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EQUIPMENT AND METHODS DEVELOPED FOR BROADCAST FACSIMILE SERVICE

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Introduction

SOME ten years ago, when the first extensive tests were being made of radio facsimile transmission for messages and pictures, the thought developed of using this process for actually printing a newspaper in the home by radio broadcast. It grew from a sudden realization that carbon paper offered a very simple way of making a mark on a piece of paper, and that it might be possible to design a mechanical scanning device which would spread carbon dots on the receiving sheet so as to form a facsimile reproduction. A stylus type of machine was tried first. In a short time, however, the printer bar and helix type of recorder was devised, and it then became apparent that a receiver simple enough for home use was an actual possibility.

During the years since then many machines have been built and many problems encountered and solved. In the recorder itself the printer unit is the heart of the device and this has been constantly improved with resulting better definition of copy. Various methods of synchronization have been investigated and some of them applied to actual operation. The structure of the recorder has passed through many stages from purely laboratory apparatus to finished designs for particular applications. Paper and paper-feeding systems have been studied. Some of this work was directed to commercial communication services, operating from shore to ship and from city to city; but the central and motivating idea has always been the one of making practical a facsimile broadcast service.

As work proceeded toward this objective, much assistance has naturally come from the parallel growth of facsimile or picture transmission equipment for wire-line and radio circuits.[1] In particular, many methods of printing the received image on the paper have appeared[2] and these have been tested and considered for the home

[1] The hearty cooperation of Mr. J. L. Callahan and his group at RCA Communications, Inc. has been helpful. Their system has been reported in "Photoradio Apparatus and Operating Technique Improvements," *Proc. I.R.E.*, Vol. 23, No. 12, Dec., 1935.

[2] "Photoradio Transmission of Pictures," Henry Shore, presented before the Photographic Society of America, April 26, 1937.

broadcast receiver. Each method has advantages and disadvantages, and they have been judged on the basis of the following factors:

a) Appearance of finished copy, in terms of definition, color, etc.
b) Sheet recorded damp or dry,
c) Processing, if any, subsequent to recording,
d) Possible speed of recording,
e) Cost of paper.

After comparing in this way the various processes, it was concluded that, in the present state of the art, the carbon-paper recording was best suited to a home-use machine.

In addition to a long period of work on the sending and receiving apparatus itself, there have been a number of facsimile trials over actual radio circuits. The equipment made for receiving weather maps on shipboard had an extensive test over a span of several years, during which time evidence was accumulated on facsimile propagation in the range from 4000 to 18000 kilocycles. Early field trials of broadcast-facsimile receivers were made in Schenectady in 1929 in this same band. In New York City in 1931 broadcast operation was carried on for a short time on 2100 kilocycles. In 1932 further trials were made on 44 megacycles with the machines self-synchronized on both a-c and d-c power systems. More recently extensive studies were completed of ultra-high-frequency urban coverage with automatic recorders operating many hours per day. Naturally much information was accumulated on the effects of fading, interference, and multipath propagation. This mass of data was very helpful when it came to choosing operating standards for a broadcast system.

Having given this brief review of the background, the rest of this paper will be devoted to the actual equipment which is now available to broadcasters, in order that they may make such trials of broadcast facsimile as will demonstrate the public value of this new service. In designing the scanning equipment and the receivers this object has been kept in mind. In other words the receivers have been made as simple as is consistent with reliable performance and with clear printing of copy. All extra devices, such as paper cutters to break the recorded copy into sheets, have been eliminated. At the scanner, on the other hand, some expense has been added to provide voltage regulators and timing devices which will make it more certain that a regular and consistent program can be broadcast, even in the hands of a relatively inexperienced operator.

Scanning Equipment

The appearance of the scanning equipment is shown in Figure 1. All parts are mounted in an attractively styled steel cabinet which is approximately 52 inches high, 32 inches wide, and 16 inches deep. The upper section of this case is a hinged cover. When thrown back it exposes a table-like surface on which is mounted the actual scanning machine. Below this level is the timer, and then come three standard panel units, the compensating amplifier, the power-supply panel, and

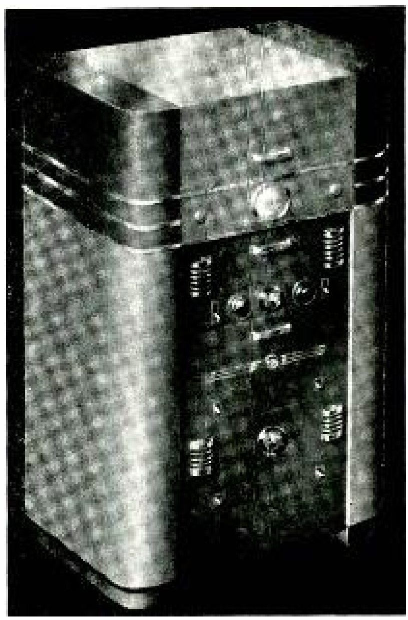


Fig. 1—Complete scanning equipment.

the voltage regulator. The apparatus thus forms a complete device ready for installation in a broadcast studio or newspaper office. The only connections required are a source of 60-cycle 110-volt power and a broadcast-control line to the radio transmitter.

The scanning machine proper is of the conventional rotating drum type, but with modifications to suit it to broadcast service. The subject-drum is rotated at 75 r.p.m. by a synchronous 60-cycle motor with a reducing gear having a ratio of 24 to 1. This motor and gear is very similar to those used in high-quality automatic phonographs. Between the motor spindle and the drum there is a single-position clutch, so that the drum can be stopped for change-of-subject copy and then re-engaged without losing the relative frame position with reference to the 60-cycle power system. The motor continues to run during this loading operation and a commutator on the spindle shaft supplies an artificial frame-line signal to keep the recorders in step.

During transmission the scanning head, which is mounted behind the subject-drum, traverses slowly down the length of the copy. It is driven by a lead screw and suitable gearing from a second motor identical with the drum motor, its rate of progress being such that 125 scanning lines are drawn per inch of drum length. The parts of the head are an optical system, a phototube, and a phototube amplifier. The light source—a 75-watt exciter lamp—illuminates a small diaphragm, and the opening in this is focused through an objective lens onto the paper, making a bright rectangular spot 0.008 inch long in the direction of the drum axis and 0.003 inch wide in the direction of travel along the scanning line. The incident light beam is normal to the surface of the paper. The reflected light is taken off by a pick-up lens and passed to the phototube, this beam being in the same horizontal plane and at 45 degrees to the incident light. The solid angles formed by the objective and pick-up lenses are so arranged that no direct reflections from the paper can reach the phototube. This limitation naturally reduces the light efficiency, but it is of real assistance where various sorts of subject-copy are used. In a direct-reflection system, for example, a shiny black ink may sometimes reflect as much light as the white paper.

The phototube is a standard gas type and is connected to a special pre-amplifier. The first stage is a direct-current amplifier. It actuates a modulator to provide signal impulses in the form of an audio tone of varying amplitude. Either phase of modulation may be used, but the system is normally adjusted for maximum on black and minimum on white. The tone voltage is supplied by a tube oscillator mounted in the same case and set to produce approximately 20,000 c.p.s. This relatively high frequency is chosen because it makes possible the recovery of faithful direct-current picture signals in the compensating amplifier, without the use of filter networks following the demodulator. Distortion of the impulse shape is thus reduced.

One may well ask why such an indirect method is adopted to produce the picture impulses in the compensating amplifier. The answer is that these signals must extend down to zero frequency and that a straight d-c amplifier of sufficient gain is not easily made stable. Thus the intermediate step of tone amplification and subsequent rectification is used. Even so, all voltage supplies must be closely regulated to prevent drift of the initial d-c stage, because the maximum output of the phototube on black is only about 0.2 volt. A bias potentiometer on the amplifier provides a static setting of this first tube, the proper conditions being chosen by observing the output-signal meter on the scanner base for black and white areas under the scanning beam.

In the compensating amplifier the modulated 20,000-cycle tone is amplified and rectified to produce signal impulses similar to those delivered by the phototube. These are operated upon by special circuits in the next two stages to produce a predetermined alteration in amplitude characteristic, the need for which will be discussed in a later section. Finally the impulses again modulate a carrier tone, this time of about 3200 c.p.s. This carrier and its side bands can be comfortably

Fig. 2—Front view of recorder with cover removed.

transmitted over a standard broadcast-wire line. The output to this line is normally set by meter at zero level.

The middle panel in Figure 1 directly below the compensating amplifier is a power-supply unit for the amplifiers and exciter lamp. The heater current in the phototube amplifier is regulated by a ballast lamp and the plate voltage by gas regulator tubes. The line-voltage regulator forms the lower panel and further improves the stability by holding constant the 110-volt supply to the whole system, thus regulating the lamp brilliance also. The need for this careful regulation lies, of course, in the fact that the shading of pictures depends directly on the amplitudes of the signal impulse, and that any fluctuations result in incorrect tone values.

No modifications are needed in a standard telephone or broadcast transmitter to handle the facsimile signals. The percentage of modulation should, of course, be set at a fixed value for "black", i.e. for maximum sub-carrier amplitude, and should not change during the schedule. It may be worth noting that this maximum modulation is a definite predetermined value and may therefore be set at 100 percent if desired without fear of overshooting.

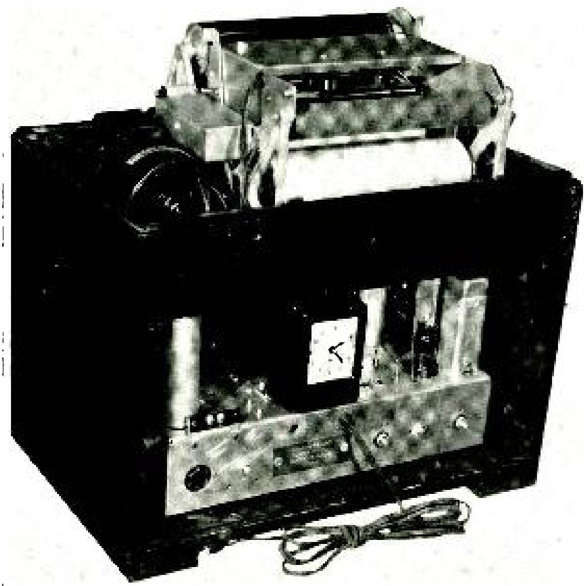


Fig. 3—Back view of recorder showing chassis and time switch.

Facsimile Broadcast Receiver

The facsimile receiver is shown in Figure 2 with the cover removed and with the recorded copy feeding out the front. It is a complete unit, in that it includes the radio receiver chassis, and a time switch; and thus requires only an antenna and a source of 60-cycle power. It is worth emphasizing this arrangement and the reasons for it. It might have been simpler to provide only a recorder for attachment to an existing radio receiver, but the proposed conditions of operation must be considered. The schedules are to be sent out, at least according to most existing plans, over regular broadcast stations between midnight and six in the morning, a period when the channel is otherwise idle. The recorders are to be turned on and off by time switch at the proper hours. Consequently, if the recorder were made as an attachment, the user, on going to bed, would have to leave his radio set accurately tuned to the right station, with volume correctly adjusted, and otherwise in a condition so that it would come on by the clock and print. This nightly pre-setting is too much to expect of anyone but an enthusiast with a good memory. On the other hand, the use of a special chassis made for facsimile service only, has technical advantages in that it can be more efficiently designed, and can give more reliable performance. This, therefore, appeared to be the best solution.

The placement of the receiver chassis and the time switch is shown in the back view of the cabinet in Figure 3. Although the chassis

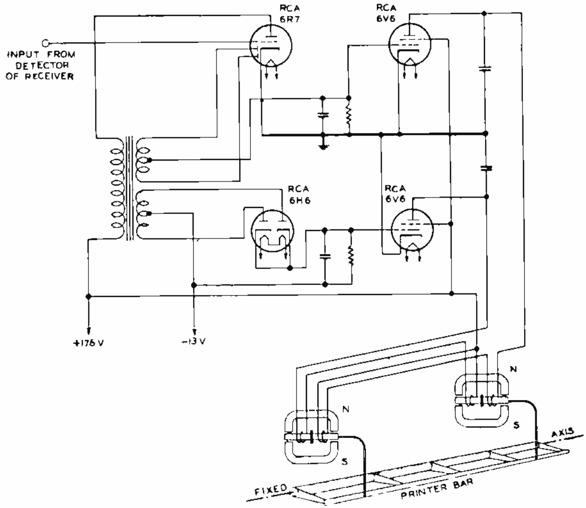


Fig. 4—Schematic of printer amplifier.

could be designed for any suitable wave band, most present requirements call for operation between 550 and 1600 kilocycles. This is met by modifying a standard broadcast receiver of the type designed for push-button tuning. The sensitivity of this receiver is approximately 500 micro-volts per meter at the lower limit of good automatic volume control. This figure is based on the intention of the broadcasters to operate facsimile recorders within the primary service area of their stations. All but two of the several tunings are eliminated and the audio system is replaced by a rectifier and printer amplifier. The circuits use approximately the same number of tubes, and are shown schematically in Figure 4. It will be seen that the 6V6 output tubes pass plate current alternately, forming a sort of push-pull direct-current amplifier. The lower or "black" tube is biased to cut-off with no signal input, but passes plate current as the bias becomes zero under full signal. The upper or "white" tube passes plate current at no signal, but no plate current at full input. The controlling bias voltages are obtained by rectification of the 3200-cycle sub-carrier, after a stage of amplification. The coils of the magnetically operated printer unit are connected as shown in the plate circuits of the printer tubes.

The facsimile recording machine is mounted in the upper section of the cabinet and is covered by a removable lid. Its structure can be fairly well seen in Figure 5. The active parts are supported between two cast side-plates, the driving motor being on the far side out of view, and the paper-feed gearing in the right foreground. The recording drum with the raised helical ridge on its surface can be seen in the center, and above it the course of the white and carbon papers, which have been torn back to afford a clearer view. The carbon paper is wound up after use on the core at the top; the white is fed out from the front of the cabinet by a cylinder like a typewriter roll. This roller can be seen under the carbon take-up core. In taking this view the printer unit was swung back to the left into the paper-loading position. The actual operating position of the printer bar is shown by the steel rule which was placed over the papers for this photograph.

The method by which a carbon recording is produced can be easily seen by considering the helix drum as rotating at its normal speed of 75 r.p.m. Whenever a signal for black is received from the transmitter, the printer bar (represented by the rule) is sharply depressed along its whole length by the two electromagnetic drivers. See Figure 4. Obviously it pinches the carbon paper against the white at the point where its edge intersects the single turn raised helix; and because of the rotation, this intersection point repeatedly scans across the page right in step with the traverse of the light spot across the original at the scanner. If complete synchronism is maintained, the dots will organize themselves into a facsimile of the original subject.

The definition obtained at a given speed depends on the rapidity with which the magnetic drivers can move the mass of the printer bar. Consequently great care has been taken in the design of this unit. As indicated schematically in Figure 4 the bar is mounted on a frame structure with a rigid pivot at the axis of the supporting tube. It is driven at two points through connecting springs from the balanced-armature electro-magnetic drivers. These are basically similar to early forms of magnetic loudspeakers, but are much improved in constructional details. The fixed field for both units is supplied by a single permanent magnet mounted between them. The natural query as to why electromagnetic rather than moving-coil dynamic drivers are used is simply answered by pointing out that the bar must respond to direct-current conditions; and that it is not very practical either to supply heavy direct-current components from the amplifier for an ordinary voice coil, or to provide enough turns on the coil to work with output tubes of reasonable size.

One loading of paper in the recorder includes a 345-foot roll of white paper on a large cardboard core, and a small roll of about 95 feet of carbon paper. The latter is slipped inside the white roll to make a compact shipping package. When reloading the machine the old carbon rolls are thrown out, as the coating has been thoroughly used after one passage through the recorder at about one-quarter the speed of the

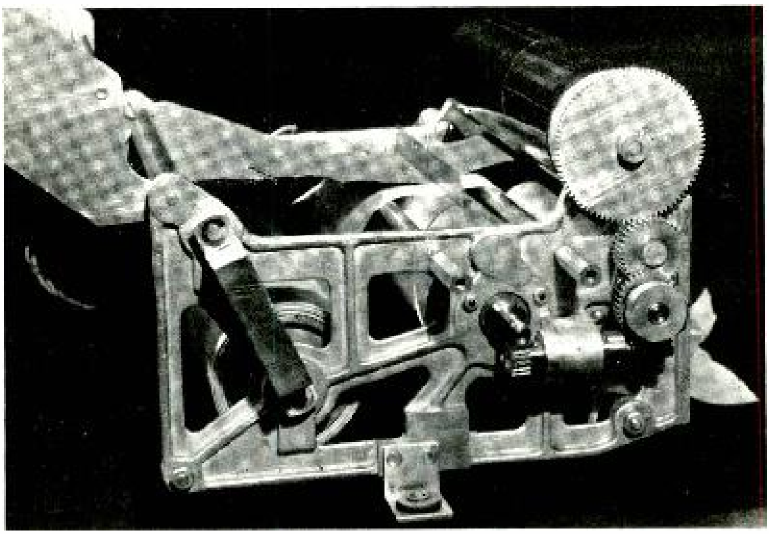


Fig. 5—Close-up photo of recorder.

white sheet. The large core from the used white roll is saved and put in position as a wind-up spindle for the succeeding loading of carbon paper. The new white roll is placed in the machine first and then the carbon roll. Each is snapped in position on centers like the film in a camera, both releases being operated by the strap handle seen on the near side plate of Figure 5. The white paper is drawn over the helix drum and passed through the feed-roller system just as a sheet is turned into a typewriter. The carbon strip is attached to the wind-up core by a gummed leader, the printer then lowered and latched in place, and the recorder is ready to function. The description of this paper-reloading process has been given in some detail to show that it can be carried out by the user of the machine without too much inconvenience. It is more difficult than loading a typewriter, but probably simpler than most cameras. It is the only service which the owner of the machine need perform himself; and it will not come often, as one loading will last over a month on a 10-page-per-day schedule.

The recorders are assumed to be completely adjusted at the time of installation. The receiver is tuned to the chosen station and the time switch set to turn it on soon after midnight and off again some time later, according to the established facsimile schedule. The volume control is correctly adjusted and the printer position checked. A cover strip is then placed over the controls leaving only the clock face exposed, so that it may be reset if necessary after a power failure. A self-starting synchronous-clock movement is employed as being probably the most satisfactory timekeeper for the purpose.

SYNCHRONIZATION

There are two parts to the problem of synchronizing facsimile recorders and scanners; first, the one of insuring that the rate of travel of the printing point in the recorder is exactly the same as that of the light spot in the scanner; and second, that of starting the stroke in the recorder in phase with the start of the scanning line at the sending end. If the former condition is not fulfilled the recorded picture will be distorted and askew, and will soon slant off the sheet. If, however, the speed is maintained, the image will be square; but it will not necessarily fall in the center of the page. The scanner may have started its stroke half a line ahead of the recorder and the machines are said to be out of frame.

The first part of the problem, that of speed control, is easily solved in a broadcast service by operating both sending and receiving machines with synchronous 60-cycle motors driven from common or interconnected-power systems. This method is used in the equipment described here and makes for very perfect and unvarying synchronization with no additional apparatus in the receiver. It is open to the criticism that there are several places in the country where independent and unconnected-power companies operate in the primary-service area of a single broadcast station; and there are also the cases where downtown-business districts still use direct-current power. But these are the exceptions, for in most cases, the homes in the suburban and adjacent country around a city are all served by a common-power system. Thus, for an initial program of facsimile broadcasting, synchronization can be well obtained in this way for a large percentage of the market.

In areas where there are two independent 60-cycle systems, as around Cleveland or New York, for example, a possible method of working is to divide time between the two systems. The receivers which are supplied by power from company A might be set for 12 midnight to 2:00 AM, and all on the lines of company B for 2:00 AM to 4:00 AM. The facsimile schedule would then be broadcast twice, once with the scanner synchronized on the A system, and again with it synchronized on the B system. This is easily accomplished at the scanner because the motors only require some 50 watts. The scheme is not very economical as it doubles the time on the air. It is mentioned here as an expedient which may be adopted for preliminary operation.

With further growth of broadcast-facsimile service it is to be expected that self-synchronizing recorders will become available when a simple system has been worked out and reduced to a reliable design. There is already much background on the subject and there is actual experience with facsimile installations made for commercial service. Perfect synchronization has been obtained between remote points by the use of tuning fork control; and there have also been a number of systems set up with a control transmitted over the radio circuit along with the picture.

The line framing or synchronization of the picture received at the recorder is the second part of synchronization. It is accomplished in these machines by a circuit-breaking device used in conjunction with a line-framing relay. The circuit-breaking device may be mounted on the helix-drum shaft or coupled thereto, and carries a breaking arrangement which comes under the relay armature at the instant the intersection or scanning point in the recorder goes off the edge of the paper. If the line-frame signal generated at the scanner by the clamps on the scanning drum arrives at this same instant, the circuit is such that the relay is not actuated, and the motor drives the recorder steadily in its correct line-frame position. If, however, the recorder circuit-breaking device is in another position when the line-frame signal comes in, the relay momentarily opens the motor circuit causing it to slip below synchronous speed. This will occur each revolution of the drum until the recorder reaches correct frame. The automatic framing function normally takes place only at the start of the program, and the machines thereafter run continuously in perfect synchronism. The only exceptions occur when the power at the recorder fails, or when the signal fades out completely. In such exceptional cases the machines will attempt to reframe as soon as normal conditions are restored, but may not complete the cycle until the margin space comes through at the end of the sheet. The remaining pages of the schedule will then be properly placed as before.

FIRST WITH THE NEWS

News Flashes

Official Weather Forecast: Fair and Warmer

SATURDAY, JULY 25, 1937 • COLUMBUS, OHIO • PAGE NO. 35

SUPREME COURT UPHOLDS TVA

Vote On Important Decision 8 To 1

SENATORS READ VERDICT

In form this particular work consisted of a double column page twenty-eight and one-half picas in width by about forty-two picas in depth, set in 8 point (brevier, then so called) solid.

Crowded Gallery Hears Hughes Read Opinion

Considerable rivalry existed between the two principal publishers each year as to which company should first be able vices to the legal profession that company issued quarterly, and in the fall of each year annually, a "Digest of United States Supreme Court Decisions," which ran up to 2,700 or 2,800 pages.

The means devised by the New York state firm was for a number of years successful in attaining this object.

Vote Goes 8 to 1

In form this particular work consisted of a double column page twenty-eight and one-half picas in width by about forty-two picas in depth, set in 8 point (brevier, then so called) solid.

To keep the size of the book within reasonable limits it was printed on an extremely thin but opaque "bible" paper.

With a force of about fifteen hand compositors and ten time hands the annual edition was scheduled to be set, made up and stereotyped in not to exceed thirty days, and was in some years done in twenty-seven days.

A little figuring on the basis of hand composition production will bring one up against a decided question mark as to how this could be done with fifteen compositors at the case, if the methods followed in the process were not known.

It has been stated that the job was first issued in quarterly form. And after each quarterly had been hand set, made up and printed, it was stereotyped on type high cored base.

The stereotype pages were stored on wooden galleys, two to the galley, and put through a preliminary operation which consisted of ad-

MAYOR PLACES GUILT ON JONES

Since the advent of mechanical type composition through the use of the Linotype, there has been a constant and consistent advancement in the art, with an accompanying ease of solution of problems having to do with mass production requirements and of time limitations.

It seems evident that the revolutionary conditions produced in the printing industry by the introduction of this machine are exemplified primarily by the tremendously increased production attained, and in the quality of the product.

Former Editor Injured

J. B. Smith Severely Cut in Freak Automobile Accident

During and before the middle nineties there was located in a midwestern city of New York state one of the two then largest law publishing houses in the country, and among numerous other serious secondly by the rapid improvement

Transmitted by RCA RADIOPRESS

Fig. 6—Recorded copy reproduced by copper etched halftone plate.

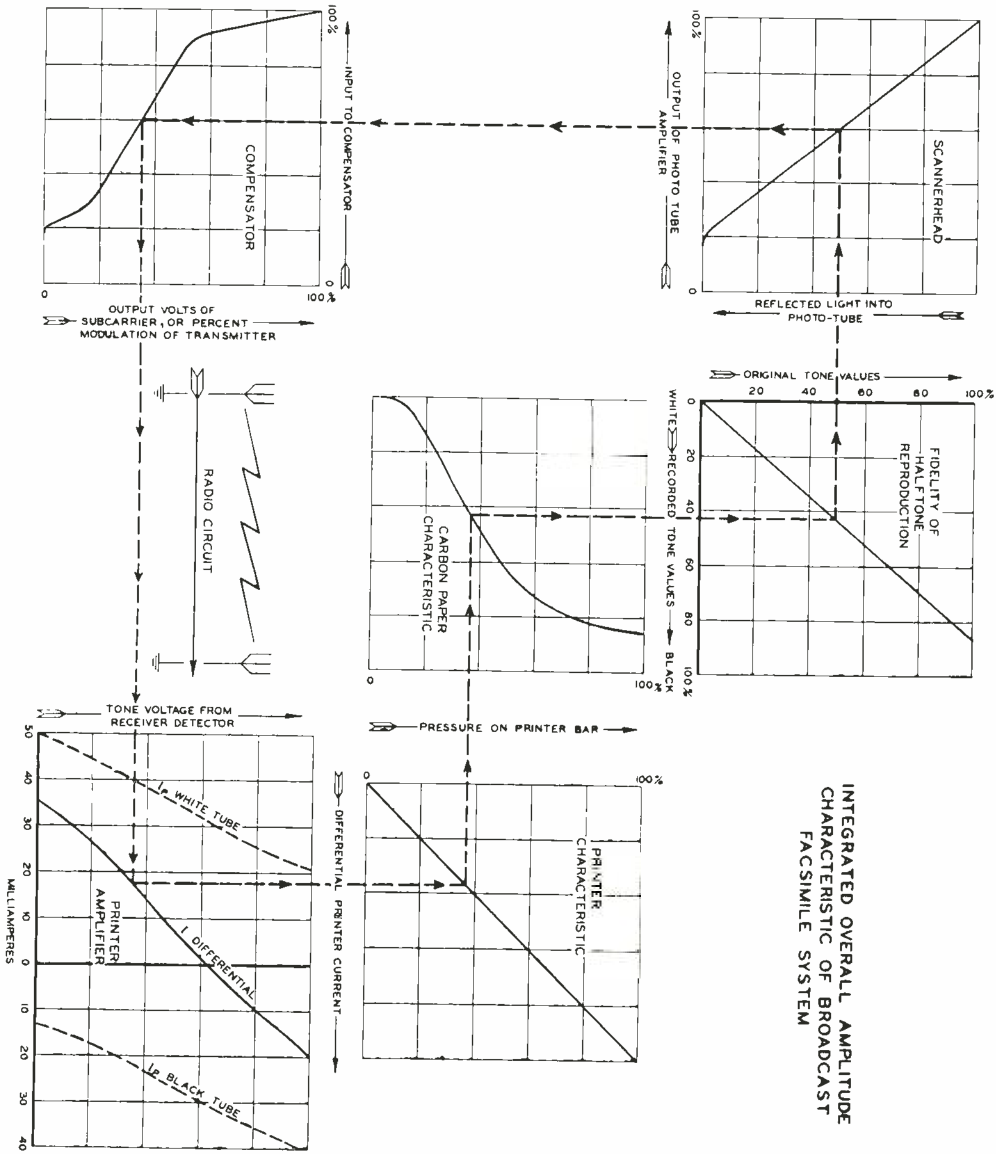
SUBJECT COPY FOR TRANSMISSION

It is not within the province of this article to attempt a prophecy of the kind of copy which broadcast facsimile can most profitably publish. On the other hand, the make-up of the copy and the nature of the printing and pictures is very definitely controlled by the characteristics of the equipment. The major factors to be considered are the size of print, or the black and white detail, as limited by the resolution of the system; and the kind of original pictures needed to give the most pleasing halftone recordings.

With reference to definition, the present system, when in optimum adjustment and under favorable conditions, will transmit and record 6-point newsprint type so it is legible. The formation of the letters, however, is not very clear, and text of this size would be tiresome to read. Furthermore, it is advisable to make some allowance for production variations in recorder performance, and for some loss of signal quality in transmission due to minor maladjustments and possible interference. For these reasons it is being recommended that no type size smaller than 10-point (approximately equal to typewriting) be used until the practicability of finer definition is proven in the field. Bold or expanded type faces are desirable and lettering should be avoided which has alternate heavy and very light strokes in its design. As to margin lines and drawings, it is being suggested that lines be at least 0.020 inch wide and that the smallest space between them be at least the same width.

The halftone or picture characteristics of the system are described in the next section. In actual practice it is found that photographs with a wide range of shade values are naturally easiest to transmit, and that it is desirable to prepare the prints so that the areas of interest are delineated in terms of the middle range of grays, rather than in the very dark or very light tones. The problems are much the same as in the preparation of pictures for newspaper printing, and one is perfectly justified in using the same tricks of trimming, retouching and the like. The actual picture placed on the scanner drum should be a photograph made on thin paper so that it can be pasted in place on the page. Pictures which have been printed from a screened plate are not satisfactory unless the screen is either finer than 150 lines per inch or of the rotogravure type which gives a random-dot arrangement. Coarser screens often result in bad moiré patterns due to interference with the facsimile line structure.

In the preparation of a complete program a series of pages can be made up and printed on the standard size sheet, 8½ inches wide and 12 inches long. The text may be set by hand or linotyped, and a single



INTEGRATED OVERALL AMPLITUDE CHARACTERISTIC OF BROADCAST FACSIMILE SYSTEM copy pulled on a proof press for each page. If finished appearance is not so important, the text may be typewritten, preferably on an electric typewriter which gives a uniform impression.

As an example of the recordings possible with the equipment which has been described, Figure 6 shows a photograph of a typical small news page. The sheet was 8½ x 12 inches as it came from the machine and the text is from 10-point type. Naturally some allowance should be made for loss of definition in the process of preparing this illustration at reduced size.

Halftone Characteristics

Any facsimile system which is to send pictures must record them with shade values which correspond fairly closely with those of the original. This requirement means that close attention must be paid to the amplitude characteristic throughout the scanner and recorder. If there is unavoidable distortion at some points, compensation must be provided at others.

In carbon-paper recording the major distortion occurs in process of transferring the color to the white sheet. A certain amount of pressure is needed on the printer bar before any carbon comes off; then, as the pressure increases, more color is transferred, until saturation is reached at the darkest tone available with the particular papers used. This condition is shown in the central square on Figure 7. Grouped around are the amplitude curves of the other parts of the system, all of them so arranged that reference lines corresponding to all tone values can be carried through complete sequence. For example, suppose an original gray shade, which might be called 50 per cent black, is chosen on the scale of original tone values at the top center. Proceeding along the dotted line to the left it is found that the scanner head amplifier will deliver instead 60 per cent of its maximum signal, because of the residual output on white. After passing the compensator this will correspond to a 35 per cent tone amplitude on the line to the transmitter. The transmitter modulation curve and the receiver up through the second detector are assumed to be linear. The lower right-hand characteristic applies to the printer amplifier shown in Figure 4. The plate currents of both "white" and "black" output tubes are shown, and their algebraic sum. This differential current is really fictitious as it does not exist as such in the output circuits; but it does represent the resultant effect of the "black" and "white" currents on the printer armatures. Returning to Figure 7, measurements show that the pressure developed on the printer bar is proportional to this difference current as shown by the straight line. The non-linear characteristic of the carbon paper has already been mentioned. Again following the dotted line, turning on the carbon-paper characteristic, one arrives finally at a recorded tone value of about 43 per cent of full black. This is seen to be the true middle-gray point for the recorder, as the maximum carbon blackness only reaches 86 per cent of the density of the original black ink. If other tone values are plotted around the chart, the final straight fidelity characteristic will be developed. Obviously this happens because the characteristic of the compensating amplifier has been worked out so as to neutralize the carbon transfer and other distortions of the system.

Constants of the System

The operating speeds, paper sizes, and so on, have been referred to already, but can be more easily visualized from the following tabulation.

Number of scanning strokes per minute (r.p.m. of drums)	75	
Total length of stroke	8¾	inches
Lines per inch	125	
Width of paper on scanner	8½	inches
Length of paper on scanner	12	inches
Width of paper at recorder	8½	inches
Maximum width of copy	7½	inches
Proposed length of page	12	inches
Useful length of page allowing top and bottom margins	11	inches
Number of pages per hour	3	
Length of white paper roll	345	feet
Length of carbon roll (for this amount of white paper)	95	feet

The first three figures given above are the basic operating parameters. For example, any discussion of standards should probably start here. The product of the total length of stroke by the number of lines gives the Facsimile Index, which in this case is 1093.75. Any two drum-type facsimile systems will work together which have the same drum speed and the same index, although an enlargement or reduction may take place in true proportion.

The 8½-inch wide paper was chosen for the recorder as a practical compromise between a page too narrow to give a good illusion in the reproduction of pictures, and a sheet so wide as to make the recorder bulky and expensive. The number of lines per inch is sufficient to permit definition of the smallest type size which the average man can comfortably read. Present apparatus does not reach this goal, and so this figure must be considered as an allowance for future improvement. A choice of fewer lines per inch would mean a loss of detail which may otherwise become possible; a finer-line structure would reduce the speed of the system for the sake of an improvement in resolution of questionable advantage.

The drum speed of 75 r.p.m. was chosen as one which could be conveniently obtained from a synchronous 60-cycle motor and which would result in well-defined copy on the carbon printer. It gives a 12-inch page in 20 minutes. If allowance is made for the margins a printed area 7½ inches wide remains, and there will be 4½ square inches of useful recording in one minute. In terms of words this is not so slow as it seems. With a solid block of typewriting it means 45 words per minute, with 10-point type about 65, and with a typical page of newsprint about 110 words per minute.

Acknowledgment

In preparing this article the author has attempted to give a general view of the equipment which has been developed for broadcast-facsimile use, the way it operates, and some of the reasons for particular solutions of its problems. Much work lies behind this practical design of facsimile equipment. Credit is due especially to Mr. Maurice Artzt who has been with the project from the beginning, and whose persevering and ingenious attack has solved many of the problems. More recently Mr. H. J. Lavery has made substantial contributions to the structure of the printer; whereas the actual design of the apparatus has been brought into finished form by Messrs. R. G. Shankweiler, B. E. Lane, and A. Blain.

MEASUREMENT OF BROADCAST COVERAGE AND ANTENNA PERFORMANCE

By

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PART I

Introduction

IT HAS been felt that there is a need for a paper presenting, in not too technical fashion, the general problems pertaining to broadcast coverage and the methods of obtaining the answers to as many of these problems as admit of solution at the present time. In accordance with this conception, the subject matter has been divided into two papers. The first paper deals directly with coverage and is presented under the general heading of "Daytime Coverage" and "Night-time Coverage."

The second paper, which will appear in a later issue of the RCA Review, will deal with the determination of the efficiency of the antenna system, by describing in detail the measurements necessary to determine the input power to the antenna and the measurements necessary to determine the effectiveness of the antenna in converting this power into radiated energy. The absolute accuracy of these measurements will be discussed, and possible sources of inaccuracy will be pointed out. A section will also be devoted to the selection of a transmitter site and a description of the procedure necessary to check the suitability of the proposed site.

Although many technical papers have been published on the various aspects of broadcast coverage, it is felt that none of them presents certain important phases of the problems encountered, and that no one paper deals with most of the major problems. It is also felt that very little has been published concerning the actual mechanics of making field surveys. Therefore, this paper is written as a guide for those not thoroughly familiar with the various problems associated with the determination of coverage and the extent to which coverage may be susceptible to improvement. This paper is largely based upon the experience of the National Broadcasting Company, in making and having made scores of surveys, and in the subsequent checking and making of new surveys, as well as the modernization of its own facilities. Many of the subjects covered in these papers are in themselves quite involved, and for those who wish to pursue particular subjects at greater length, frequent references are made to books and to various technical publications.

Daytime Coverage

Measuring Equipment

An accurate field-intensity meter is the only equipment necessary to make a field-intensity survey. To facilitate the making of measurements it is desirable that this equipment be mounted in and be capable of operation within a car. The National Broadcasting Company uses RCA type TMV-75B field-intensity meters for all of its field-intensity

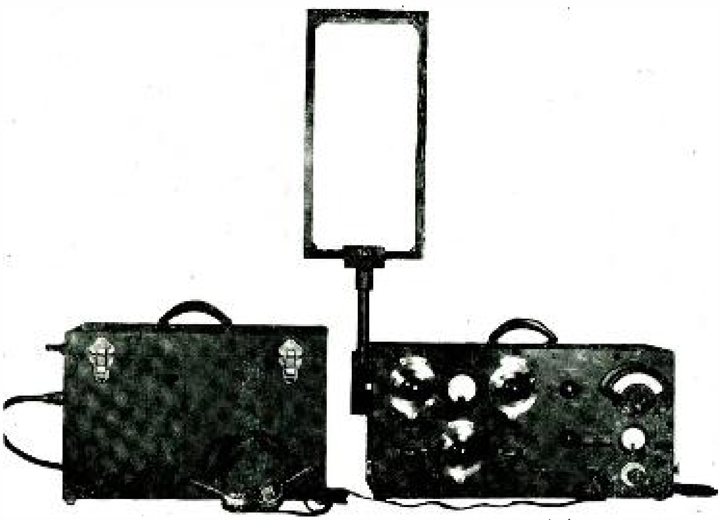

Fig. 1—The TMV-75-B field-intensity meter modified to operate a 5-ma recorder direct.

measurements. The latest model TMV-75B is shown in Figure 1. This has been described in detail in a previous publication[1] and the details of its design can be referred to there.

Certain factors should be kept in mind when designing the mounting for the field-intensity measuring set. It should be supported on a shock-absorbing mounting, such as sponge-rubber cushions, and preferably be located in such a position that the driver can make a measurement without leaving the driver's seat. The loop antenna may be mounted on top of the car with a shaft extending through the roof so that the loop may be rotated from the driver's seat. The capacitance of the connections between the loop and field-intensity set should be kept as low as possible. Figure 2 shows the NBC field-intensity-measuring car with the loop mounted on top. Figure 3 shows the interior of the car with the field-intensity set as well as a fading recorder. Since the field-intensity meter is held only by a strap secured to the handle, it may be easily removed from its mounting and carried out into the field if necessary.

SELECTION OF MEASURING POINTS

The task of making a field-intensity survey would be simple if it were possible to make representative measurements anywhere. As a

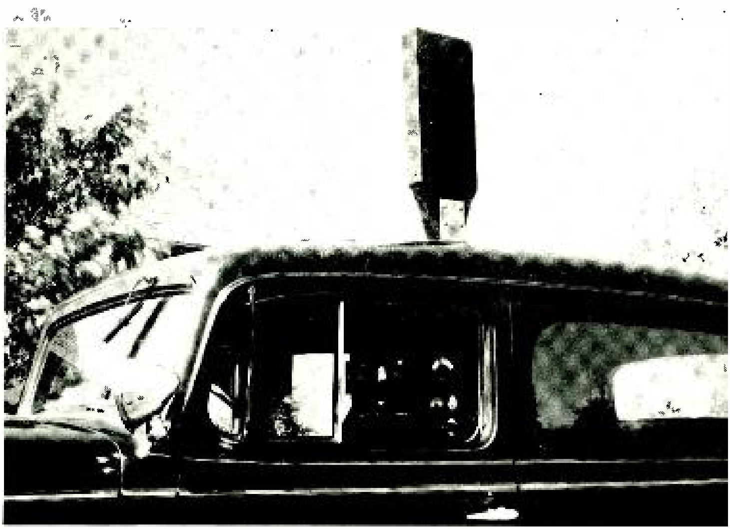

Fig. 2—NBC field-intensity car with loop mounted on top.

matter of fact, experience has shown that good measuring points are at least 300 or more feet from telephone wires, power wires, or buildings. This is so because all wires or metallic objects act as re-radiators which change the electromagnetic-field distribution in the vicinity of the re-radiators. This distorts the undisturbed field which we want to measure, giving a misleading measurement. This field intensity may be higher or lower than would be observed without these re-radiators, but it is usually lower. Hence, in making a survey it is necessary to avoid those roads which have overhead wires. Unfortunately most roads have overhead wires. If no side roads are available, the equipment must be taken out of the car and set up in the field well away from the wires.

One might then ask how satisfactory measuring points are obtained in a city. Admittedly this is more difficult, but frequently permission may be obtained to make measurements in parks, on parkways, or in cemeteries. As a last resort the equipment may always be carried to the tops of buildings which are free of obstructions.

A great number of field-intensity surveys have been made in the past by following the contour around the perimeter. For instance, if the location of the 2-millivolt contour is desired, the measurements would be made circumferentially by weaving back and forth across the 2-millivolt line until a complete circuit is made. This method is open to the serious objection that in a given direction the contour

Fig. 3—Interior of one of NBC's TMV-75-B equipped cars.

is determined by but a few points. Experience has shown that under ordinary circumstances much better results may be obtained by making measurements along radials. The measurements should begin less than a mile from the station and extend in a straight line to the limit of the station's service area. In this way irregularities caused by broken terrain and irregularities caused by poor measuring points are more accurately evaluated.

Number of Points Required

A minimum of eight radials spaced every 45 degrees is generally needed to get an accurate survey of a station. More should be taken if the antenna pattern is not circular. The measurements should be made at least once every mile near the station, approximately every two miles from 10 to 30 miles from the station, and approximately every five miles from 30 miles to the limit of the station's service area. Measurements should be made more frequently where the measuring points are not in the open and may be made somewhat less

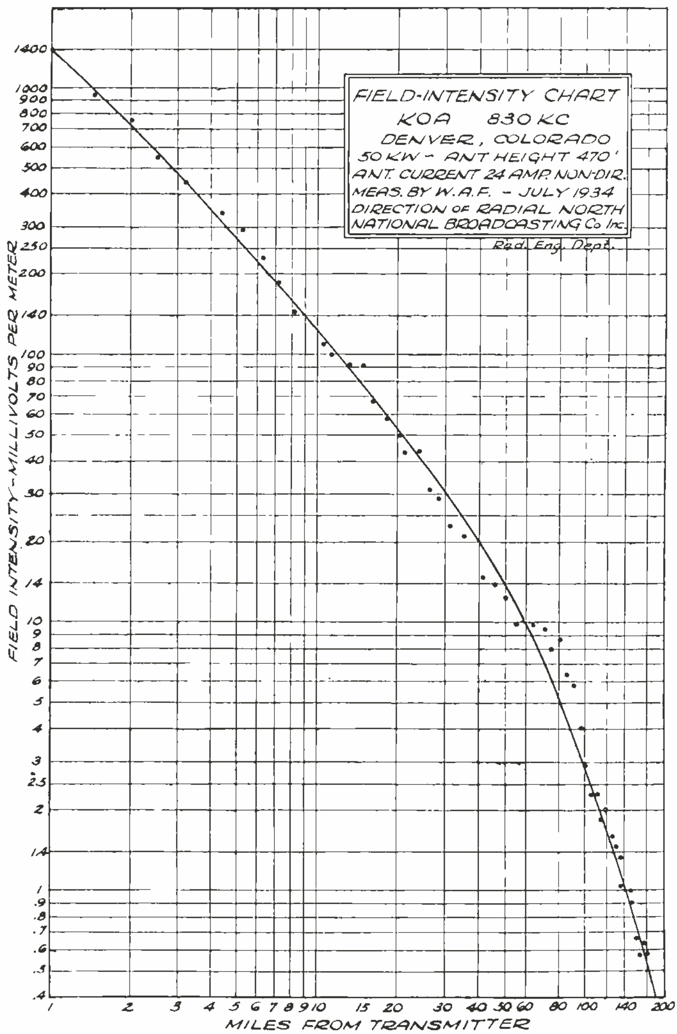

Fig. 4—Field-intensity radial.

frequently if very uniform ground and attenuation characteristics prevail.

If a city falls on a radial it is generally possible to determine quite accurately the average field intensity within the city by a well chosen group of measurements on the near and far sides of the city. This procedure is ordinarily not sufficiently accurate if the city is large or if the city is located near the transmitter.

PLOTTING THE DATA

Figure 4 shows how the data should be plotted. It is a radial in the northern direction from KOA, the 50-kw transmitter at Denver, Colorado. The data are plotted on log-log paper with distance as abscissae and the field strength in millivolts as ordinates.

The deviations of the measured points from the average line shown are largely caused by the rolling and broken terrain over which this radial passes. Sometimes a wavy curve is drawn passing through each measuring point. No doubt the curve through each measuring point would represent more accurately the field intensity at that point. However, it would be of little value to be so exact in drawing a wavy curve unless an almost infinite number of measurements were taken. This radial (Figure 4) illustrates the superiority of the radial method over the "follow-the-contour" method. The curve shows the 10-millivolt contour to be 60 miles from the station. If the "follow-the-contour" method were used one engineer might locate the 10-millivolt contour at 55 miles, whereas another engineer would be equally right in locating the 10-millivolt contour 65 miles from the station.

CALCULATION OF CONDUCTIVITY

Once the radial has been plotted, it is possible to calculate the conductivity by using Sommerfeld's attenuation formula[2,3,4,5,6,7,8,9]. This is a fairly complicated expression but one of the authors has previously published[10] a simplification of the attenuation formula so that a single set of Sommerfeld curves cover all the broadcast frequencies and soil conductivities. This makes the calculation of conductivity much easier. The basic chart used for the conductivity calculation is repeated here in Figure 5, for convenience. To find the soil conductivity, first convert the radial to an inverse field strength of 1000 millivolts at one mile. Then find the frequency of the ground-wave curve it follows. This is the conversion frequency. The soil-constant curve passing through the intersection of the operating and conversion frequencies on the conversion chart gives the conductivity. This conversion chart was prepared from the following:

$$f_1 = f\sqrt{\delta/\delta_1} \tag{1}$$

f = operating frequency
δ = standard conductivity of chart (100×10^{-15} EMU)
δ_1 = actual soil conductivity
f_1 = conversion frequency

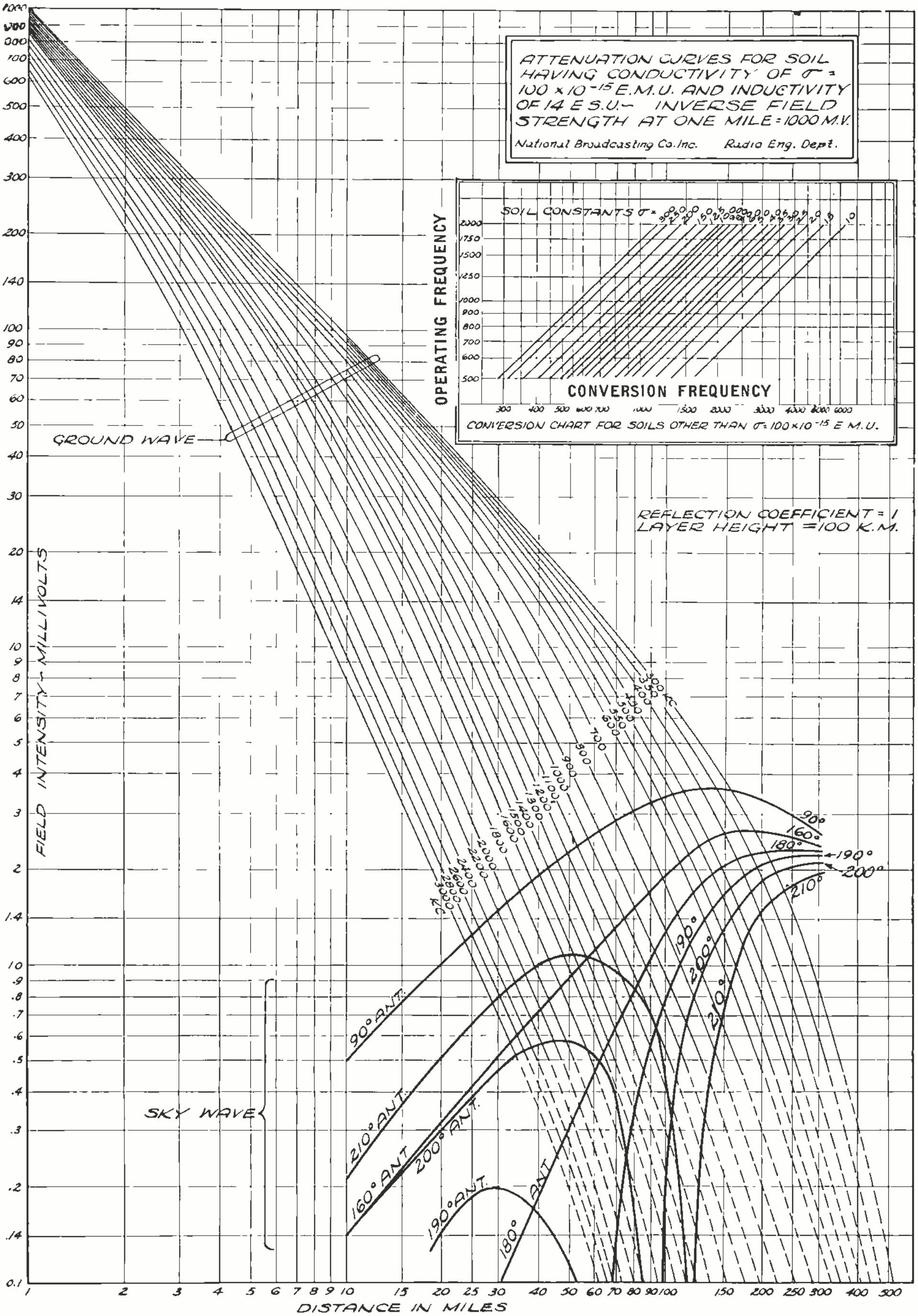

Fig. 5—Ground and sky-wave field-intensity curves.

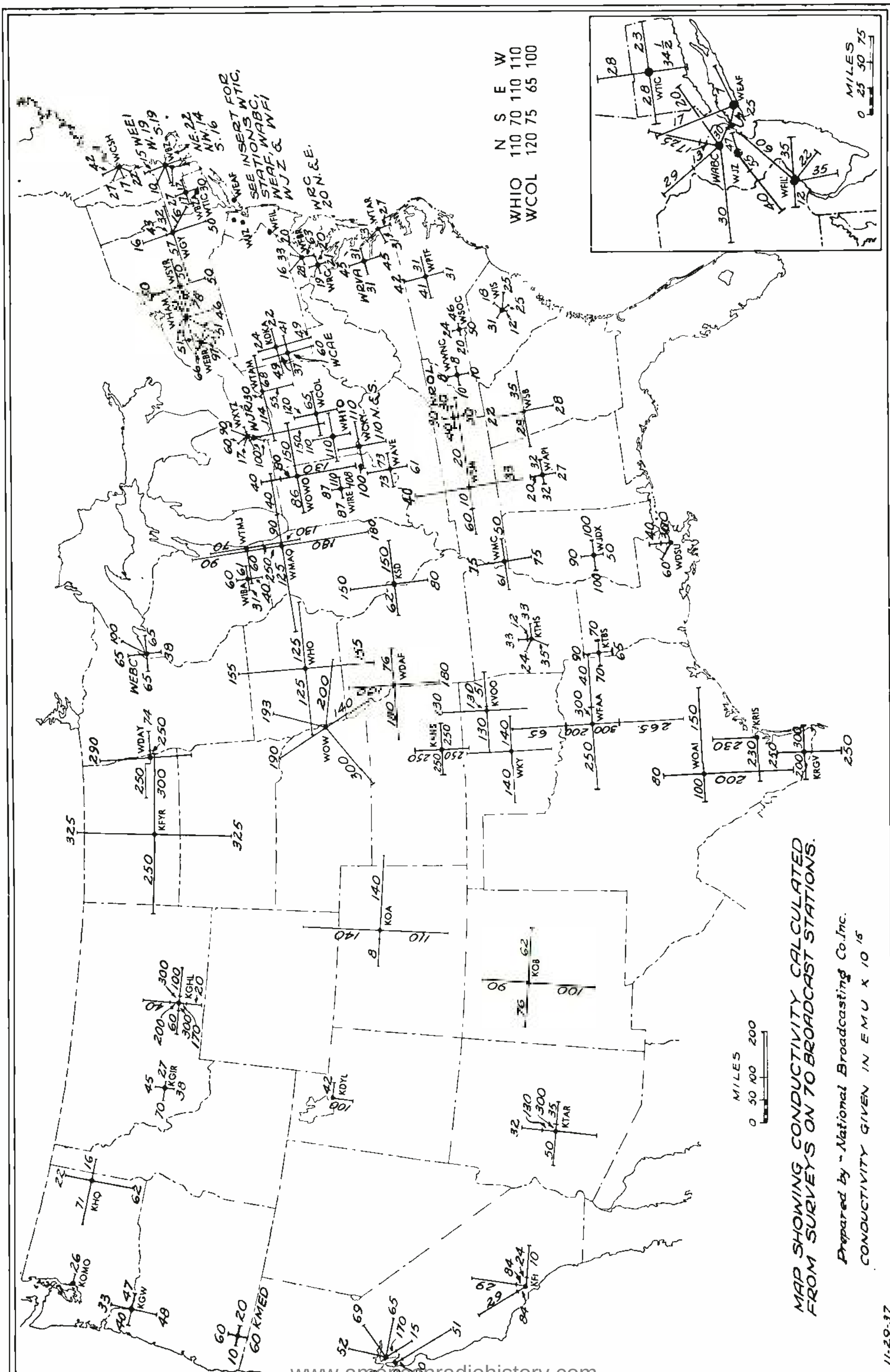

Fig. 6—Map showing conductivity calculated from 70 NBC broadcasting stations.

For instance, the station operates on a frequency of 1000 kc and the field strength radial follows the 1400-kc curve. The conversion chart then indicates the conductivity is 50×10^{-15} EMU. Using this method, the conductivity in the vicinity of 70 NBC stations has been calculated and is given by Figure 6.

Figure 7 is also useful for a rough determination of the conductivity when the only information available is the distance to the ½-millivolt contour. The abscissae of Figure 7 are the inverse field intensities at

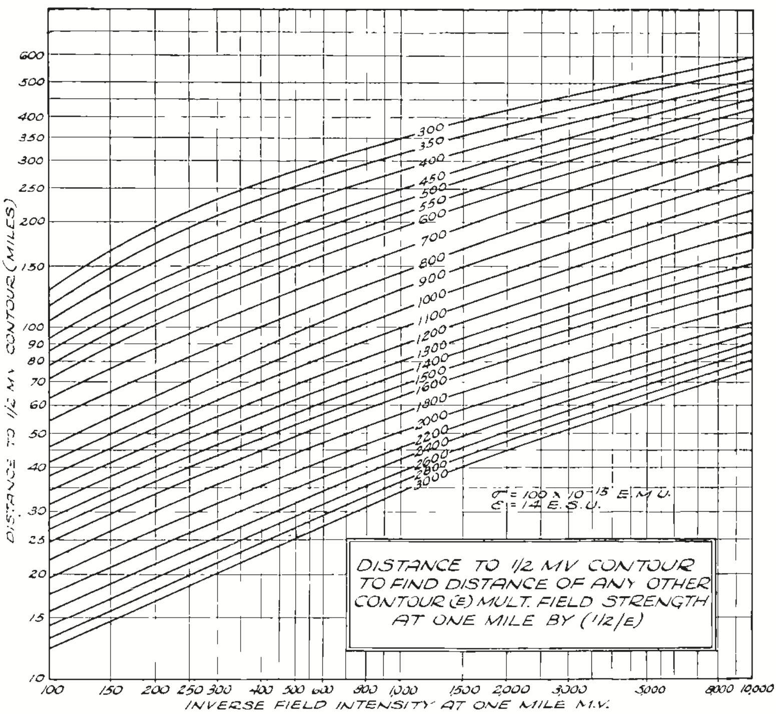

Fig. 7—Distance to ½-mv contour for various powers and frequencies.

one mile. The ordinates are the distances to the ½-millivolt contour. The relation between the field strength at one mile and the distance to the one-half millivolt contour is given for a series of frequencies from 300 to 3000 kc when the soil constant is 100×10^{-15} EMU. For instance, suppose the field strength at one mile of a station operating on 600 kc is 200 millivolts and the distance to its ½-millivolt contour is 64 miles. From Figure 7 the conversion frequency is found to be 900 kc. Using the conversion chart of Figure 5 the soil conductivity is found to be 45×10^{-15} EMU. This method is not as accurate as fitting the actual radial to the curves of Figure 5 because only two points are used to determine the conversion frequency. It gives an average conductivity to the ½-millivolt contour. Frequently the conductivity changes along a radial. This would not be detected using only Figure 7. This chart may also be used to determine the average conductivity if some other contour is given. Simply multiply the field strength at one mile by $\frac{1}{2}/E$ where E is the value of the contour given in millivolts per meter. Thus if the distance to the 2-millivolt contour is given, the conductivity may be obtained by multiplying the field strength at one mile by 0.5/2 or 0.25 and proceeding as outlined above.

Preparation of Contour Map

In plotting the field-intensity contours on a map, the distance to the contours should be obtained from the radials. Figure 8 shows a typical survey map. Note that there are no sudden changes of curvature in these contours, such as would be likely to occur if the measurements were made by "following the contour."

The contour map should contain such vital information as (a) Station call letters, (b) Licensed power, (c) Antenna current, (d) Date of survey, (e) Name of maker of the survey, (f) Scale of the map, (g) If directional operation is used, there should be stated phasing, spacing, and ratio of antenna currents.

Signal Intensity Necessary for Good Coverage

Much has been published concerning the field intensity required for good broadcast reception.[11,12,13,14,15,16,17,18] The Federal Communications Commission and the National Association of Broadcasters have recommended the following field-intensity levels.

Cities	10 to 25 millivolts per meter
Residential sections	2 to 5 " " "
Rural localities	.1 to .5 " " "

These figures are based on the fact that the electrical noises are greater in cities than in residential and rural parts of the country. If the city has many tall steel buildings. it may be necessary to have a free-space field of 50 millivolts over the city in order that the field strength at the receiving antenna may be 10 millivolts.[16] In a city like New York the field strength at an average antenna may bear an even greater ratio to the free-space field due to the shielding effect of the conglomeration of skyscrapers.

Night-Time Coverage

Fading

The night coverage of broadcast stations is affected considerably by energy returned from a reflecting layer called the "Heaviside

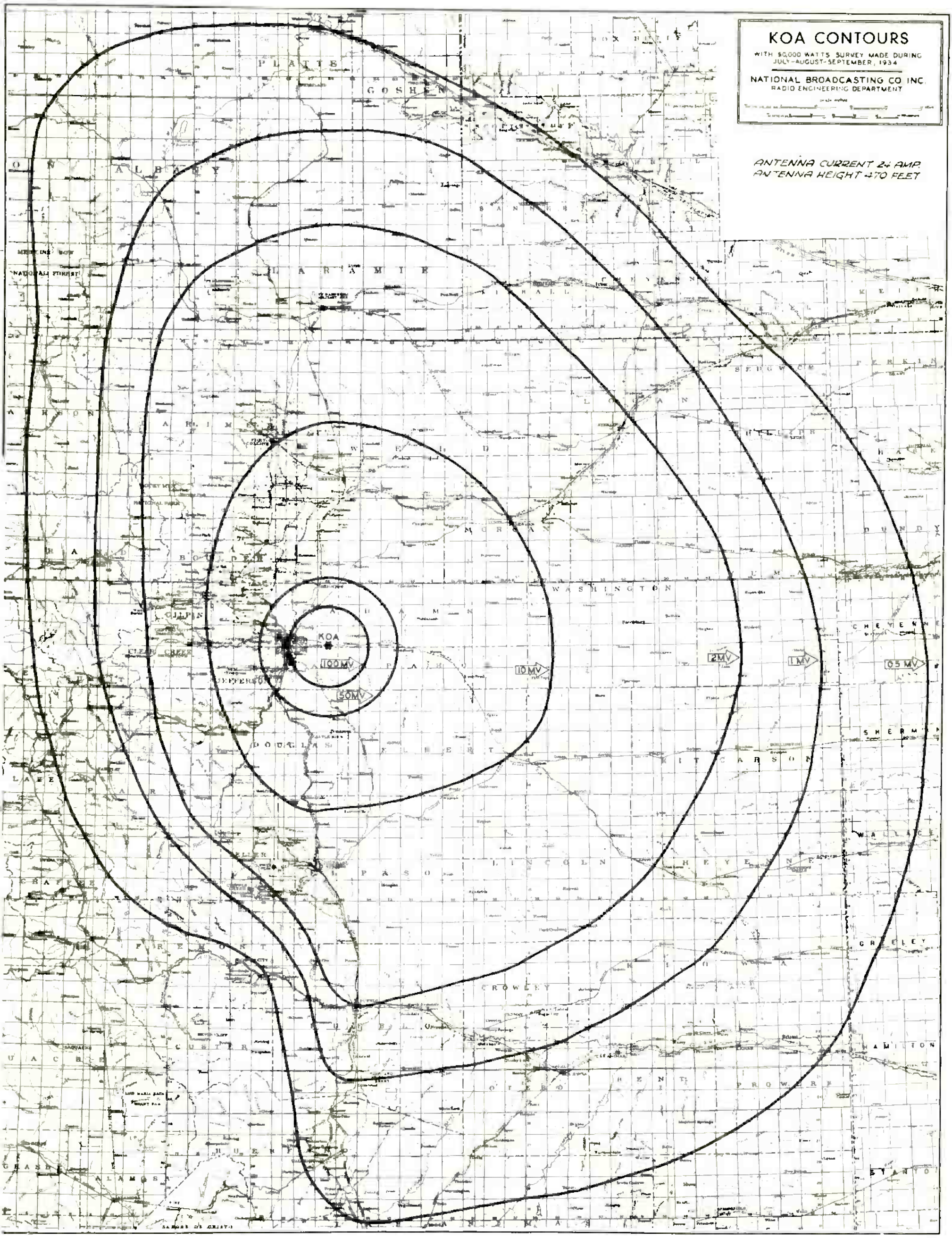

Fig. 8—Field-intensity contours of KOA.

Layer," which is aproximately 100 kilometers above the surface of the earth. This Heaviside Layer does two things. First, it reflects energy radiated from the antenna at high angles above the earth, bringing it back to the earth at great distances and giving rise to long-distance reception. This is one form of secondary coverage. The ground wave here is negligible compared to the sky wave. Secondly, the Heaviside Layer may also reflect energy to points near the transmitter where the ground wave is still useful. Here it has the detrimental effect of interfering with the ground wave and causes fading. We generally term the area within this fading boundary as the primary-service area, although where interference exists from other stations, either on the same channel or on neighboring channels, the primary area may be much more restricted.[16] In other words the primary-service area of a broadcasting station is that area wherein a signal is produced free enough from fading and interference to give continuously good service.

Thus in proceeding outward from a station, one passes first through the primary-service area of a broadcast station where the signal is sufficiently free of fading and interference to give good service. Passing further outward, where the night sky wave and ground wave often cancel, is found an area subject to violent fading and distortion frequently resulting in unsatisfactory service. This latter area is in the form of a band, about the transmitter, and is sometimes as much as 50 miles wide. Passing beyond this band, the fading is found to be less severe and the distortion less frequent or practically absent. This is called the secondary area. It extends out as far as a reasonable signal-to-interference ratio exists. In this territory slow fading takes place, and there are variations in the steadiness of the signal. However, under favorable conditions of the Heaviside Layer, the signal still may be usable with an automatic-volume-control receiver several hundred miles from a clear-channel station. The coverage of the regional or local station may be limited at night by interference from other stations on the same channel. The interference from other stations on the same channel generally prevents any service outside its fading band.

The position of this fading band may shift slightly back and forth with seasons and changes in the sun-spot cycle. It is, however, entirely independent of the transmitter power. Its location is largely determined by the antenna design and respective ground-wave and sky-wave attenuation.

Fading Measurements

Let us consider the measurement of fading. It is advisable, first, to calculate approximately the distance to the fading band so as to eliminate unnecessary recording points. This is done by means of Figure 5. The curves at the bottom of the chart give the intensities of the reflected sky wave for different height antennas and for 1000 millivolts at one mile. Since the Sommerfeld ground-wave curves are also calculated for 1000 millivolts at one mile, the intersection of the ground-wave curve with the sky-wave curve gives the distance at which they are equal when the coefficient of reflection is unity and the Heaviside Layer is 100 kilometers high. For example, suppose the antenna is 568 feet high and the operating frequency is 870 kc. This corresponds to an electrical height of 190°. Assume that the daytime measurements show that the conversion frequency is 900 kc. Looking at Figure 5 we see that the 900-kc curve intersects the 190° sky-wave curve at 105 miles. Thus the ground wave and sky wave are equal at this point. This would be the middle of the fading band and reception here would be the poorest. Hence it would be desirable to make recordings at 6 points—say 70 miles, 80 miles, 90 miles, 100 miles, 110 miles, and 120 miles. Certainly the fading band would fall in this range. The fading band does not always come at the exact distance calculated because the antenna pattern is not always ideal. Perhaps the transmission line or other nearby wires are affecting the sky-wave pattern. If the measured fading band extends as far as the calculated value, it may be presumed that the antenna sky-wave pattern is normal.

A convenient formula useful for determining the electrical height of an antenna is as follows:

$$\theta = \frac{h \times f}{2600} \tag{2}$$

θ = electrical height of antenna in degrees
h = height of antenna in feet
f = operating frequency in kc.

This formula is based on a reduced velocity of propagation equal to 95 per cent of that of light.

A receiving set and output meter are all that are required to observe fading. If a record of the intensity of fading is to be made, a recorder and field-intensity meter is needed. The National Broadcasting Company uses RCA TMV-75B field-intensity meters in conjunction with 5-milliampere recorders. This equipment is shown in Figure 3. The early model RCA 75-B field-intensity measuring sets were not arranged to work directly into a recorder. It was necessary to use a direct-current amplifier between the field-intensity measuring set and the recorder. Recently a modification of the circuit of the RCA 75-B has been made which permits the direct operation of a 5-milliampere recorder. The current model of these meters incorporates this feature. This modification is easily made and has been described in a recent publication.[19]

The distance to the fading band may be determined by making field-intensity recordings at about 10-mile intervals beginning at the inner edge of the expected fading band. These points should be in the open and away from all wires. The signal is recorded at each point for the three hours following sunset, for at least five successive nights. There should be very little fading at the first point. The equipment is then moved about 10 miles further out and the above procedure is repeated. The fading here should be a little more pronounced. This process is repeated at 10-mile intervals until a point is reached where the sky wave at times entirely cancels the ground wave. The distance

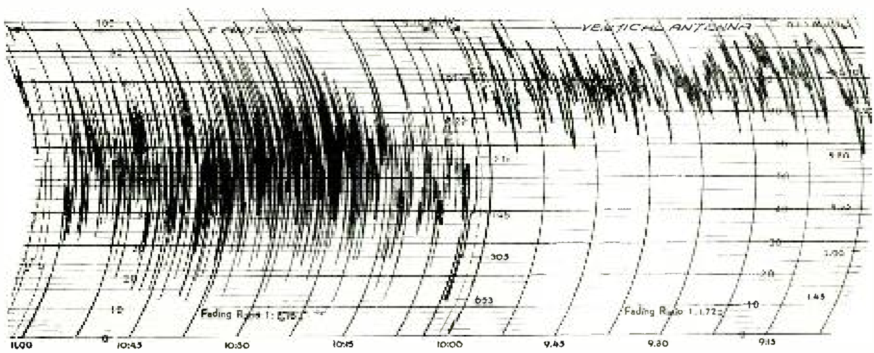

Fig. 9—A typical recording taken on KOA at a distance of 50 miles.

of this point from the station is approximately the distance to the middle of the fading band.

Figure 9 shows a typical recording taken on KOA at a distance of 50 miles. This record gives a comparison between the performance of the new 470-ft. vertical radiator compared to the old "T" antenna.

Interference from Other Stations

In addition to causing fading, the Heaviside Layer affects the coverage of broadcast stations in another way. It greatly increases interference at night from other stations on the same and adjacent channels. This is due to the fact that the Heaviside Layer acts, at times, as a fairly good conductor of the radio waves. It is common to receive strong field intensities at night from distant stations which are so weak in the daytime that they cannot even be detected. The unfortunate thing about the Heaviside Layer is that it is not steady. A sky-wave signal may be strong one minute and weak the next. Hence interference from distant stations may be severe one minute and not noticeable the next.

In order to better understand sky-wave propagation the Federal Communications Commission, in collaboration with the National Association of Broadcasters, conducted a survey of night-time propagation from February to May 1935. The results of this survey are described in Federal Communications Commission docket No. 18108. Through their courtesy one of the most important charts in this report is repro-

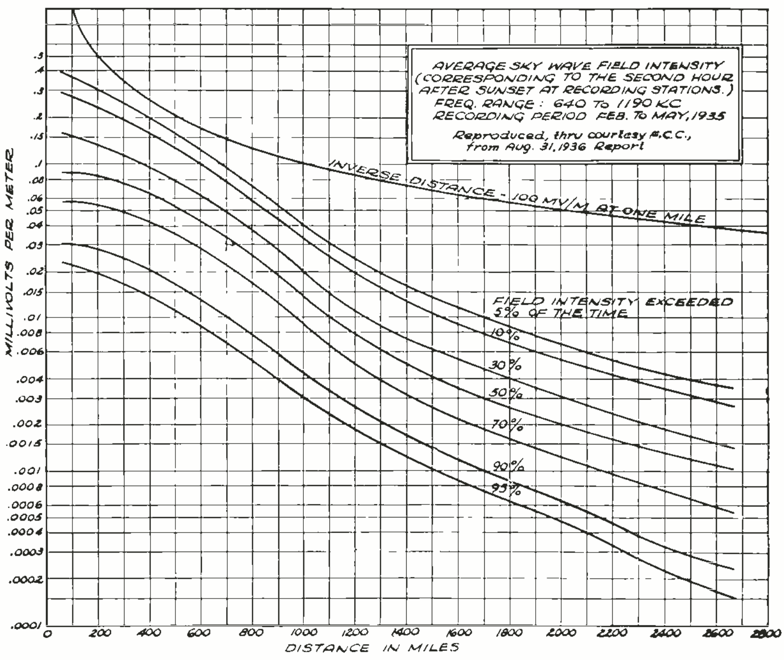

Fig. 10—Average sky-wave field intensity.

duced as Figure 10. This chart shows the average sky-wave field intensity (corresponding to the second hour after sunset) at the recording station. Curves are given for the average field intensity exceeded 5 per cent, 10 per cent, 30 per cent, 70 per cent, 90 per cent, and 95 per cent of the time. For interference measurements the signal intensity exceeded 10 per cent of the time has been standardized as the intensity of the interfering signal. Thus an interfering signal intensity of 50 microvolts for 9 minutes and a signal of over one-millivolt for one minute would be classed as an interfering signal of one millivolt.

Using the 10-per-cent curve of Figure 10, it is possible to calculate the interfering-signal intensity from any station at night within certain limitations. That is, the curves of Figure 10 are based upon an average antenna. If the vertical pattern of the interfering station's antenna gives less sky-wave than an average antenna, then a somewhat lower field intensity of interfering signal should be expected. The reverse is true also. However, this limitation applies only to stations located less than about 300 miles apart, because all practical antennas have approximately the same shape pattern for angles between the horizon and 22 degrees above it. Radiation in these angles is reflected from the Heaviside Layer and returns to the earth at points 300 miles or more distant.

To find the interfering-signal intensity from Figure 10, the reading of the 10-per-cent curve at the separation distance is multiplied by the field strength of the interfering station in millivolts, and the results are divided by one hundred. For example, suppose the interfering station is 1000 miles away and radiates 150 millivolts. The 10-per-cent curve at 1000 miles is 0.032 millivolts. The interfering signal is

$$\frac{150}{100} \times 0.032 = 0.048 \text{ millivolts.}$$

The service area of a broadcast station may be limited by stations on the same frequency, stations separated by 10 kc, stations separated by 20 kc, and stations separated by 30 kc.

The amount of interference depends upon the intensity of the interfering signal, the frequency separation, and the selectivity of the receiver. A large number of measurements have been made on the selectivity of receivers.[20]

The Federal Communications Commission has, in the determination of interference problems, indicated its approval of the following protection ratios for the average receiver.

	Ratio desired-signal to undesired-signal
Same frequency	20.
± 10 kc	2.
± 20 kc	0.1
± 30 kc	0.02

On the basis of the foregoing table it is possible to have 10 times as much signal on an adjacent channel as is permissible on the same channel. Similarly on a channel ± 20 kc removed it is possible to have 200 times as much signal; and on a channel ± 30 kc removed it is possible to have 1000 times as much signal as is permissible on the same channel. Thus, it is seen that stations on the same channel must be separated by a much greater distance to prevent interference. An example will show this. Suppose two stations operate with 1-kw power and have 200 millivolts field strength at one mile. We desire to have protection to the 0.5-millivolt contour. Using the foregoing table and the 10-per-cent curve of Figure 10, the following separations are obtained.

Same frequency	1400 miles
± 10 kc	500 miles

On higher power stations radiating 50 kw or more the separation must be much greater to prevent interference.

The radio industry is still growing. New receivers with greater selectivity will be made. New transmitters with greater range and capabilities will be installed. This will call for new coverage standards. This paper was written with existing standards in mind. New standards will modify the sections of this paper to which they apply.

The treatment of problems connected with the determination of the efficiency of antenna and transmitter site selections will be presented in a later issue of the RCA REVIEW.

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THE MONOSCOPE[1]

By

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Introduction

"MONOSCOPE" is the name which has been given to a developmental type of tube designed to produce a video signal of a test picture or pattern enclosed in the tube. Since the picture must be enclosed in the tube, the Monoscope is not suitable for developing a video signal which represents action. However, a signal of excellent fidelity can be obtained for a "still" picture which contains half-tones or consists only of lines.

Two general types of tubes which can be used for this purpose are: first, the type which utilizes the primary current of the scanning beam to produce the video signal, and second, the type which makes use of the secondary-emission current obtained when a suitable material is scanned with an electron beam.

Briefly, the first type of tube has a signal plate of some desired configuration cut from a conducting surface. When the plate is scanned, a signal current is obtained each time the beam strikes the plate. As a result, this video signal will produce a picture of the plate when applied to a suitable reproducer.

The second class of tube can be made in a number of workable combinations.* In general, two materials having different secondary-emission ratios are used to make the signal plate. As this plate is scanned, one magnitude of secondary-emission current is obtained from one material and another magnitude is obtained from the second. The difference in the magnitudes of these secondary-emission currents determines the amount of video current. Therefore, if two materials which have a numerical difference in secondary-emission ratios greater than one are used, it is possible to develop more video current than would be possible if only the primary current of the beam were utilized. Because of the attractiveness of this arrangement, a number of combinations of two materials having different secondary-emission ratios was investigated. A technique of preparing signal plates was developed which permits the accurate reproduction of all types of subject matter. The structure of a tube employing this principle will now be described.

* British Patent No. 465715.

[1] This paper was delivered at the Fall Meeting of the Institute of Radio Engineers, Rochester, N. Y., Nov. 8, 1937.

MONOSCOPE STRUCTURE

The photograph of Figure 1 shows the Monoscope. The tube consists of an electron gun, a signal plate, and a collector enclosed in a highly evacuated envelope. The electron beam is scanned over the signal plate by an electromagnetic deflection system.

The electron gun which supplies the scanning beam must be of high quality if the best video signal is to be obtained. The electron beam should be very small when it strikes the signal plate if good resolution is desired. The beam current should be reasonably high because the video current varies directly with beam current. However, the size of the beam should not be sacrificed to obtain high beam currents. The electron gun developed for Iconoscopes, provides a

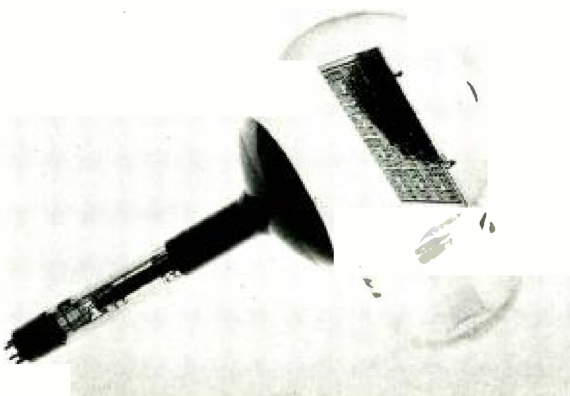

Fig. 1—Photograph of Monoscope.

small beam with adequate current, and therefore, was readily adapted to the Monoscope. The final anode of this gun operates at 1000 volts, and a very small beam can be obtained for currents of several microamperes. The use of this gun proves to be an advantage in test work when it is desired to use a Monoscope in an Iconoscope camera.

The signal plate is made from aluminum foil and carbon. The surface of the aluminum has a natural coating of aluminum oxide which has a reasonably high secondary-emission ratio while the carbon has a relatively low ratio. It was found that aluminum foil developed for advertising and packing purposes as well as special inks developed for printing on metal foils were satisfactory materials for signal plates. As a result the advantages and flexibility of commercial printing processes can be utilized. The desired picture or pattern is printed on aluminum foil with a black-foil ink. The only other processing necessary before sealing the signal plate in the tube is to fire it in hydrogen. This process removes the volatile matter from the ink and thus leaves it practically pure carbon.

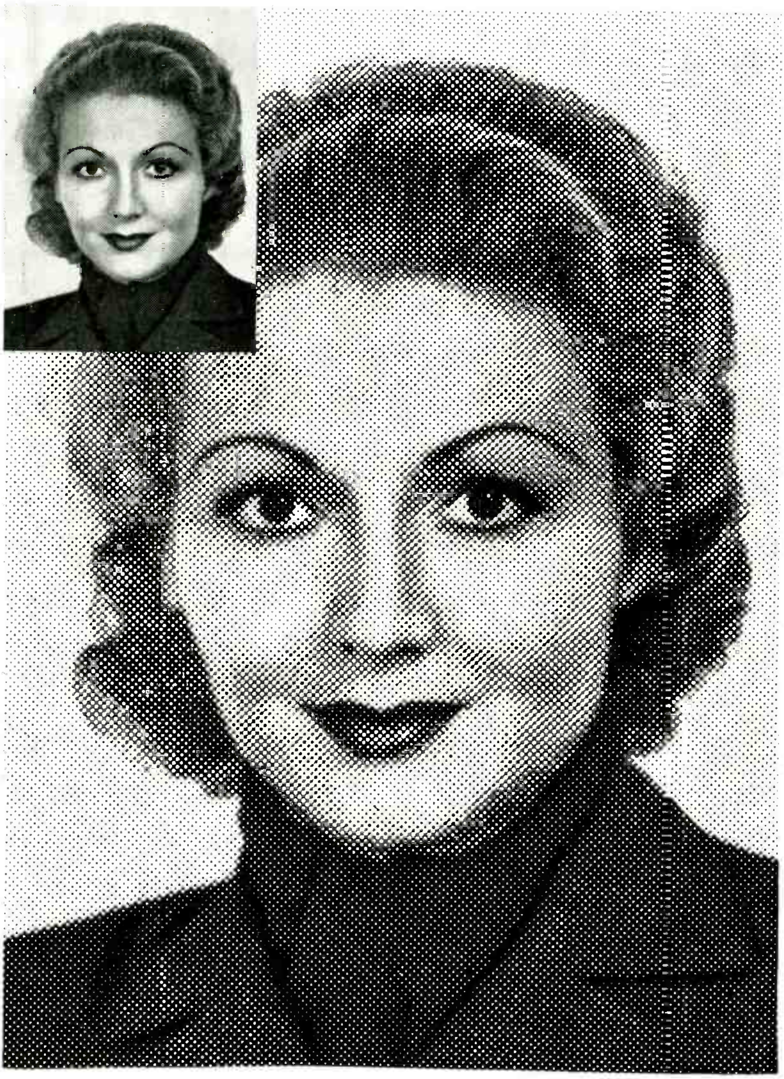

Fig. 2—Enlargement of photograph inset to show effect of screen in the half-tone process.

Subject matter for reproduction on a signal plate can be divided into two classes: black and white, and half-tones. Cartoons are a good example of the first, while snapshots, which contain tones between black and white, illustrate the half-tone group. Photo-engravings are made of the subject matter for printing the signal plates. The black-and-white material is treated as a line-cut, but the half-tone material must be broken into a number of dots of various sizes depending on the half-tone value. This is done when the photo-engraving is made by photographing the material through a suitable screen. A screen is used which will break the picture into more elements than are used in the television scanning system for which the tube is designed. As a result, this technique of obtaining half-tones does not limit the resolution of the television system and the half-tone effect is reproduced just as in a newspaper photograph. This is illustrated in Figure 2, which shows an enlargement of the inset photograph after the latter was photo-engraved. It will be noted that the enlarged picture is now made up of numerous dots of various sizes.

In order to give the picture the correct polarity on the Kinescope, i.e., so that white corresponds to white in the original, it is necessary to make the signal plate in a definite manner, depending on the number of stages in the video amplifier. If the video amplifier has an odd number of stages (as is normal between Iconoscope and Kinescope) the picture on the signal plate of the Monoscope should have blacks and whites reversed, but should not have printed matter reversed. The reversal of blacks and whites is necessary because the aluminum oxide, although white in appearance, has a higher secondary-emission ratio than the carbon, and, therefore, produces a signal which corresponds to black.

The secondary-emission current from the signal plate is collected by a conductive coating on the bulb wall. This coating is operated at a potential positive with respect to the signal plate, which is operated at the same potential as the final anode of the electron gun.

Operation of the Monoscope

The electrical operation of the Monoscope is very similar to that of the Iconoscope except that a collecting voltage is required for the secondary-emission from the signal plate. However, no optical system is required because the test picture or pattern is enclosed in the tube. A typical connection is shown in Figure 3. For convenience, the second anode is operated at ground potential. The first stage of the video amplifier may be operated with self-bias or fixed bias. In the latter case the bias adds to the collecting voltage, but the value of the combined voltage is not critical for potentials above 20 or 30 volts.

The video amplifier must be of high quality to amplify faithfully the video signal. If the signal is to be used for test work, the frequency band of the amplifier should be broader than the circuits under test so that limiting conditions will not be confused.

USES OF THE MONOSCOPE

The Monoscope may be used for a variety of purposes. In commercial applications, frequently repeated announcements and advertisements could be taken from a Monoscope. Fixed backgrounds for studio work could be obtained—the final signal being a suitable combination of video signal from an Iconoscope for action and from a Monoscope for background.

However, the biggest field for the Monoscope is in television testing. The same video signal can be obtained from day to day, and the quality is not affected by such variables as poor optical focus, dark spot, and amplifier noise. The Monoscope, therefore, is an important device for checking performance of Kinescopes, receivers, and studio systems.

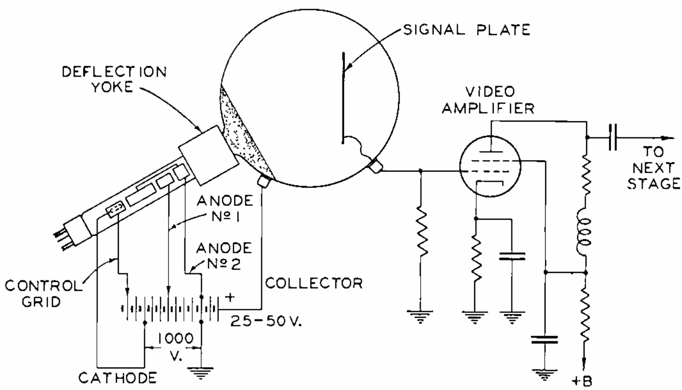

Fig. 3—Schematic diagram to show Monoscope connections.

1. Kinescope Tests

The television-tube manufacturer is concerned with how well his product will perform when reproducing video signals. Short-cut tests have been tried, but give poor correlation with the results obtained when an actual picture is reproduced. However, the quality of the latter is difficult to reduce to a quantitative basis unless the test picture or pattern has a specific character which can be accurately converted into a reliable video signal. The Monoscope is admirably suited for this purpose.

Simple tests insure the quality of the video signal used for rating the Kinescope. If the scanning on the Monoscope is reduced and that on the Kinescope is maintained at normal, an enlargement of the scanned portion of the signal plate will be seen on the Kinescope. This enlargement removes the possible limitation of Kinescope resolution. Also, the reduced scanning lowers the frequency band of the video signal so that the video amplifier does not limit the resolution. Under these scanning conditions, the focus of the electron gun in the Monoscope can be accurately set to give maximum resolution. The electron gun used in the Monoscope will give a resolution of 500 to 600 lines without difficulty; therefore, it more than fulfils the requirements of the present system of 441 lines. Figure 4 shows a test pattern which is often used for checking resolution. The lines used to form the half-tone circles in the center can be easily seen when the scanning is condensed.

After the focus of the Monoscope is set for maximum resolution, the resolution of the video amplifier can be checked. This is done by making the Monoscope scanning normal size and increasing the scanning on the Kinescope. The latter is necessary to remove the possible limitation of Kinescope resolution. If a test pattern similar to Figure 4 is used, the resolution of the amplifier is easily checked by noting the resolution of the "V" in the upright position. The resolutions of the Monoscope and video amplifier should be appreciably more than the resolution to which the Kinescope is to be rated. Under these conditions, the limits of the Kinescope resolution can be determined and reliable test data obtained.

Experience has shown that the resolution in all parts of the scanning pattern on a Kinescope may not be uniform. Figure 5 shows a test pattern which is suitable for checking all parts of the scanning pattern under similar conditions. Each section carries "V's" which correspond to resolutions of 150 to 450 lines. Also, tones between black and white are included to give a check on the modulation characteristic. With such a pattern as this, the Kinescope can be rated under different bias conditions with various amounts of video signal input. An illuminometer can be used to check the light output for a definite signal. Experience has shown that such elaboration is necessary to obtain reliable test information. Perhaps, as the art progresses, suitable short-cut tests can be devised.

2. Receiver Tests

A standard source of high-quality signal has numerous advantages in the development and production testing of receivers. Various resolution patterns serve as good "yardsticks" for measuring receiver characteristics if they can be converted into video signals of good fidelity. As has been pointed out, the Monoscope is particularly useful for this purpose. By adding standard synchronizing impulses to the Monoscope signal and modulating a small transmitter, a very useful test signal can be obtained for readily checking the receiver.

3. Television System Tests

When a television system is installed, numerous tests must be made to adjust the various circuits. The Monoscope materially aids such testing. For instance, any extraneous signals entering the grid circuit of the Iconoscope can be easily detected. Since the video signal from the Monoscope is directly proportional to the beam current, any variation in beam current is revealed as a modulation of

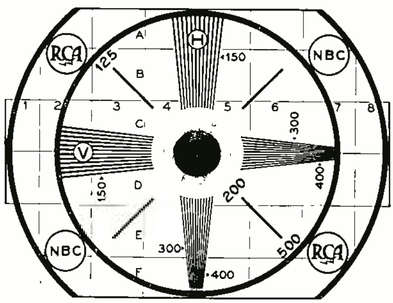

Fig. 4—Test pattern for checking resolution.

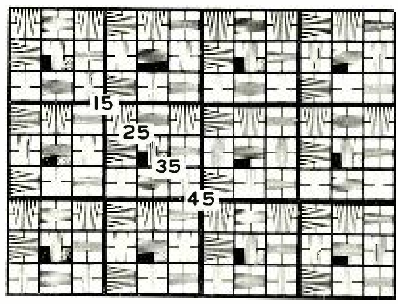

Fig. 5—Test pattern for checking all parts of scanning pattern.

the video signal. Therefore, any extraneous signal or hum in the circuits is revealed.

When the shading signals which are sometimes added to the Iconoscope video signal are removed, the video-amplifier can be checked for pick-up and frequency response by using a Monoscope video signal. Such tests help to separate confusing factors which often combine to give poor over-all operation.

Because there are not any half-tones in the video signals from a Monoscope except those that are created by the limitation of resolving power of the beam, the signal is rich in the higher-order harmonics which make up the corners of a square wave. This type of signal is exceptionally good for showing the transient response of video amplifiers.

The Monoscope is a type of tube which has proved very useful for testing of television devices and circuits. It is believed that the Monoscope will aid materially in advancing and perfecting the art of television.

SOME NOTES ON VIDEO-AMPLIFIER DESIGN

By

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I. HIGH-FREQUENCY RESPONSE—GENERAL CONSIDERATIONS

THE theory and design of a video-amplifier stage for television purposes have been ably covered in many articles, and a partial list of these is given here in the bibliography so that the reader may consult it, if necessary, before proceeding with this article.

When a multi-stage amplifier is built, however, slight inaccuracies in adjustment, as well as departures from the ideal characteristics involved in the simplification of the theory, often result in an overall characteristic much inferior to that of a single stage, and it is the purpose of this article to deal with some of these features.

It is possible to approach the analysis of a stage from several viewpoints, but the one preferred by the author is that of the well-known filter theory. Thus, referring to Figure 1, (A), the actual tube circuit may be regarded Figure 1, (B) as a half-section or L low-pass filter connected to a constant-current generator. This is essentially the case in practice since almost invariably pentode tubes are employed of such high internal resistance that they may be regarded as generating a constant current e_1G_m regardless of all reasonable values of external load impedance Z_L. Furthermore, the grid-coupling circuit—C_g and R_g in series—is usually of such high impedance as to constitute practically a negligible shunt on Z_L. (The latter is assumed to consist of the load resistance R_L, the "peaking" coil, L, and the tube and wiring capacity, all lumped together in the parameter, C).

There are marked differences in the manner in which the half section is employed here and in normal practice. Thus, here, the voltage is picked off the generator end, instead of the load end R_L, and furthermore, the section is fed by a constant-current generator of theoretically infinite internal impedance, whereas the ordinary filter is assumed to be fed by a generator having constant generated voltage and an internal impedance equal to the image impedance of the section.

We cannot, therefore, expect the circuit to behave exactly as in ordinary filter theory; nevertheless some of the concepts corresponding to the latter can be carried over to advantage and modified as required.

The cut-off frequency of an L-section filter is

$$f_o = \frac{1}{\pi \sqrt{2L \times 2C}} = \frac{1}{2\pi \sqrt{LC}} \qquad (1)$$

since the L and C are half that of a full section, for which the formula is normally written. The image impedance (which value is usually used to terminate the section), is approximately

$$Z_I = \sqrt{\frac{L}{C}} \qquad (2)$$

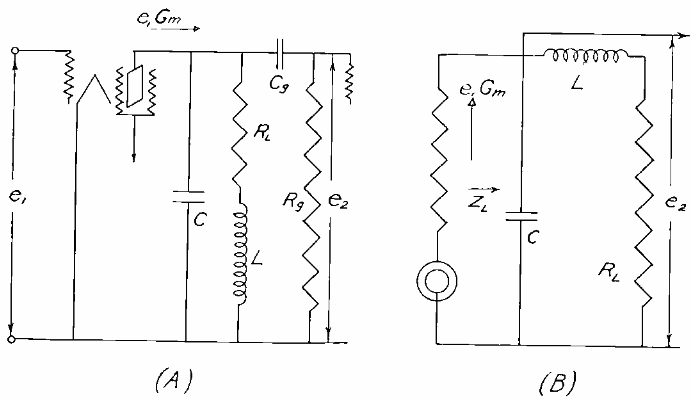

Fig. 1—Video-amplifier stage and equivalent circuit.

over most of the pass band, although it increases to infinity as the cut-off frequency is approached. In video-amplifier practice, however, we desire the input or driving-point impedance to be constant, and to have a phase angle that varies linearly with frequency, since the gain is

$$G = \frac{e_2}{e_1} = G_m Z_L \qquad (3)$$

It is impossible to obtain a Z_L which remains constant in amplitude and varies linearly in phase shift over the range of frequencies given by Equation (1), when the section is terminated in an ordinary resistance. Hence, a more restricted frequency range must be employed, and the terminating resistance be made other than that given by Equation (2).

II. Analytical Considerations—k Factor

The input impedance of the half section can be shown to be, for any terminating impedance R_L,

$$Z_L = \frac{R_L - j\omega\left[CR^2_L + L\left(\frac{\omega^2}{\omega_o^2} - 1\right)\right]}{\omega^2 C^2 R^2_L + \left(\frac{\omega^2}{\omega_o^2} - 1\right)^2} \quad (4)$$

where $\omega/2\pi$ is the frequency at which Z_L is to be determined, and $\frac{\omega_o}{2\pi} = f_o$. When $\omega = \frac{\omega_o}{\sqrt{2}}$, or at 71 per cent of the cut-off frequency, Z_L becomes $\sqrt{\frac{2L}{C}}$, regardless of the value of R_L. This is rather striking, and has been used to modify Equation (2). Thus, at low frequencies Z_L is practically equal to R_L, while at 71 per cent of f_o it is $\sqrt{\frac{2L}{C}}$. If we make R_L equal to $\sqrt{\frac{2L}{C}}$, then Z_L will be the same at these two points in the spectrum, and so will the gain. In between these values, Z_L and the gain will be approximately constant, and the phase shift fairly linear. Hence if we choose f_o so that it is $\sqrt{2}$ times the highest frequency, f_h, to be amplified, and R_L so that it is not equal to $Z_l = \sqrt{\frac{L}{C}}$, but $\sqrt{2}$ times this value, we may expect reasonably satisfactory results for one stage.

In general, we may write

$$R_L = k\sqrt{\frac{L}{C}} \quad (5)$$

and

$$f_o = \frac{1}{2\pi\sqrt{LC}} = \left(\frac{1}{m}\right) f_h \quad (6)$$

The value for k suggested above is $\sqrt{2}$, and for m is $1/\sqrt{2}$. For these values

$$|Z_L| = \sqrt{\frac{L}{C}} \sqrt{\frac{2+\left(\frac{\omega}{\omega_o}\right)^2}{1+\left(\frac{\omega}{\omega_o}\right)^4}} \tag{7}$$

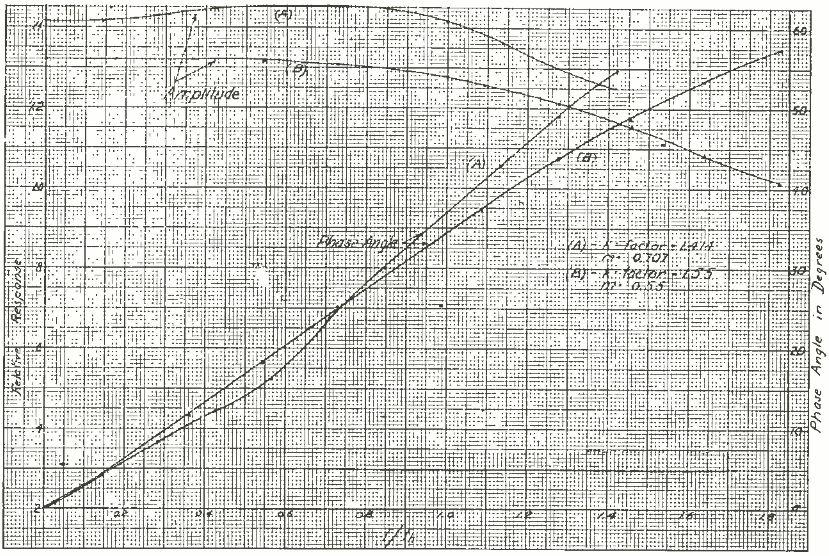

Fig. 2—Video-amplifier high-frequency response.

and hence, the phase angle for Z_L, between e_2 and e_1, is

$$\psi = \tan^{-1} \frac{\sqrt{2}}{2} \left[\left(\frac{\omega}{\omega_o}\right)^3 + \left(\frac{\omega}{\omega_o}\right)\right] \quad \text{(lagging)} \tag{8}$$

In general, for a given value of m, the value of k which gives the most nearly constant amplitude response does not give the most nearly linear phase shift. There is reason to believe that the latter factor is possibly even more important than the former in determining the quality of the reproduced image, since it determines the relative positions of the detail and the main outline of the image on the screen, and its importance increases with the number of stages employed. When we consider that a studio system may employ as many as twenty-four stages including a monitoring kinescope, we are in a position to realize the importance of maintaining as nearly linear as possible phase shift and constancy of amplitude response.

The most nearly linear phase shift per stage is obtained when k (the so-called k-factor) is equal to 1.697, but the amplitude response falls off rapidly. A satisfactory value in practice is $k = 1.55$. Even for this value the response falls off for values of ω greater than approximately $.55\omega_o$. But if we make $f_h = .55f_o$, or rather $f_o = 1.825f_h$, and $k = 1.55$, we shall obtain a satisfactorily flat response and linear phase shift not only for one stage, but for many stages, and the adjustments will not be nearly so critical as for $m = .707$ and $k = 1.414$. The disadvantage is a 14.75 per cent reduction in gain as compared to that obtained with the latter values, but the results justify the use of the former.

Curves for the two sets of values are shown in Figure 2. It is to be noted that the amplitude curve for the circuit having the higher k factor and smaller m tapers off to zero more slowly than the former, and that the phase-shift curve is considerably closer to linear. It appears that these are desirable characteristics as regards transient response of the system, in that the higher damping tends to cut down the possibility of transient oscillations. The disadvantage of the prolonged response is that more of the noise-voltage spectrum is included, but this appears to be the lesser of the two evils.

For the suggested values of k and m, the input impedance is

$$Z_L = \sqrt{\frac{L}{C}} \frac{\sqrt{2.403 + \frac{\omega^2}{\omega_o^2}\left[1.403 + \frac{\omega^2}{\omega_o^2}\right]^2}}{\left[2.403\frac{\omega^2}{\omega_o^2} + \left(\frac{\omega^2}{\omega_o^2} - 1\right)^2\right]} \tag{9}$$

and the phase shift is

$$\psi = \tan^{-1} \frac{\frac{\omega}{\omega_o}\left[1.403 + \frac{\omega^2}{\omega_o^2}\right]}{1.55} \quad \text{(lagging)} \tag{10}$$

III. Low-Frequency Response—General Considerations

The low-frequency response of a video amplifier is affected by the grid-coupling circuit, which tends to attenuate the lower frequencies, and produce a leading phase shift, which—at such low frequencies—may amount to considerable time delay even if the angle is small. The frequency range under consideration is from about 200 cycles and down, and the response even at 20 cycles is important, since it is so close to the frame frequency of 30 cycles. In this range, however, the "peaking" coil and shunt capacitance have negligible effect.

To compensate for the effects of the grid-coupling circuit, as well as to minimize feed-back through the common power-supply, a plate-decoupling circuit consisting of R_F and C_F is employed as shown in Figure 3. In analyzing this circuit we shall assume, as before, that the grid circuit constitutes a negligible shunt across the plate load, Z_L, and that a pentode tube is employed. No restrictions, however, are placed on R_F: it may be as low or as high as desired.

IV. Analytical Considerations—Gain and Phase Shift

The gain of this stage may be written as

$$G = G_m R_L \, \omega \left[\frac{(\omega - j/T_{LF})}{(\omega - j/T_F)\ (\omega - j/T_g)} \right] \tag{11}$$

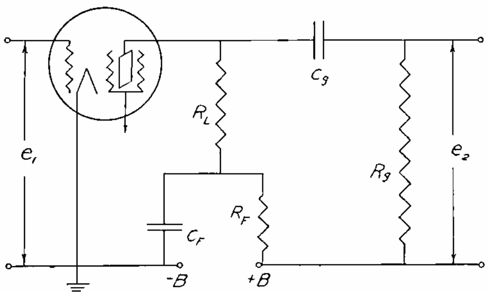

Fig. 3—Video-amplifier stage, Low-frequency response.

where

$$T_{LF} = C_F R_{LF}, \text{ where } R_{LF} = \frac{R_L R_F}{R_L + R_F}$$

$$T_F = C_F R_F$$

and $$T_g = C_g R_g$$

If R_F is very large, then $R_{LF} \approx R_L$, and $T_{LF} \approx R_L C_F$, while $(\omega - j/T_F)$ becomes approximately ω, so that the gain becomes approximately

$$G = G_m R_L \left[\frac{(\omega - j/T_{LF})}{(\omega - j/T_g)} \right] \tag{12}$$

In this case, if $T_{LF} = T_g$, then G becomes $G_m R_L$, or independent of ω (frequency), and has zero phase shift. However, it is doubtful whether in practice R_F is sufficiently high to be negligible in effect, and if this is not the case, it is questionable whether the two time constants T_{LF} and T_g should be made equal. In order to see more clearly the general effects, assume n stages, and let numerical subscripts denote the respective stages. Thus S_{m3}, R_{L3} and T_{g3}, for instance, denote respectively the tube transconductance, the plate load resistance, and the grid time constant of the third stage. The gain of n similar stages is the product of the individual stage gains, and may be written as

$$G_n = (G_{m1}G_{m2} \ldots . G_{mn}) \quad (R_{L1}R_{L2} \ldots . R_{Ln}) \left[\frac{\omega^n (\omega - j/T_{LF1}) \ldots . (\omega - j/T_{LFn})}{(\omega - j/T_{F1}) \ (\omega - j/T_{g1}) \ldots . (\omega - j/T_{Fn}) \ (\omega - j/T_{gn})} \right] \quad (13)$$

In order that G_n may be constant and independent of frequency, the bracketed expression must reduce to a numeric. But both numerator and denominator are polynomials of $2n$th degree in ω, and written in factored form. As such, the reciprocals of the various time constants are the roots of the corresponding polynomials. Since the numerator has n zero roots, corresponding to the factor ω^n, and n imaginary roots of the form $1/T$, while the denominator has $2n$ roots of the latter form, we see that the two polynomials cannot be identical for all values of ω, and so, in general, the bracketed expression cannot reduce to a numeric independent of ω, for finite values of the time constants.

V. Effect on Form of Rectangular Wave

In practice, the grid time constants are adjusted by varying each R_g, since the R_L's have been determined by the high-frequency response. When this is done experimentally, such as by using a 60-cycle rectangular wave, peculiar distortions of the latter wave may occur, which are readily explained by Equation (13). In Figure 4, A, B, C, and D, are shown some of the distortions which may occur to a rectangular wave. In (A) we have a case where $T_{LF} < T_g$ in some stage, while in (B), $T_g < T_{LF}$ in some stage. In neither case are the tops and bottoms of the wave really straight, particularly in case (B), but for some tilts they may appear so to the eye. The important factor which causes the tilt is the non-linear phase shift of the lower frequencies (fundamental) relative to the higher frequencies (harmonics) —lagging for (A), and leading for (B).

Case (C) represents a situation where the amplifier has a "gain in lows" (lower frequencies—such as fundamental-overemphasized) but no phase shift, at least of the fundamental relative to the very high harmonics. Case (D) represents a "loss in lows", but no phase shift.

These latter two cases may be readily explained by Equation (13). The bracketed expression consists of the product and division of a series of vectors, each of the form $(\omega - j/T)$. The magnitude of each vector is

$$|V| = \sqrt{\omega^2 + \left(\frac{1}{T}\right)^2} \qquad (14)$$

while the phase angle is

$$\psi = \tan^{-1} \frac{1}{\omega T} \qquad (15)$$

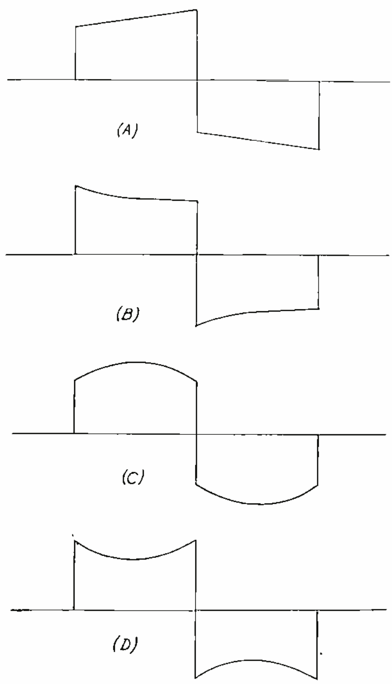

Fig. 4—Distortions of rectangular wave forms.

As T varies from ∞ to zero, $|V|$ varies from ω to infinity, while ψ varies from 0 to 90°. Because of the different range of values which the magnitude and phase angle may assume, it is possible for the magnitude of some of the above vectors to be very large, and for the phase angle to be but little greater than 45° or thereabouts. Suppose the vector under consideration is in the numerator, and the frequency 60 cycles. The reason for the large magnitude of the vector may be that the stage under consideration is a so-called "peaking" stage, and employs a low value of R_L to peak the higher frequencies. Such a stage will cause a distortion as shown in Figure 4 (A). Now suppose that its lagging phase shift is corrected by the effect of several grid time constants (the vectors of which are in the denominator). The result will be that the magnitudes of the latter vectors need be only moderate, and hence unable to offset the value of the large vector in the numerator, and yet the sum total of their leading phase angles may be sufficient to balance the lagging phase angle of the vector in the numerator. The total result is that the bracketed expression at 60 cycles is a magnitude greater than one, but having no phase angle. Above this frequency the magnitude decreases to unity, and exhibits first a small phase shift, which reaches a maximum and then decreases to zero. The effect of all this is that a 60-cycle rectangular wave will appear in the output with an exaggerated fundamental of zero phase shift (relative to the input) and the form will be approximately that shown in Figure 4 (C). The form shown in Figure 4 (D) represents a very small grid time constant in some stage, which is being corrected by several plate time constants. There is little reason for this latter condition to arise in practice.

VI. Adjustments for Optimum Low-Frequency Response

We thus see that various amplitude-response and phase-shift curves are possible in a multi-stage amplifier because of the presence of many time constants. The conclusions to be drawn are:

1) The proper adjustment is to compensate for any small plate time constant (T_{LF}) with *one* correspondingly small grid time constant (T_g).

2) It is inadvisable to compensate for several grid circuits with but one plate de-coupling circuit, since a bowed wave may be expected. If, however, the various time constants are sufficiently large, then the above result may be small even down to a very low frequency. In any event the effect may be calculated by Equation (13).

3) If the power supply is of the regulated type, and has a very low internal impedance, then de-coupling circuits may not be required to prevent feed-back. In this case, if the gas current of the tubes is sufficiently low, a large T_g, due to a large R_g, may be employed, and the total leading phase shift for even six stages may be as small as in the case where de-coupling compensating circuits are used, since the presence of R_F in the latter prevents perfect compensation.

4) In general, it is simplest to compensate each stage at a time, so that one small time constant there may be immediately balanced

by another. This avoids a bowed wave in the final output. The time constants should be made as large as possible, and adjustment for zero phase shift made at as low a frequency as possible.

VII. Cathode-Coupled Stage

A circuit of value for the output stage is the cathode-coupled stage shown in Figure 5. The circuit gain may be written as

$$G = \left(\frac{\mu}{\mu + 1} \right) \left[\frac{R_L}{\dfrac{r_p}{(1+\mu)} + R_L} \right] \tag{16}$$

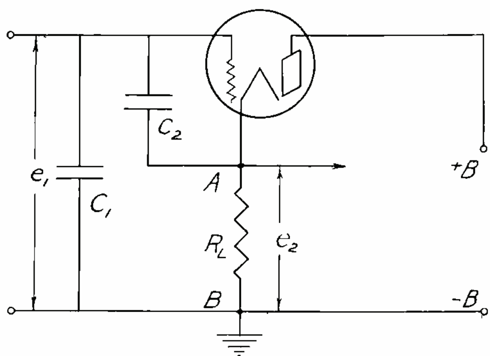

Fig. 5—Cathode-coupled stage.

where μ is the amplification factor of the tube, and r_p the internal plate resistance. If $\mu \gg 1$, then the gain is approximately

$$G = \left[\frac{R_L}{1/G_m + R_L} \right] \tag{17}$$

where G_m is the transconductance of the tube.

Examination of Equation (16) shows that the circuit is equivalent to the ordinary plate-load type of coupling, employing a tube the amplification factor of which is $\left(\frac{\mu}{\mu + 1} \right)$ or less than unity, and the plate resistance of which is $1/(1+\mu)$ of that of the actual tube.

Any impedance Z_{gK} between the grid and cathode is made to appear higher by the presence of the feed-back voltage e_2. Its apparent impedance is

$$Z'_K = \frac{Z_{gK}}{(1 - G)} \tag{18}$$

where G is the circuit gain. Thus a grid-coupling resistance, if tied to the cathode, can be quite low as far as grid gas current is concerned, yet high with respect to the signal component. The grid-to-cathode capacitance C_2 will appear, by Equation (18), to be of value

$$C'_2 = C_2 \ (1 - G) \tag{19}$$

or reduced in magnitude, which is an advantage. But a grid-to-ground capacitance, such as C_1, will be unaffected, as will also, obviously, the grid-to-plate capacity.

Further advantages of cathode coupling are:—

1) All the advantages of inverse feedback.

2) The load is at ground potential—at least at one end—and, hence, coupling to a coaxial cable is simple to accomplish, without the need of a coupling condenser.

Since the stage is used mainly to couple to a coaxial cable it is necessary that the impedance, looking back from the cable into terminals A B, be the image of the cable impedance. Let this be R_I. The impedance, looking into terminals A B, is R_L and $(r_p/1 + \mu)$ in parallel. The value of R_L to make this latter impedance assume the value R_I is

$$R_L = \frac{r_p R_I}{r_p - R_I \ (1 + \mu)} \approx \frac{R_I}{1 - G_m R_I} \tag{20}$$

if $\mu \gg 1$.

A larger value of R_L can be used than for straight plate coupling for the same value of R_I because for cathode coupling R_L is shunted by $r_p/(1 + \mu)$ whereas in straight plate coupling it is shunted by the higher value of r_p. The effect is to produce about the same voltage output to the cable for a given input voltage in either case, while the other features of cathode-coupling give it a decided advantage in practical application.

VIII. General Conclusions

1) Because of the closer tolerances required in multi-stage video amplifiers, a k-factor of 1.55 and a value of m equal to 0.55 is prefer-

able to those usually advocated, namely 1.414 and 0.707, respectively.

2) Best low-frequency response is obtained when the various time constants are as large as possible, and zero phase shift is obtained at as low a frequency as possible. If a low time constant must be had, as in a "high-peaker" circuit, then a balancing low-time constant should be provided in a grid-coupling circuit, rather than attempting compensation for the above over several grid circuits.

3) Cathode coupling provides a valuable means of obtaining a low-impedance output stage as well as reducing the input admittance. The loss in voltage amplification, or step-down effect is no worse than for an equivalent plate-coupling stage designed to present the same input impedance to the load—usually a coaxial cable. The advantages of cathode coupling are those of inverse feed-back in general, namely, higher input impedance, flatter frequency response, reduced phase shift, and reduced distortion products.

In conclusion the author wishes to express his gratitude to the National Broadcasting Company, to Mr. R. M. Morris, in charge of the Development Group in that company, and in particular to the members of the television group, who have afforded him valuable data pertinent to the material given here, as well as an opportunity to study the problems which have arisen in the course of this work.

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EFFECT OF THE RECEIVING ANTENNA ON TELEVISION RECEPTION FIDELITY

BY

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Summary—*Interference between direct and reflected signals from a single transmitter injects a factor into antenna design for television receivers which is not present in broadcast-receiver installations.*

Means for minimizing such interference when it exists in free space and for preventing the production of multiple signals in the antenna system itself are explained.

Some data are given on the behavior of transmission lines and long wire antennas. The latter may become necessary at, or near, the boundaries of service areas to improve adverse signal to noise ratios.

I. NATURE OF THE PROBLEM

IN BROADCAST-RECEIVER practice a simple wire of from a few feet to one hundred or more in length will suffice as a receiving antenna, and its operation is completely satisfactory if the received signal is sufficiently above the local and extraneous noise level. A television receiving antenna will have to be erected with much more care and must conform to more complete specifications. This is true because of the introduction of an additional factor in visual reception not present in sound broadcasting. This factor is the necessity for preventing reflected waves, which have travelled a few hundred feet or more further than the direct wave, from entering the receiver. Fortunately this can be done in all cases, and quite easily in most cases. It is the object of this paper to point out that the problem exists in visual reception, and to describe certain methods of meeting it which have been found effective.

Space Wave Reflections

When reproducing a 441-line, 30-field per second picture, the cathode-ray spot travels across the screen of a 12-inch Kinescope at a speed of about 2½ miles per second. This is $\frac{1}{75000}$ times the speed of light or radio waves in free space. In other words the spot will move about 0.060 inch while a radio wave is traveling 400 feet. Therefore, if both a direct and a reflected wave arrive with comparable magnitude at the input terminals of a television receiver, and one has traveled 400 feet further than the other, a double image will result. The displacement of the two images in such event will be about one-sixteenth of an inch and will cause blurring of all vertical lines in the picture. Actually such a condition results in even more complication than is immediately apparent from the above example. The reflected wave may have any phase with respect to the direct wave. Furthermore, each has its own side components, and those of the direct and reflected wave may be entirely different. Thus interference in the form of cancellation or reinforcement frequently causes a black line to be repeated as a white line or vice-versa. If the reflected wave travels 1000 feet or more further than the direct wave a distinct double image will result.

Thus it is readily apparent that the antenna must supply a television receiver with one signal only from a desired transmission. In metropolitan areas, reflections from large buildings may give rise to several images and the problem of proper construction, location and orientation of the receiving antenna becomes extremely important. However, at *any* location an improperly constructed antenna or antenna network and feed system may produce multiple signals of sufficient intensity and time-phase displacement to be objectionable.

Transmission Line Reflections

Under ordinary conditions, at most installations, it is necessary to use transmission lines between the antenna proper and the receiver in order to control properly the point of signal pick-up. If the maximum dimension of the antenna system (transmission line plus antenna) is of the order of 100 feet or more, and the line is not properly balanced and terminated at the receiver, reflections in the antenna network may cause a loss of detail in the reproduced picture. Thus the problem of preventing blurring or double images caused by multiple-signal reception may be divided into two parts. First, the antenna must be made non-susceptible to strong secondary waves from external reflecting media, and second, the antenna and its transmission line must be so constructed and terminated that reflections from the receiver end of the system can not bound back to the outer end of the antenna and be reflected there to re-enter the receiver as a delayed signal.

It is difficult to describe in words the appearance of images produced by multiple-signal reception, and difficult to show it clearly by illustrations produced by the photographic and printing processes necessarily involved. Figures 1 to 4 are illustrations showing a small section of a Kinescope screen reproducing a transmitted pattern, under different conditions of multiple-signal reception. The illustrations are of course not clear or representative of the general appearance of the screen when viewed by the eye, and are intended merely to show the relative effects of antenna changes. The pictures were taken on the same receiver with different antennas, but without any changes in receiver tuning. A detailed description of the antennas and the effect of each on the received image will be given later.

II. Source of Space Wave Reflections

It is to be understood that the reflecting medium need not be a metallic object. The specific inductive capacities of building stone, brick, paving material, and ordinary soil, are sufficiently greater than

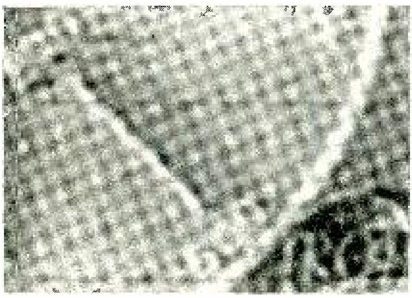

Fig. 1.

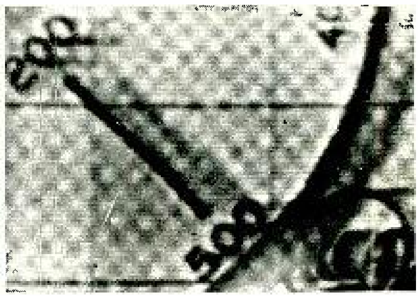

Fig. 2.

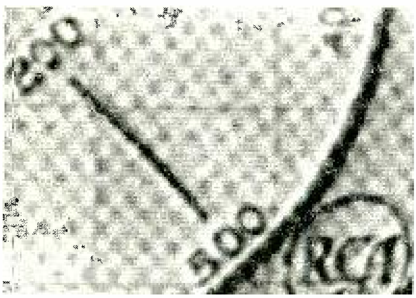

Fig. 3.

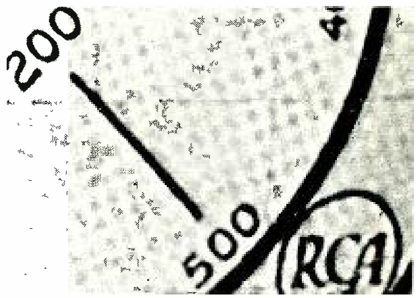

Fig. 4.

Figures 1, 2, and 3 show a small section of the Kinescope screen to illustrate the effect of various receiving antennas on reproduction. The receiver was operated with reduced contrast for best photographic results. Figure 4 is the same as 3 except that the receiver was operated with normal contrast.

that of air to have high coefficients of reflection for television frequencies at some angle of incidence. Therefore almost any surface can act as a reflector, if its dimensions are comparable to, or greater than, one-half wavelength.

If the transmitting antenna is within line of sight of the receiving antenna, and a plane surface parallel to the ground is located between the two and within sight of both, the strength and delay factor of the reflected energy will depend upon all of the dimensions of the geometrical orientation of the three objects. However, it can be shown by simple calculations that only within a radius, from the transmitter, of about six times the combined transmitting and receiving antenna heights (above such a surface) can reflections of this nature be sufficiently delayed to cause a loss of detail in the reproduced image. This, of course, is based on our present standard of 441-line, 30-frame per second transmission. Therefore, at most receiving locations, more than a mile or two from the transmitter, where reflections are troublesome, the reflecting area must lie in some plane other than that parallel to the ground.

Large buildings surrounding a receiving location offer ample opportunity for multiple-path reception even when the transmitting and receiving antennas are within line of sight. If the two are hidden from each other by tall buildings or by hills, the direct signal may be so greatly attenuated that the reflected energy exceeds that which travels the direct path. One example of this was noticed recently at a receiving location which was hidden from line-of-sight of the transmitting antenna by a nearby building. In this case, the single strong reflected wave produced an image misplaced by an amount which indicated it had travelled about nine hundred feet further than the direct wave. The receiving doublet was rotated to a position which eliminated the direct signal (which was much the weaker of the two) and good reproduction was obtained.

The most satisfactory indicator for determining the presence of undesired reflected waves and for aiding in the determination of their source, is a television receiver equipped with a portable doublet on the end of a long pole. It is necessary, of course, that the transmitter be in operation at the time of test, and that the transmitted image be stationary and of such a nature that either blurring of horizontal detail (at the edges of vertical lines) or the presence of a secondary image, is readily apparent. A single black vertical line in the middle of a white background would suffice.

The effect of orientation and rotation of the portable doublet on the relative strength of the direct and reflected signals, as reproduced by the receiver, together with a calculation of the difference in path lengths by a measurement of the displacement of the two images on the screen, will usually indicate the probable source of the reflection quite accurately. However, in many cases such information may turn out to be of only academic interest, since it will often be found that the correct answer to the problem of proper location and construction of the fixed receiving antenna can be determined only by empirical investigation.

III. Minimizing Secondary Signals

Probably the most generally useful type of television-receiving antenna will be a simple doublet, or double doublet, connected to the receiver by means of a low-impedance, twisted-pair transmission line. At the majority of receiving locations this will undoubtedly give completely satisfactory reception if normal care and thought are used in its installation. Even at many places where multiple-path reception is encountered, the same type of antenna may be made to serve satisfactorily by orientation to minimize the reflected signal, or by shielding it from the reflecting source. This might be done by placing it in proper relation to existing conductors such as metal flashings, copings, eavestroughs, etc. Usually such location can be found only by trying different positions and noting the effect on the received image. Another method of shielding a receiving doublet from reflected waves is to place a second, unloaded, dipole near it and in proper position to minimize the reflection image. Here again the cut-and-try method will probably yield the best results.

If several strong reflected signals are present at the receiving location more drastic action will probably be necessary. This was the case at the RCA License Laboratory which is located about 6000 feet north of the transmitter on the Empire State Building. Figure 1 was taken to illustrate the maximum number and relative strength of reflected signals which could be picked up at this location. The antenna was a half-wave doublet at the end of a 60-foot twisted pair which, however, was connected with the two wires in parallel to act as a "T" antenna against ground. In this case the first reflection arrived with proper phase and intensity to invert a large amount of the direct-signal detail into negative values of light intensity. This was followed by five more reflected signals varying in time of arrival and amplitude. The last of these is displaced by an amount which indicated that it had travelled 3.8 microseconds longer, and thus about 3700 feet further, than the direct wave.

It is interesting to note that in this case horizontal synchronization of the receiver was seriously impaired. The whole pattern moved to the left as though the receiver had synchronized on one of the reflected signals. This was undoubtedly the case due to partial destruction of the true horizontal pulse by the strong, short-delay, out-of-phase reflection.

Figure 2 was taken with the doublet and transmission line connected normally to the balanced-input terminals of the receiver, and with the doublet adjusted to the position which minimized secondary images. However, it can be seen that this antenna would be entirely unsatisfactory for good reception. Two principal reflections are still apparent. These are displaced by amounts which indicate additional path lengths of 800 feet and 2300 feet. A very faint trace of the 3700-foot reflection, which is strong in Figure 1, still remains.

The antenna for Figure 3 was the same as for Figure 2 except that one end of the doublet was lengthened by adding a three and one-half wavelength wire toward the transmitter. This was supported one-quarter wavelength above a wide copper coping parallel to, and about 150 feet directly above, Fifth Avenue. Resistance termination at the outer end of this antenna had little or no effect on the reproduced image, so Figure 3 was taken with the far end open. In this case the 2300-foot reflection is still faintly visible, but probably represents an acceptable minimum of direct to reflected-signal ratio.

Of a large number of antennas tested, that used for Figure 3 seems to be the only one which gives acceptable performance for reception at this location. Reflection conditions at this point are unusually severe and do not, by any means, represent the average to be expected. Although objectionable secondary images are picked up by simple half-wave doublets at various locations within the range of the transmitter, there are many more where no reflections are apparent.

IV. Behavior of Transmission Lines and Long Wire Antennas

The long wire antenna at the License Laboratory is necessary only because its directional characteristics improve an adverse direct to reflected-signal ratio. At, or near, the boundaries of the service area of a television transmitter it will sometimes be necessary to use something other than a simple dipole and twisted pair for the antenna system in order to raise the signal well above the receiver hiss level.

Rubber-dielectric, twisted-pair lines dissipate a considerable amount of the received energy if they are more than a few wavelengths long. Measurement of several types of such lines indicates that the average attenuation to be expected is between 1.5 and 2.0 db per wavelength at 50 mc. Therefore, a fair increase in signal strength at the receiver can often be obtained by the use of an open-wire line, particularly if the distance from the antenna to the receiver is 50 feet or more. The attenuation of the average, close-spaced, open-wire line is about one-tenth of that of twisted pairs. However, if an open-wire line is used, its increased impedance will cause the antenna to operate less efficiently unless the two are connected together in such a manner that the damping of the antenna is about the same as with the lower-impedance line. This can be done by the use of the well-known Y connection which is common in amateur transmitter practice.

It is also necessary for the input impedance of the receiver to be at least approximately matched to the higher-impedance line in order to realize the increased-signal level. In some recent tests it was found convenient to have a small residual-inductive component as part of the input impedance at the balanced-input terminals of the receiver. The resistive component of this impedance measured about 100 ohms; therefore, when using a 100-ohm line, two small series condensers (one in each wire) were inserted to cancel the reactance. If, however, the reactance was cancelled by shunt tuning, the input resistance became 500 ohms, which was the impedance of the open-wire line. This made it possible to analyze the behavior of the two lines without making changes in the receiver input-coupling circuit.

Under some conditions the energy picked up by the two wires of the transmission line acting in parallel may exceed that in the antenna proper. If the entire system, and the receiver input in particular, is well balanced to ground, the signals from this source cannot enter the receiver. If, however, an unbalance does exist, energy from this source may give rise to considerable trouble. This is particularly true if the entire length of line and antenna is of the order of 100 feet or more. In this case the unwanted signals may be reflected back and forth between the receiver and the outer end of the antenna producing a new image, slightly displaced from the previous one, on each round trip, and thereby obliterating much of the horizontal detail.

The energy loss in twisted-pair lines is usually sufficient so that signals cannot travel in them (back and forth) for a sufficient length of time to cause blurred reproduction before being attenuated below a disturbance level. However, energy travelling on the two wires in parallel is often subjected to much less attenuation and can make trouble, if lack of balance in the system allows some of it to enter the receiver.

A marked example of this effect was noticed recently. At a particular location, a half-wave doublet and twisted-pair line gave no indication of extraneous reflections, but the signal level (about 800 microvolts) was somewhat too low for a good signal-to-receiver-noise ratio. Therefore, it was decided to install some type of long-wire antenna and open-wire line as an experiment to determine just how much this could be increased without resorting to means other than those which will be at the disposal of the average serviceman. Existing supports were not available for a rhombic antenna which would have had to extend from the lead-in point in a direction toward the transmitter. Therefore a single-wire, five-wavelength antenna, was placed between two tall trees which were on a line about 20 degrees from the direction of the transmitter. The 2-inch spaced transmission line was Y connected to the antenna across a point one-quarter wavelength from the end toward the transmitter. With this arrangement it was realized that the major portion of the received energy would have to travel to the far end of the antenna, be reflected there, and then travel back the entire length before entering the transmission line. Furthermore, the whole system was, of course, unbalanced with respect to ground.

A test of the operation of this antenna showed that it delivered about ten times as much signal voltage to the receiver as the doublet and twisted pair. A large portion of this was due to an increase in height above the old antenna; the rest of it was accounted for by increased antenna and transmission-line efficiency. However, the reproduced image was decidedly poor. The radical loss of horizontal detail which resulted was at first assumed to be due to a too sharply defined resonant characteristic of the antenna proper; however this proved not to be the case. The cause of the trouble was found to be end-to-end reflection of that energy which flowed down the transmission-line wires in parallel. The distance from the receiver to the outer end of the antenna was about 175 feet. The blurring of the edges of vertical lines extended for a distance which indicated that at least three complete round trips (1050 feet) were made over this path by the extraneous signal before it was sufficiently attenuated to be unnoticeable.

The difficulty was corrected by shorting and grounding the transmission line at its bottom end and tapping off a short length of low-impedance line (for a lead-in) at an empirically determined point a few feet above the ground rod. It would normally be expected that a terminating resistor between the shorting bar and the ground connection would be required to prevent reflection of unbalanced signal energy at that point; in this case it was not necessary.

In its final form the antenna delivered somewhat less signal to the receiver than when first tried with a direct connection; but it still gave a 15 db improvement over the half-wave doublet. This was sufficient to raise the signal well above an acceptable minimum.

Conclusions

Some locations within the service area of a television transmitter will require individual receiving-antenna study and design to meet conditions at those locations.

It appears at present that a standard antenna design, or any single preventative of multiple reception, can not be prescribed for all receiving locations, especially where service from two transmitters in the same area is to be obtained.

Satisfactory performance has been obtained in every case studied, by means described in the paper.

A 200-KILOWATT RADIOTELEGRAPH TRANSMITTER

By

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Engineering Department, R.C.A. Communications, Inc.

Synopsis—This paper gives a general description of a 200-kw short-wave telegraph transmitter. Some of the special features of the transmitter are described in detail.

Difficulties overcome during preliminary tests and the final performance are discussed. Photographs, diagrams and curves are used to illustrate the various features and the performance characteristics.

Introductory

IT is only rather more than a decade since the ultimate development in the transoceanic radiotelegraph transmitting art was represented by the 200-kw Alexanderson alternator associated with a multiple tuned antenna. This combination operating at the low frequencies then employed for such services, was capable of launching toward the receiver, a signal of about 20-kw power. With the introduction of high frequencies for transoceanic services, the power output of these short-wave radiotelegraph transmitters has been normally about 40 kw. The need for an improved service to northern Europe during certain hours of the business day compelled R.C.A. Communications, Inc. to make the application of higher power described below. This transmitter has a power output capacity of 200 kw. With its associated directive antenna, it is capable of launching a signal toward a distant receiver equivalent to 10,000 kw fed into a nondirective antenna. The frequency channel chosen for this unit (10,620 kc with call letters WEF) was one already available to RCA Communications in the frequency band which is most effective during those above-mentioned daytime periods. The transmitter was first used for commercial traffic on August 27, 1936.

Description of Transmitter

The transmitter consists of two high-frequency units and their associated power supply equipments.

Exciter Unit

The exciter is piezo-electric quartz-crystal controlled with self-contained power-supply rectifiers. It is a type of equipment already well known in the art and has been standard in the service of R.C.A. Communications, Inc. for several years.[1] It is used in this transmitter to deliver a keyed output of about 500 watts at 3540 kilocycles to the power-amplifier unit.

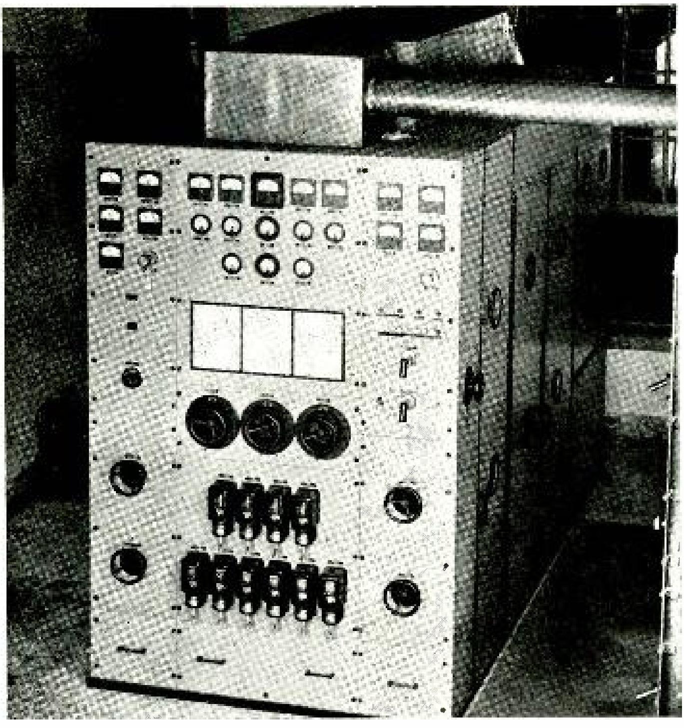

Fig. 1—Front view of the power-amplifier unit. In this view the air filter may be observed located centrally on top of the unit. The exciter transmission line is shown in front and the output-transmitter transmission line may be seen in the back.

Power-Amplifier Unit

This high-frequency unit contains three high-frequency amplifiers in cascade. A front view is shown in Figure 1, and Figure 2 shows a schematic circuit diagram of the transmitter. The first amplifier, equipped with two RCA-846 tubes is a balanced, or push-pull, capacity-neutralized frequency tripler (see Figure 3). The second amplifier is equipped with four RCA-846 tubes in a balanced capacity-neutralized circuit (see Figure 4) and the final amplifier is equipped with four special graphite-grid three-electrode tubes similar in dimensions to the RCA-899. This stage is illustrated in Figure 5. The tubes in the intermediate-amplifier stages and the power-amplifier stage are supplied with individual filament transformers. The tubes in the power-amplifier stage are also supplied with individual filament rheostats because of the importance of maintaining proper filament voltage on these large tubes. The filament heating power is quarter phase. Each phase supplies power to half the tubes in the intermediate-amplifier and power-amplifier stages for the purpose of balancing out the hum in the radio-frequency power output caused by the a-c filament voltage.

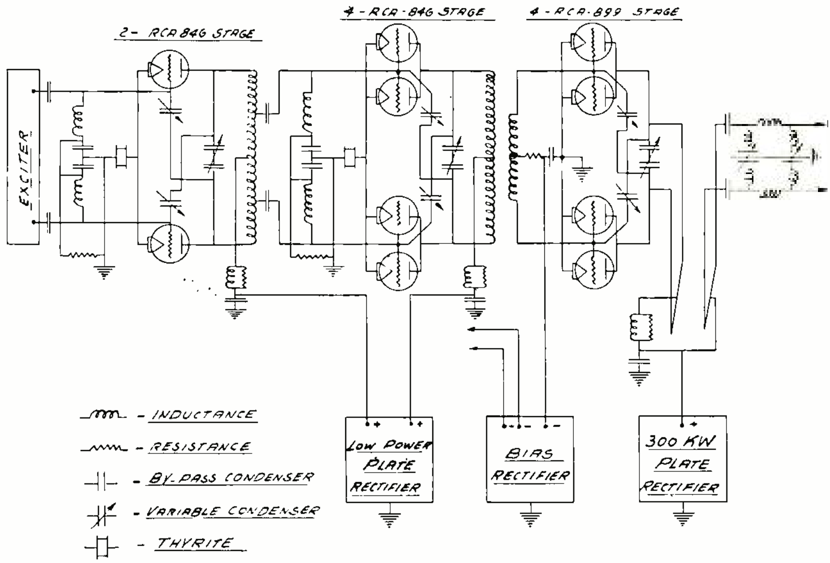

Fig. 2—Schematic circuit diagram of the 200-kw transmitter. This diagram gives a general idea of the radio-frequency circuits in the transmitter.

Not only is the transmitter of general interest on account of its large power output at high frequency, but it is believed to be of special interest because of a number of strikingly novel features in the design.

One of these features to which attention is directed is the special design of variable condensers used to balance or neutralize the capacity between the anodes and grids in the tubes of the intermediate and power-amplifier stages. Figure 6 illustrates one of the compressed-air condensers for neutralizing two RCA-899 tubes. These condensers consist of concentric tubular elements as shown in Figure 7 and employ a dielectric of compressed air at a pressure of about 12 to 13 atmospheres. The inner element is supported and insulated from the outer element by a cone-shaped insulator. All joints are made air-tight by the use of rubber or varnished-silk gaskets. The outer condenser element, which is made rigid and strong to withstand the internal air pressure, is connected electrically to and supported by the amplifier tank condenser. The latter supports the tubes and is electrically connected to their anodes. The inner condenser element is made variable by the use of metal bellows. This element is electrically connected to the grids of the tubes. An adjusting nut on the outer end of the variable condenser element is operated by the neutralizing control gear to extend or contract the metal bellows of the inner element by means of a push-rod, thus varying the capacity of the condenser. Each condenser is equipped with a filling valve and a pressure gauge. The ultimate breakdown voltage as determined by test for the small condenser was 30,000 volts rms, and that for the large condenser was 111,000 volts d.c. In both

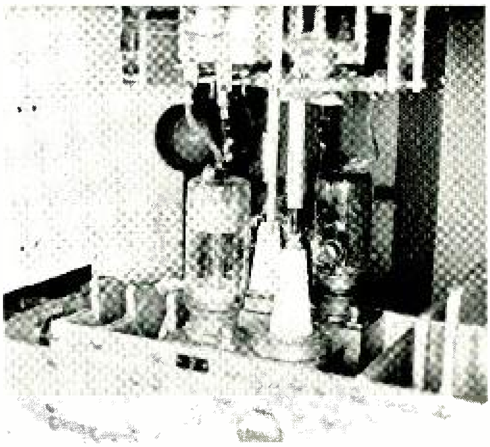

Fig. 3—First intermediate power-amplifier stage. A right-hand side view is illustrated.

cases the breakdown occurred outside of the insulator between the corona shields. The ultimate strength of the small condenser was found by actual test to be 2500 pounds per square inch and that of the large condenser 1500 pounds per square inch. The inside elements were removed for these tests. The maximum working pressure of the condensers is set at 200 pounds per square inch since that is the maximum pressure rating of the bellows. This type of condenser offers the advantages of large safety factor and small space requirements and freedom from dust. The voltage rating above atmospheric pressure is substantially proportional to the pressure. Assuming equal voltage rating for open-air and compressed-air condensers the overall space requirements are over ten to one in favor of compressed-air condensers. The dielectric volume is reduced approximately one hundred to one in compressed-air condensers.

Another feature of interest in this transmitter is the type of condenser used for tuning the anode oscillating, or tank, circuit. The tun-

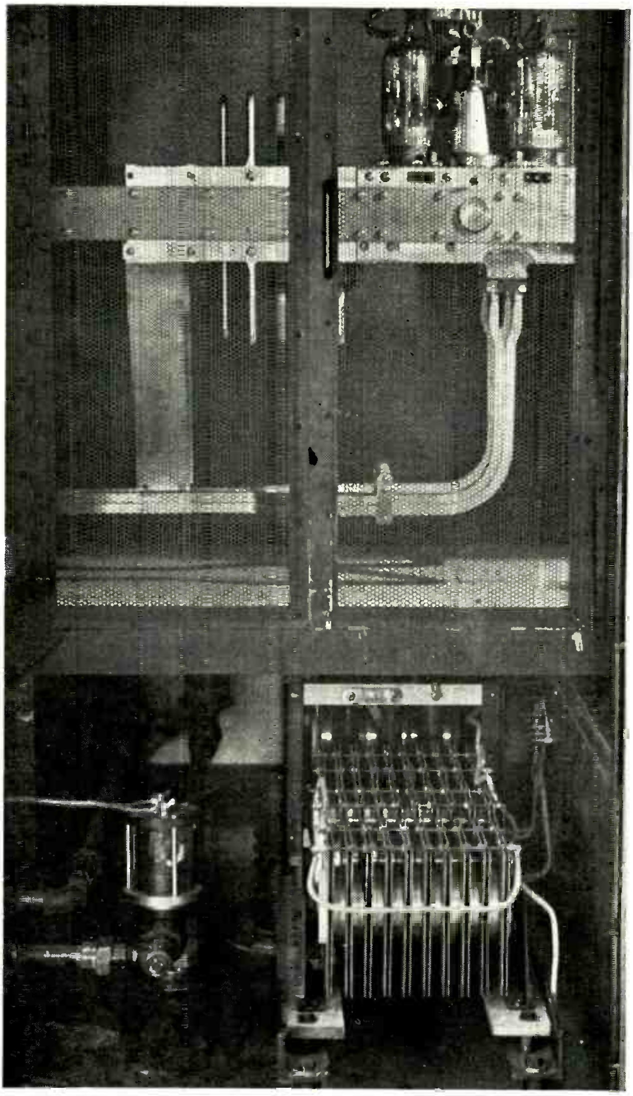

Fig. 4—Thyrite units for filament bias of RCA-846 tubes. These units may be seen in the lower part of the picture. The upper part of the picture shows, through the screen doors, a left-hand view of the second-intermediate power-amplifier stage.

ing condenser for the power-amplifier stage is shown in Figure 5 and that for the intermediate stages is shown in Figure 3. Three-eighthsinch solid duralumin plates are used in the intermediate stages and one-inch solid duralumin plates are used in the power-amplifier stage. The minimum total dielectric spacing across the condenser for each intermediate stage is one inch and that for the power-amplifier stage is two inches. All corners and edges are well rounded and all surfaces are polished. Part of the capacity of these condensers is fixed and part is variable. The variable portion consists of one or more spaced butterfly or figure-eight shaped plates pivoted on a common shaft at the center and rotatable between two or more spaced "Vee"-shaped plates mounted on fixed side plates. These side plates connect to and support the tube anodes. The complete assembly including tank condenser, tubes, and neutralizing condensers, is braced and supported by strong micalex and isolantite insulators. The tank tuning is adjusted by rotating the butterfly-shaped plates. This type of condenser provides variable capacity without sliding contacts and it has low distributed inductance. These factors are important in high-frequency transmitter design.

The inductance coils for these tank circuits are made from rectangular copper tubing. Each tank-circuit conductor consists of two parallel rectangular tubes soldered together. Five-eighth by three-eighth-inch tubing is used for the intermediate stages and one and one-quarter by three-quarter-inch tubing is used for the power-amplifier stage. The copper tubing of the tank circuit serves the dual purpose of tank inductance and piping for the water supply for cooling the tube anodes. The cooling-water supply system is connected at the center point of the tank inductance. This point is at minimum radio-frequency potential to ground thus preventing a considerable amount of radio-frequency power loss. If the water hose were connected directly to the water jackets on the tube anodes a considerable amount of radio-frequency power would be lost in the water column. Water connections between tubes on each side of the power-amplifier stage make use of metal bellows instead of rubber hose. This provides flexibility, electrical connection, and a neat appearance as shown in Figure 5.

Variable inductive-antenna coupling is provided on this transmitter. The power-amplifier tank-circuit inductor is U-shaped with the back or central portion turned down in a vertical position. The antenna-coupling inductance is also U-shaped and is supported at the top by series d-c blocking condensers to which it is fastened by hinges and flexible connections. The output coupling may be adjusted by changing the spacing of the coupling inductor from the tank-circuit inductor. The coupling is controlled by a handle-wheel on the front of the unit and the indication of the setting is given by a calibrated dial. The handle-wheel can be locked, thereby setting the coupling inductance in any desired position.

An harmonic filter is provided to reduce harmonic radiation. It is connected between the output d-c blocking condensers and the antenna transmission line. The filter was designed to match the transmission line and consists of a low-pass single-pi section for each of the two transmission-line conductors with the shunt elements connected be-

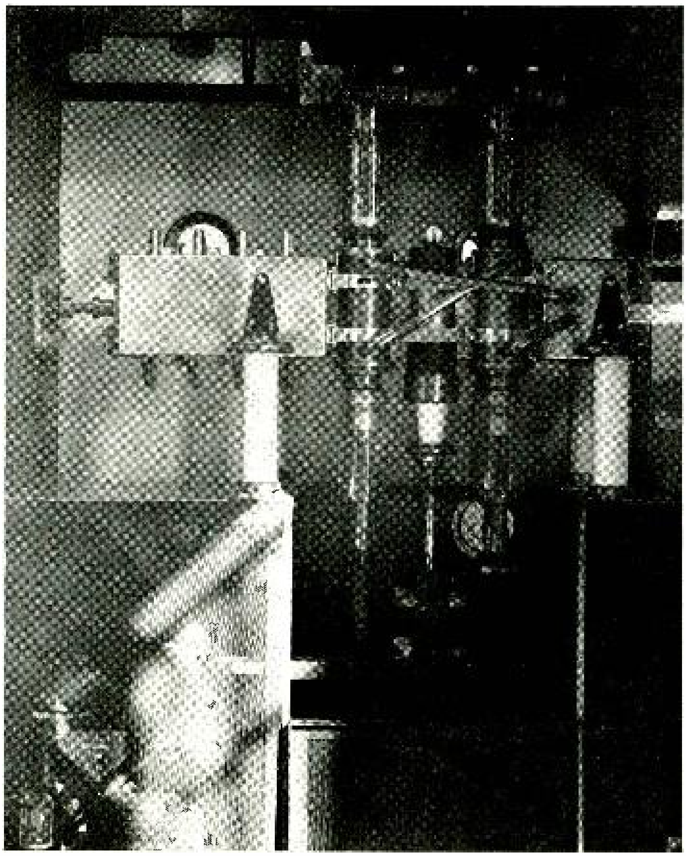

Fig. 5—Third or final power-amplifier stage. A right-hand view is shown. Four carbon grid tubes, similar to the RCA-899, are used and the maximum output of this stage is 200 kw.

tween the transmission-line conductors and ground. In addition to the low-pass characteristic of the filter, one shunt element in each half of the filter is adjusted to attenuate the second harmonic and the second shunt element is adjusted to attenuate the third or fourth harmonic as desired. Additional variable condensers are provided to facilitate filter adjustments. This type of filter is not difficult to adjust and it is very effective.

An important feature in the suppression of harmonics is the shielding which surrounds the power-amplifier unit as illustrated in Figure 1. Small screened-glass windows are provided in the shielding in convenient places for observing various parts of the equipment. Shielded lamps are provided to illuminate the interior. The solid shielding performs other useful purposes in this transmitter. In addition to its normal function of electrical shielding it keeps the apparatus inside the unit free of dust and forms a part of the air-cooling system.

The blower of this air-cooling system is located on top of the unit, and takes in air through a large air filter (see Figure 1), provided for the purpose of screening-out dust particles. The air from the blower is forced through a system of air ducts to cool the glass-filament seals, the grid stem, and the glass envelopes of the tubes in the power-amplifier stage. Since the power-amplifier-unit shielding is practically air tight, outlet openings are provided for the heated air to pass up through the antenna-transmission-line shielding and out into the room near the ceiling. The shields of the transmission line aid ventilation by acting as chimneys. The blower has a capacity of about 500 cubic feet per minute.

All filament by-pass condensers and filament transformers in the intermediate and power-amplifier stages are protected from high-voltage surges by Thyrite[2] disks. One or more Thyrite disks one-eighth inch thick by three inches diameter are connected to ground across each condenser and transformer.

The usual method of obtaining bias potentials is from rectifiers. In an effort to obtain greater freedom from service interruptions, we have introduced a method whereby biasing potentials are obtained for the RCA-846 tubes in the intermediate stages of the power-amplifier unit partly from rectified grid current flowing from ground through a resistance to the grid circuit and partly from plate current passing from the filament through a Thyrite unit to ground. The Thyrite is used for the purpose of reducing the plate current in the tubes when they are not excited because in this condition the bias potential due to rectified grid current is not present. Although the biasing method described above uses more power than a bias rectifier would require, it is quite simple and reliable whereas rectifiers are an added complication. Figure 4 shows the Thyrite units which are connected between the RCA-846 tube filaments and ground for bias purposes.

Low-Power Rectifiers

An intermediate plate rectifier supplies d-c plate power to the two RCA-846 amplifier stages in the power-amplifier unit. This rectifier consists of a standard three-phase full-wave circuit using six RCA-869A mercury-vapor hot-cathode rectifier tubes. The rectifier has a maximum output rating of 45 kilowatts at 7500 volts d.c.

A bias rectifier supplies negative-bias potential for the grids of the four tubes in the power-amplifier stage. It is also arranged to provide bias potentials to the RCA-846 amplifier stages if it is desired. The rectifier uses four RCA-869A tubes in a quarter-phase circuit, that is, two single-phase full-wave rectifiers. The nominal power rating is 10 kilowatts at 3100 volts d.c. Figure 8 shows a side view of this rectifier.

In the intermediate-plate rectifier and the bias rectifier the following features will be of interest. For example, Thyrite disks are shunted across the d-c ammeter and overload relay to protect them from high-power surges. The bias rectifier is equipped with a potentiometer made

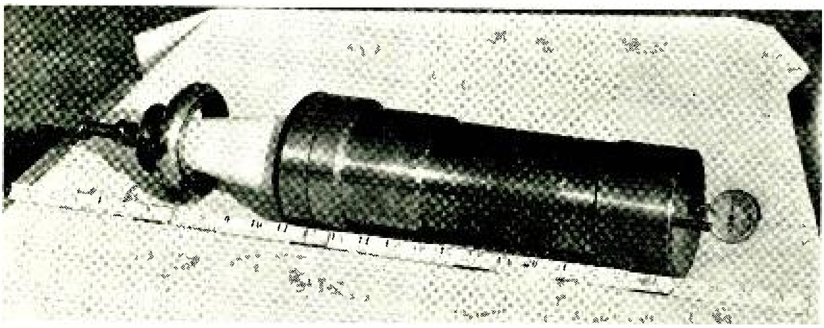

Fig. 6—Neutralizing condenser for the power-amplifier stage. An assembly of one condenser is shown. This condenser has a capacity equal to two RCA-899 tubes with which the condenser was designed to operate. The maximum air pressure used is 200 lbs. per square inch and the breakdown potential is approximately 100,000 volts d.c.

up of Thyrite which effects a great improvement in rectifier smoothing and regulation. In fact about ten times as much power would have to be wasted in an ordinary resistance potentiometer to obtain the same degree of regulation. Consequently a rectifier of about ten times the rating now used would be required.

A special feature common to both the low-power rectifiers is the method of temperature control and temperature-distribution control for the hot-cathode mercury-vapor tubes. All mercury-vapor tubes are sensitive to internal pressure and consequently they are sensitive to temperature. Improper tube temperature and temperature distribution cause arc-backs which shorten tube life and interrupt service. A frequent source of arc-back, aside from improper tube temperature, is caused by improper temperature distribution. If mercury condenses on the anode or on some upper portion of the envelope and falls on the anode, the application of anode voltage under these conditions may cause arc-back. This may account for the arc-backs usually experienced in starting a rectifier. Arc-back may be defined as the condition when a tube ceases to rectify and conducts current in both directions. The temperature-control system adopted for this unit performs two important functions. It maintains the lower part of the tube envelope at a regulated temperature cooler than any other part of the envelope and it keeps the anode warmer than any part of the envelope.

The tubes in each rectifier are enclosed in an asbestos heat-insulating box. The box is divided into an upper, a middle and a lower compartment. The tubes occupy the middle compartment. A thermostat is mounted in this box at about the level of the bottom of the tubes. On the back of the box are mounted a blower, with a second thermostat located in its outlet and a motor-operated ventilator gate in the blower intake controlled by the second thermostat. Special tube sockets support the tubes and also serve as outlets for the air-cooling ducts to each tube. A schematic diagram of this temperature-control system is shown in Figure 9.

The control arrangements are such that when the rectifier is not delivering anode voltage, the ventilating blower is shut down and the cathode-filament temperature is regulated by the first thermostat intermittently applying partial filament voltage to keep the cathodes and anodes hot and to regulate the tube envelope and box-air temperature at a predetermined value. This insures that the lower part of the tube envelope will be cooler than the upper part and that the anode will be warmer than any part of the envelope. This is the best condition for starting. When the rectifier is energized the blower is started and the first thermostat is shorted, causing the cathodes to be brought up to full operating temperature. After proper time delay anode voltage is applied. The added heat due to anode current in the tubes will tend to increase the air temperature in the box. The blower takes air out of the top of the box and forces it in again at the bottom compartment. This air is forced up through the insulated air ducts to the special tube sockets where it is directed on the tube base and upward along the tube envelope. As the circulated air heats up, the thermostat in the blower outlet operates to open the gate in the blower intake. This causes a part of the air to be interchanged with the outside air and thus lowers its temperature. The second thermostat regulates the intake of new air so that the temperature of the air directed on the base of the tubes is under control and since the air flows upward over the tube the warmer part of the envelope will be the upper portion. Also the cathode and anode will be hotter than any other part of the tube. When these thermostats are adjusted to maintain specified temperatures the best operating conditions will be obtained. This system has been very successful in promoting long tube life.

Main Rectifier

The d-c plate power for the power-amplifier stage of the 200-kw transmitter is furnished by a 300-kw, 20,000-volt, mercury-arc, tank-type rectifier supplied by the Westinghouse Electric & Manufacturing Company. The power supply to the rectifier is 2300 volts, 3-phase, 60 cycles. The rectifier is based on Westinghouse standard design for power service except that special features were added to make it adaptable for use with a radiotelegraph transmitter. Some of these features are mentioned below. The rectifier is a twelve-phase rectifier requiring twelve anodes. This together with the smoothing filter makes it possible to deliver d-c power having an a-c power component of less than 1 part

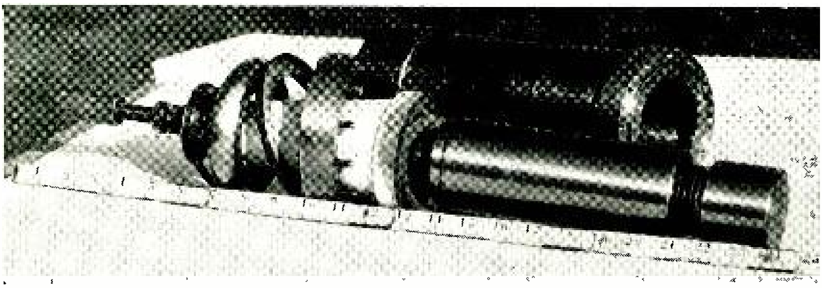

Fig. 7—Neutralizing condenser for the power-amplifier stage. A partially assembled view is shown.

in 100,000 of the d-c power. In addition to the usual oil circuit-breaker control of the input power the rectifier anodes are each equipped with grids for controlling the d-c power. There are two methods of controlling the anode current in case of d-c overload or rectifier arc-back. One of these involves the application of negative-blocking bias to the grids by means of a high-speed control system, and in the other the phase of the grid excitation is shifted approximately 180 degrees by means of an induction-regulator-type motor-operated phase-shift control. When power is again applied, the phase-shift apparatus operates, with a time-delay mechanism to bring the grid-excitation voltage slowly back in phase with the anode voltage so that rectification takes place. The rectifier is normally remotely controlled from a panel located on the right-hand side of the power-amplifier panel. From this position the rectifier may be started or stopped manually or its control may be made entirely automatic. There are ten voltage taps giving a range of output voltage from approximately 9000 to 20,000 volts d.c. at which the rectifier may be operated. The voltage tap is also controllable from the power-amplifier panel. Any attempt to change taps when the rectifier is delivering load automatically trips off the power. Status lights on the remote-control panel indicate the tap position, overload relay lock-out, and other such needed indications. The rectifier is equipped with apparatus to reclose automatically the circuit breakers after each operation of the a-c overload relays, unless three trip-outs should occur within a predetermined short interval of time. In the latter case the apparatus locks out. The lock-out starts a horn and lights a signal light to notify the operator. The lock-out may be reset on the remote-control panel at the power-amplifier unit, thus restoring normal operation. Time meters are provided to record the total hours of operation and also the hours of operation on each tap.

The main plate rectifier and the intermediate plate rectifier both have keying filters connected in series with their d-c output lead for the purpose of cutting down the initial signal peak due to the rectifier regulation characteristic. This filter consists of a reactor of approximately 0.5 henry shunted by a 300 to 500-ohm resistor.

Transmitter Control Circuits

The control circuits are so arranged that the transmitter may be started or stopped by the closing or opening of a single switch. This is accomplished through a master start-stop relay. Interlock circuits are provided which remove any dangerous voltage if a gate or door is opened. Flow interlocks shut down the transmitter in case of cooling-water failure. The rectifiers are protected from a-c overloads and each tube in the intermediate and power-amplifier stages is protected by individual d-c over-current relays. Operation counters are provided on the over-current relay for each tube in the power-amplifier stage. A totalizing counter is also provided for the power-amplifier tubes. The totalizing counter enables the operator to keep track of the number of trip-outs due to power-amplifier overload and the individual tube counters enable the operator to tell which tubes are the worst offenders. It may be stated here that counters are also provided on the main plate rectifier for counting the total number of outages due to overload in the power amplifier and main rectifier. Automatic reclosing apparatus is provided for the d-c overload relays of the intermediate power-amplifier stages. This apparatus will reclose each overload relay operation unless four trip-outs should occur within a certain time. In the latter case the recloser locks out and normal operation can be restored only by resetting the overload relay by hand. An indicator notifies the operator of a lock-out. The bias, intermediate and main rectifiers are provided with time recorders for showing the total number of hours operation.

Modulation and Monitoring

The transmitter is keyed in one of the exciter stages. The exciter

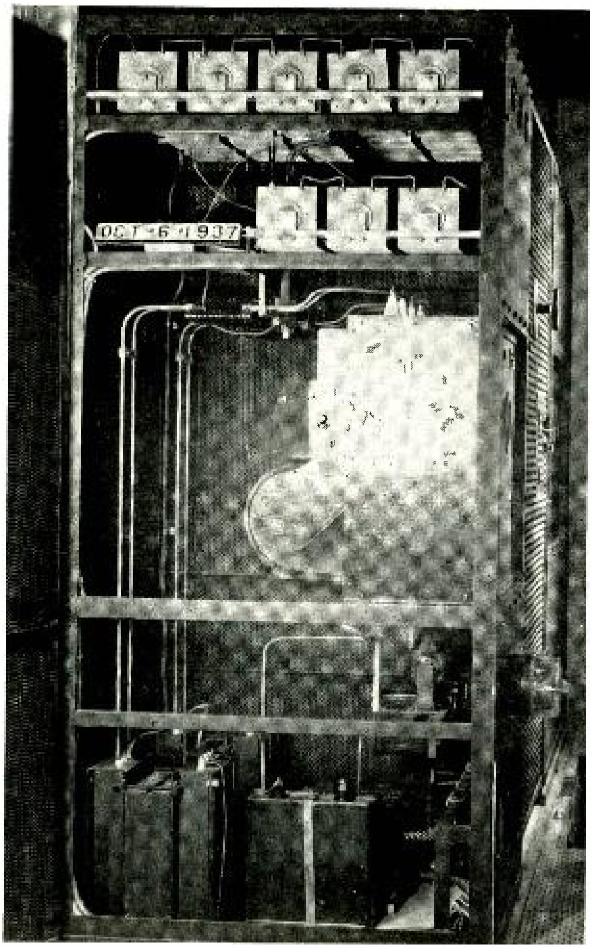

Fig. 8—Bias rectifier (left side view). The upper part of the unit contains the Thyrite potentiometer. The temperature-regulated tube box may be observed in the center of the unit. Transformers and condensers occupy the bottom part of the unit.

for this transmitter is provided with a special crystal-oscillator unit in which phase modulation can be introduced. It has been found that such modulation produces side frequencies which, although spaced only a few hundred cycles from the carrier, have different fading characteristics at the receiver and thus provide a frequency diversity which reduces the overall fading of the received signal. The transmitter is monitored locally by receivers and also by a cathode-ray oscilloscope energized by a small amount of rectified energy picked up from the antenna transmission line.

ANTENNA

The antenna used on this transmitter is of the double Vee type[3]. The transmission line and antenna require special care in regard to insulation since the potential across the transmission line at full output is about 10,000 volts rms. The antenna transmission line is constructed of two No. 4 copper wires spaced one foot apart. A number of otherwise unaccountable transmitter trip-outs at high power are attributed to transmission line arc-overs caused by birds alighting on the conductors.

DIFFICULTIES OVERCOME

During the test period before the transmitter was put in commercial operation, a number of difficulties had to be overcome. Chief among these were parasitic oscillations. There was the more or less familiar "push-push", or in other words, parallel type of parasitic oscillation in which all of the tubes in the amplifier stage oscillate in parallel. This parasitic oscillation was stopped by the use of a resistance-shunted air-core choke coil connected between the center of the plate-tank coil and the d-c plate supply which is normally by-passed to ground with a by-pass condenser. In a similar manner the center point of the grid inductance was connected to a similar ground by-pass condenser through approximately eight ohms of non-inductive resistance.

Another very persistent type of parasitic oscillation occurred between the tubes on each side of the power-amplifier stage at a wave length of about 7 meters. This was a push-pull, grid-to-filament, grounded-plate type of oscillation. This particular type of parasitic oscillation was difficult to stop without resorting to circuit changes that would make the amplifier inoperative. However, it was finally stopped by increasing the length of individual tube grid leads somewhat and shortening the length of filament connections between tubes as much as possible. This reduced the regeneration in the parasitic circuit to such an extent that the parasitic oscillations were stopped without the use of resistance.

At the beginning of the tests metal-grid tubes similar to the present RCA-899 tubes were used in the power-amplifier stage, but secondary grid emission caused uncontrollable parasitic oscillations and flash-overs in the tubes. Carbon-grid tubes, which are practically free from secondary grid emission, were substituted and showed considerable improvement. However, these tubes were subject to frequent flash-overs probably due to heating of the grids by radio-frequency current. When the air-cooling system as described above was applied to the tubes in the power-amplifier stage these flash-over troubles immediately

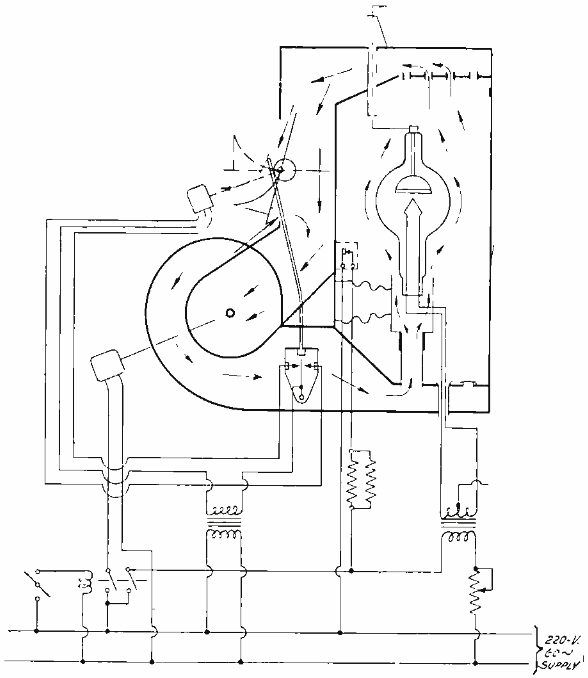

Fig. 9—Schematic diagram of the temperature-regulating system for the low-power rectifiers. This diagram pictures a simplified end-view cross-section of the temperature-control system.

became very rare. This improvement may be attributed to two causes; first, the grid structure which previously must have been operating at a very high temperature was cooled down, and second, the cooler glass-envelope temperature may have affected the distribution of adsorbed gas on the inside surfaces of the tubes. Generally the gas will be adsorbed on the coolest parts of the tube which, in a water-cooled tube, is often the anode. This is the place where adsorbed gas can cause the most trouble when it is knocked loose by electron bombardment. The cooler glass surfaces brought about by air cooling may have adsorbed more of the gas usually present on the anode and in this way have reduced the cause of flash-over since the gas adsorbed on the glass would not be liberated by heat or by electron bombardment.

The damaging effects of tube flash-over current on the tube structure was greatly reduced by connecting about 40 ohms resistance in the plate-supply conductor between the main plate rectifier and the power-amplifier anode circuit. This limits to a reasonable value the otherwise

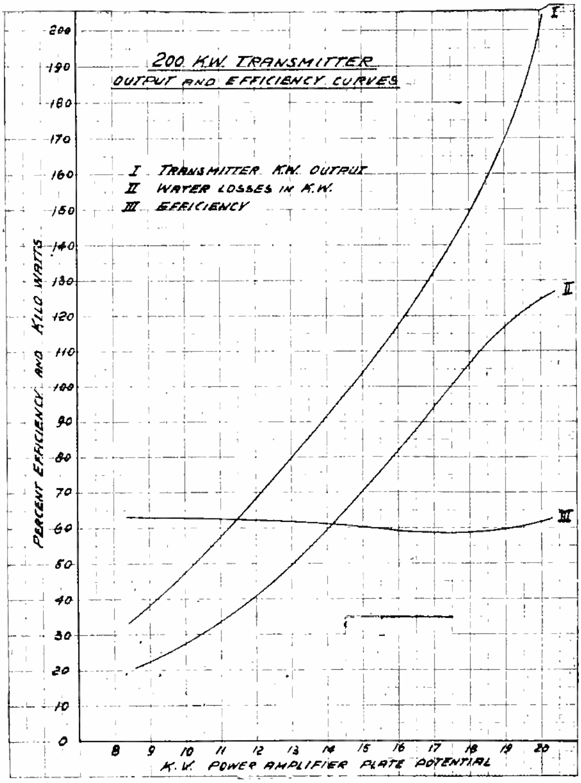

Fig. 10—Efficiency and output curves. These curves show what output power and efficiency may be expected at various power-amplifier plate potentials when the transmitter is adjusted for 200-kw maximum power output.

tremendous current discharged from the rectifier smoothing condenser through the tube. In fact slight tube flash-overs seem to clean up the gas in a tube so that it will thereafter withstand higher voltages.

Performance Results

The maximum nominal transmitter power output, at 20,000 volts plate potential, is 200 kw. However, a power output of more than 200 kw was obtained during the test. Such high-power operation is not normally used because of the resulting decrease in tube life. For most economy it is preferred to work the transmitter below 180-kw output. The average plate efficiency of the power-amplifier stage at these large outputs is around 60 per cent. Lighter loading will result in higher efficiency. The curves in Figure 10 give an idea of the transmitter performance at various plate voltages when the transmitter is adjusted for 200-kw maximum power output.

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DESIGN TRENDS IN MOBILE RECEIVERS IN AMERICA

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(Continued from January issue)

AS THE art advanced, crystal control of the transmitter became the rule rather than the exception. Because of possible power savings, tube life, interference, etc., transmitters were operated only during the period of modulation. This made necessary a receiver embodying many more refinements. As a result, the superheterodyne circuit for use in the ultra-high-frequency band was developed. Figure 8, reading from top to bottom, shows the receiver unit, the dynamotor power supply unit and the loud speaker. The receiver was mounted either on the inside of the fire wall of the automobile or in the trunk at the rear; the dynamotor either on the forward side of the fire wall (i.e. in the engine compartment) or adjacent to the receiver in the trunk. The loud speaker, which has the volume control integral with it, was mounted on the header. A very small panel not shown in Figure 9 contains a pilot light and an on-and-off switch which is mounted on the dash. The mounting of these units represents the latest advance in this type of equipment. Figure 9 shows the mounting bracket which is secured to the automobile by means of the spring-and-catch arrangement shown. The power cable enters the receiver at the plug socket shown on the right hand side. A clamp with thumb nuts is arranged to secure the plug and to bond the plug to the receiver case externally. This arrangement very greatly reduces ignition interference which may be present in the form of standing waves on the shield of the supply leads. This equipment represents the most advanced design, both mechanically and from a performance standpoint, so far attained in the United States. Figure 10 shows a view of the receiver with the front cover removed. The cover is removed by releasing spring latches at each side exposing the unit for tube replacement and such maintenance adjustment as tuning, noise circuit balance and squelch threshold adjustment.

The circuit of the receiver shown in Figure 8 consists of a stage of radio-frequency amplification, first detector, temperature-compensated oscillator, three intermediate-frequency amplifier stages resonating at a frequency of 4.1 megacycles, circuits to obtain AVC, squelch, noise limiting and the conventional audio circuits. In general, the equipment is used on a small vertical rod of quarter-wave length or less. This rod is located either adjacent to the trunk, or in front of the header. The antenna is coupled directly to a low-impedance coaxial-transmission line. The transmission line is coupled magnetically to the first tuned circuit of the receiver to obtain optimum antenna gain. A link circuit is used between the radio-frequency amplifier tube and

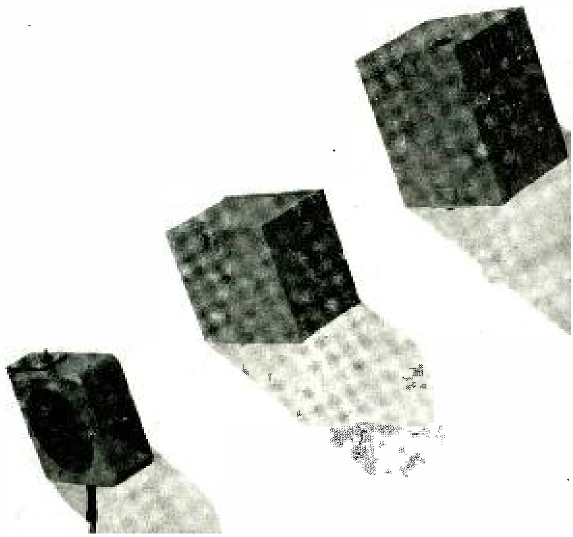


Fig. 8—Ultra-high-frequency receiver and accessories for police automobile use.

the first detector to further reduce image response and allow multiplex operation when desired in connection with a talk-back transmitter. The temperature compensation of the oscillator is obtained by careful design of the inductance and by the use of the compensator shown in the center of Figure 10. This compensator consists of strips of bimetallic material adjacent to which is located a grounded metal disc. The degree of compensation is adjustable by varying the spacing between the disc and the plate. As the sensitivity of receivers was increased and the circuits improved, it was found that the range of communication was limited almost entirely by ignition interference either on the police car or on adjacent gasoline-powered vehicles. To reduce this interference, the "back door" interference was eliminated by the proper grounding of shields external to the unit and careful filtering done in such a manner that the filters did not couple to the remaining portion of the circuit. There then remained essentially only the ignition interference coming in through the antenna. Since these receivers operate at frequencies in the region of maximum ignition-interference radiation, it is not practical to apply the customary antenna-filter circuits, since these circuits would necessarily be tuned approximately to the desired frequency. It was found that the ratio between the peak modulation of the carrier and the peak of the noise developed in the final detector from ignition interference was very great and it was also found that the duration of a given impulse of ignition interference

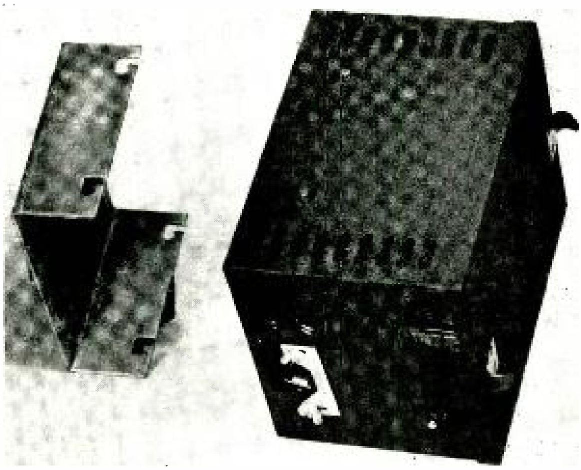


Fig. 9—Mounting support for receiver shown in Figure 8.

was very short. Therefore, if the peak of interference is reduced to approximately the level of the modulated peak, negligible distortion occurs, but a marked improvement is obtained in the effective signal-to-noise ratio.

Figure 11 shows a simplified circuit of the noise suppressor used. The circuit shown is simplified for purposes of explanation and is not complete. It consists essentially of a wheatstone bridge. In the upper two legs of this bridge there are diodes; one of the lower legs contains a resistor; and the other leg contains a resistor and a diode. There is fed into one diagonal of the bridge, the output of the i-f amplifier. The output of the bridge is tuned across the opposite diagonal and feeds the audio-amplifier system. If no signal is received, the lower diode passes current. The bridge is then balanced and any noise received does not generate audio frequency across the output diagonal. When a signal is received, voltage is impressed across the lower diode from the primary of the signal i-f amplifier transformer. The bridge is now unbalanced for any input less than the voltage developed across the lower diode and the modulation of the signal is impressed upon the audio amplifier. The ratio between primary and secondary voltage of the intermediate-frequency transformer is so arranged that the bridge is always unbalanced for inputs less than twice the carrier. In this manner distortion does not occur even at 100 per cent modulation. If noise is present at the same time carrier is being received, the

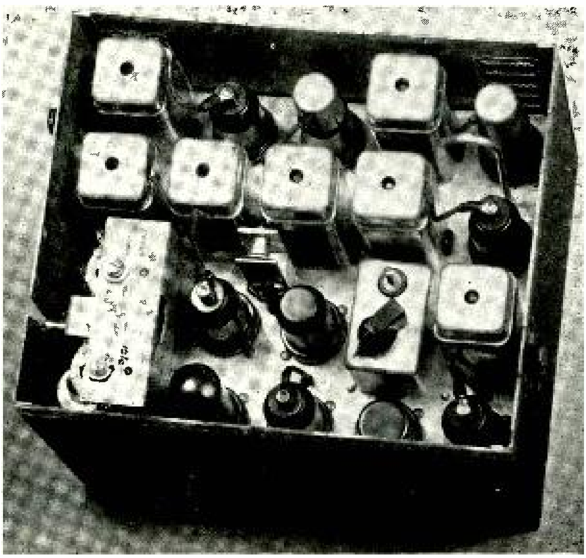


Fig. 10—Top view of receiver shown in Figure 8.

bridge is balanced for peaks of noise greater than twice the carrier and these peaks of noise do not appear as noise at the input of the audio amplifier. In the complete diagram, additional capacitors are shown which properly phase the legs of the bridge and overcome unbalance resulting from the two electronic capacities. It has been found that the use of this device extends the usable range of a given police system more than 2 to 1 and enormously simplifies the servicing problem in connection with car ignition systems since many cars can be operated successfully without suppressors and other precautions previously necessary. The use of the noise suppressor greatly improves the action of the squelch circuit since it is possible to avoid operation of the squelch circuit by the noise itself to a very much greater degree. Therefore, complete absence of output may be obtained with squelch adjusted to be operated on very weak inputs. The sensitivity of the receiver is 6 microvolts at 50 mw output. The tube noise with no modulation is 12.5 mw. The image response is approximately 80 db at 30 megacycles and 52 db at 41 megacycles. The stability of the receiver is best expressed as follows:

Warm Up—Shift in oscillator frequency due to warm-up is 55 kc which takes place in the first 10 minutes = .157 per cent.

Temperature Change—Shift in oscillator frequency due to changing ambient temperature from + 30° C to − 20°C and back again to + 50° C is 25 kc (for 70° C change) at oscillator frequency 35 mc = 0.00102 per cent per degree C.

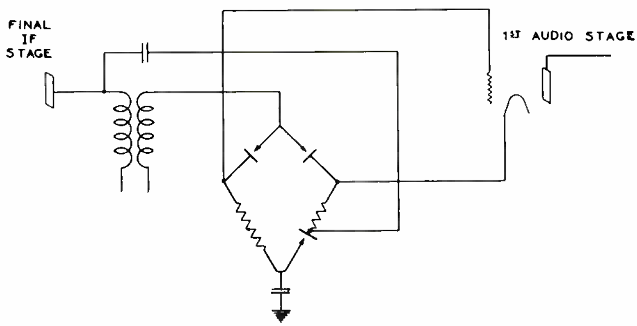


Fig. 11—Noise-suppressor circuit.

Battery Voltage—Shift in oscillator frequency due to variation in battery voltage is 35 kc with oscillator at 35 mc and voltage changed from 8.3 to 5.3 v = 0.0333 per cent shift per volt.

The maximum power output is approximately 2 watts. The battery drain is approximately 7 amperes at 6 volts.

It is believed that the saddle-bag type of motorcycle receiver and the ultra-high-frequency car receiver just described, are indicative of the trends in the design of this class of equipment. The sizes of these units approach the minimum required for the accommodation of the necessary components with a reasonable degree of accessibility. The outstanding trend at the present time is toward the use of noise-suppression circuits of the limiter type or of other types. The limiter circuit employed in the ultra-high-frequency automobile receiver described is probably outstanding in performance although it is one of several which has been used with a reasonable degree of success.

Another type of limiter circuit which has received some attention from designers is a super-regenerative second detector. Its inherent disadvantages, however, probably outweigh the advantages gained in limiter action. During the past few years the demand for greater selectivity with consequent greater stability have been items of considerable importance. The ultimate selectivity, based on the present state of the art, is undoubtedly represented by crystal-controlled transmitters and crystal-controlled receivers. In general, the stability of a crystal-controlled oscillator is of the order of $\pm$ 0.025 per cent at 40 megacycles. This represents a band width of about 40 kilocycles whereas the receiver just described has a band width of about twice this value.

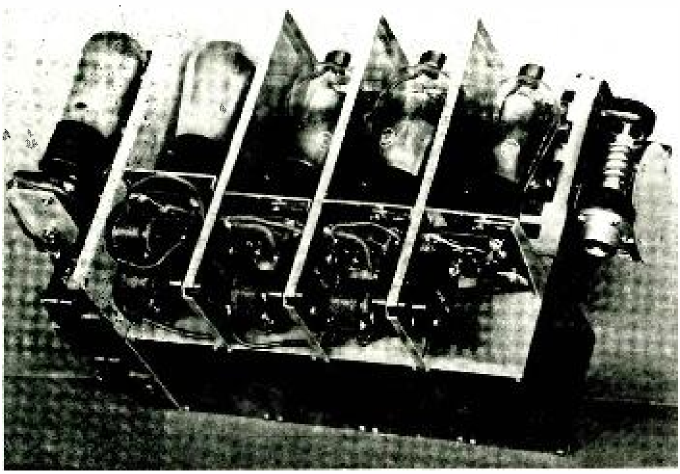


Fig. 12—An early radio beacon receiver of the tuned-radio-frequency type.

Aircraft Receivers

One of the initial radio requirements of the receivers used in American transport planes was to receive the radio range signals in the 200 to 400-kilocycle band. About the first application of radio to air transport craft occurred in 1928-29 when it became apparent that passenger traffic might be a source of considerable revenue. As soon as adequate radio range stations were available throughout the United States, the addition of a simple beacon receiver to the airplane made it possible to fly both mail and passengers along scheduled routes. At that time the air-transport companies became definitely interested in radio receivers. By 1930, the air-transport business had increased to a point justifying larger expenditures for aircraft radio equipment and indicated the possibility of night flying and some bad weather flying by the use of these radio aids.

At this time 400-watt medium-high-frequency ground station transmitters operating in the range of 2600 to 6500 kilocycles were established by the air-transport operators at about 200-mile intervals along the airways, and the aircraft were equipped with 50-watt radio-telephone transmitters for use in this medium-high-frequency band together with both a medium-high-frequency telephone-communication receiver and the aforementioned beacon (or radio-range) receiver.

An early radio-beacon receiver together with its associated remote-control equipment was of the tuned-radio-frequency type. It had a sensitivity of the order of 5 microvolts and a maximum output of about 0.5 watt. A battery, separate from the ship's battery, was used

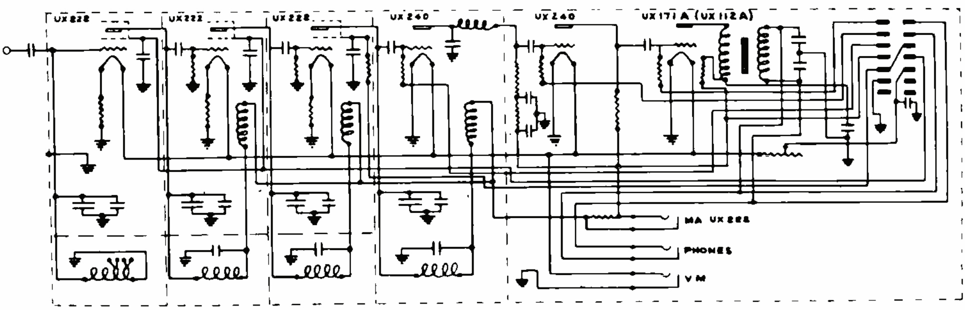


Fig. 13—Schematic circuit diagram of the receiver shown in Figure 12.

for filament supply and a separately housed "B" battery was used for high-voltage supply.

The use of a remote-control mechanism, which consisted essentially of a control head mounted in the pilot's cockpit and connected to the rotating controls in the receiver by means of flexible shafts, made it possible to install the receiver either in the passenger or baggage compartments or in the tail of the ship. The tuning knob was connected to the flexible shaft through bevel gears of unity ratio. The condenser was driven through a worm and pinion of 20-to-1 ratio and the dial was driven through spur gears of the same ratio.

Figure 12 illustrates the chassis of the receiver and Figure 13 its schematic wiring diagram. It will be noted that three stages of radio-frequency amplification, together with a triode detector and two stages of audio-frequency amplification are used. Inasmuch as a 6-foot insulated vertical antenna was then commonly used for radio range reception, it was possible to couple the antenna to the first tuned circuit through a small capacity and still maintain relatively accurate alignment. It is of interest to note that because of aircraft vibration conditions, each tube was separately shock mounted and in addition the entire receiver unit was shock mounted. Sponge-rubber shock mounts were used in shock mounting the receiver to a separate mounting member bolted to the fuselage of the ship. The construction of this receiver is particularly interesting in view of later developments. The condenser frame was a heavy aluminum casting to which the other components were secured, the condenser frame thus becoming the chief stiffening member of the receiver. Another interesting feature of this receiver was the use of rather elaborate choke coils for filtering. These have since been replaced by resistors, in more modern receivers.

During the next few years the necessity for more sturdy construction became apparent. Furthermore the advent of indirect-heater tubes made it possible to operate the receiver directly off the ship's battery. It also became apparent that dry batteries were not a satisfactory solution for this type of service. The first attempts at more adequate power-supply systems utilized wind-driven generators. These, however, soon gave way to small dynamotors operating directly from the ship's storage battery.

The circuit diagram of a beacon receiver with a cast aluminum base is much the same as that shown before, the principal difference lying in the use of heater-type tubes and more rugged mechanical construction. Because of the wide variation in the ship's battery voltage due to charging rate changes and variable load drain, a ballast lamp was employed in the filament circuit to reduce the fluctuation of the filament voltage.

The communication receivers employed in transport aircraft service were generally similar to the beacon receiver just described from a circuit and mechanical standpoint. With the advent of indirect heater tubes, separate shock mounting of the receiver tubes became unnecessary, but shock mounting the receiver chassis continued to be used. The same general type of remote control as that just described was generally used.

It became apparent as soon as radio was first employed aboard airplanes that proper suppression of ignition interference was a problem of considerable magnitude. After some experience it appeared desirable to develop a complete shielding harness for the ignition system rather than use any type of suppressor in the high-tension-ignition system. One of the factors influencing the decision to avoid the use of suppressors in the ignition system was the necessity for extreme reliability of the engines under all conditions of operation. In shielding the spark plug, it became necessary to maintain normal operating plug temperatures to prevent detonation from overheated plugs or actual plug failure through cracking of the ceramic due to excessive heat. This necessitated a special design of plug in certain instances and in other instances the arrangement of a proper plug shield to radiate the excess heat. The ignition harness completely enclosed the spark plugs, ignition wires, outlet terminals, magneto, all other ignition wiring, and the control switches. In addition, the charging generator, together with associated wiring and control units, was also carefully filtered and, in some cases, shielded. It soon became common practice to use aluminum conduit for all wiring in the plane, to reduce the fire hazard, to assist in the reduction of interference and for convenience of wiring.

On planes of non-metallic construction, all of the metal parts of the structure were bonded together at frequent intervals. All hinges, brackets acting as bearings for control surfaces, and other parts in which metal was used were also by-passed by flexible copper bonding around the movable joints. In the case of ships in which very little metal was used, it was customary practice to apply metal ribbon to wooden struts, wing braces, and etc. to prevent charges which might collect on wires and other parts of the ship from building up voltages which might result in radio interference. Wires which made intermittent contact were carefully insulated from each other and in addition were tied into the main ground system. It was found necessary to by-pass turnbuckles, control rods, terminals, etc., with copper straps. All of the grounded parts of the plane were then connected to the engine block. In metal planes, considerable care was also taken to bond all of the metal portions of the ship carefully together. The necessity for careful bonding of aircraft is largely a function of weather conditions. In some types of weather, bonding is almost unnecessary while during other atmospheric conditions, static charges readily build up on insulated portions of the plane making it almost impossible to receive signals of less than 10 millivolts without resorting to bonding. The shielding and bonding of aircraft has continued in much the same form until the present time. It is, however, the general practice now to properly shield and bond a ship at the aircraft factory if radio equipment is to be installed at that point or if it is intended that radio apparatus will be installed at a later date. As a matter of fact, shielding and bonding is now a part of the manufacturing specifications. Shielding of the ignition system is so effective that a signal of one microvolt may be received on board an average aircraft with perfect freedom from ignition interference. As a matter of fact, the reception of signals on board aircraft is now limited either by natural atmospheric conditions or by receiver noise.

The standard radio-range receiving antenna, as previously explained, initially consisted of a vertical streamlined mast extending above the top of the ship, and insulated from the metal parts of the ship. At that time the communication antenna was generally suspended between the wing tips and the tail fin to form a "V". The "V" antenna was used for both transmitting and receiving and was switched between transmitter and communication receiver by a relay located in the transmitter. At the time these antennas were popular the cruising speed of most aircraft was in the neighborhood of 90 to 150 miles per hour. As higher-speed planes became available the drag of these antennas became excessive and steps were taken toward drag reduction. In particular the streamlined radio-beacon-receiver mast at high speeds gave trouble not only from drag, but from vibration as well. As the speed of the planes increased the turbulence rapidly grew greater and the mast was subjected to a whipping action and tended to oscillate mechanically at its natural period. This action rendered the mast unsafe unless guys were used and the guys, in turn, brought about additional drag. It was, therefore, necessary either to use a much shorter mast or some other type of rigging. Many installations were made by supporting a horizontal "T" antenna structure between the tail fin and the forward part of the fuselage either above or below. It is now general practice to place the radio-beacon antenna below the fuselage. It was still desired to retain as great a vertical component of the antenna as possible in order to accentuate the cone of silence experienced in passing over a radio-range station.

In connection with the radiation from these stations there is a cone of silence present over the type of stations which use vertical radiators. This cone of silence is experienced whether or not the receiving antenna has a horizontal component. However, to obtain a cone of silence over the closed loop type of radio range it is desirable to use a vertical receiving collector. When radio ranges first came into general use it was found that directive receiving antennas would change the apparent course of the radio range depending upon the angle at which the plane approached the course. It is for this reason that the beacon antennas are constructed symmetrically. More recently it has been found that it is preferable to locate the beacon antennas underneath the structure of the plane to avoid change in signal strength as the altitude of the plane changes. When the antenna is on top of the plane, a considerable mass of metal will be present, particularly during the time when the plane is close to the radio range station, and it will be between the antenna and the source of signal. This metal distorts the received field, acts as a partial shield, changes the relative strength of the beacon signal as the plane banks or turns, because it reduces or increases the amount of metal in the field, and it may cause disconcerting fading.

The successful reception of radio-range signals has been seriously limited because of rain, snow, and sand static which at times paralyzes the aircraft receiver, rendering reception of the radio-range signal difficult or impossible. Such conditions may prevail at times at distances of 20 or 30 miles from the radio-range transmitter, depending upon the power of the transmitter, the antenna system, terrain, and the intensity of the disturbance. Such disturbances are not limited to overcast or cloudy areas, nor to the regions immediately above and below such formations. Very little is known of the origin or nature of this type of static. It is believed however to be due to charged particles of sand, dust, raindrops, or snowflakes coming in contact with the antenna or the metal fuselage of the plane. Although the condition does not prevail consistently, it generally occurs at times when weather conditions are such as to make mandatory the use of radio communication and navigational aids. It has been found that a very marked reduction in interference of this type is obtained by the use of a loop antenna. These antennas are now becoming widely used for the purpose of reducing precipitation static interference, although, in general, they are also applied for use as a navigational device either as a null type of direction finder or a right-left indicator type of radio compass. The loop is generally streamlined in some manner and consists of either a streamlined cross-section circular loop or a shielded loop housed in a teardrop type of casing. Streamlining is resorted to in order to decrease the drag of the loop antenna structure. It is preferred to mount the loops beneath the fuselage for the same reasons discussed above in connection with the radio-range receiver antenna problem. The loop is mounted symmetrically with respect to the athwart ship dimensions of the plane so that essentially uniform deviation results no matter which way the plane is turned with respect to the signal source. Care is taken to place the loop in such a position that large masses of metal will not be in line with the normal wave as received, and particular attention is directed toward placing the loop free of any closed metallic loops formed by structural members of the plane or other antennas. However, on the smaller ships, particularly those employed by itinerant flyers, this is not always feasible and acceptable results are obtained by mounting the loop above the fuselage. In general, all antennas are placed as far away from the engine as is consistent with the length of lead-in required and the aerodynamic properties of the plane.

Many of the newer planes are designed so that the skin of the ship actually is stressed. Under these conditions the skin of the ship subjects the apparatus mounted upon it to an abnormal degree of high-frequency vibration. For example, if a loop is mounted on the skin of the skin-stressed ship, all of the wires and mechanism must be rugged and extremely well secured and supported to withstand the vibration to which it is subjected.

Another problem which confronted the designer of aircraft radio equipment is that of extreme vibration. While the cabins of modern airplanes are sound-proofed and vibration-proofed to a large extent, the radio apparatus and its associated equipment is mounted in other parts of the ship where vibration is prevalent. Vibration ranges from landing shock, consisting of low-frequency high-amplitude components, to extremely high-frequency low-amplitude vibration of the order of several thousand cycles per second. Shock mounting of the radio receiver largely takes care of the vibration problem so far as the receiver alone is concerned. However, the antennas and control boxes which are not shock mounted suffer considerably more from high-frequency vibration than from low-frequency vibration. Vibration is in some cases entirely longitudinal depending upon the position in the ship, in other cases latitudinal, and in some cases torsional. The latter is particularly destructive to the loop mechanism. Inasmuch as it is not practical to shock mount all of the equipment associated with receivers, considerable care has been taken in the design of these components to withstand the strains due to excessive vibration particularly in high-speed ships. The problem of breakage is not a matter of any considerable moment. However, creepage of wires, spring members, etc., due to high-frequency vibration in the apparatus not shock mounted has been one of the most difficult problems encountered in the design of this type of apparatus. In general, remedies have been effected through proper strengthening of the apparatus, changing of the period of vibration, and in the use of bearing surfaces strategically located and of sufficient dimension to prevent excessive motion.

Aircraft apparatus is probably subjected to greater and more rapid changes in temperature and humidity than most mobile apparatus. It is not uncommon in planes flying over the western part of the United States to encounter changes in temperature of the order of 40 to 50 degrees or more within the space of one hour, and in some cases, a few minutes. Moreover, planes leaving the ground to fly over mountainous terrain frequently encounter extremely humid conditions or leave an extremely humid atmosphere for one which is relatively dry. This has called for the use of temperature-compensating equipment, and components which vary slowly with temperature and requires extremely careful and complete impregnation of the apparatus components used in this type of design. Some attention has been paid to the prevention of the accumulation of dust particles within the apparatus itself, but inasmuch as much of this apparatus is approaching minimum cubical content consistent with reasonable temperature rise, it has not been feasible completely to dustproof radio receivers for this type of service. As a result, attention has been given to the dust-proofing of components rather than the instruments themselves.

By 1931 radio was almost universally used on all air transports carrying passengers as well as on all mail ships. As this equipment was retired, some of it was purchased by itinerant and private flyers who preferred to fly along the airlines and maintain contact with their ground stations when making long over-land trips by air. During the past few years the use of radio has become so generally applicable to aircraft that two classes of radio equipment are now available in America. The more expensive and more elaborate equipment is used by the air-transport operators, while simpler, lighter and less expensive equipment is available for the itinerant and private flyer.

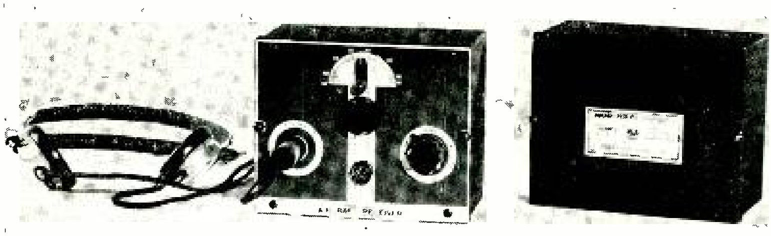


Fig. 14—Modern radio range receiver for private flyer.

Figure 14 illustrates a 2-tube beacon receiver covering a frequency range of 200 to 400 kilocycles intended for the private flyer. This receiver employs multi-element tubes, and is of the tuned-radio-frequency variety. This receiver operates either from a dry battery or from the ship's 6-volt or 12-volt storage battery, and uses a small external vibrator-power-supply unit similar to that previously described under entertainment automotive receivers. Figure 15 shows a schematic diagram of this receiver. This type of equipment is intended for use either with a fixed or trailing wire antenna. The latter is becoming more popular on small ships both because of its freedom from ignition interference and because of its property of better signal pickup. This type of equipment is intended for use on small craft of the $1,000 to $3,000 price class. In general it is mounted either directly on the instrument panel or in the cockpit so that it may be directly controlled by the pilot.

Figure 16 illustrates a type of receiver constructed for the itinerant and private flyer having a more expensive airplane and needing both transmitting and receiving facilities. It is also employed as an emergency or auxiliary receiver in a great many air-transport planes. The frequency range is 200 to 400 kilocycles and 2200 to 6800 kilocycles, being covered in two bands. This receiver is of the superheterodyne type and uses four multi-element tubes. Figure 17 shows the schematic wiring diagram. The first detector and oscillator are combined in the

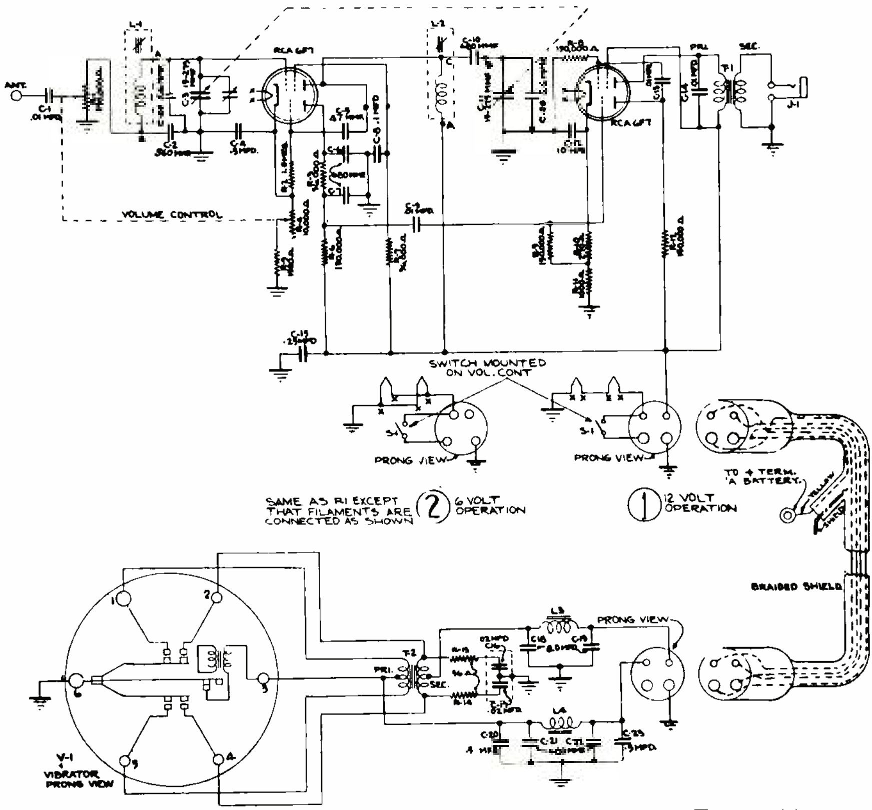


Fig. 15—Schematic circuit diagram of receiver shown in Figure 14.

6A7 tube; the intermediate-frequency-amplifier pentode and diode detector are combined in the 6B7 tube; a first audio triode amplifier and triode pentode are combined in the 6F7. Particular care has been exercised in the physical arrangement of the parts to eliminate essentially the radio-frequency as well as the audio-frequency interference from the vibrator, although the vibrator is mounted on the same chassis as the receiver. It will be noted that a resistor is inserted in series with the head phones by means of a switch. When this resistance is inserted the output circuit is very badly matched to the pentode section of the 6F7, thus greatly reducing the power output capability of this tube. When so used it is necessary to increase the volume-control setting and the interference peaks are limited because of the inherent overload characteristic of the receiver. This device is particularly useful in preventing pilot fatigue under conditions of severe static, particularly when flying the radio range. If the volume control is sufficiently reduced to prevent overloading of the output tube by the range signals, no reduction in course definition is obtained, but a marked improvement in the signal-to-noise ratio results due to

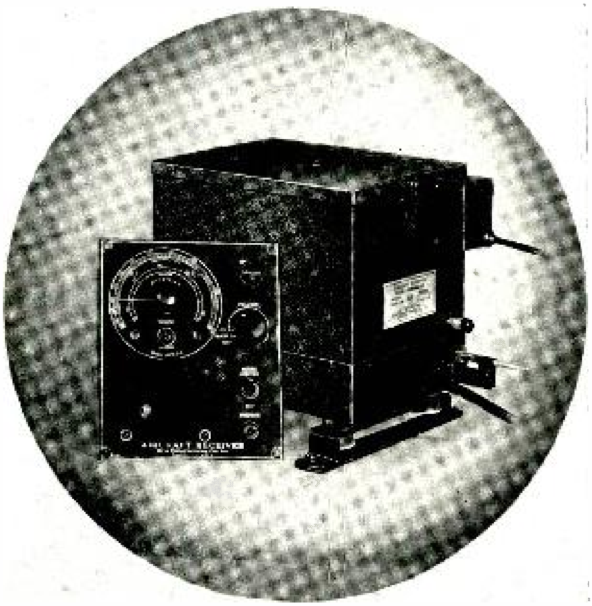


Fig. 16—Modern transport emergency receiver.

the limiting action of this circuit. Power output is approximately 700 milliwatts into a pair of 600-ohm head phones. The power drain is approximately 1.4 amperes on a 12-volt primary power source. Tuning is accomplished remotely by means of a flexible shaft and a direct-reading calibrated dial remotely indicates the frequency to which the receiver is tuned. The frequency band is selected by means of a Bowdin wire or push-pull control. The receiver unit with tubes and shock mounts (including the power supply unit) weighs 17 pounds. The complete receiver equipment with approximately 12 feet of remote control and electrical cables, fuse, head phones, plugs, etc., weighs 23 pounds.

During the past few years, the better equipped itinerant pilot has

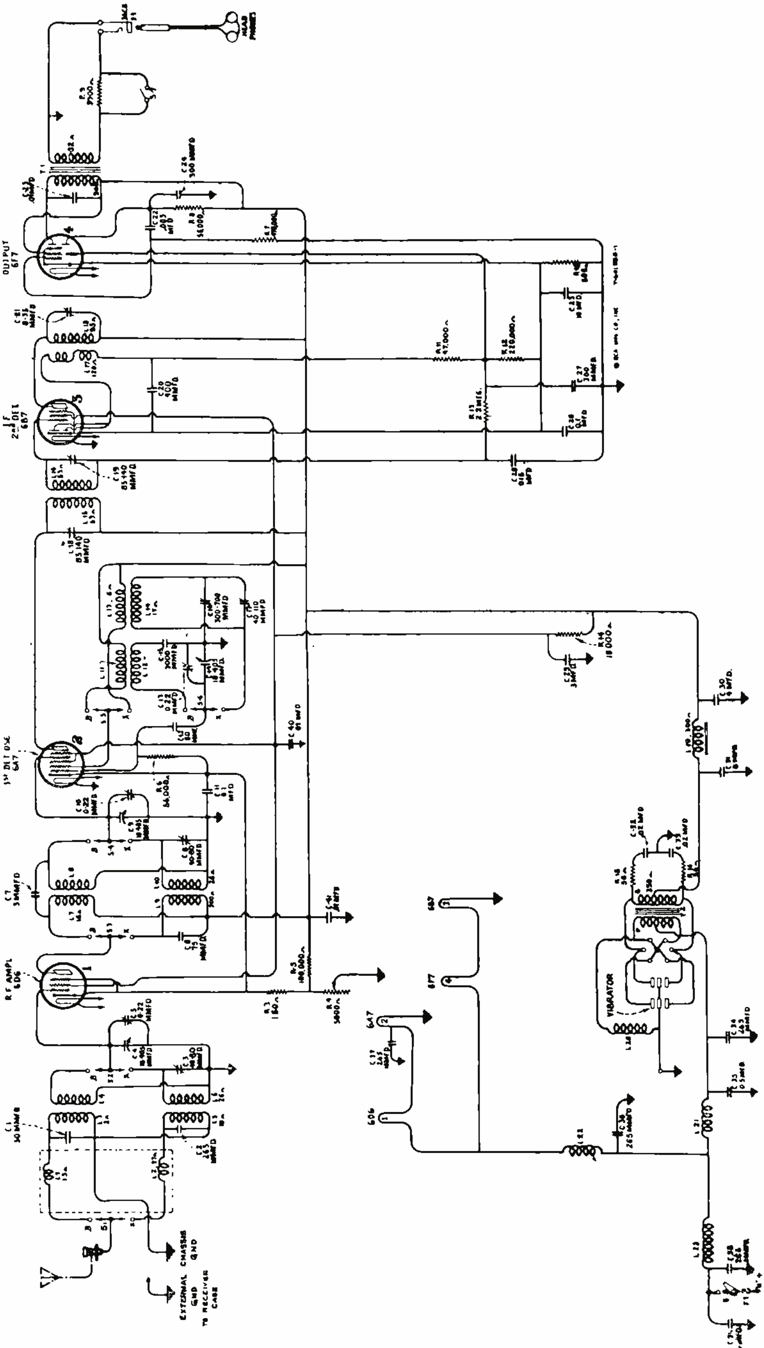


Fig. 17—Schematic circuit diagram of receiver shown in Figure 16.

shown considerable interest in radio navigational equipment in addition to communication equipment. Figure 18 illustrates a radio compass designed fundamentally after the teachings of Rudolf Hell.[3]

The loop antenna is mounted in a streamlined bakelite housing having a length of about 24 inches and a maximum diameter of 9 inches. The loop itself is 8 inches in diameter and is arranged to be rotated through 360 degrees of azimuth within the housing. The loop is tapped so that it is operable over the range of 200 to 410 kilocycles and 550 to 1500 kilocycles. Collector rings and brushes are incorporated in the base of the unit together with a band switch for selecting the proper taps on the loop. The loop is electrically connected to the receiver through an 8-foot flexible conduit. Rotation of the loop as

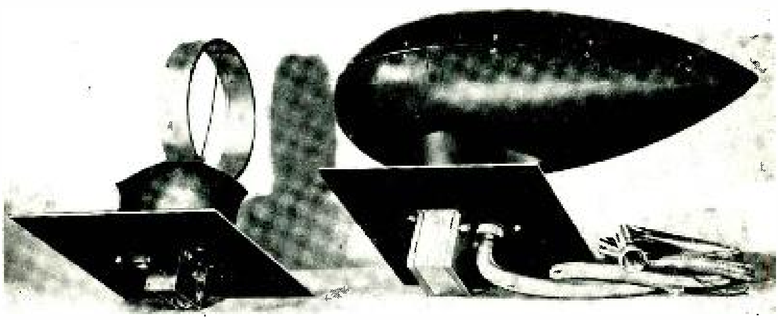


Fig. 18—Modern radio direction finder for aircraft use.
Loop cut away.

well as band selection is accomplished from the control boxes in the cockpit through flexible shafts geared at either end. The receiver unit is approximately 16 x 10 x 7½ inches in dimension and weighs approximately 30 pounds. It is shock mounted and readily removed from its case. It may be used as a weather broadcast receiver or as a beacon receiver either with the loop antenna as a precipitation static reducer means or on the separate "sense" antenna. It may also be used in the medium-frequency band of 2200 to 6700 kilocycles as a communication receiver. The loop is usable on the two low-frequency bands only. The indicating meter is a d-c microammeter having a well damped movement. This instrument is suitable for mounting on the instrument panel or elsewhere in the cockpit.

Figure 19 shows a simplified functional schematic of this instru-

[3] Rudolf Hell—"Jahrbuch der Drahtlosen Telegraphie and Telephonie" V. 33, No. 4, April 1929, pg. 138-145. This noteworthy contribution was based on Thesis work done several years prior to publication.

ment when used as a radio-direction finder. The conventional receiving components are shown in block form. The headphone audio-frequency amplifiers and indicator audio amplifiers are connected to the first audio stage through separate controls. Automatic volume control is applied to the grids of the radio-frequency and intermediate-frequency tubes in the broadcast and communication frequency range at all times.

The loop modulator tubes are connected with their grids in a push-pull arrangement and their plates in parallel. The plates are connected through a blocking capacitor to the mixing point which is the antenna circuit.

The audio oscillator is adjusted to operate at approximately 95 cycles. The choice of frequency is determined by several factors. The frequency should be such that it is readily passed through the receiver system; it should be of an unobjectionable pitch to the ear; and it

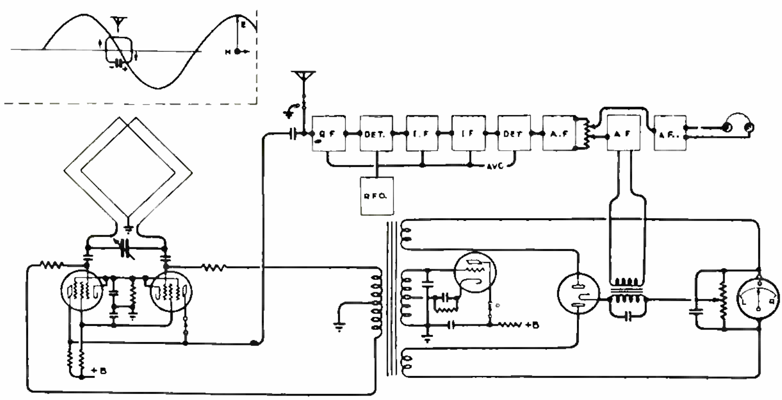


Fig. 19—Schematic functional diagram of radio direction finder shown in Figure 18.

should avoid as far as practicable tones commonly used in broadcasting so that interfering beats between the oscillator and modulated carrier are avoided.

The low-frequency oscillator is provided with three output windings, one of which is used to modulate or key the loop tubes while the others control the direction of current flowing through the indicator. The indicator is arranged in a normally balanced circuit. The indicator is a heavily damped instrument which is not capable of following the relatively rapid keying impulses and therefore, indicates the average value, which in the case of no output from the receiver is zero.

The upper figure represents a radio wave normally polarized with the electrostatic vector in the vertical position and the electromagnetic vector in the horizontal position (looking into the plane of the paper).

For purposes of illustration the loop is shown in the position of maximum voltage reception. Since the loop voltage is controlled by the rate of change of magnetic flux, it will be seen that maximum voltage induced into the loop will occur at the instant of minimum voltage in the open antenna. Therefore, the loop and antenna voltage are substantially 90° out of phase and remain in this relation at the mixing point.

It is convenient to use the open antenna as a reference for phase changes in the loop. It is necessary to shift the loop voltage at the mixing point so that the loop voltage may be added in phase to the antenna voltage. There are several ways to accomplish this. The method chosen for this instrument is to tune the loop circuit to a frequency 2 or 3 per cent higher than the desired signal so that it presents a capacitive reactance at the frequency of the desired signal. The output from the loop tubes are now in such phase that they add to or subtract from the signal from the open antenna.

The loop has opposite potentials at opposite ends of the winding. It can be seen that if one loop-tube is used at a time, as is accomplished by the grid keying voltage supplied from the audio oscillator, one tube will cause an increase of voltage at the mixing point (adding to the antenna voltage) and the other will cause a decrease in voltage at the mixing point. If the antenna and loop are adjusted so that the antenna pickup is exactly equal to the voltage at the plates of the loop tubes, which is seldom the case in practice, there will result double the voltage into the receiver on one-half of the audio-keying cycle and no signal on the other half-keying cycle.

Since the output meter or compass indicator is synchronized with the loop keying, the audio voltage from the receiver must pass through the indicator along one branch of the bridge for a given half-cycle of keying. Therefore, if the left-loop tube gives an increase in output voltage, the meter will move to the left of zero, and similarly, the right-hand-loop tube will cause a decrease in output and the meter will tend to move toward the right in proportion to the output current.

Rotation of the loop so that its plane is normal to the approaching signal places the loop in a position in which both sides of the winding are cut by the magnetic flux at the same instant. The voltage difference developed across the winding is, therefore, zero and no energy is passed through the loop tubes to the antenna mixing point. Continuing the loop rotation further in azimuth reverses the phase of the voltage in the loop. The variation of loop energy is proportional to the sine of the angle as referenced from the null point or point of zero pickup. The reception pattern of the open antenna is assumed to be circular in shape and the reception pattern of the loop is a figure eight or cosine pattern.

When the phase of the voltage in the loop is shifted by 90°, the pattern and the voltages are added algebraically.

Keying the loop tubes by the audio oscillator is equivalent to rotating the loop by 180°, producing the opposite pattern.

It is obvious that with a signal approaching from the zero azimuth angle of the loop, the open antenna energy only is received. There is no addition or subtraction from this energy due to the loop, and the compass indicator remains in the zero or balanced position.

When used as a receiver, the input necessary to obtain 50 milliwatts output is less than 12 microvolts in the beacon band, less than 8 micro-

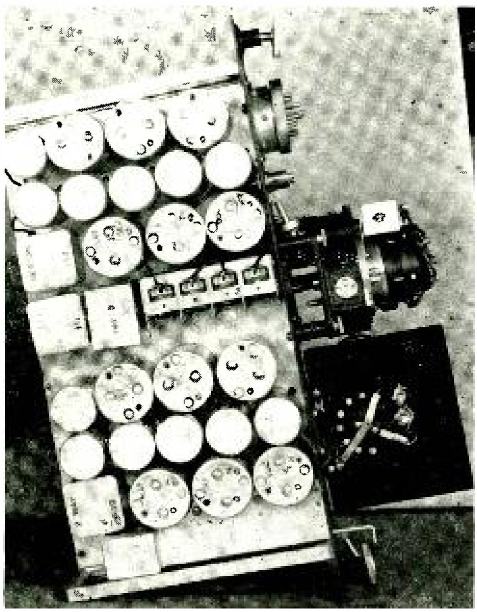


Fig. 20—Rear panel of modern aircraft transport radio equipment.

volts in the broadcast band and less than 10 microvolts in the communication band. When used with an antenna having an effective height of 0.3 meter, the equipment is capable of taking accurate bearings at any frequency in the beacon or broadcast band on field strengths exceeding 20 microvolts per meter. On signals of 20 microvolts per meter, the loop rotation does not exceed 50° from the zero azimuth for full left or full right reflection of the meter. The bearing error does not exceed 1° for any field strength between 100 and 100,000 microvolts per meter and reciprocal bearings are within 1° of the true bearing.

Figure 20—the radio receiver equipment of a modern transport plane, less standby and emergency receiver. A common dynamotor is used for the two receivers and the pilot's control unit is arranged for convenient mounting in the cockpit. Both the communication and beacon receivers are mounted in the same unit and the whole assembly is intended for shock mounting from brackets permanently built into the plane. This construction is indicative of the trend toward standardized accessible equipment, space for which is provided in the aircraft before delivery.

The same intermediate frequency is used on both receivers (515 kilocycles). Eight channels, each employing a separate crystal for oscillator-frequency control, are used in the communication receiver. Both receivers are of the superheterodyne type. Remote switching between crystals of the communication receiver is accomplished electrically by means of an impulse motor located on the front of the receiver unit. The beacon receiver is continuously tunable throughout the range of 200 to 405 kilocycles. The tuning drive and dial setting indicator unit are located on the front of the receiver panel and enclosed in a protective covering. The first component is a reversible d-c motor controlled from the pilot's cockpit control unit. The motor is geared approximately 2500-to-1 to the beacon-condenser tuning shaft and obtains its power supply from the aircraft 12-volt battery. Its mechanism is equipped with a brake which controls the speed of rotation and prevents the motor from over-running after voltage has been removed from the motor. The second component is a synchronous motor indicator assembly employed to transmit the condenser setting or frequency to which the receiver is tuned back to the operator's unit in the cockpit. This is a synchronous "Autosyn" motor. A similar type of "Autosyn" motor located in the cockpit control unit operates a dial scale, thus accurately indicating at all times the frequency to which the receiver is tuned. This system eliminates the use of mechanical drive cables which require extreme care in installation, and insures a smooth running tuning mechanism free from errors and backlash.

A separate power unit mounted on a common power-supply unit base supplies the 32-volt, single-phase, alternating current necessary for operation of the "Autosyn" control system. While the possibility of failure from this remote controlled tuning unit is very unlikely, an emergency tuning unit has nevertheless been designed and furnished which may be readily substituted for the remote control unit assembly on the receiver, thus permitting direct manual tuning of the beacon receiver unit. A hand-operating provision is also built into the communication receiver to allow hand manipulation of the crystal selector switch.

Separate antennas are used on the two receivers. The communication receiver employs the same antenna as the transmitter, and the antenna as well as the power supply for the communication receiver is switched by a relay located in the transmitter assembly. In general the transmitting antenna is an "L" antenna suspended between a stub mast on the front of the ship directly above the pilot's cabin and the tail fin or else is a trailing wire antenna. The beacon receiver employs the "V" type or "T" Belly antenna, which is connected to the beacon receiver at all times regardless of whether the transmitter is operating or not. The sensitivity of the two-way communication receiver and the beacon receiver is approximately 1 microvolt for 50 milliwatts output. The maximum power output of each receiver is 2½ watts. The image suppression on the communication receiver varies from 50 to 60 db, whereas on the beacon band it is 85 db. The communication receiver has an automatic-volume-control characteristic, but no automatic-volume-control action at all is used on the beacon receiver.

The present tendency in the design of aircraft radio receivers for transport use is toward higher stability and higher selectivity. This is particularly true in the communication band in which it is necessary to receive a signal of a few microvolts while the plane is still within the induction field of the antenna of an interfering transmitter which is sometimes separated from the desired frequency by as little as 10 kilocycles. Crystal-filter pre-selectors have in some cases been utilized to meet conditions of this sort. They are not generally used at the present time however, and it now appears probable that the congestion in the band may eventually be relieved through the assignment of additional channels in the ultra-high-frequency spectrum for communication purposes.

At the present time "Approved Type Certificate Ratings" are required for aviation components such as parachutes, landing gear, engines, propellers, instruments, etc. It is now proposed that the radio equipment to be carried on the transport planes will likewise be required to have an "Approved Type Certificate Rating." This rating will require that design and construction practices followed in the design of aircraft radio equipment be the best that the art affords. This applies not only to the apparatus components, but to the completed instruments as well. It is proposed to establish this requirement first with regard to radio equipment carried in the transport ships, but it is believed that in a relatively short time all radio equipment carried by any aircraft will as a matter of course comply with this rating.

At the present time very little passenger traffic is handled at altitudes in excess of approximately 10,000 feet sea level. At times it is necessary to go to altitudes of 12,000 to 15,000 feet or so for short periods in order to fly over storm areas. Although the airplanes themselves have the capability of flying at much higher altitudes, a maximum of 10,000 to 12,000 feet is generally maintained because of passenger comfort requirements.

A great deal of experimental work has been going on during the past few years relative to the development of aircraft that are capable of flying at high altitudes in order to obtain more economical and faster transportation services for long-distance flights. It has been found necessary to sound-proof and insulate the cabins of the present airplanes which fly at the 10,000 to 12,000-foot levels. In order to be able to carry passengers at altitudes of 30,000 to 40,000 feet it will be necessary to insulate the cabins further and in addition to this it will be necessary to maintain a pressure within the cabin the equivalent of that existing at an altitude of some 10,000 to 12,000 feet for passenger-comfort reasons.

At the high altitudes it is a known fact that the insulation resistance of air becomes only a fractional part of its value at sea level. This means that the radio equipment including all of its component parts, power supply, etc., must be designed for use at these higher altitudes. This has already made it necessary to change the spacing of the wires in vacuum tube bases and vacuum tube sockets as well as the spacing of high-voltage terminals, etc., on both transmitters and receivers, to operate at these lower pressures. With some of the new planes now under construction it will be general practice to fly at altitudes of 30,000 to 40,000 feet which will necessitate the design of radio apparatus for this type of service. It is already apparent that both for this reason, as well as for greater accessibility, the size of radio equipment of a given complexity is increasing.

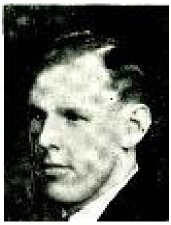
At the present time all of the electrical power required for operation of an aircraft is obtained from a 12-volt storage battery which is kept in a charged condition by generators driven by the main engines. This power supply is entirely adequate to take care of the rather small electrical requirements that now exist.

In the future, however, for the proposed 40-passenger or larger airplanes it has been calculated that it will require approximately 15 kva of electrical energy in order to operate all of the various electrical devices that will be used on these planes. It has been proposed that an alternating current of approximately 115-volt potential be used. Because of the great saving in weight that can be realized by using higher frequencies than the commercially used 60-cycle supply, it has been suggested that a frequency in the order of 400 to 800 cycles be used. A considerable amount of this electrical energy will be required for the operation of electrical motors. It has been thought that a split-phase type of motor of the capacitor type when operated from a single-phase supply of alternating current will give essentially polyphase-motor operational characteristics.

In order to generate this 15 kva of energy in the safest possible manner, it has been proposed that two 7½ kva alternating current generators be driven by small auxiliary gasoline engines. These gasoline-driven alternators will no doubt be mounted one within each wing between the two outboard engines.

In conclusion the authors wish to acknowledge the valuable assistance received in the preparation of this article from Messrs. C. A. Brokaw and C. A. Gunther.

OUR CONTRIBUTORS



CARLOS E. BURNETT received a B.S. degree in electrical engineering from the Southern Methodist University in 1931; a B.S. degree in electrical engineering in 1932, and an M.S. degree in electrical engineering in 1933 from the Massachusetts Institute of Technology. He was a student engineer in the signal department of the Texas and Pacific Railway Company, half-time, from 1926 to 1931, and a student engineer in the plant department of the New York Telephone Company in 1932. Since 1933 he has been an engineer in the Research and Engineering Department of the RCA Manufacturing Company, Radiotron Division, at Harrison, N. J. Mr. Burnett is an associate member of the American Institute of Electrical Engineers and an associate member of the Institute of Radio Engineers.

LEWIS M. CLEMENT, Vice-President in Charge of Engineering and Research of RCA Manufacturing Co., started his radio career in 1914 as assistant chief engineer in the California-Hawaii radio communications service. Two years later he joined the Bell Telephone Laboratories and supervised the establishment of the first radio-telephone link between Catalina Island and Los Angeles. During the war he was in charge of design and development of all electric-radio apparatus for use by U. S. Government services. In 1925, Mr. Clement became Chief Engineer of the Fada Radio Co., three years later Vice-President and Chief Engineer of the Kolster Radio Co., for a year Assistant Manager of the Radio Department of the Westinghouse Electric and Manufacturing Company, and then Chief Engineer of radio receiver design for the International Standard Electric Co., until his present RCA appointment.

WILLIAM S. DUTTERA, after receiving his E.E. degree from Gettysburg College in 1929, took the two years of Masters work at Union College in 1930 and 1931. He started in transmitter test work for the General Electric Company in 1929 and in 1930 became a member of the High Power Group in the Transmitter Engineering Department. His assignments included development of the power amplifier and rectifier for the television transmitter in the Empire State Building. He transferred to the National Broadcasting Company in 1931 on television and in 1932 joined the Radio Facilities Department where he engaged in transmitter work, radio wave propagation studies and, to a major extent, in the development of improved directional and non-directional antenna systems and associated equipment.

WILLIAM A. FITCH received his degree of B.S. in Electrical Engineering from Michigan State College in 1926. Following his graduation he entered the General Electric Test Department and later engaged in radio development in the Engineering Division. While with the General Electric Company he obtained an M.S. degree from Union College in 1931. Mr. Fitch joined the Engineering Department of the National Broadcasting Company in 1933, specializing in coverage surveys and propagation problems. He is a member of the Institute of Radio Engineers.

CLARENCE W. HANSELL received his B.S. degree in Electrical Engineering from Purdue University in 1919. Following graduation he spent one year in the test department and Dr. Alexanderson's Laboratory at the General Electric Company, and assisted with the installation of Alexanderson alternators. Since 1920 he has been connected with the Engineering Department of the Radio Corporation of America and R.C.A. Communications, Inc., and in charge of transmitter research and development since 1927. Mr. Hansell is a member of I.R.E. and associate member of A.I.E.E.

ALBERT PREISMAN received his A.B. and E.E. degrees from Columbia University in 1922 and 1924, respectively, and is now taking graduate courses at Columbia University and the Brooklyn Polytechnic Institute for a Doctor's degree. After working with the Wagner Electric Corporation of St. Louis and the New York Edison Company, he joined the RCA Photophone organization in January, 1929. In 1932, he transferred to RCA Institutes, where he specializes in audio frequency engineering and vacuum tube theory and design.

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.

STUART W. SEELEY received his B.Sc. Degree in Electrical Engineering from Michigan State College in 1925. He was an amateur experimenter and commercial radio operator from 1915 to 1924. Following this he joined the experimental research department of the General Electric Company, and a year later became Chief Radio Engineer for the Sparks Withington Company. Since 1935 he has been an engineer in the RCA License Laboratory.

GEORGE L. USSELMAN received his B.S. degree in Electrical Engineering from the Kansas State College in 1916. After his graduation he spent three years in the General Electric Company's test department. In 1920, shortly after the Radio Corporation of America was formed, Mr. Usselman joined its operating division. In 1925 he transferred to the Engineering Department and, engaged in transmitter design and research problems. Mr. Usselman is an associate member of I.R.E. and A.I.E.E.

CHARLES J. YOUNG graduated as a Bachelor of Arts from Harvard University in 1921. After spending a year at the Harvard Engineering School, he joined the General Electric Company. Since 1930 he has been engaged in research work for RCA Manufacturing Company at Camden, N. J.