schenectady	40	9,530
W2XAD	Schenectady	20	15,330
W8XK	Pittsburgh	40	15,210
W8XAL	Cincinnati	10	6,060
W1XK	Millar, Mass.	10	9,570
W9XF	Downers Grove, Ill.	10	6,100

NBC signed off at 3:00 P.M., ending one of the most difficult switching jobs ever attempted. It was another example of rapidly tying together long and short lengths of radio and wire channels to weave an interesting story.

On the 21st, equipment was gathered together and at 5:00 P.M., the New York engineering contingent left Union Station by special car, arriving in New York at 9:00 P.M.

AUTOMOBILE RECEIVER DESIGN

BY

JEROME C. SMITH

Development Engineer, Automobile Receiver Section, RCA Manufacturing Co.

THE use of a mobile radio receiver is almost as old as radio itself. The necessity of making field strength measurements over wide areas within a reasonably short space of time possibly was one of the first reasons for operating a radio receiver in an automobile. Stories are told of accelerating the car to gain speed, then shutting off the motor and coasting while the measurements were taken. Somewhat later, special installations were made for advertising purposes. One such combination used in 1922 consisted of a loop receiver with separate "A" battery for filament supply and a motor generator for "B" supply.

In 1926 a tuned radio-frequency receiver with two tuning controls, using a two-gang condenser on each control, was available to the public. Figure 1 shows a receiver of this type installed in an automobile. The controls were mounted in the instrument panel, which was removed from the car to make the installation. The receiver was mounted on rods stretched between the dash and the instrument panel. The speaker was of the horn type, usually mounted on the header bar. The antenna was installed in the roof, the installation depending upon the amount of upholstery mutilation the car owner would allow. The car battery furnished the filament voltage, while the plate voltage was supplied by "B" batteries. These were placed in a water-proofed box which was mounted through a hole cut in the floor of the car. While the motor was in operation, the receiver could be used only on local stations, due to ignition interference. No automatic volume control was incorporated.

Beginning in 1927, distributor and spark plug suppressors were used to reduce ignition interference, and a great deal of other work was done in this field over the next two years. This work involved both the automobile and the receiver and has continued from that day to this, progressing from complete shielding of all parts of the ignition system to the so-called suppressorless operation possible on many cars today, with no shielding of any sort.

Through the year 1929 the receivers were generally so designed and mounted that no remote-control mechanism was used for tuning or volume adjustment. One such receiver, a battery-operated unit constructed by mass production methods, was mounted on rods directly behind the instrument panel. The tuning control and the volume control were concentric and direct connected, and were built into the instrument panel. A magnetic-type cone speaker mounted in a metal box was connected to the receiver by means of plug-in cables. The box was designed to mount in any convenient location, usually on the dash.

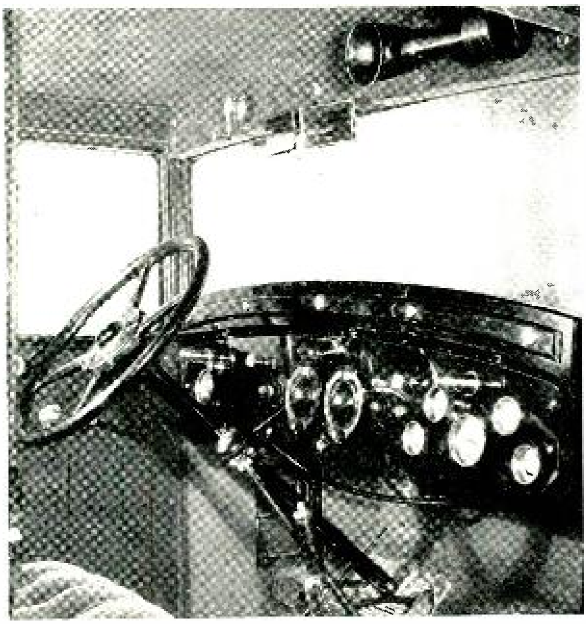

Fig. 1—Early two-dial receiver. Custom installation.

At about this time A.V.C. began to make its appearance in an important way, although its use was by no means universal until several years later. At this time also, the need for control mechanisms which would allow the receiver proper to be mounted more readily was manifest. Practically all receivers were installed in the field. The necessity of removing the instrument panel and drilling large holes was a major cost item and a great detriment to sales. Some work was done on electrical remote control systems similar to those available on home type receivers of that day, but these did not come into commercial use. Tension wire and torsional shaft drives made their appearance in 1930, and the latter type has since won almost complete acceptance on account of its simplicity. For several years the steering column control unit was very widely used except on custom-built factory installations, which were slowly growing in importance. The steering column control usually housed tuning and volume control knobs and a dial indicator, each knob actuating its appropriate unit in the receiver through a tension drive or a flexible shaft. These developments greatly simplified the installation problem and became a major factor in the increase of public acceptance of automobile radio. The flexible shaft control unit was also adapted for mounting under the instrument panel, and in custom installations, in the panel. In this form it dominates the present market, although in a current model discussed later in this paper the end of this dominance may perhaps be foreseen.

In 1930 tuned radio frequency receivers with battery "B" supply and filament type tubes were still almost universally used. The year 1931 saw the superheterodyne come into wide use. The use of a

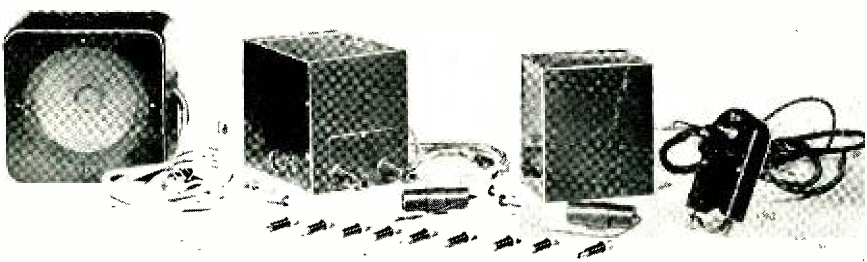

Fig. 2—Automobile Receiver—1932. Permanent magnet dynamic speaker, receiver unit, dynamotor unit, and steering column control, with typical accessories.

class "B" audio system in conjunction with a permanent magnet dynamic speaker was a feature of one receiver of this period. For the first time a fair output was available with reasonable battery drain, and in conjunction with the dash-mounted, permanent-magnet dynamic speaker the optimum in performance with low battery drains was approached.

The introduction of the six-volt indirectly heated cathode type tube in mid-summer of 1931 was a most important advance. While it had not been uncommon to find the 2.5 volt heater type tubes used, their power consumption was excessive for the generators and batteries of that day, and the six-volt tubes mark a major advance in automobile radio.

The advent of the six-volt tubes left the "B" battery supply as the obvious weak spot in design, and the best engineering talent of a rapidly growing industry now attacked this problem. The limitations of the "B" batteries were many and obvious—high upkeep cost, excessive weight, and installation difficulties. Their installation was often more troublesome than that of all the other units of the receiver. Most serious of all they represented a major barrier to progress in respect to increased power output and stability of performance. There were motor generators and dynamotors, expensive, inefficient, noisy, and mechanically cumbersome, available as substitutes. Nevertheless in 1932 the "B" batteries were discarded and the rotating machines substituted. Proper shielding and filtering were devised, and quite satisfactory operation resulted. Figure 2 shows a receiver of this period. Receivers were often designed to use either batteries or generators, as the customers desired. The electrodynamic speaker came into practically universal use at this time, and for the first time, overall operation came within range of performance as we know it today.

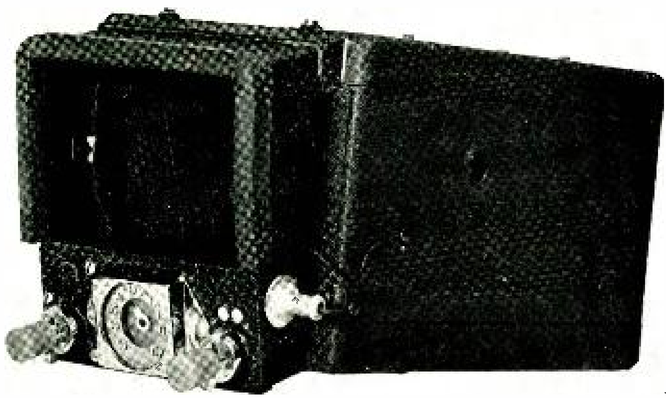

Fig. 3—Single-Unit Commercial Receiver.

There had long been in use a piece of equipment almost as old as modern electricity—the vibrating reed rectifier. In another form, that of a simple interrupter or pole changer, it had been used to generate direct-current power. Engineers, working under the pressure of commercial need demonstrated what can be done in the way of developing and adapting old ideas. This piece of apparatus soon became a cheap and efficient substitute for the rotating machine, and today the vibrator stands without a rival as the source of "B" power supply in automobile receivers. It is in use in two types, the synchronous and the non-synchronous. The former acts to convert six-volt d.c. to a.c. by impressing the battery voltage alternately across the halves of the transformer primary. The alternating voltage is then stepped up and rectified on contacts operated synchronously with the primary contacts. The non-synchronous type performs only the first function, while the second is performed by a tube rectifier having an indirectly heated cathode and designed to operate with the "B" potential between heater and cathode. The unit was usually either partially or completely shielded and was incorporated as an integral part of the receiver. This greatly simplified the installation problem, and 1933 and 1934 witnessed a tremendous growth in public acceptance of automobile radio.

In major items the 1934 receivers were much as are those of today. The greater part of the engineers' work since 1934 has been in the refinement of circuit components and performance, the elimination of spark plug suppressors, the lowering of costs, and in the improvements and adaptations that have come through the closer coordination of the automobile and the radio engineers' efforts, particularly through their association in the design of custom installations. As the popu-

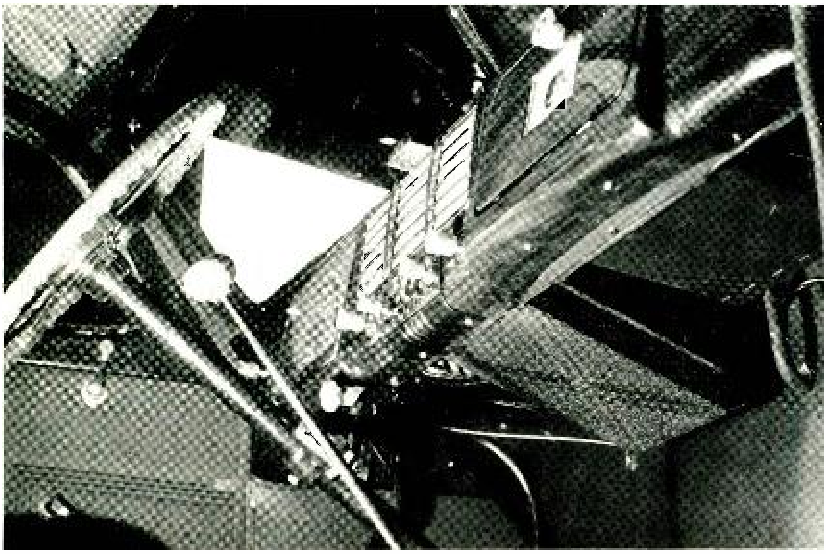

Fig. 4—The receiver as the installation man sees it.

larity of the automobile radio increased, its sales possibilities and engineering requirements became of increasing importance to the motor car manufacturer. Battery and generator capacities were increased. Provision was made for mounting the set without the necessity of drilling the dash of the car. Provision was made for speaker installation in the header, just above the windshield, and for custom control box installation. More care has been taken in the layout of the electrical system to avoid excessive ignition interference, although in many cases this is still far from satisfactory.

The receivers of 1937 mark a new high in radio performance. Of particular interest is a current model shown in Figure 3. This is a single or double unit receiver which mounts directly on the center line of the instrument panel (Figure 4). It is supported at the rear by a hanger suspended from the rear hood saddle bolt. The usual control box and flexible shafts have been eliminated. The controls are built as an integral part of the receiver. The speaker opens through an ornamental grille in the instrument panel as shown in Figure 5. This speaker location provides excellent sound distribution and clarity; in conjunction with the case and the electrical circuit design, adequate low frequency response is obtained as well. In the DeLuxe installation, the receiver is supplied with an auxiliary dash-mounted speaker. A suitable tap on this output transformer provides the correct impedance match. It is believed that this type of installation will become increasingly popular.

The designer of automobile radio has to face most of the problems of household radio, often in an aggravated form, in addition to several others which do not concern the household radio designer. One of the most serious of these is the necessity for making the receiver as small as possible. This results in the crowding of major components in such a way that continual compromise must be made between size, accessibility, and performance. The components themselves must be made small, but not so small as to be costly or undependable, or to sacrifice performance. They must be so placed that the external connections, the battery lead, antenna connector, control box fittings, and possibly the tone control, squelch switch, or local-distance switch are readily accessible. The cover must be removable and the design such that tubes and vibrator can be easily serviced without removal of the receiver from the car. All these conditions must be met while insuring that the power supply and antenna circuits are not adjacent or electrically interwoven, that heat-generating units are not placed near the electrolytic capacitors, that the unit as a whole will perform at zero or 125° Fahrenheit, that water will not enter the unit if the cowl ventilator is left open, etc. ad infinitum.

It is only by constant detailed attention to layout requirements that electrical circuit trouble can be avoided. Every lead must be carefully considered with respect to its neighbors from the standpoint of regeneration, tweets, image response, vibrator interference, ignition interference, audio buzz and hum, strength and stability of alignment under shock and vibration, and last but not least, ease of manufacture.

This necessity for crowding of parts aggravates many of the other special problems such as "vibrator interference." The vibrator power unit in performing its normal function generates random high-frequency voltage components, from which the high-gain radio circuits must be carefully shielded. All power leads must be filtered and so routed as to avoid excessive coupling to critical circuits. The power circuits must be brought into the receiver and controlled to keep the currents localized even within the metal of the chassis base. The radio and audio-frequency circuits must be grounded so as to avoid impedances in the chassis in common with those of the power supply currents. Unfortunately, "ground" is a very indeterminate word in automobile receivers.

In a performance check on a sample, care must be taken that interference has not been introduced into several circuits in such a way as to be self-neutralized. This neutralizing is relatively easy to do on

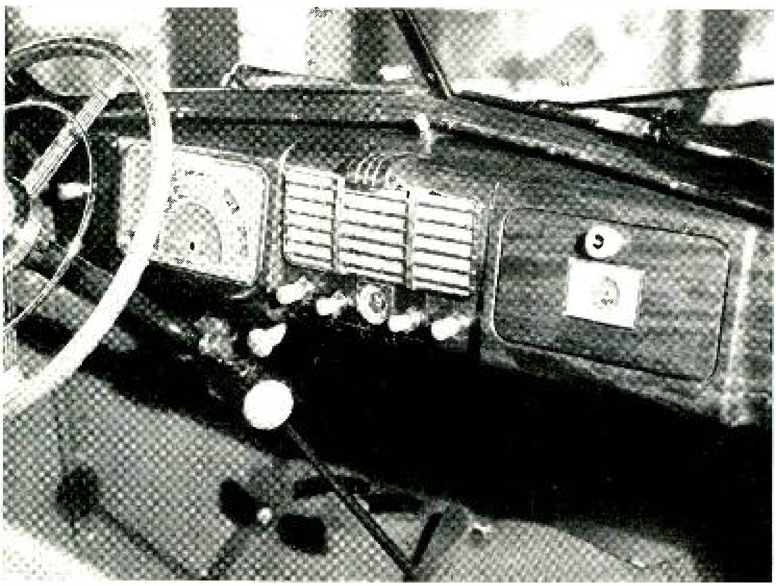

Fig. 5—The receiver as the owner sees it.

a single sample, sometimes even accidentally, but is almost impossible to control in mass production. The general problem of vibrator interference has been closely interwoven with the design of the components of the power supply system.

The design of the vibrator and power supply components for proper life and stability is a major problem. Figure 6 shows the transformer primary wave-form of a synchronous vibrator. Its operation is briefly described as follows: Assume the vibrator in operation. At *A*, both primary and secondary are in contact and the instantaneous voltage is approximately equal to the battery voltage. At *B* the contacts open. The magnetizing current of the transformer tends to remain constant. It is supplied by the buffer capacitors on the secondary, whose voltage, referred to the primary, drops to point *C* in the process. At *C* the contacts close in the opposite polarity, sending a surge of current into the capacitor and almost instantly (depending on the circuit resistance and leakage inductance) raising its voltage to *D*, where leakage reactance resonance or contact chatter will produce irregularities until the energy is dissipated, or uniform contact obtained. The cycle is then repeated.

The problem in design lies in the proper correlation of the magnetizing current of the power transformer, the size of the buffer capacitors, and the frequency and time-efficiency of the vibrator, i.e. the percentage of the time that the vibrator contacts spend in the

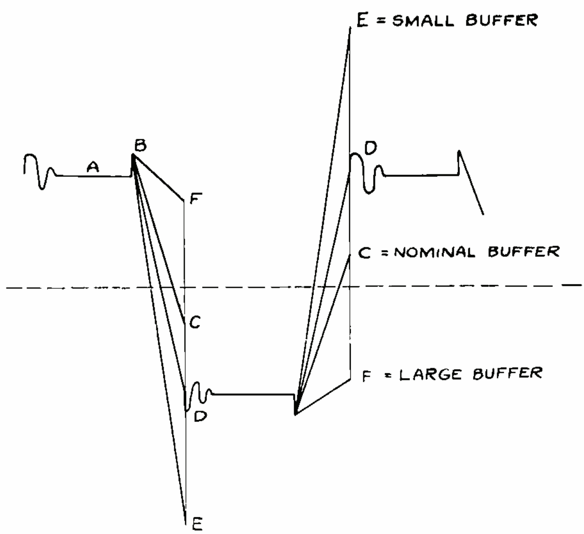

Fig. 6—Vibrator transformer primary wave form.

air-gap. These factors can be so balanced that points *C* and *D* coincide, producing a minimum of sparking at the contacts and, of course, a minimum of radio-frequency disturbance. For a number of reasons, however, this is not as desirable an adjustment as it would seem at first glance. Suppose that a unit is so adjusted, and is then placed in a receiver in which the buffer capacitor is below the nominal value, and the magnetizing current of the transformer is above nominal. In this case, the voltage reaches point *E* before contact is made, placing a severe overload on the buffer capacitor units. As the vibrator contacts burn away the time interval between *B* and *E* is increased; the voltage at *E* increases, as does the sparking and contact burning. The cycle is obviously unstable and breakdown eventually takes place. With adjustment as at *F*, the buffer is too large, and unnecessary burning of the contacts takes place when the capacitor is shorted. Radio-frequency disturbances generated are very great though operation is entirely stable. With adjustment as at *C*, the sparking tends to decrease as wear occurs at the contacts, or as the magnetizing current increases, and the result is stable operation until point *D* is reached. Care must be taken that the vibrator transformer will not saturate at high battery voltages, that the buffer capacitors do not change capacity with life or at the temperatures reached in the receiver, and that the driving excitation of the vibrator is stable so that a relatively constant time-

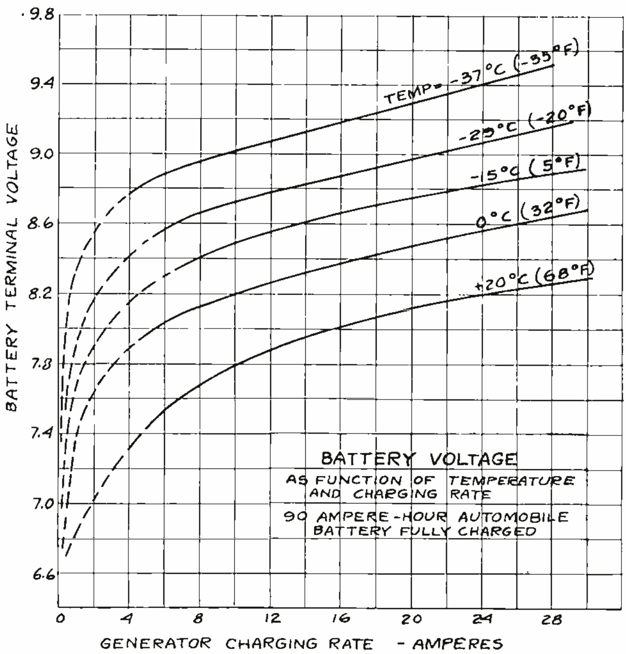

Fig. 7—Variation in battery voltage with charging rate at various battery temperatures.

efficiency is attained. As previously mentioned, minimum sparking and vibrator interference are obtained with adjustment for operation at *D*, but much of the trouble with vibrators during their early use was due to the difficulty in maintaining such an adjustment during the life of the vibrator. The non-synchronous or tube-type vibrator has a similar problem during the tube warm-up period, and either buffer capacitor or rectifier tube may be broken down. After the tube functions, the peaks cannot exceed the normal operating voltage appreciably. The load currents of the transformer, both primary and secondary, are a minor problem as they involve little storage of energy, provided the leakage reactances of the transformers are kept reasonably low.

As we have noted, much of the early so-called vibrator trouble was due less to the vibrator design, than to the lack of correlation of the design and adjustment of the vibrator on one hand, and the design of the associated transformer and buffer capacitors on the other. A contributing factor was a lack of knowledge of the variation in car battery voltage with the consequent effects on heating and on transformer saturation. Figure 7 shows the results of temperature and charging rates on the voltage of a typical fully charged automobile battery. It will be noted particularly that at low though fairly common temperatures, the battery voltage rises sharply with only a few amperes of charging current. This results in a number of serious problems for the designer. Although a fully charged battery which is not being charged will operate the tubes at or below their rated heater voltage (6.3 volts) and with corresponding plate and screen voltages determined by the power supply, allowance should be made for regular operation at 7.5 to 8 volts and possible operation up to 9 volts. This applies both to the permissible heater voltage and the plate potential which corresponds to these higher battery voltages. Electrolytic capacitors must be designed to withstand the surge voltage under these conditions. Power transformers should not saturate or the buffer capacitors may be broken down. Temperatures in the receiver must not be excessive at the higher voltages. Fortunately the battery voltage tends to decrease with increase in ambient temperature, so that heat runs may usually be satisfactorily made at 7.5 volts and 90 to 100° F. ambient. The vibrator should be designed to withstand the higher voltages and currents, and vibrator power circuits must remain stable. In general, factors involving life of components may be determined on a basis of a 7.5 volt battery, while breakdown must not occur at 9 to 9.5 volts. Fortunately the battery voltage situation is slowly improving. Many 1937 cars have voltage regulators which so reduce the charging rate that it is practically impossible for the potential to rise above 8 volts with the receiver in operation. It does not seem to be too much to hope that within a very few years automobile receivers can be designed to operate within as close voltage limits as are present household receivers.

Probably the major recent problem of automobile radio has been the antenna and antenna circuits. By its very nature it will possibly never be said that it is solved—there is always another station in the background which could be received if the antenna were larger or the circuits better designed. Unfortunately, antenna progress has at times been retrograde. One of the oldest, simplest, and generally most satisfactory antennas yet devised, the netting placed under the cloth top, has been eliminated with the adoption of all steel bodies. This roof antenna offered a fair effective height as automobile antennas go; and its output impedance (capacitive corresponding to the order of 175 micro-microfarads) was of a value relatively easy to incorporate into a circuit to good advantage. Its passing has caused the increased use of undercar antennas, consisting of metal straps, rods, wires, or plates fastened at a distance of two to four inches beneath one or both running boards. Their capacity is of the same order as that of the roof antenna, but their effective height is usually somewhat less. Moreover, they are easily torn off in going over curbs or in rutted roads. They collect mud and ice, change capacity, and lose efficiency seriously in adverse weather. They are peculiarly susceptible to tire or wheel static interference.

Various parts of the car have been insulated and used for antennas: steel insert tops, bumpers, rear trunk doors, and running boards. Of these, the latter type is probably the most satisfactory. With proper circuit design it offers performance comparable to that of the best roof type antenna. It, of course, requires careful engineering in order to incorporate it properly into the car design. It is thus available only on certain 1937 model automobiles.

A large variety of rod, whip, and overhead "towel rack" antennas are now coming into wide use. In general, these are of relatively great effective height, but of low capacity. Because of this capacity mismatch they are often not well adapted for use with receivers now commercially available. Their potentialities are very great, however. If the automobile body designers can be reconciled to their use, they may well be the antennas of the future. One popular 1937 car uses a rod-type antenna with the circuit properly designed to match. Performance at least comparable to the roof type is obtained even though the output capacity is but 12 micro-microfarads and the rod is only of the order of two feet in length. The "towel rack," or over-roof type, usually has a capacity of the order of 65 micro-microfarads. It gives good performance when properly matched to the circuits, provided it is placed five inches or more above the car. The sale of this type of antenna to the general public is increasing rapidly. The whip antenna is quite similar in performance and probably the lowest in cost of any type. It can be quite readily connected to the receiver without necessarily requiring special transformers at the entrance to the lead-in cable as does the rod-type referred to above.

Because of the present state of change in antennas, the design of the antenna circuit is naturally a troublesome problem. In a receiver designed for general sale, the best compromise must be made for operation on the various types of antennas. In a custom-built receiver the

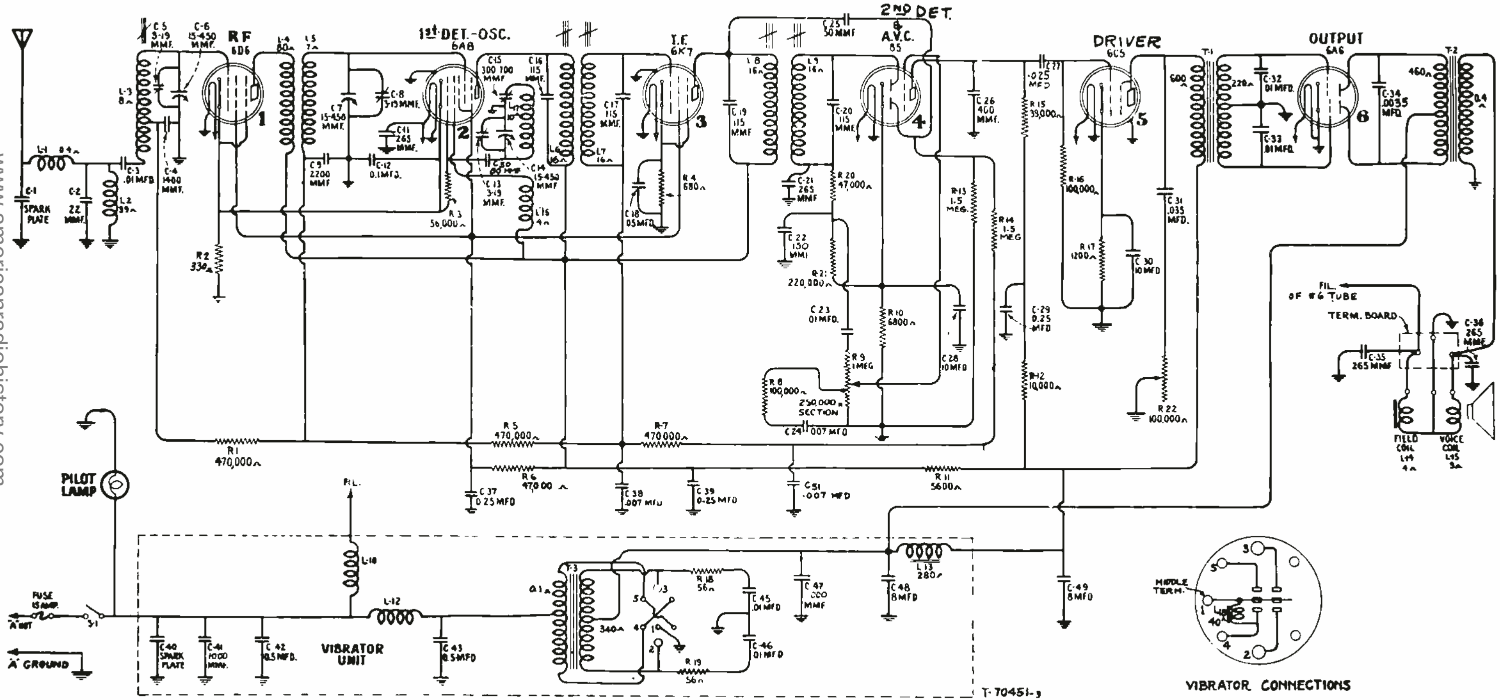

Fig. 8—Circuit diagram of a modern automobile receiver.

antenna is usually specified by the car manufacturer, though it is often not the most desirable type electrically. In any case, given the antenna, the problem of the designer is to make use of the available signals most efficiently. He is limited primarily by these factors: locally generated interference either external to the car, as street-car noise, or internal, as ignition noise, vibrator interference, and wheel static; secondly "natural" static; and in the absence of these, hiss in the form of thermal agitation voltage in the tuned grid circuit in the first amplifier stage. Let us assume that the installation is free from all of these except the thermal agitation effect. This is the "rushing noise" of which the customer complains when the receiver is made too sensitive. It is caused by the random motion of the electrons in the first tuned circuit of the receiver, and, in a properly designed automobile receiver, will predominate over all other noises generated in the receiver. The designer aims to arrange the circuits so that at any given low input from the specified antenna, this noise is made as small as possible. Thus, the true criterion of performance is not the ability to receive a signal, but rather to obtain it with as little "hiss" as possible. The "one microvolt" receiver has often been the goal of radio designers. Unfortunately, as we can readily observe, it has little fundamental significance, even assuming that the antenna capacity were specified, for it expresses nothing about the hiss to signal ratio* at the given output level. A truer criterion, somewhat more cumbersome to measure, is the input required to produce a specified hiss-to-signal ratio. A better figure of merit would be the hiss ratio at a standardized small carrier input or the standard of the Institute of Radio Engineers, the Equivalent Noise Side Band Input. These bases of comparison would apply only between receivers designed to operate from the same antenna. A satisfactory rating of hiss-to-signal behavior of receivers designed to operate from different antennas must express the performance of the antenna, together with its associated receiver. This could be done in terms of the field strength of a carrier of specified modulation depth which is necessary to produce a given hiss-to-signal ratio, or conversely, the hiss ratio at a given field strength. In general, sensitivity expressed as input for a standard audio power output† is

* This quantity is determined by introducing a carrier of arbitrary modulation percentage, usually 30 per cent, through the proper dummy antenna. The modulation is removed and the residual noise voltage is measured and expressed as a percentage of the output when the carrier is modulated.

† Because of the fact that the *average* output level of automobile receivers in normal operation is higher than that of receivers for home use, it is usual to use a greater value of standard audio output for performance measurements than has been usual for checks on home receivers. Generally the value of 1.0 watt is chosen as standard for automobile set work.

not a problem. Even a four-tube circuit can be designed to give a greater value of sensitivity than can be used, hiss-to-signal ratio being the limiting factor.

For similar reasons, antenna gain is not an infallible measure of performance, even when comparisons are made with a given dummy antenna. The gain may in one case be obtained by close coupling, in another by high secondary impedance with loose coupling. Identical gain would mean that the former is superior in regard to usable station-getting ability. The writer recalls two receiver designs of

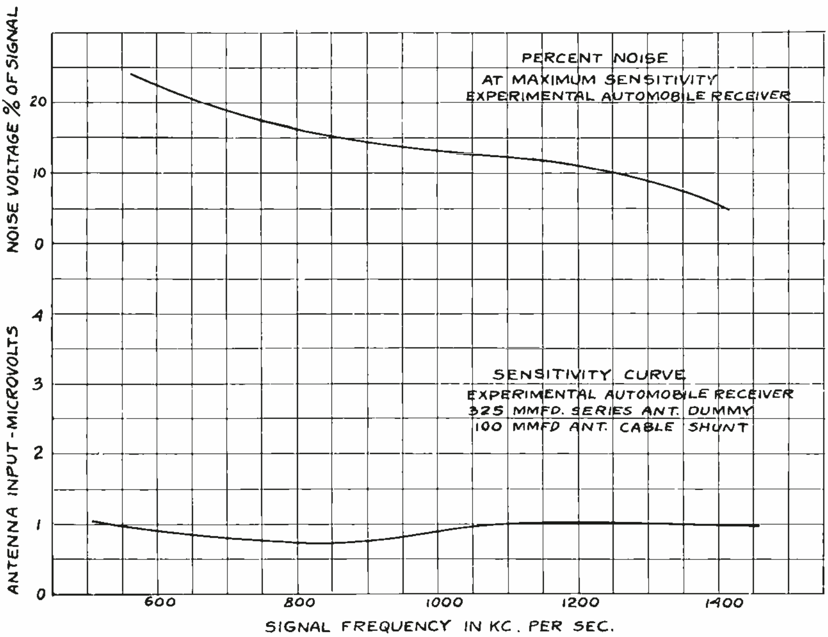

Fig. 9—Sensitivity and noise percentage curves of an experimental receiver.

equal over-all performance. One had a sensitivity, measured through its 12 micro-microfarad dummy capacity, of approximately one-tenth that of the other, which, in turn, was measured through its dummy capacity of four hundred micro-microfarads. The antenna gains, similarly measured, were in the same ratio. The former operated from a rod, the latter from a running board. Yet, they were very closely comparable in over-all performance on low signal strength reception.

The acoustic problem is another consideration which has been of major importance and difficulty. It has had two phases, that of securing satisfactory bass note response, and of securing proper sound distribution. The former is of course due to lack of sufficient baffle area around the speaker, or of sufficient volume of air behind it. In practice, the header speaker gives good distribution of sound throughout the car and excellent reproduction of voice, but very poor musical quality. The dash speakers, when carefully designed, give good musical quality, although low-frequency response is not, under all conditions, all that may be desired. A type of dash installation which offers good low-frequency

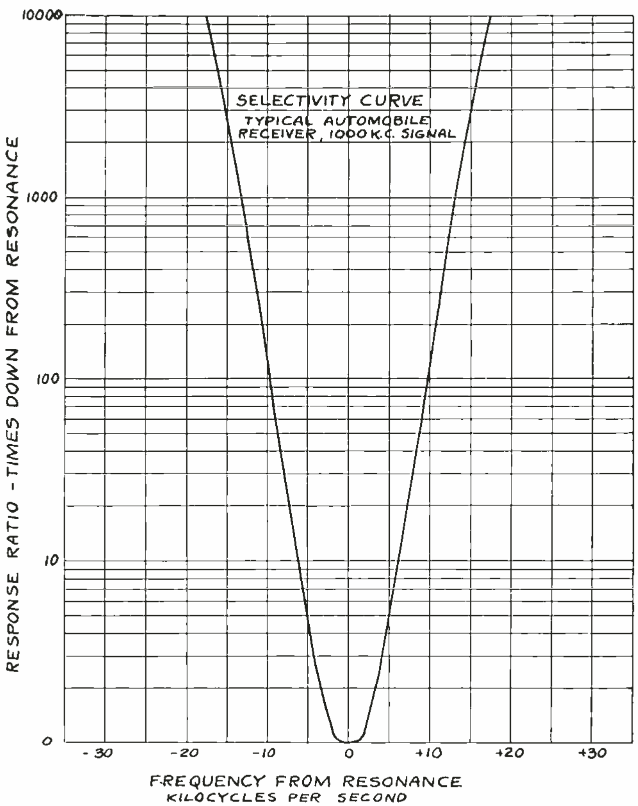

Fig. 10—Selectivity curve—modern automobile receiver.

response, with freedom from objectionable resonance effects (barrel tone), was offered in the acoustic equalizer in 1936. The tendency at the high-frequency end of the audio spectrum is towards the reduction of the objectionable high frequency hiss components by cutting the audio-frequency range as much as possible. This is a natural consequence of the small signals available in most locations, and in the absence of satisfactory bass note response, has not been seriously detrimental, particularly in view of the fact that the customer's first move often is to adjust the tone control to the bass position.

A major barrier to advance in fidelity of tonal quality lies in the noises and rumbles of a car in motion. They have a striking masking effect upon the ear at both the extreme high and low frequencies. Fortunately the automobile industry is closing in on this problem. At 50 miles per hour the air-conditioned car of the future may be almost as quiet as one's living room.

Ignition noise is caused by the radio-frequency pulses set up by the spark generating equipment necessarily used to cause combustion to take place in the cylinders of the automobile engine. Fundamentally, the ignition system of a car has most of the components of a damped-

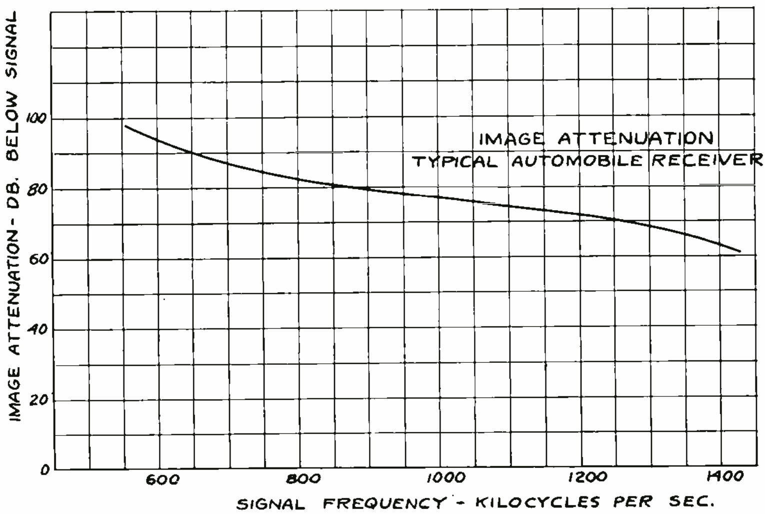

Fig. 11—Image attenuation of a typical automobile receiver.

wave transmitter. Therefore, from the automobile radio installation point of view, the hood of the car contains a small partially shielded transmitter, and unless special precautions are taken in making an automobile radio installation, the ignition noise will be the loudest and most persistent signal received. The obvious and fundamental method of attack is that of complete shielding of all parts of the ignition system. This method is now generally used in aircraft installations. While moderately successful in automobiles, it is very expensive, and often introduces difficulty with electrical leakage and consequent motor trouble. Often it is very inadequate because it fails to take care of chassis currents set up by the primary or because the location of coil and leads is such as to make complete shielding extremely impractical. The use of the resistance-type suppressor in the high-tension leads is a powerful weapon in the engineers' struggle with this problem, as it reduces the interference at its source.

Very early in the development, it was noticed that material improvement in ignition noise could be obtained by carefully arranging the antenna lead-in with respect to the wires under the instrument panel, and especially with respect to the "A" lead of the receiver. Most early installations considered the proper placing of antenna and "A" lead as one of the regular procedures for reducing ignition noise. This was dependent upon introducing a small amount of out-of-phase ignition noise into the antenna circuit through coupling with the "A" lead. It is rather startling how completely a rather bad case of ignition noise can be cleaned up by properly balancing the feed-back

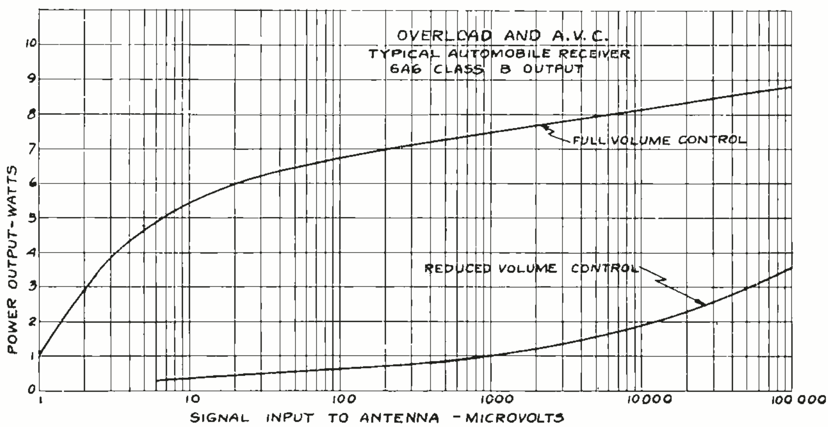

Fig. 12—Overload and automatic volume control curves of a modern automobile receiver.

voltage. It is quite obvious that this system has many difficulties, such as the necessity of obtaining the balance with the driver (and sometimes the passengers) in the car, and the great tendency to become unbalanced as the grounds and bonds of the car change with use. Moreover, in many cases it is impossible to obtain a balance at all points of the broadcast band.

A major step was accomplished when the automobile receiver was carefully shielded and the "A" supply lead sufficiently filtered that the receiver was entirely free from ignition noise with the antenna disconnected. By removing all the noise except that which was picked up directly upon the antenna, a marked improvement was made. On most cars in good condition, the spark-plug suppressors could be entirely removed and the one remaining distributor suppressor reduced until there was a very slight, if any, harmful effect on the starting and operation of the car.

The next step was to make improvements in the actual radiation from the ignition systems. The average modern car is fairly well shielded for radio frequencies extending well through the broadcast band, but at higher frequencies the shielding becomes more and more inadequate. Another factor is the poor bonding or grounding of the motor and body to the frame of the car. Again the high frequencies are the most difficult to control because a bonding lead has a certain amount of inductance, and therefore there is a rise in the voltage between component parts (such as the motor to the frame and the frame to body) as the frequency increases.

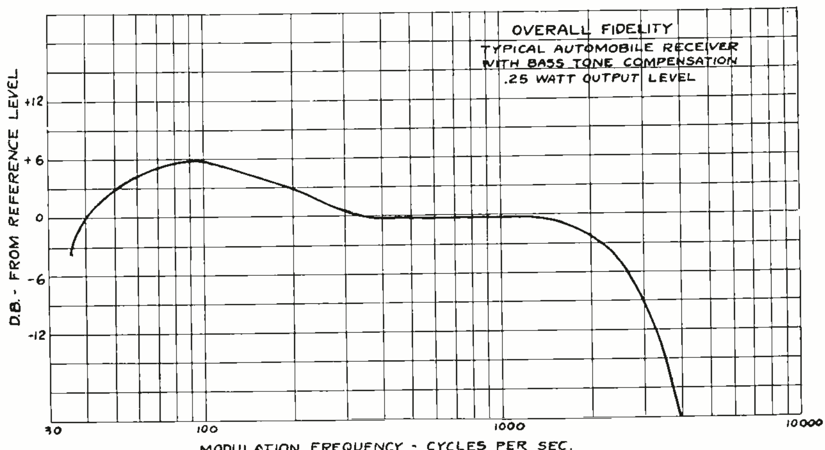

Fig. 13—Overall fidelity curve, typical automobile receiver incorporating bass compensation.

When these facts were presented to the car manufacturer, most of them have seriously attempted to reduce high-tension lead lengths and to keep low-tension wiring and connections for lighting circuits well separated from the high-tension leads. Some ignition manufacturers operate the switch mechanically from the instrument panel to the coil. This removes primary coupling to the wires on the instrument panel, and also diminishes direct radiation to a roof antenna. Another manufacturer has completely shielded the spark plugs as an indirect consequence of the type of motor design used. On this particular make of car, by properly by-passing the primary circuit at the coil and adding a small metallic cover to shield the distributor, all ignition noise is completely removed without the addition of either spark-plug or distributor resistance. Thus, this problem of automobile radio performance, once a most serious one, is well on the way to solution.

Figure 8 shows the circuit diagram of a current model automobile receiver. Graphs of the major performance items of rather typical or experimental receivers are shown in Figures 9 to 13. Figure 9 shows the noise percentage and sensitivity curves (taken at one watt output) of a developmental receiver designed to match an antenna capacity, including lead-in, of 425 micro-microfarads. The design is open to criticism on the basis that the noise percentage (usable sensitivity) is not uniform over the broadcast band. Figure 10 shows the selectivity of a modern receiver using flat-topped (critically coupled) high-Q, magnetic-core, intermediate-frequency transformers. The stability of such a design is very good, and optimum performance is obtained without sacrifice of desired high-frequency response. With such a design, tuning is made easier for a given selectivity performance. Figure 11 shows the image attenuation of a typical automobile receiver. Image rejection problems in automobile radio are not greatly different from those of home radio. Figure 12 shows the overload and automatic volume control curves of a receiver incorporating a class "B" 6A6 output system and delayed automatic volume control. This system offers exceptional output power. This automatic volume control is very good for signals above the delay point, but poor for signals below this level. The undelayed type of circuit is also widely used. It offers poorer performance on strong signals, although better on signals below the delay threshold. Figure 13 shows the overall fidelity (voltage across the voice coil) of a receiver incorporating bass compensation. This circuit arrangement is commonly used on better grade receivers as a means of obtaining more satisfactory low-frequency response and partial aural compensation.

ACKNOWLEDGMENT

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SUPPLEMENTARY REFERENCES

LLEWELLYN, F. B.: "A Study of Noise in Vacuum Tubes and Attached Circuits", *Proc. I.R.E.* Feb. 1930.

FARNHAM, PAUL O.: "Broadcast Receiver for Use in Automobiles", *Proc. I.R.E.* Feb. 1930.

BALLANTINE, STUART: "Fluctuation Noise in Radio Receivers", *Proc. I.R.E.* Aug. 1930.

LLEWELLYN, F. B.: "A Rapid Method of Estimating the Signal-to-Noise Ratio of a High Gain Receiver", *Proc. I.R.E.* March 1931.

CURTIS, LESLIE F.: "Electrical Interference in Motor Car Receivers", *Proc. I.R.E.* April 1932.

Reports of joint R.M.A.—S.A.E. Committees—
"Automobile Radio Standards", *S.A.E. Journal* Nov. 1932, Page 26.
"Car Antenna Problems", *S.A.E. Journal*, June 1933, Page 12.

Report of the Standards Committee of The Institute of Radio Engineers, 1933, Page 106.

NORRIS, R. F.: "Automotive Quieting", *Journal Acoustical Society of America 8* 100 (1936)

SOME PROBLEMS OF AVIATION RADIO*

By

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IT IS obvious that the aviation industry is faced with many special problems. Not the least of these problems, however, comes under the heading of Aviation Radio, for while to many radio is a necessary evil of aviation it has become the guiding and controlling force of the modern air transport systems and as its design features are alike in finesse to the proverbial Swiss watch, its possible ailments due to its inherent close tolerances become many. However, its ailments go beyond the more simple devices of engineering and production, going far back into the research laboratories. For example, as our modern air transport began flight through bad weather conditions involving "instrument" flying, the reported radio failures jumped alarmingly. For some time radio engineers and technicians were puzzled. For that matter they still are—by a particular phenomenon, which for lack of a more expressive term was aeronautically called "Rain", "Snow", or "Sand" static. Pilots began reporting some years back that as they entered certain overcast or cloud conditions and even when flying under or over certain of these meteorological conditions that their radiobeam and weather broadcast receiving apparatus, and in instances also their two-way communication high-frequency receiver equipment, first began to produce a very high and unusual sounding static response after which it went dead. The reports were varied, greatly varied, sometimes sounding mysterious. A pilot would report that the static increased in volume along with his speed as he began a take-off although there had been little or no static evident as he tested his equipment prior to take-off, the static increasing in frequency and volume until as he reached cruising speed it became almost unbearable to wear the headphones, and then suddenly the receiver apparatus became dead. In some cases the report would indicate that this condition existed throughout the flight. Other instances, however, indicated that the apparatus gradually returned to life later during the trip and worked satisfactorily throughout the remainder of the trip.

Many reports on interference to scheduled airline flight operations from this rain static condition have been to the effect that the inter-

* Presented before the Fifth Annual Meeting of the Institute of Aeronautical Sciences, January 27, 1937.

ference was experienced during only a small portion of the flight, whereas the extreme has been a condition where no radiobeacon-weather broadcast reception was possible throughout a trip.

Acting promptly in efforts to determine the causes and thereafter the cure for this disturbing condition, the service technicians and the engineers obtained very discouraging data. The phenomenon of rain static would appear only under those adverse or instrument flight conditions where it was impracticable or extremely hazardous to experiment.

All of the tricks known to the radio industry for the suppression of undesired noises were tried in various ways and to various lengths, in an effort to obtain a solution to the problem by reduction or elimination of the bothersome condition within the radio apparatus itself. None of these efforts brought about the least degree of success.

Engineering study failed to reveal any means of duplication of this phenomenon in the laboratory and, thus being unable to simulate the condition in the laboratory, it has been difficult to deal technically with this very important situation.

However, every cloud has its silver lining. During the anxious days of investigation of this phenomenon which we now refer to as "Rain Static", some one happened to remember that a somewhat similar condition had been noticed in the operation of marine direction finder apparatus some years previous and remembered, too, that at that time it was found that an electrostatically shielded loop antenna assisted greatly in getting around this disturbing condition.

An electrostatically shielded loop antenna as referred to here is simply a conventional loop wound antenna around which is a complete metallic shield or housing which is broken at only one place in its periphery.

Experiments were immediately begun to determine if the same solution might apply to the aeronautical situation and while these experiments are not complete at this date, indications are that the electrostatically shielded loop antenna properly applied practically eliminates the effect of this rain static on aircraft radio reception. The importance of the investigation and work on this particular project is seldom understood. It will be recalled that beacon lights have often been called an unnecessary luxury—for in clear weather one doesn't need them particularly, and in bad weather one can seldom see them. Radiobeacons with the resulting radiobeacon courses, have provided, to a marked degree, the guiding path for aircraft flight under poor visibility conditions. When the aircraft encounters conditions where the airway lights are not usable, it is confronted with a problem of navigation which revolves largely around the use of radio, especially the radiobeacon system. If this same aircraft encounters meteorological conditions wherein its radio receiver apparatus becomes useless, as has usually been the case in the past whenever rain static was encountered, then the aircraft literally becomes sightless and navigation becomes entirely a problem of dead reckoning or astronomical calculations. Dead reckoning has never been applied very satisfactorily to the operation of airline aircraft and, likewise, astronomical navigation has been considered economically impractical.

The application of electrostatically shielded loop antennas appear to offer a solution to this difficulty and the radio industry looks forward to the application of such shielded loop antenna to all aircraft, especially of the instrument flying type, believing this application offers a definite advance toward obtaining maximum usefulness of radio in aviation.

Another problem likewise presented to radio by the increase of instrument flight activity is the application of standard aircraft receiving equipment to the aircraft in such a way that the receiving system will properly indicate minimum course width of radiobeacon transmission and definitely indicate the silent zones directly over the radiobeacon stations. Minimum course widths are essential to operation economy. Silent zones directly above radiobeacon stations are a necessity in the safe use of the radiobeacon system during the process of "letting" down through the overcast and making instrument approaches to airports. The application of standard receiver equipment to aircraft in a manner to provide this desired result has been a most difficult one. The antenna system required to do this job most efficiently has become practically prohibitive because of the increased speed of aircraft and the consequent increased drag of such antenna. Compromises have had to be effected and a compromise between the desired and the most economical is a rather hard one to arrive at, particularly in aviation.

Because of the fact that a large number of the existing radiobeacon stations in this country employ crossed-loop-type antenna systems and the creation of silent zones above a radiobeacon with minimum course widths is a function dependent upon having vertical polarization of the waves striking the antenna of the aircraft receiver system, only two types of aircraft antenna will, therefore, do the job satisfactorily. A mast antenna with the receiver located directly at the base provides the most favorable condition, but, as will be appreciated, presents a real drag problem and consequently an unbearable operation cost. A symmetrical "T" antenna located either above or below the aircraft, arranged with its lead-in dropping or rising vertically to the receiver equipment, provides the next best arrangement. This antenna also produces some drag effect, but is by far the most economical in a cost-per-mile calculation. Either type of antenna is susceptible to the afore-mentioned rain static condition which requires the carrying of a separate electrostatically shielded loop antenna arranged preferably for rotation, but at least with its plane in the line of flight, together with a switching arrangment to permit switching the radio receiving equipment to the antenna when rain static conditions make its use imperative.

In the use of a radiobeacon silent zone for making approaches to airports it will be appreciated that this method of employing the silent zone, together with a certain type of installation of equipment on the aircraft, is a negative method. Because of the ever-present deficiencies of any negative method, engineers of the U. S. Bureau of Air Commerce recently completed the basic development necessary to provide a positive indication to the aircraft of its location directly over a radiobeacon. This new development presumes the use of an ultra-high-frequency marker transmitter located on the ground at the radiobeacon station with a special directive type of antenna system. The aircraft is equipped with a small, light-weight, ultra-high-frequency receiver arranged to provide both aural and visual indication of the presence of the aircraft over this new type of transmitter. This new, positive "zone of silence" equipment, known as the "Z" marker, gives promise of very satisfactory application and elimination of another variable of aerial navigation and will, in addition, reduce the afore-mentioned problems of radiobeacon-weather broadcast receiver application to aircraft.

Another problem of large magnitude which has confronted the industry for some time has been the design of the radiobeacon-weather broadcast ground station system. Some operators have wanted radiobeacon signals transmitted continuously, with weather broadcasting on a separate radio frequency; others have desired that both services be operated on the same frequency, which, of course, has entailed cutting off the radiobeacon signals during the weather broadcasts. But everyone has looked forward to the time when both services might be operated simultaneously on the same frequency, in order that the pilot might have continuous radiobeacon guidance as well as weather information continuously and simultaneously available. When one reasons out the method of making a low-ceiling approach or "letting" down through the overcast at a terminal station, the reasons for desiring simultaneous operation will be very apparent. The radio engineers of the U. S. Bureau of Air Commerce have just recently concluded the essential design work on a system which it is hoped will ultimately provide this desired simultaneous operation. The new system projects the use of low powered, simultaneous type radiobeacon-weather broadcast stations located approximately every fifty miles along all airways. The low power and close spacing has proven desirable from years of experience in order to get around the swinging and multiple courses, signal fading, etc., which has become evident from service use of the higher powered, more widely spaced stations. Also, a general feeling has grown in the industry that an airport is of little use today without radiobeacon-radio-telephone facilities, the contention going back to the afore-mentioned light system. What good is an airport if you can't find it when flying on instruments or over the top, and the only known satisfactory way of locating a field is through the use of such a radio aid?

The present development of the larger transport aircraft with which it is indicated future transcontinental service will be maintained with possibly only one stop enroute and, further, which may fly at sufficient altitude to be above all average weather conditions, has brought to radio other problems of major magnitude. This aircraft, because of the distance between its terminals, will require much greater range of communication equipment than has been heretofore, or is at present available. The industry has begun the development of a transmitter of approximately 250 watts power output, in comparison to the present standard 50-watt equipment. This increase of power output has brought forth many problems in transmitter design, not the least of which is the provision for the most economical primary power supply. In stepping up the size of equipment, it becomes apparent that the presently used 12-volt direct current power systems of aircraft cannot be expected to furnish sufficient power at an economical rate to operate properly the proposed radio equipment. The radio load on the new super transport is, of course, only a part of the total electric load. It has been indicated that the total primary electrical load on these new ships will be approximately fifteen kilowatts. Direct current systems of the 12-volt type are obviously impractical for requirements of this type. While development of this new aircraft and its accessories has not progressed sufficiently to state definitely what its finally manufactured equipment may be, it is indicated that a 110-volt, 800-cycle a-c power supply system will probably be used. The usage of alternating current, and especially high-frequency alternating current, has brought many problems into the design of the radio apparatus.

Increasing numbers of aircraft, airline and airway aids have presented us with an acute problem with respect to available radio channels upon which we are able to operate the desired or necessary communication and navigational services. This shortage of frequency channels in the portions of the radio spectrum which are now being generally used is leading the industry into many investigations of the use of ultra high frequencies.

Particularly pressing is the need for expansion of airport traffic-control operations. At the present time there is but one frequency available for this most important service, requiring all airports of this country to operate their radio traffic-control systems on this universal frequency. Low power is, of course, employed: first, because only short-distance communication is necessary, but also because of possible interference between closely adjacent airport stations. It is believed that the first widespread application of ultra-high-frequency communication apparatus to the aviation field will appear in this airport traffic-control section, forgetting for a moment the afore-mentioned use of the "Z" type of cone of silence marker for radiobeacons. This appears to be an excellent place for the transition to the ultra-high-frequency portion of the spectrum to begin. Development of instrument landing systems has for some time involved the use of ultra high frequencies. The close tie-in of installation, operation, maintenance, etc., of instrument landing equipment with that of airport traffic-control equipment brings about one encouraging aspect on the economics of the situation. It appears that a single receiver, probably of multiple-purpose design, could suffice for the aircraft for usage of the "Z" markers, radio traffic control, and possibly instrument landing.

It is felt that within a reasonable number of years we may expect all of the services we now operate in aviation to be conducted upon the ultra high frequencies. This very wide transition involves innumerable separate major projects of research and product development.

As radio advances toward its ultimate goal in aviation, just so will advance the reliability and safety of flight. Radio engineering of the magnitude involved cannot advance proportionately without the fullest cooperation of the aircraft, engine and accessory engineering groups. There has been no shortage of such cooperation throughout the past, and those of us in the radio industry look with pleasure to a continuance of this situation so as to allow us to efficiently and quickly improve the present radio apparatus, and to develop and apply new radio aids for aircraft navigation.

300-WATT MARINE RADIO TELEGRAPH TRANSMITTER

By

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THE intermediate frequency band of 375 to 500 kilocycles (800 to 600 meters) is of paramount importance for radio communication in the maritime mobile services. Practically all of the 15,000 vessels throughout the world which are equipped with radio apparatus are capable of communicating in the intermediate band. The 500 kc. frequency is used universally for distress calls while the 375 kc. channel at the other end of the band is employed when a vessel transmits to shore radio-compass stations for radio bearings. Frequencies between 375 and 500 kilocycles are used for message traffic between ships and shore and from ship to ship.

The original shipboard transmitters for service in the intermediate band were spark sets. With the development of vacuum tubes simple antenna oscillator circuits were first devised and were used with some success until demands for improved frequency stability required better performance. This led to the development of tube transmitters using closed oscillator or tank circuits, loosely coupled to the antenna. Such circuit arrangements when properly designed are effective and find considerable application for low-powered transmitters.

For transmitters of medium power and higher power, the master-oscillator power-amplifier type of circuit offers several advantages. The output frequency is determined in the master-oscillator circuit, which in turn supplies grid excitation to the power amplifiers. Improved overall efficiency is obtained, compared to simple oscillator tank circuits, because it is not necessary for circuit stability to maintain such a large amount of circulating energy in the power amplifier tank circuit. Care must be taken, however, to minimize harmonic radiation when the power amplifier tubes are operated at high efficiency.

Two forms of signalling are desirable in an intermediate frequency shipboard transmitter. Continuous waves (A-1) are necessary for transmission with the minimum amount of interference to other stations and to permit highly selective receivers to be used. Modulated wave signalling (A-2) is also required for use in distress, for calling purposes, and other cases when it is desired to make contact with another station as quickly as possible. Automatic break-in operation is of value so that transmission and reception can be carried out on the same antenna and to enable the local receiver to be effective instantly whenever the transmitting key is open.

A new design of radio telegraph transmitter for shipboard service has recently been developed. Views of this transmitter are shown in Figures 1 and 2. The power delivered to the antenna on A-1 or con-

Fig. 1—300-Watt radio-telegraph transmitter.

Fig. 2—Side view of transmitter.

tinuous wave signalling is 300 watts. For modulated wave or A-2 signalling the antenna power is approximately 400 watts. In order to enable the radio operator to make suitable adjustments for efficient operation, various meters are provided on the transmitter panel. Correct input to all tubes is determined by means of a plate voltmeter and plate ammeter. Power output may be readily controlled by means of a generator field rheostat. By reducing plate voltage on the tubes the antenna power may be readily lowered for communication in harbors or at other times when short ranges are desired. Since considerable vibration may be encountered aboard ship, the entire weight of the transmitter (175 pounds) is supported by four special rubber shock mounts. In addition a fifth rubber mount is used to brace the rear of the transmitter to prevent excessive lateral motion.

In the design of a transmitter for this service, various methods were considered for adjusting the circuits to the desired frequencies so that they could be quickly selected by the operator after the initial adjustments have been completed. In the past one method has been to employ bare wire coils or coils wound with copper strip, with flexible leads from the frequency change switch connecting to various portions of the inductances. Such a method requires considerable time for the initial set-up of frequencies and is subject to the disadvantage of accidental change in frequency due to movement of the tapped leads. Transmitters have been designed in which the frequency range is controlled by means of variometers or variable condensers from the front panel, with mechanical positioning devices or stops to enable quick adjustments to specified frequencies. In the transmitter described in this paper, four small variometers, each covering a portion of the total frequency range, are used in the master oscillator and power amplifier tank circuits.

A side view of the transmitter (Figure 2) shows the controls for the variometers in the master oscillator and power amplifier tank circuits. Since it is necessary to be able to adjust the transmitter to any four frequencies within the intermediate band, taps are brought out from the tank coils and are arranged to be connected to each variometer. After the correct taps have been selected, the rotors of the master oscillator variometers are adjusted to the desired frequencies, and similar units in the power amplifier tank circuit are employed to tune the P.A. to resonance. The variometers are then locked in position and the panel switch used to select quickly any of the four frequencies.

A total of four Type 11 tubes is used in the transmitter. One of these tubes is in the master oscillator circuit while the other three are connected in parallel in the power amplifier circuit. Access to the tubes is obtained by removing a ventilating shield on the left side of the transmitter.

The method used to obtain modulated or A-2 transmission is of interest. Earlier designs of equipment have utilized motor driven choppers to interrupt the oscillations at an audio rate while in some designs use is made of a low power audio oscillator to modulate the control grids of the tubes. Either of these methods provides mainly negative modulation, with the result that the power output on modulated signalling is approximately one-half of that obtained on continuous waves. In this new design of transmitter, however, 500-cycle plate modulation is introduced into the power amplifier plate circuit through a suitable step up transformer. The 500-cycle energy is obtained from a small alternator, which is a part of the main motor-generator set. Approximately 90 per cent modulation is obtained, resulting in greater effective power output during modulated wave signalling, than is obtained on continuous waves.

Radio equipment for use aboard ship must be designed with particular attention to insulation requirements on account of marine moisture conditions. All power circuits for the transmitter are run in lead covered conductor to prevent absorption of moisture. Parts which operate at radio frequency potential, such as switches, tube sockets, and choke coils are insulated with glazed ceramic materials.

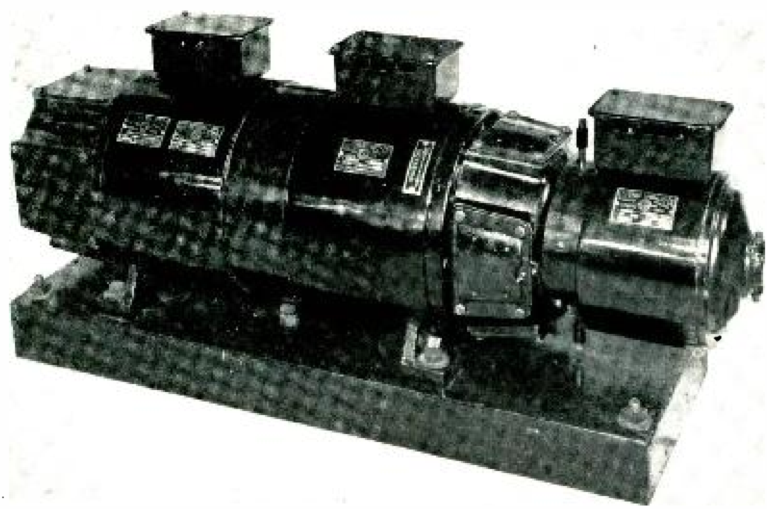


Fig. 3—Motor generator set.

The main antenna used with this transmitter aboard ship may have a capacity ranging from 500 to 1500 μμf. The resistance is usually quite low, seldom exceeding 10 ohms and in the average case is approximately 4 ohms. The natural wavelength of the shipboard antenna rarely exceeds 450 meters, with the result that inductive loading is required to resonate the antenna over the intermediate frequency band. Since the antenna current is quite high, even for medium power, the antenna loading inductance must not introduce excessive losses when carrying currents to the order of 8 to 10 amperes. In order to maintain the efficiency at a high value, the section in which the loading inductance is mounted is arranged to be free from closed loops. This is done by using an insulating member for the upper part of the framework construction, as well as nonmetallic sides and top where the antenna loading inductance is enclosed.

Power supply available on the average merchant vessel is 110 or 220 volts direct current. A radio transmitter of the type described requires three sources of energy, namely low voltage A.C. for filament circuits, high voltage direct current for the plate circuits, and 500-cycle power for modulation. Whether or not a thermionic rectifier is used for the plate supply, some form of rotating machinery is required to convert the ship's power. It was, therefore, decided that the most efficient and compact source of power for the transmitter would be a suitable motor generator set. This unit, shown in Figure 3, consists of a D.C. motor with slip rings to provide 31 cycles A.C. for filament supply, a 1200-volt, 780-watt generator for plate supply and a 110-volt, 500-cycle, 200-watt alternator for modulated wave signalling. Approximately 1700 watts are required from the ship's line for full power key locked operation.

A schematic diagram of the transmitter is shown in Figure 4. The master-oscillator tube uses a Colpitts circuit with a special arrangement of three tank capacitors to provide grid excitation and neutralizing voltage for the power amplifier tubes. The grid of the master-oscillator tube is coupled through a condenser to the grids of the three power amplifier tubes. Direct-current plate supply for all tubes is obtained through suitable chokes in the conventional manner. The method of coupling the power amplifier tank circuit to the antenna is of interest. The r-f component of the power amplifier tank circuit passes through a relatively large capacitance, which is variable, this latter capacitance being connected in series with the low side of the antenna inductance. Several values of coupling capacitance are available in the power amplifier tank circuit in order to permit the correct value to be obtained to load the power amplifiers into the antenna. This circuit arrangement provides a high degree of discrimination between the fundamental-frequency output and the harmonics. Harmonic energy encounters considerable reactance in passing through the power amplifier tank inductance, and at the same time the large values of antenna coupling capacitance present relatively small reactance to harmonic frequencies. On a typical 4-ohm antenna the coupling capacity has a value of approximately .016 μf.

A break-in relay capable of following keying speeds of 50 words per minute is used. One pair of contacts on the break-in relay transfers the antenna circuit automatically to the receiver whenever the key is open. When the key is closed these contacts complete the circuit of the transmitter to the antenna and in addition "key" the circuits by simultaneously closing the negative high voltage and grid leak circuits to the mid-point of the filament transformer. The break-in relay is designed so that the antenna contacts always open slightly after and close slightly before the keying contacts close.

Modulated waves for A-2 signalling are obtained through the modulation transformer. The primary of this transformer connects to the 500-cycle alternator on the motor generator set. The secondary winding is connected in series with the 1200-volt d-c supply to the power amplifier plate circuit. With this arrangement the 500-cycle power alternately aids and opposes the d-c input, resulting in modulation similar to that obtained in high level modulation broadcast circuits.

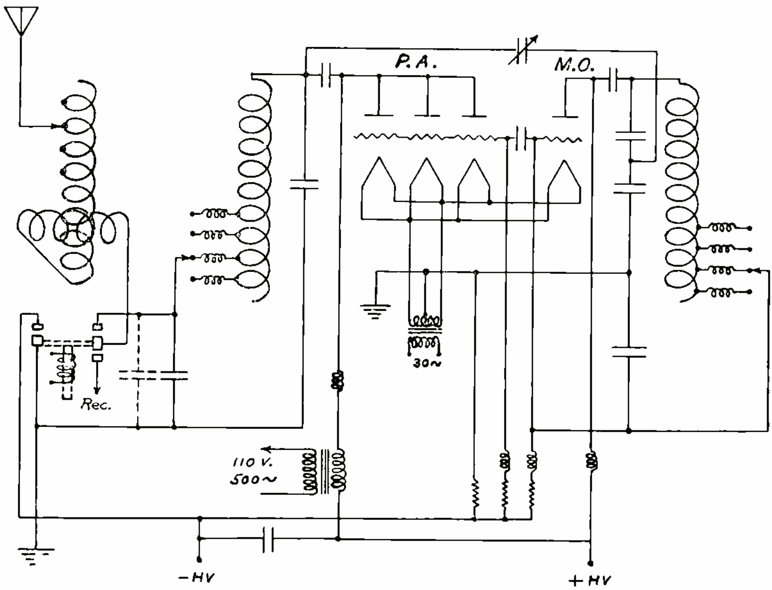


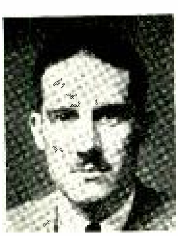
Fig. 4—Schematic circuit diagram of the transmitter.

The modulation transformer is designed to permit the secondary winding to carry the full d-c component of power amplifier plate current. While this results in a larger transformer than would be required if the conventional choke coil and blocking condenser method were employed, it has the considerable advantage in a telegraph transmitter of reducing transient voltages which would otherwise occur when the set is keyed. The modulation transformer is left in circuit for both A-1 and A-2 signalling and aids in reducing key clicks because the secondary inductance tends to round off the wave front each time the break-in relay closes. For continuous-wave transmission the primary of the modulation transformer and the field circuit of the 500-cycle alternator are opened by means of the signalling switch on the front panel.

OUR CONTRIBUTORS

WILLIAM F. AUFENANGER began his radio career twenty-two years ago as a wireless operator with the Marconi Company. During the war he served in the Military Intelligence Division of the United States Army and upon discharge joined the Westinghouse subsidiary, The International Radio Telegraph Company, as a ship radio inspector. When that company was absorbed by RCA in 1921, Mr. Aufenanger was appointed an inspector in the RCA Marine Department, which later became the Radiomarine Corporation of America. He was subsequently promoted to the posts of Chief Inspector, Assistant Superintendent and Superintendent, leaving the latter position in 1932 to become Superintendent of RCA Institutes, the school he attended as a student seventeen years before.

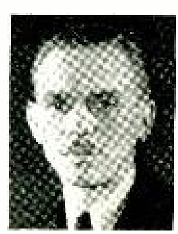
IRVING F. BYRNES entered the General Electric Test Department in 1918 and later engaged in radio development in their Engineering Laboratory. From 1920 on he was occupied in the development of radio equipment for commercial and military vessels, submarines and aircraft. He participated in the design and tests of the early ship-to-shore duplex radio telephone equipment used on the *SS. America* in 1922. Mr. Byrnes joined the Engineering Department of RCA Manufacturing in 1930, later in that year transferring to the Radiomarine Corporation of America of which he has since been in charge of engineering activities.



DUDLEY E. FOSTER received his E.E. degree at Cornell University in 1922. Prior to his college days he served during the war as a commercial radio operator for the Marconi Company. Following his graduation from Cornell he became associated as electrical engineer with the Electrical Alloy Company and Driver-Harris Company. In 1925 he joined the Malone-Lemmon Products Company as Production Engineer, and the next year became Chief Engineer of the Case Electric Company. Two years later he went with the United States Radio and Television Company as Assistant Chief Engineer and soon after was promoted to Chief Engineer. In 1933 he became Chief Radio Engineer of the General Household Utilities Company and in 1934 took up his present duties as engineer in the RCA License Laboratory. Mr. Foster is an associate of the Institute of Radio Engineers.

RAYMOND F. GUY entered the service of the Marconi Company in 1916 and left in 1918 to enlist in a Signal Corps Replacement Company. Following the war he entered Pratt Institute and graduated in electrical engineering in 1921. After short periods with the Shipowners Radio Service and The Independent Wireless Telegraph Company, he became one of the small staff that built and operated station WJZ, then located at the Westinghouse plant in Newark. After two years of pioneering in the new service of broadcasting, Mr. Guy went along with WJZ when it was moved to New York City. In 1924 he joined the RCA Research Department, heading the broadcast engineering section, where he engineered the RCA stations and directed development of new RCA broadcast transmitters and associated apparatus. In 1929 he transferred to the National Broadcasting Company to organize and head the Radio Facilities Department. He is a member of the Institute of Radio Engineers and has served on various technical committees for the past seven years.

O. B. HANSON, Chief Engineer of the National Broadcasting Company, has, since the inception of broadcasting, been a very large contributor to its technical development. Many of the achievements made in that field have been due largely to his knowledge and efforts. Mr. Hanson's radio career began in 1912 when he attended the school now known as RCA Institutes. Upon completing his course he went to sea as a radio operator and was later transferred to the testing department of the Marconi Company, where he became Chief Testing Engineer. In 1920 he took another turn at sea. When radio broadcasting came into being Mr. Hanson became associated with WAAM, a pioneer station in Newark. In 1922 he accepted a position as assistant to the Plant Engineer of WEAF, then owned and operated by the American Telephone and Telegraph Company. With the formation of the National Broadcasting Company in 1926, Mr. Hanson went with the new company and since that date has directed technical operations and engineering activities for NBC. He supervised the designing and construction of the NBC studios at 711 Fifth Avenue (vacated when NBC moved to Radio City), and the NBC Chicago studios. When the time came for creating the NBC studios at Radio City, Mr. Hanson was well equipped to carry out the ambitious plans. The results of his work have attracted world-wide interest both on the part of technicians and laymen.



JEROME C. SMITH received his B.A. degree from the College of Idaho in 1925 and his B.Sc. in Electrical Engineering from the University of Minnesota in 1927, following which he took the General Electric Advanced Engineering Course. In 1930 he joined the RCA Manufacturing Company as Development Engineer. He is now in that capacity in the Automobile Receiver Section.

EDMUND A. LAPORT was radio operator at the original KDKF broadcasting station in 1921. The following year he was transferred to New York to become receiver service technician for the Westinghouse Company. In 1923 he went with the General Electric Company at Schenectady as laboratory assistant of transmitter development. Rejoining Westinghouse a year later as transmitter engineer, his work at Chicopee Falls included transmitter test, production, broadcast transmitter design and in charge of installation and field engineering. In this period he installed three high frequency telephone stations in China, two broadcasting stations in Italy and several in the United States. Mr. Laport was a radio consulting engineer in 1933-34, and then joined Wired Radio, Inc., as transmission engineer specializing in modulation developments. He started his present engineering activities on high power broadcast transmitter design for RCA Manufacturing Company in June, 1936. He is a member of IRE and of the American Meteorological Society and is author of publications on antennas.

GEORGE MCELRATH, Operating Engineer for the National Broadcasting Company has been associated with radio since 1918. He attended the U. S. Naval radio school and after the war was employed in the plant department of the American Telephone and Telegraph Company. In 1922 he was transferred to the radio broadcasting department of that Company and assisted in the installation of station WEAF. He worked in the studio and field groups and in 1924 was appointed Engineer in Charge of NBC operations at their Washington office. He was assigned to his present position in 1928. Mr. McElrath is a member of the Institute of Radio Engineers.

DR. HARRY F. OLSON received his B.E. degree in 1924, M.S. in 1925, Ph.D. in 1928, and E.E. in 1932, from the University of Iowa. Eight years ago he became an RCA engineer and in that time spent two years in Photophone development work. He is now Research Engineer in the Victor Division of the RCA Manufacturing Company, Inc. Dr. Olson is a member of Sigma Xi, and of the American Physical Society, and is a Fellow of the Acoustical Society of America.

F. X. RETTENMEYER is a native of Oklahoma. He received his E.E. degree from the University of Colorado in 1922 and the same year joined the Western Electric Company. In 1930, following a short period with F. A. D. Andrea, Inc., he entered the Bell Telephone Laboratories where he remained until 1935 when he was placed in charge of the receiver department of the Engineering Division of the RCA Manufacturing Company.

DIRECTORY OF SCIENTIFIC ORGANIZATIONS

With Dates of Meetings

ACOUSTICAL SOCIETY OF AMERICA; founded 1929; President, Paul E. Sabine; Vice-President, V. L. Christler; Treasurer, G. T. Stanton; Secretary, Wallace Waterfall, The Celotex Corporation, Chicago, Ill.; F. R. Watson, Editor, Journal of the Acoustical Society of America, University of Illinois, Urbana, Ill.; Meeting at Washington, D. C., May 4-5.

AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE; organized 1848; President, George D. Birkhoff; General Secretary, Otis W. Caldwell; Treasurer, John L. Wirt; Permanent Secretary, Forest R. Moulton, Smithsonian Institution Building, Washington, D. C.; Publications: Science; Scientific Monthly; Science News Letter; Meetings: Denver, Colo., June 21-26, 1937; Indianapolis, Ind., Dec. 27, 1937, to Jan. 1, 1938.

AMERICAN CERAMIC SOCIETY; founded 1899; President, Robert B. Sosman; Vice-President, Victor V. Kelsey; Treasurer, C. Forrest Tefft; General Secretary, Ross C. Purdy, 2525 North High St., Columbus, O.; Publications: Bulletin of the American Ceramic Society; Journal and Ceramic Abstracts.

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS; organized 1884; President, A. M. MacCutcheon; National Treasurer, W. I. Slichter; National Secretary, H. H. Henline, 33 West 39th St., New York; Publication: Electrical Engineering; Summer Convention, Milwaukee, Wis., June 21-25; Pacific Coast Convention, Spokane, Wash., Aug. 31-Sept. 3; District meetings: Buffalo, N. Y., May 5-7; Akron, O., Oct. 13-15, 1937.

AMERICAN INSTITUTE OF PHYSICS; founded 1931; Chairman of the Governing Board, Dr. John T. Tate; Director, Dr. Henry A. Barton, 175 Fifth Ave., New York; Publications: Journal of Applied Physics; Journal of Chemical Physics; Review of Scientific Instruments.

AMERICAN PHYSICAL SOCIETY; Secretary, W. L. Severinghaus, Columbia University, New York; John T. Tate, Managing Editor, Physical Review; Reviews of Modern Physics, University of Minnesota, Minneapolis, Minn.

FRANKLIN INSTITUTE OF THE STATE OF PENNSYLVANIA; founded 1824; President, Philip C. Staples; Vice-Presidents, Samuel S. Fels, Walton Forstall, Henry Howson, W. Chattin Wetherill; Treasurer, Benjamin Franklin; Secretary and Director, Henry Butler Allen, Parkway at 20th St., Philadelphia, Pa.; Publication: Journal of The Franklin Institute; Annual meeting, third Wednesday in January; monthly meetings, third Wednesday of the month.

INSTITUTE OF THE AERONAUTICAL SCIENCES; incorporated 1932; President, Clark B. Millikan; Vice-Presidents, Sherman M. Fairchild, Jack Frye, G. W. Lewis, Eugene E. Wilson, T. P. Wright; Treasurer, Elmer A. Sperry, Jr.; Secretary, Lester D. Gardner, RCA Bldg., Rockefeller Center, New York; Publication: Journal of the Aeronautical Sciences; Meetings: Denver, Colo., June 21-26; Cleveland, O., Sept. 3; New York, Dec. 17, 1937.

INSTITUTE OF RADIO ENGINEERS; formed 1912 through amalgamation of Society of Wireless Telegraph Engineers and the Wireless Institute; President, H. H. Beverage; Vice-President, P. P. Eckersley; Treasurer, Melville Eastham; Secretary, Harold P. Westman, 330 West 42d St., New York; Dr. Alfred N. Goldsmith, Editor, Proceedings of The Institute of Radio Engineers; Silver Anniversary Convention, New York, May 10-12, 1937.

OPTICAL SOCIETY OF AMERICA; organized 1916; President, A. C. Hardy; Vice-President, R. C. Gibbs; Treasurer, Henry F. Kurtz; Secretary, L. B. Tuckerman, National Bureau of Standards, Washington, D. C.; F. K. Richtmyer, Editor, Journal of The Optical Society of America, Cornell University, Ithaca, N. Y.; Annual meeting, Lake Placid Club, New York, October 14-16, 1937.

RADIO CLUB OF AMERICA; Organized 1909; President, John H. Miller; Vice-President, J. F. Farrington; Treasurer, J. J. Stantley; Recording Secretary, J. K. Henney; Corresponding Secretary, F. A. Klingenschmitt, 11 West 42d St., New York; L. C. F. Horle, Editor, The Proceedings of the Radio Club of America; Annual meeting, within first week of December; regular meetings at Columbia University, New York, second Thursday of month excepting July and August.

SOCIETY OF MOTION PICTURE ENGINEERS; President, S. K. Wolf; Executive Vice-President, G. F. Rackett; Treasurer, L. W. Davee; Secretary, J. Frank, Jr., 90 Gold St., New York; Sylvan Harris, Editor, Journal of the Society of Motion Picture Engineers, Hotel Pennsylvania, New York; Spring convention, Hollywood-Roosevelt Hotel, Hollywood, Cal., May 24-28; Fall convention, Hotel Pennsylvania, New York, Oct. 11-14, 1937.

SOCIETY OF RHEOLOGY; Secretary, Wheeler P. Davey, Pennsylvania State College, State College, Pa.