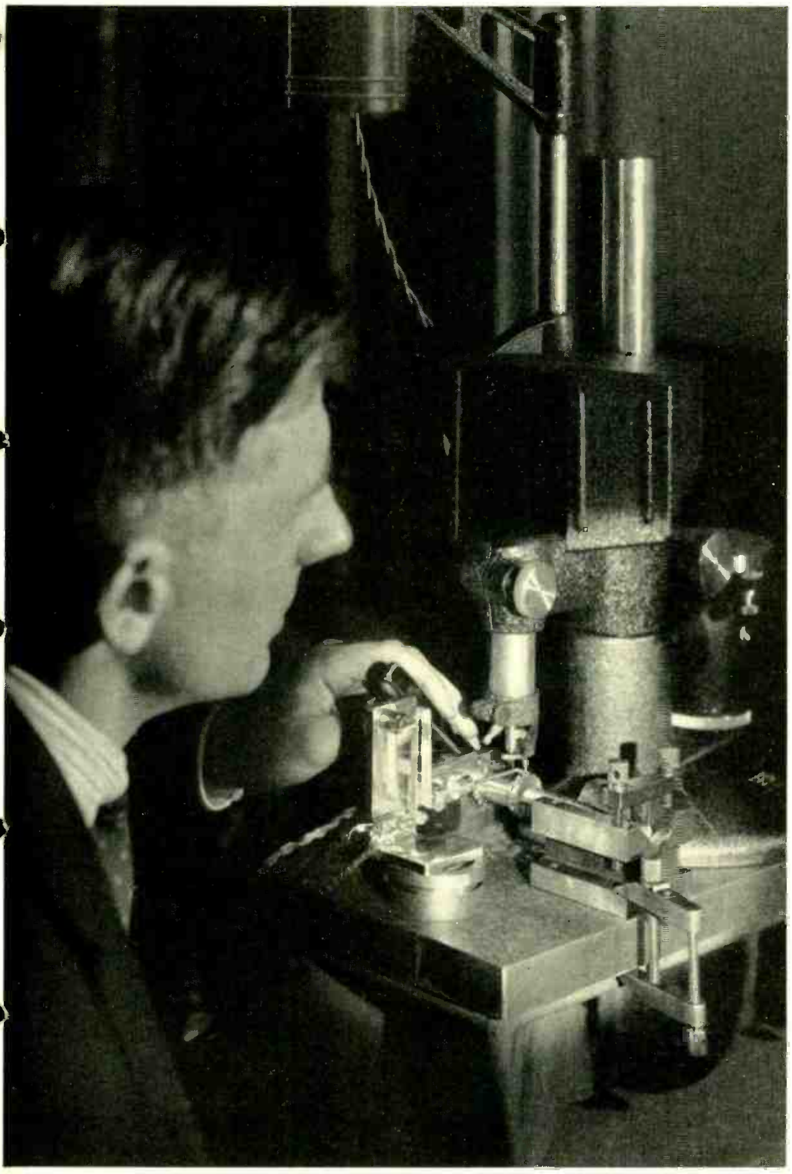
BELL LABORATORIES RECORD



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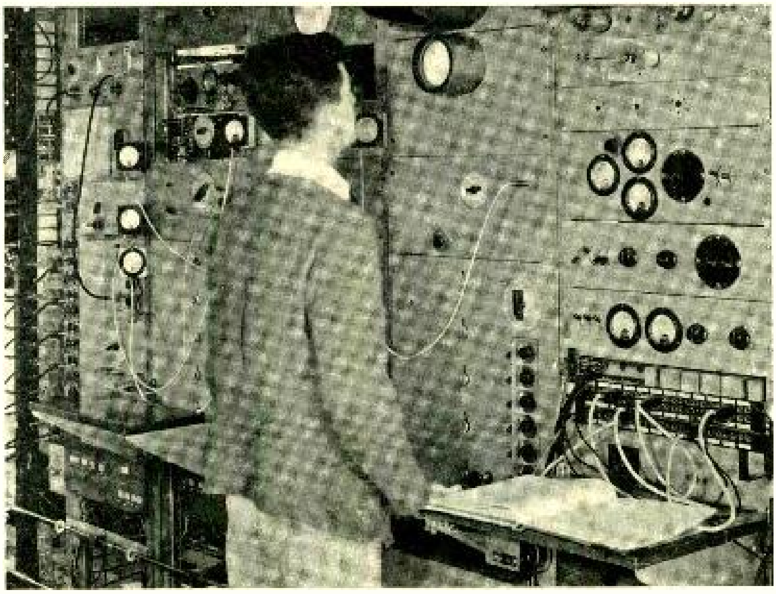
Measuring apparatus optically to 0.00005 of an inch.



Principles of the Musa

By C. B. FELDMAN
Radio Research Department

FOR more than a decade, point-to-point short-wave radio services have employed directional antennas for both transmitting and receiving. A directional antenna at the transmitter increases the field intensity at the receiving location, while one at the receiver discriminates against noise. The effect of directivity both at the transmitter and the receiver is thus to improve the signal-to-noise ratio of a given circuit, and to permit operation under more adverse transmission conditions than would be possible without them—thus increasing the reliability of the circuit.

Antennas in present use on the longer circuits, such as that between New York and London, represent about the limit of fixed directivity. Further increase or "sharpening" of the directivity would seriously encroach upon the range of directions over which the wave paths vary in passing from the transmitter to the receiver. Although there is some variation both in horizontal and vertical angle of reception, that in the horizontal plane is usually much smaller and, as a result, of comparatively little importance.

The variation in the vertical plane has already been discussed in the RECORD.* The reasons for it are indicated in Figure 1. Waves leave the transmitter over a range of vertical angles and thus reach the refracting layers of the ionosphere at various positions and angles. Only those components which reach the ionosphere at less than a certain critical angle are refracted back to earth. Of these only certain ones have directions such that

*RECORD, *June*, 1934, *p.* 305.

they reach the earth at the receiving location. Even some of these portions of the transmitted wave may be lost by excessive attenuation, but as an overall result, there are generally several more or less discreet vertical angles at which the signal may be received. These angles vary from time to time with variation in height of the refracting layers, and if the directivity of the receiver is not broad enough to cover the range of the most prominent signals, there will be times when practically no signal is received even though the field strength is high enough for reception with a properly directed antenna.

Increased sharpness of directivity, however, results in a higher ratio of signal-to-noise, so that if the directivity of the receiver were made very sharp, and some method provided for changing its angle of reception to enable it to be kept pointed at one of the most prominent signals, reception would be greatly improved. With a number of such antennas separately directed, several signal components could, after proper adjustment for their different transmission delays, be combined in a single receiver. It is just this that the musa does—the word musa standing for multiple-unit steerable antenna.

The musa consists of a number of similar and equally spaced directional antennas laid out along the great-circle direction of the transmitter. These antennas are not sharply directional in themselves, but are designed to receive over the normal range of vertical angles. The reason for the directive action of such an array will become apparent from a study of Figure 2, where the circles represent the antennas, and the received signal is shown arriving at an angle δ with the ground. It is obvious that the signal arrives at antenna 2 before it does at antenna 1, or in other words, that the phase of the signal at antenna 2 leads that of antenna 1. Similarly the phase of the signal at antenna 3 is ahead of that at antenna 2 by the same amount, and so on for the entire array. As a result the phase of the signal at antenna 2 will lead that at antenna 1 by some angle that may be called θ, while that of the signal at antenna 3 will lead that at antenna 1 by an angle 2θ, and so on for the entire array.

If the receiver is considered to be located at antenna 1, however, it is obvious that the signals from the other antennas also suffer a phase shift in passing over the transmission line from the antenna to the receiver. If this phase shift for the signal from antenna 2 is called α, then that for antenna 3 will be 2α, that from antenna 4 will be 3α and so on. In general, α differs from θ, but it is possible to put a phase-shifting network in the transmission line for antenna 2 to produce a phase shift ϕ of such a

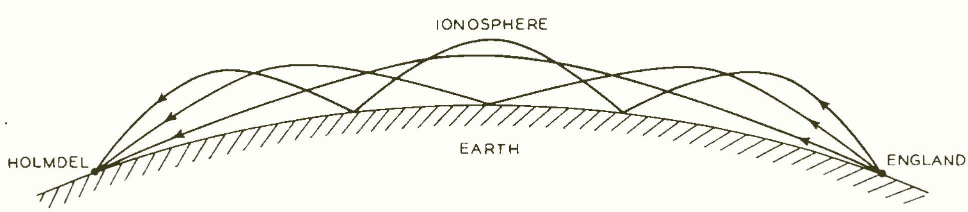


Fig. 1—A simplified conception of the short-wave transmission path between England and America

value that the sum of θ, α and ϕ will be zero. Similar networks could be put in all the lines—that in the line to antenna 3 being 2ϕ in value, and so on. When this is done the signals from all the antennas will be in phase at the receiver and the combined signal will be equal to their sum.

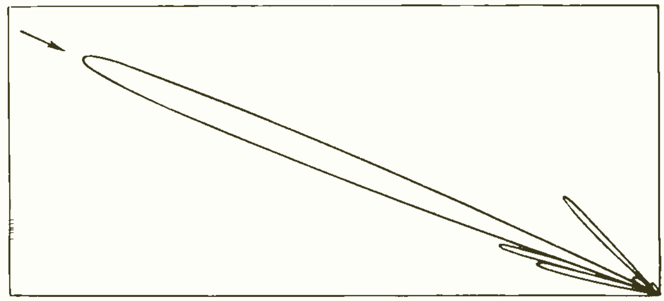


Fig. 3—Receiving characteristic of the experimental musa

Since the angle ϕ is equal to the difference between θ and α, and since θ varies with δ, ϕ also will vary with δ. For any one value of ϕ, in other words, the signals at the receiver will be in phase for only one angle of reception. For other angles of reception the signals from the various antennas will be out of phase, and their vector sum will thus be less than when they are in phase. As a result, a directional characteristic is obtained, and—other things being equal—the characteristic will be sharper the greater the number of antennas in the array. If with such an antenna array some provision is made for changing the phase-shifting networks in unison, so that when that for antenna 2 is changed from ϕ to $(\phi+\Delta)$, that for antenna 3 will be changed to $2(\phi+\Delta)$ and that for antenna 4 to $3(\phi+\Delta)$ and so on, then the angle of most effective reception can be changed merely by changing the values of the ϕ's.

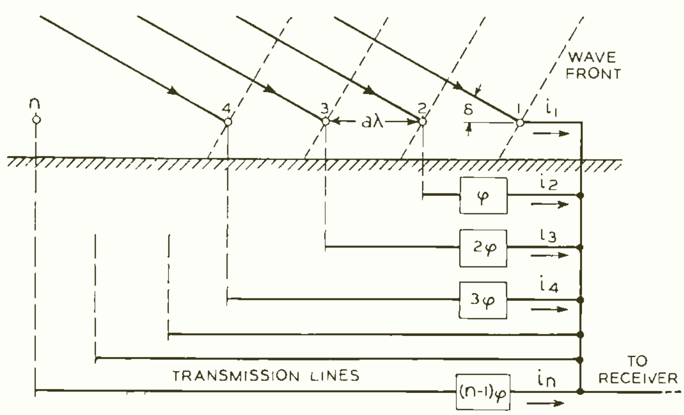


Fig. 2—The musa consists of a number of equally spaced directive antennas with phase-shifting networks in the transmission lines from them

The experimental musa now set up at Holmdel consists of six rhombic antennas, and gives a sharp receiving characteristic as indicated in Figure 3. Besides the main lobe there are several minor ones on each side, but the magnitude of these is comparatively small. There will also be other main lobes, but by the design of the array and the individual antennas these are made to fall outside of the range over which the musa is designed to act. The direction of the main usable lobe may be made to vary over the steering range depending on the value of ϕ, and the steering range, in turn, will be larger or smaller depending on the design of the individual antennas and on the distance between the centers of the antennas.

As already pointed out, there may be prominent signals arriving in several directions at the same time, and to obtain the maximum receiving advantage all of these signals should be separately received and suitably combined at the receiver. The musa readily permits this to be done by providing a number of parallel circuits connected to the same antenna but each having a separate set of phase-shifting networks. Each of these branch circuits with its phase-shifting networks becomes in effect an independent musa, and each may be set to receive at a different angle. Since the length of path, as is evident from Figure 1, is different for each direction of arrival, the transmission delays of the various paths must be equalized, which is readily accomplished by delay networks in the branch paths.

In the experimental musa at Holmdel, three such branch paths are provided as indicated in Figure 4. The three branch circuits are formed at the outputs of the first detectors for the six antennas of the array, and the three sets of phase shifters in the branch circuits are separately controlled by three dials. One of the branches, shown at the right of Figure 4, is used only to explore the angle range to determine the angles at which waves are arriving. Its output is connected to a cathode ray oscilloscope which shows amplitude as the ordinate with phase shift as the abscissa. The plot in the illustration indicates strong signals at two values of ϕ.

The other two branches pass through separate branch receivers, and then one is passed through an adjustable delay network to equalize the transmission delays before the two outputs are combined. The correct delay is indicated by a second oscilloscope as indicated in the illustration. When the delays are properly equalized the oscilloscope will show only a diagonal line, or compact elongated figure, as indicated. In this way, the musa may be held at all times on the two most prominent incoming signals, and the sharp directivity of the individual lobes insures the high ratio of signal-to-noise that is desired.

A front view of the experimental musa receiving equipment is shown in the photograph at the head of this article. The high-frequency bay is at the left and the audio-frequency bay at the right. The three middle bays include the branch receivers and the phase-shifting networks, and at the top of one of them are the two oscil-

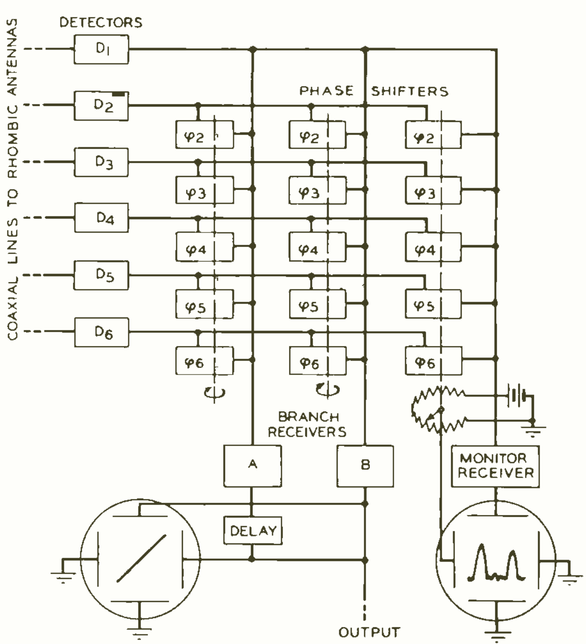
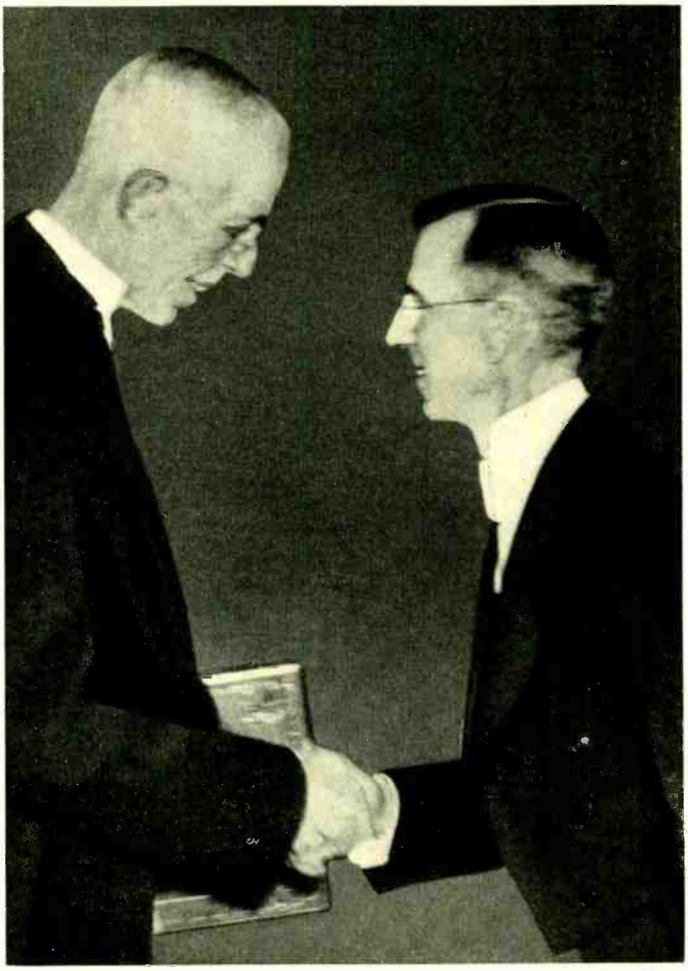


Fig. 4—Simplified block schematic of the musa system at Holmdel

loscopes—the larger one, of which only the bottom edge can be seen, being used for monitoring. The number of branches provided is not limited to three, of course, and in a system proposed for commercial transatlantic service, four will be provided.

As outlined in the foregoing, the operation of the musa depends upon the waves being propagated in an orderly manner such as depicted in Figure 1. Such a ray picture is considerably idealized, but nevertheless experience with the experimental musa indicates that with a few refinements such a receiving system can be expected to increase substantially the reliability of short-wave telephone circuits.



Times Wide World

King Gustaf of Sweden on December 10 *presented a Nobel Prize in physics to Dr. Davisson*

Musa Apparatus

By W. M. SHARPLESS
Radio Research Department

THE requirements placed on the musa apparatus differ considerably from those the more ordinary radio receiver must meet, chiefly because of the necessity of combining the outputs of an array of separate antennas* in precise phase relationship. The steerability of the musa and the sharpening of its directional characteristic are secured in the experimental system by the use of six separate antennas and high-frequency detectors which feed the receiver through phase-shifting networks. The proper functioning of the system depends on a very accurate control of the phasing of the signals up to their point of combination.

**Page* 148, *this issue.*

To simplify the experimental equipment of the musa, it was decided to dispense with the selectivity that would have been afforded by high-frequency amplifiers ahead of the detectors, and to employ the simple circuit shown in Figure 1. The capacitive coupling to the transmission line is a convenient means of matching the low-impedance lines to the high-impedance circuits. Plug-in coils are provided for the tuned circuits to cover the range from 4.5 to 22 megacycles. The first detectors are of the balanced two-tube type which isolates the beating oscillator from the input circuits, and thus prevents crosstalk between the six inputs, and secures independence of the tuning. This arrangement also prevents two incoming signals that differ in frequency by the intermediate frequency from causing interference in the intermediate circuits that are involved.

Power from the beating oscillator is supplied to the detectors at low impedance between the cathodes. The transmission lines from the oscillator to each of the detectors are all of the same length so that the six oscillator inputs to the detectors are of the same phase. The six input-circuit controls, together with the coaxial patching cords for connecting the transmission lines to the input circuits, are shown in Figure 2.

The phase shift along each transmission line should be proportional to the distance to the antenna with which it is associated. To simplify the attainment of this objective, the six coaxial lines are run in a common trench along the axis of the array, so that the physical length of each line is of the correct value. Even when this is done, the phase shift along each line will not be of the proper amount unless the lines are very accurately terminated to avoid reflection effects. If the input circuits to the receivers are not precisely adjusted, the proper phase will not be applied to the grids of the detectors, and the system cannot be made to function as it should.

To determine the correct adjustment of the input circuits, a test oscillator with an impedance equal to that of the coaxial line is plugged into the input jack, and the tuning and coupling condensers are alternately adjusted until a maximum output voltage appears on an indicating meter connected in one of the three branches. To secure high precision a square-law vacuum-tube voltmeter is employed in which the major part of the current is balanced out and the remainder is read on a microammeter that has a full scale reading of only thirty microamperes. This permits the maximum current to be determined to a high degree of precision.

The ultimate criterion of correct termination is the degree of suppression of standing waves on the transmission line. To insure that setting for maximum current gave the correct adjustment, therefore, a standing-wave detector was installed in the experimental equipment. This detector consists of about sixteen meters of the coaxial line arranged in a coil. This line is terminated in the input

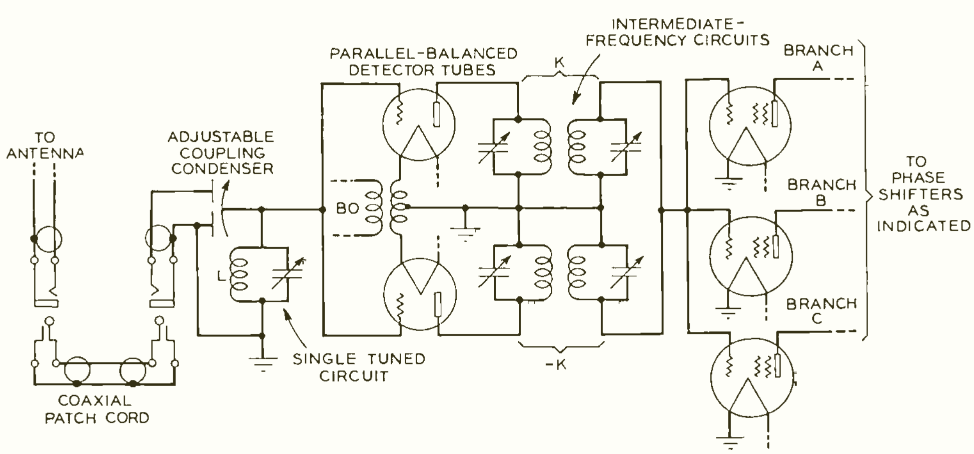


Fig. 1—Simplified schematic of the musa circuit

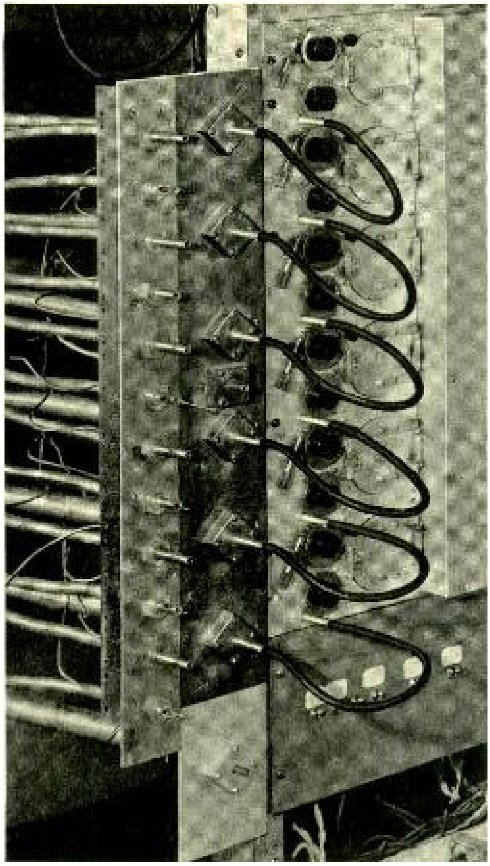


Fig. 2—The transmission lines from the antennas terminate in coaxial jacks and are connected to the input circuits by coaxial patching cords

circuit to be tested, and fed at the other end by a test oscillator. Six taps are brought out from this coil to the low-capacity switch, and a selector arm connects the taps as desired to an auxiliary receiver of high input impedance. The absence of standing waves is indicated by equal readings at the six positions. It was found, however, that the adjustment for maximum current with the vacuum-tube voltmeter resulted in standing-wave suppression of such an order as to make routine operation of the standing-wave detector unnecessary under ordinary conditions.

The outputs of the intermediate-frequency circuits following the first detectors are divided into three branches, each including its phase-shifting circuits. This branching is accomplished physically by providing a rectangular coaxial bus from the output of each of the six intermediate circuits, and tapping the equipment of the three branches to it as shown at the head of this article.

Phase shifting in the branch circuits is accomplished by a circuit shown schematically in Figure 3. There are six of these circuits for each of the three branches. The points "a," "b," "c," and "d" have equal voltages to ground but are ninety degrees apart in phase: that of "b" being $+IR$; that of "c," $-IR$; that of "a," $+jI/\omega c$, and that of "d," $-jI/\omega c$. These points connect to four sets of stator plates of two condensers. The rotors of the condensers are mounted at right angles to each other on a common shaft, and are shaped so that the difference in exposure to opposite stator plates is proportional respectively to the sine and cosine of the angle of shaft rotation. Thus, the current in the rotor is constant and of a phase proportional to the shaft angle.

The six phase shifters of each branch

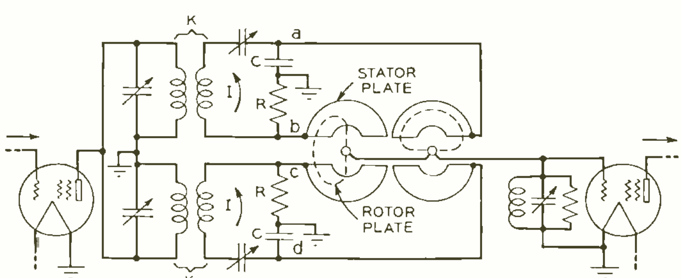


Fig. 3—Simplified schematic of the phase-shifting circuit

are connected to the steering shaft through helical gears with multiple ratios. One of these drives is shown in Figure 4. The individual shafts may be shifted with respect to the main drive when the musa is adjusted. This adjustment is independent of

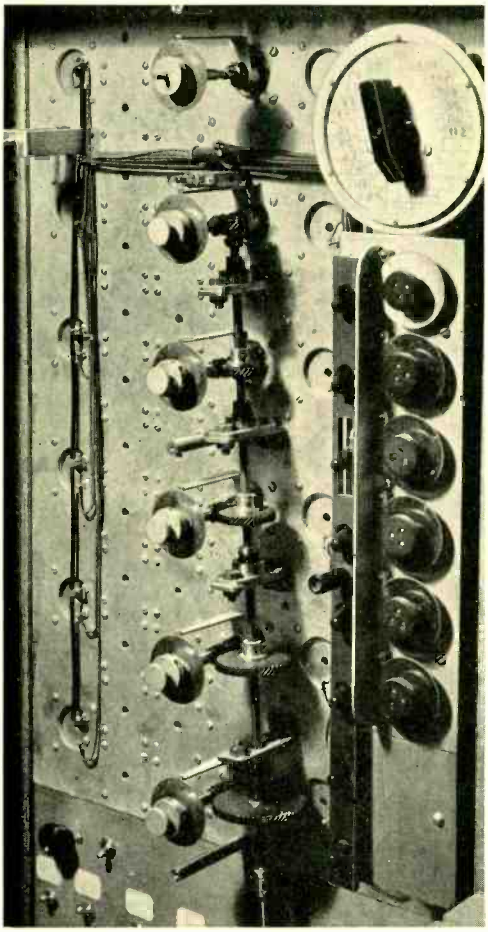


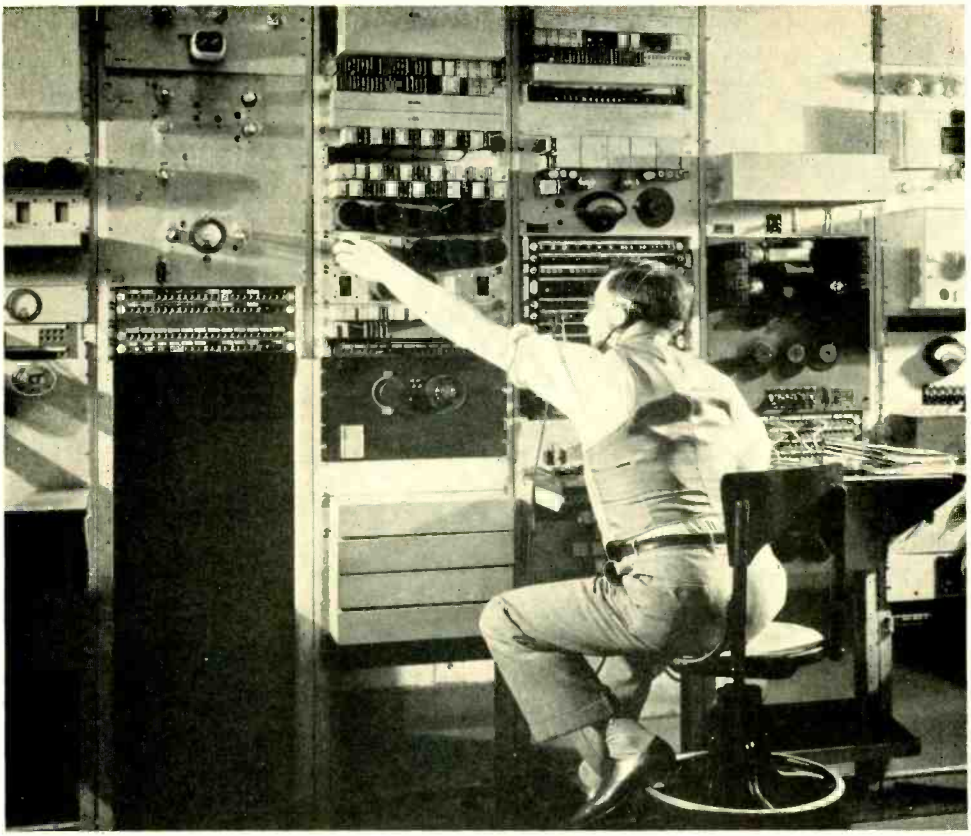
Fig. 4—One of the steering drives showing the helical gears and the shafts of the six phase shifters

signal frequency. The gains of the phase-shifter circuits may be adjusted independently to compensate for differences in the line losses.

The remaining intermediate- and audio-frequency apparatus does not differ greatly from other equipment of this type, with the exception of the audio delay networks used in combining the outputs of two branches. This delay is inserted in the low-angle branch, and although it could theoretically be provided at intermediate frequency, it is actually obtained electrically in the audio circuits. The delay network is an artificial line of forty sections terminated by its characteristic impedance. Each section provides a delay of 68 microseconds. A switch permits a high-impedance output circuit to be tapped across any section—thus providing a total delay of 2.7 milliseconds adjustable in 0.068-millisecond steps. An equalizing network, designed by P. H. Richardson, equalizes the transmission loss for each step and also equalizes the loss-frequency characteristic to make the response flat up to 5000 cycles.

In this experimental equipment, both linear and square-law detectors are provided for final demodulation, and either may be switched into the circuit as desired. Automatic gain control for either demodulator is obtained from linear rectifiers, but to secure as nearly as possible a constant output volume, a different connection is made for each type of detectors employed.

This experimental system was designed for double-sideband reception. Equipment has recently been completed, however, which may be substituted for the double-sideband equipment when single-sideband signals with reduced carrier are to be received. This new equipment may also be employed to select one sideband of a double-sideband signal by the use of crystal filters.



Automatic Adjustments in Radio-Telephone Control Terminals

By D. MITCHELL
Radio Transmission Development

WHEN typical radio links become parts of the telephone connection between two subscribers, the circuit is composed of an ordinary two-way telephone channel from the calling subscriber to the radio control terminal; two one-way channels including the radio portion; and another two-way channel to the called subscriber. In Figure 1, which shows such a circuit, it will be noted that there are three possible paths for energy to circulate around the circuit—A, B and C—although in most cases we are only concerned with path A. If in any of these paths the total gains exceed the losses singing may take place. To avoid the possibilities of this occurring positive means must be provided, such as relays controlled by the voice waves, which will keep possible singing paths broken at all times. The device which does this, the "vodas," has already been described in the RECORD.* Its

*RECORD, *November*, 1927, *p*. 80.

operation, briefly, is as follows: Speech currents from the subscriber are diverted by the hybrid coil (Figure 2) into the outgoing radio channel. After passing through the transmitting volume control, a portion of the speech currents pass through attenuator TS and then into the amplifier-detector AD which in turn operates relays 1 and 2. Relay 1 enables the path to the radio transmitter while relay 2 disables the path from the radio receiver, thereby suppressing echoes and preventing singing. It is necessary that practically all of the voice waves of the outgoing speech operate these two relays or parts of words will be clipped.

Incoming waves on the other hand pass through the contacts of relay 2 which in the "idle" condition are closed, and part pass up through the attenuator RS and thence into the amplifier-detector AD where they may operate relay 3. If relay 3 were not used relays 1 and 2 would operate a large part of the time because of echoes from the telephone line.

Receiving sensitivity control RS must often be set so that the weaker parts of the speech waves do not operate relay 3. This is done when static is high so that static will not hold relay 3 operated and prevent outgoing waves from getting through. When relay 3 is unoperated, echoes which come back from the subscriber's line may operate the transmitting relays 1 and 2 if they are strong enough. In that case, subsequent incoming waves are cut off on the receiving side until relays 1 and 2 release. Then when sufficient speech waves have come through to again operate relays 1 and 2 by their echoes, the waves arriving after these are cut off again for a time. Successive cycles of this kind produce a chattering effect, called "echo operation," which makes the circuit unworkable.

The way to prevent this effect is to adjust the losses and sensitivities in the circuit so that waves which are just too weak to operate relay 3 are also just too weak as echoes to operate relays 1 and 2. "Echo margin" is said to be zero when this condition exists. It is positive when echoes of the waves which just fail to operate relay 3 are too weak to operate relays 1 and 2 and

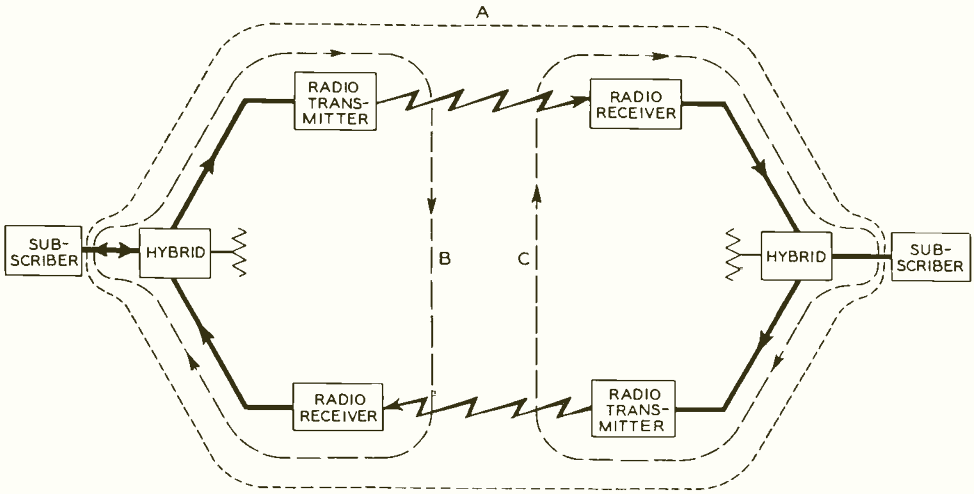


Fig. 1—Echo paths in a two-way radio link: A, around the entire radio portion; B, C, from a transmitter to local receiver

negative when these echoes are strong enough to operate relays 1 and 2. Evidently, echo margin must be maintained at zero or some positive value to prevent echo operation.

The susceptibility of relays 1 and 2 to operation by echoes which are too weak as direct signals to operate relay 3 depends on five variables: first the sensitivity of relay 3 as controlled by attenuator RS, second the loss in the receiving volume control, third the return loss of the subscriber's line, fourth the gain in the transmitting volume control and fifth the sensitivity of the transmitting amplifier detector as controlled by attenuator TS. The return loss of the two-wire line is a fixed quantity for any particular connection. Three of the remaining variables have optimum values for any particular connection and these should be used for best operation. Thus receiving sensitivity should not be set higher than is allowed by static. The gain of the transmitting volume control is determined by the volume received from the subscriber, since most effective use of the radio transmitter is attained when the volumes for all subscribers are made substantially constant in order to fully load the transmitter. The sensitivity of the transmitting amplifier-detector should be such that practically all of the outgoing speech waves operate relays 1 and 2. Therefore the only quantity which should be changed in order to avoid the penalty of echo operation is the receiving volume control.

Automatic adjustment of this variable has received considerable attention during the last few years. As part of the general program of radio terminal development, a semi-automatic control terminal was worked out which was on experimental trial for about a year under actual service conditions. Although this device, which is known as the "C-1 terminal," does not represent a final solution of the problem, it was found to take care of a large percentage of the calls without any manual assistance. In this terminal apparatus, receiving volume is regulated automatically.

In order to determine the setting of the receiving volume control it is apparent that the four quantities named above which are predetermined for

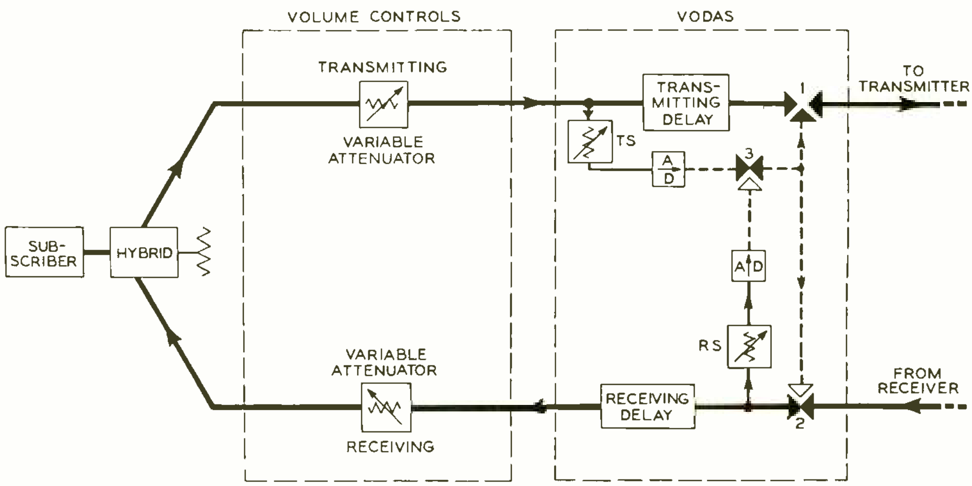


Fig. 2—Simplified diagram of one control terminal. The diagonal arrows, shown in four small squares, indicate adjustable elements

any call must be added in some manner. In the C-1 terminal a local pilot channel serves this purpose. It is confined to the terminal circuits as illustrated by Figure 3 and originates in a 6000-cycle oscillator. The output of this oscillator passes through a device called a "vogad,"* which automatically regulates transmitting volume, and thence through three variable attenuators. The first of these attenuators is varied as the transmitting sensitivity (TS) is varied, being associated with it by relays. The second, known as return loss (RL), can be adjusted manually. The third is adjusted by relays associated with the receiving sensitivity control (RS) in such a way that the attenuation is increased as the receiving sensitivity is increased. The 6000-cycle tone which has passed through these three attenuators is then used to regulate the receiving volume.

When the gain of the transmitting volume control or transmitting sensitivity is increased there is more chance for echo operation and, therefore, less echo margin. Thus an increase in either the transmitting volume control or transmitting sensitivity causes the pilot tone to increase. The RL control may be adjusted to compensate for different return losses; when return loss is high there is less chance of echo operation, so the pilot tone may be lowered by increasing the loss in RL. When the sensitivity of the receiving relays is increased, echo margin is increased and loss is therefore inserted in the pilot channel. Hence RS and its complementary control in the pilot channel change oppositely.

Figure 4 shows schematically the tone operated loss adjusting circuit which adjusts the receiving volume. Voice waves and tone from the pilot channel are combined in the hybrid coil and then passed through a vario-repeater. At its output the voice waves go on through the low-pass filter which rejects the 6000-cycle tone. The tone passes downward through a high-pass and band-pass filter which effectively suppress voice waves and practically all of their harmonics. From there the tone passes into the pilot tone detector. This de-

*The word vogad is made up of the initial letters in the expression "volume operated gain adjusting device." The action of the pilot channel would be the same if the transmitting volume were controlled manually.

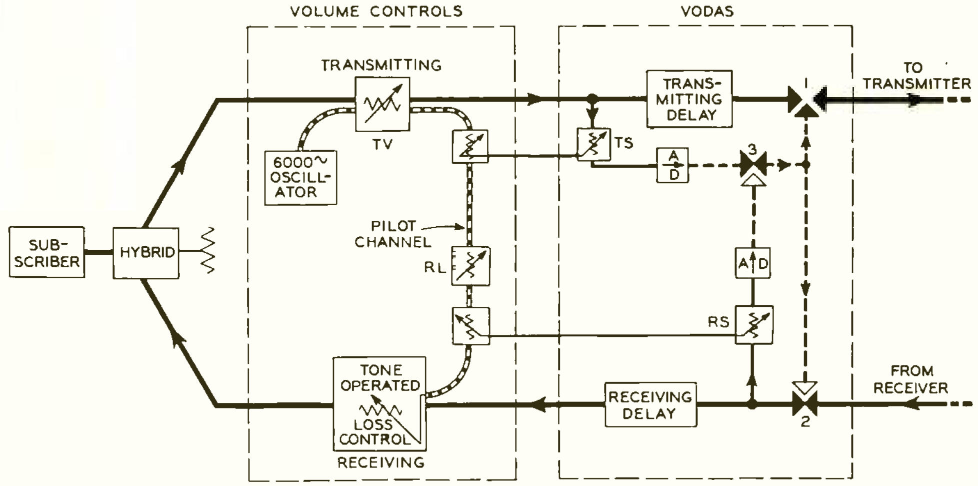


Fig. 3—C-1 control terminal for semi-automatic operation

vice causes a bias to be placed on the grids of the vario-repeater which becomes more negative as the tone at the output of the vario-repeater increases. Thus, the gain of the vario-repeater is lowered or raised as the pilot tone becomes stronger or weaker.

The vodas prevents singing, the transmitting volume control compensates for different speakers' speech volumes, and the pilot channel regulates receiving volume. There remain but three manual controls in the C-1 terminal. These are transmitting sensitivity TS, receiving sensitivity RS, and the return loss control RL. The transmitting sensitivity is very seldom adjusted, so this control requires little attention. The return loss control is usually set to take care of the lowest return loss ordinarily encountered and is also very seldom changed.

Receiving sensitivity must be adjusted to take care of changes in radio noise. This adjustment is ordinarily made at intervals ranging from about every five minutes for the more severe types of rapidly changing noises, to perhaps thirty minutes or more for some types of very steady noises. For a small portion of the calls, conditions of line noise and talker volume are so extreme that they require considerable manual attention. On the whole, however, except for these extreme conditions, the C-1 terminal automatically takes care of the important adjustments required.

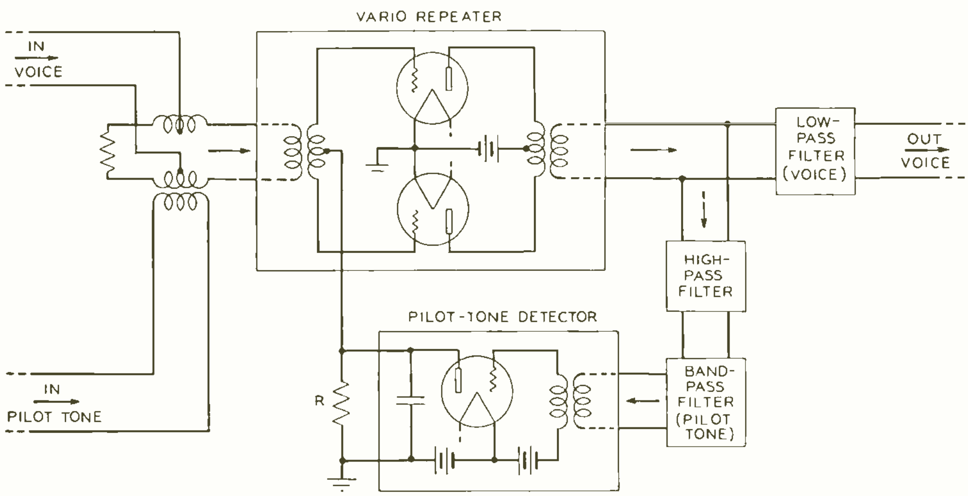
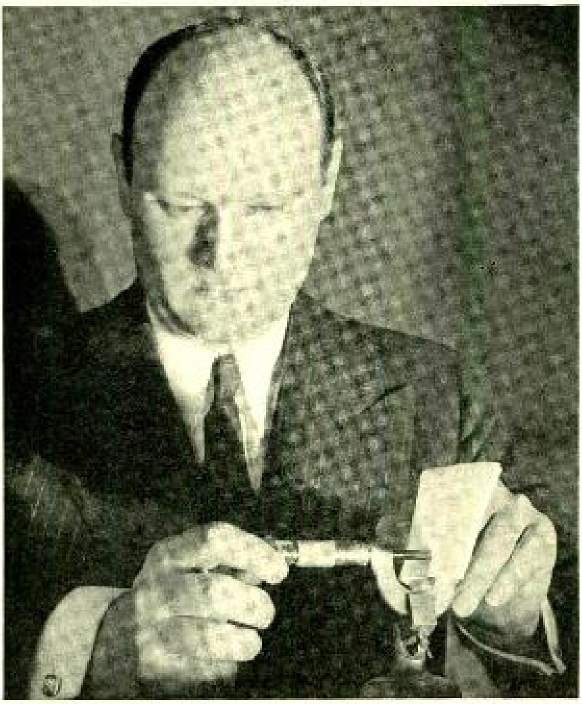


Fig. 4—Pilot tone, flowing through the detector, changes the grid bias of the vario-repeater tubes and consequently controls the gain of the repeater



A New Micrometer Ratchet

By W. W. WERRING
Telephone Apparatus Electro-Mechanical

BY substituting a helical spring for a ratchet to transmit the torque of the operator's fingers, the Laboratories have recently been able to improve the accuracy of the machinist's micrometer calipers. This device, which is probably the most universally used precision measuring instrument, will be recognized as an old friend from the illustration above and from Figure 1.

In spite of the long use and apparent simplicity and accuracy of the micrometer, measurements made with it may vary quite widely and efforts to eliminate this variation have not been fully successful. Differences in the pressure with which the object being measured is clamped cause differences in the reading of the instrument due to slight compression of the material or distortion of the instrument itself.

The necessity of making measurements under a definite pressure has led to the development of the traditional "feel" or practiced touch which distinguishes the craftsman from the novice in the use of the micrometer. To make the feel automatic the micrometer ratchet has been used to produce a constant pressure or "feel" mechanically. It is attached to the end of the barrel of the micrometer and the operator turns the ratchet instead of turning the barrel directly. The ratchet may be of several designs but as the name implies the essential element is a "ratchet" or saw-toothed piece which transmits turning moment to the screw. The turning effort is produced when a pin or other member which is held in contact with the ratchet by a spring slides up the sloping surfaces of the ratchet as the operator turns the outer housing of the device. If the micrometer ratchet is rotated continuously it emits a series of clicks as the pin snaps down the straight side of each successive tooth. At each click the turning effort reached its supposedly constant maximum. This ratchet type of pressure control worked reasonably well as a substitute for skill in ordinary measurement, and its accuracy was sufficient for the measurement of various kinds of metals.

In the measurement of somewhat compressible materials such as paper and fabrics it is obviously necessary that the degree to which the material is compressed by the measuring instrument be more accurately controlled. The measurement of paper has long been a problem of the industry and has led to the use of a wide variety of instruments. The need for accuracy is indicated by the fact that large quantities of condenser paper are produced in thicknesses of 0.0003, 0.0004, and 0.0005 inch.

The new device developed by the Laboratories does not depend on friction for its functioning, since the torque of the operator's fingers is transmitted entirely by winding a helical spring through a fixed angle. Its operation can be understood readily by comparison with the conventional ratchet. It has a member which is rotatable independently of the micrometer barrel and is turned by the operator. This member, instead of being in contact with the micrometer barrel through the friction surface of the ratchet, is connected to it by a light helical spring. The rotatable member is turned to bring the micrometer spindle into contact with the work and the turning continues, not until the ratchet clicks, but until scribed lines on the rotatable member and the micrometer barrel are brought into alignment. When these lines are aligned the helical spring has been given a predetermined displacement from its rest position and the proper torque has been applied to the micrometer spindle.

A model of the new device with the outer housing removed to expose the helical spring is shown in Figure 1.

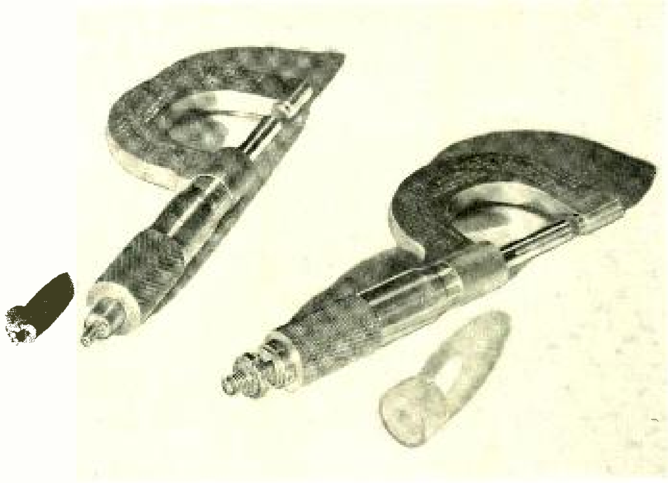
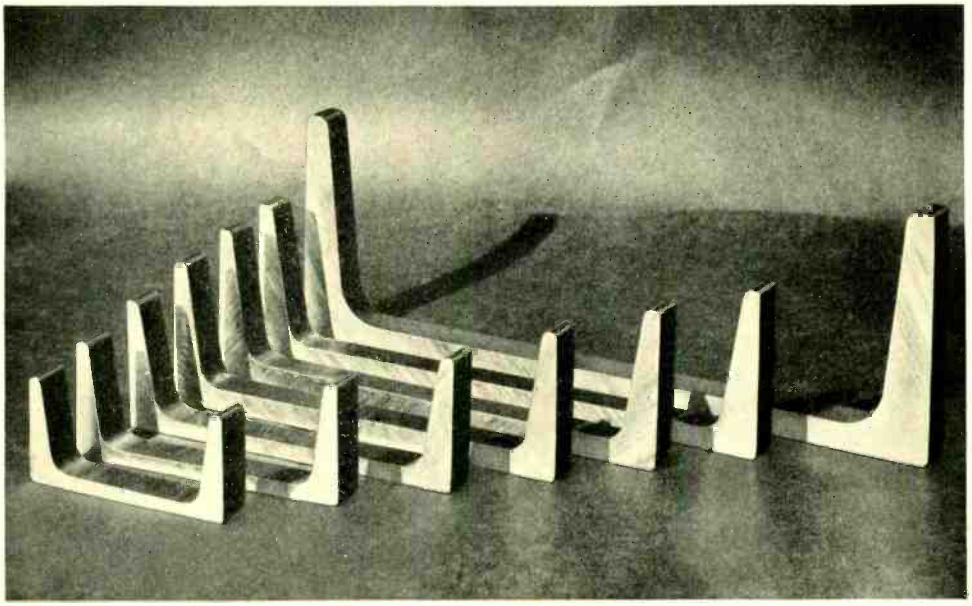


Fig. 1—The new calipers at the right has a coiled spring to control the pressure on the specimen instead of the usual ratchet shown on the calipers at the left

To permit calibration and adjustment of the ratchet to give a definite torque one end of the spring is mounted in a washer which may be locked in any angular position on the rotatable sleeve.

The new "ratchet" is not only less subject to changes in calibration than the older friction type but it may be readily adjusted while assembled on the micrometer by merely removing the cover. This contrasts strongly with the calibration of the old type which requires a series of cut-and-try operations, each involving disassembling and reassembling the ratchet.



Aluminum Alloy Structural Materials

By W. J. FARMER
Materials Development

IN common with numerous industries in the country, the Bell System has greatly extended its use of aluminum and of aluminum alloys during recent years. Where lightness of weight is an important factor, or where lower costs or increased efficiency result from its use, aluminum in many instances has replaced steel, brass or bronze. Several years ago the adoption of sheet aluminum alloys* for diaphragms in receivers and transmitters made possible a higher standard of voice quality and operating efficiency than was attainable with other common metals. Many Bell System apparatus parts are now die-cast from aluminum alloys†.

The use of aluminum alloys dates back twenty-five years when Dr. A. Wilm was engaged in his laboratories at Duren, Germany, in experiments with aluminum to which small amounts of other elements had been added. He heated the combination to about 500° C., quenched it, and found that its strength was greatly increased. At the time of this discovery, practically all metallic structural material was made of steel. It was little thought that in the span of a few years aluminum alloys would become keen competitors of steel for such structural purposes.

Aluminum alloys are particularly useful in equipment where maximum mechanical strength with a minimum of weight is required. A rough comparison between a strong heat-treated aluminum alloy and soft structural steel shows that they have approximately equal strengths and elonga-

*Record, *January*, 1929, *p*. 190.
†Record, *June*, 1930, *p*. 468.

tions. The cost of the aluminum alloy per pound is at present approximately five times that of steel but corresponding aluminum parts weigh only 1/3 as much. Consequently the actual cost of using heat-treated aluminum alloys is only about twice that for steel of equal volume. Where light weight alone is desired and strength is not of major importance, an aluminum alloy which does not respond to heat treatment may serve the purpose. Such alloys are only slightly more costly than steel from the standpoint of volume.

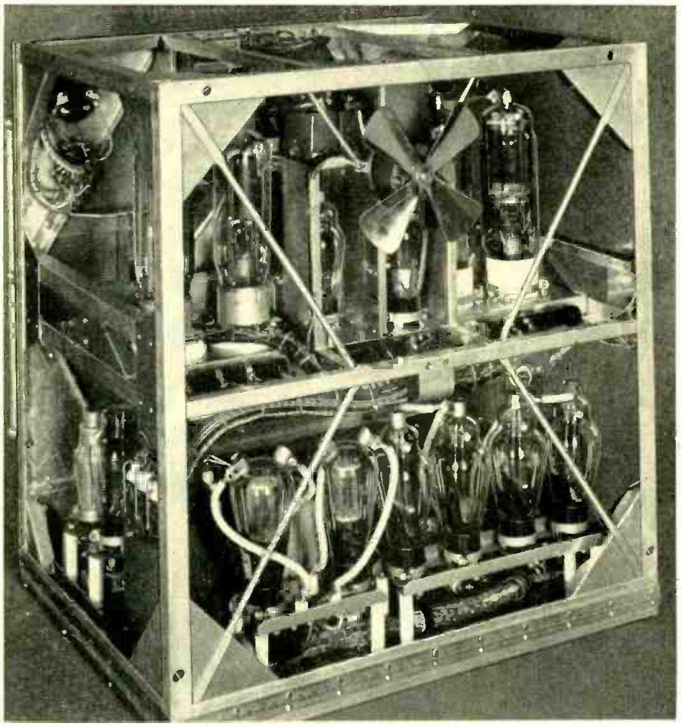


Fig. 2—Aluminum alloys are used extensively for radio telephone apparatus in aircraft

Standard structural parts are available in aluminum alloys and these can be supplied in the heat-treated condition. Hundreds of special shapes are made in addition to wood and machine screws, nuts, washers, rivets, nails and bolts. The standard sizes in wire, rod, bar, strip, sheet, tubing, pipe and pipe-fittings are also readily obtainable.

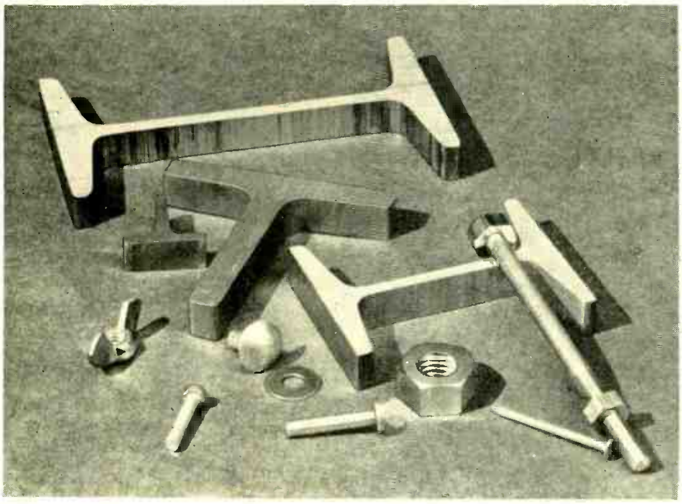


Fig. 1—An assortment of structural parts made from aluminum alloys

These materials are to be had in several aluminum-alloy compositions and may be procured in various temper conditions. This variety of shapes, alloys and tempers is advantageous in meeting the requirements of design for telephone apparatus.

Other factors to consider in selecting an alloy are corrosion and finish. Aluminum and aluminum alloys are generally far superior to steel from a corrosion standpoint. In many cases, especially for inside use, the finishes on the product as it leaves the manufacturer are sufficient. A considerable saving is thus effected in substituting aluminum materials for those that must have a protective finish even indoors. Structural aluminum shapes are furnished in surface finishes designated as machined, dipped or satin, bright, extra bright, and buffed.

A great many accessories are now made from aluminum alloys and these are quite essential in the maintenance of light weight in a complete assembly. These accessories include rivets, machine and wood screws, nuts, bolts, escutcheon pins, turn buckles, nails, washers, and so forth. The machine screws meet the four classes of limits in the American National coarse and fine thread series. These parts are strong, dependable, non-corrosive and a satisfactory substitute for steel, brass or bronze in those many instances where they are used in the extensive plant of the telephone system.

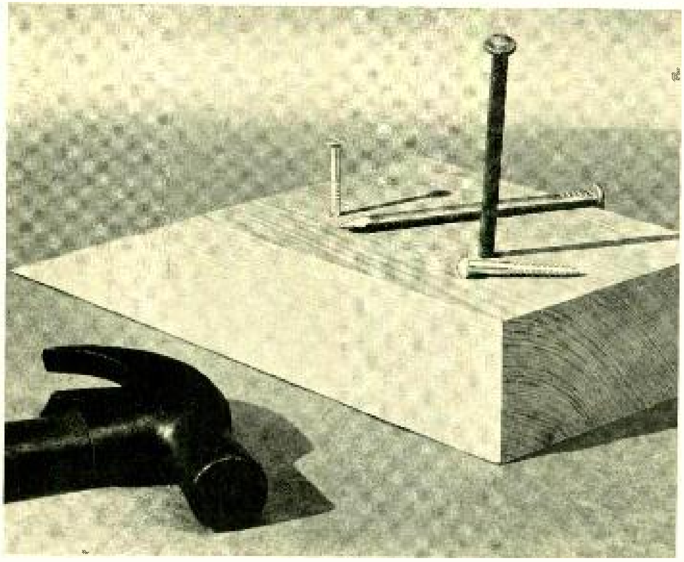


Fig. 3—Large nails and flat-head and round-head wood screws made from aluminum alloys have about one-third the weight of similar pieces made of steel

The great increase in the use of aluminum products within recent years is chiefly attributable to the reduction in weight their use affords. Minimum weight is a factor given greater consideration than ever before in industry, and particularly is this true in telephone work. Along with low weight, it has been convincingly demonstrated that aluminum possesses many of the other advantages that were popularly thought to be confined to the heavier materials.

An outstanding factor contributing to the remarkably low weight of Western Electric aircraft radio apparatus is the employment of many aluminum parts. Uses in the telephone plant, in central office and other apparatus, are already extensive and constantly increasing. Aluminum has its limitations particularly when high elastic strength is a factor and there are conditions where it is obviously unfit for the services performed by materials in present use; but the fact remains that it is steadily pushing its way into wider use as new and improved alloys are developed.

The Teletypewriter Exchange Network

By FRED J. SINGER
Telegraph Switching Engineer

THE nation-wide teletypewriter exchange service offered by the Bell System permits any subscriber to the service to request a connection to be established between his station and one or more other stations in the network in much the same manner as with the telephone service. To set up these connections, teletypewriter centers have been established in about 160 cities and towns. Direct circuits between all of these centers would require a complicated and expensive plant so a regional switching plan has been worked out on a basis similar to that used for long-distance telephony.

The country has been divided into regions with one teletypewriter center in each region designated as "regional center." These centers (New York, Atlanta, Chicago, St. Louis, Dallas, Denver, San Francisco, and Los Angeles) are interconnected by direct trunks, which form the backbone of the complete network. In each region there are a number of smaller centers known as "routing centers" which generally have direct trunks to the regional center. In a large number of cases the "routing centers" in each region are also interconnected. Still other centers in each region, which because of their geographical location are not required to handle through connections, have direct trunks to only one routing center or to the regional center. These centers are known as "single outlet offices."

At each center a manual switchboard is provided, which contains the necessary line and cord equipment,

Fig. 1—A typical teletypewriter station

open wire is used, neutral or direct-current duplex operation is employed with a repeater at one or both ends of the subscriber's line. In certain isolated cases a carrier or metallic telegraph circuit, either alone or in tandem with a grounded telegraph circuit, is used as the interconnecting link between switchboard and station.

In still other isolated cases, where telegraph line facilities are not available or where it is not economical to use them, service between the switchboard and the outlying station is furnished over a telephone circuit. When the subscriber calls, a lamp signal appears in the nearest telephone switchboard; an operator there establishes connection, by telephone methods, with the teletypewriter board; and the operator there communicates with the subscriber by teletypewriter. With this plan of operation the station and switchboard terminating circuits are arranged to convert the d-c teletypewriter pulses to a-c voice-frequency pulses, which pass over the telephone circuit.

including teletypewriters, to permit various connections to be established and supervised. In the large switching centers where the traffic requires a considerable number of operators, the No. 1* multiple type teletypewriter switchboard is provided. In the medium-sized centers either a No. 3 or No. 3A† multiple type of teletypewriter switchboard is installed and, in the smaller centers where one or two appearances of each line or trunk are sufficient, either the No. 65-B-1 PBX‡ type of teletypewriter switchboard or modified telegraph boards are used. Through all of the switchboards, transmission is on a direct-current basis. Subscribers within about a 35-mile radius where all-cable circuits are available are connected directly to the switchboard without repeaters.

For greater distances, or where

Between switching centers the system has been designed to permit the use of standard telegraph line facilities as trunks. The major portion of the trunks now in use are voice-frequency or high-frequency carrier telegraph, although in cable areas where the distance between switching centers is not too great a considerable amount of metallic telegraph is employed. The neutral, differential du-

*Record, *January*, 1932, *p.* 145.
†Record, *January*, 1936, *p.* 146.
‡Record, *October*, 1931, *p.* 58.

plex, bridge polar duplex and two-path polar methods of operation are also in use to a limited extent on a grounded open-wire or cable basis. Since all of these facilities are identical to those employed by the Bell System in its extensive private-wire telegraph network, it is evident that the maximum flexibility of this important part of the telegraph plant is obtained.

To simplify the planning and engineering of the plant layout, the transmission requirements of the various overall connections and of the links comprising each of these connections are expressed in terms of "telegraph transmission coefficients." In this service the number of links of various types connected in tandem are assumed to be limited to amounts such that the maximum distortions produced in the teletypewriter signals passing over the complete connection do not exceed that required for satisfactory commercial service under comparatively unfavorable plant conditions, such as bad weather, and with sufficient margin that adjustments need not be made when connections are established. With these limitations set for an overall connection, the limit of the arithmetical sum of the values of the transmission coefficients of the various links in such a connection is arbitrarily assumed to be 10. Based on transmission measurements and experience, values of transmission coefficients have been assigned to the various types of links used in TWX service.

It is therefore a simple matter of addition to determine the amount of transmission impairment to be expected for any particular connection involving a number of links of various types. This information, together with information on the volume of traffic between various centers, has made it possible to arrange the plant in a manner to minimize the amount required, and to provide sufficiently reliable facilities to insure satisfactory service with a relatively small amount of switching.

At the present time it is possible to establish approximately 80 per cent of all inter-city connections without involving more than two switching centers. Of the remaining inter-city connections, except for conference connections which involve several stations, only 1.7 per cent require more than three switching centers. By providing high-grade telegraph line facilities as inter-toll trunks between the regional centers, and either high-grade or good facilities in other cases, all connections can be set up

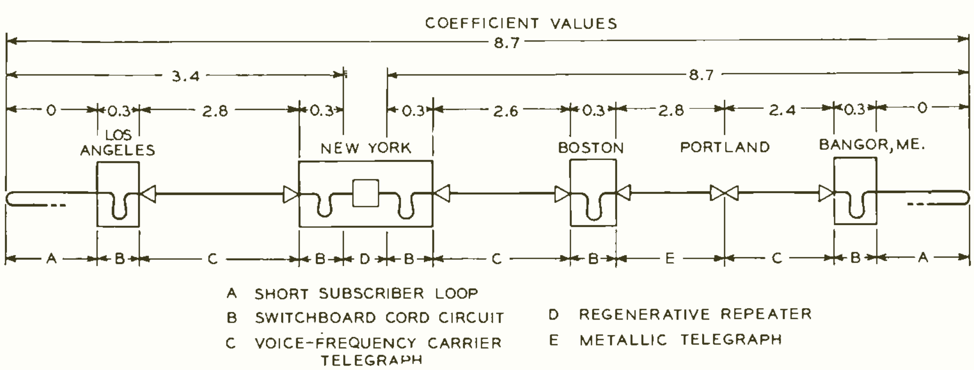


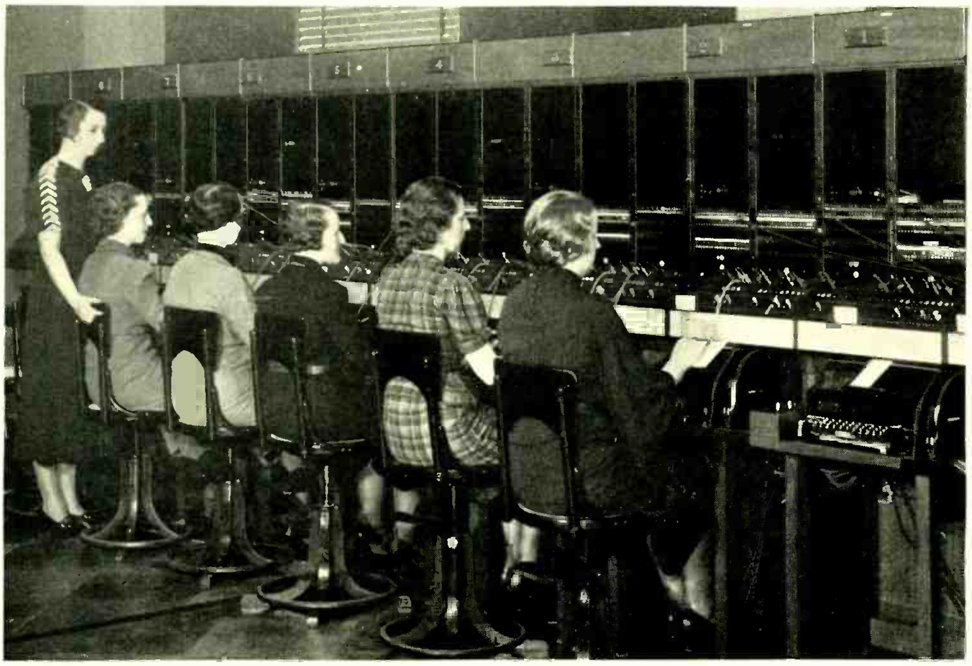
Fig. 2—A typical connection involving four switching centers and a regenerative repeater

promptly on request and satisfactory transmission is obtained without any special line-up or adjustment of circuits or apparatus.

In certain cases, such as multi-switch connections to and from the smaller centers particularly where outlying stations are involved, distortion of the signal elements would bring the overall transmission coefficient to exceed 10 if it were not corrected. This is done by inserting a regenerative repeater* — a device which restores to their original "square-topped" form the signal impulses which have become rounded off by line attenuation of the higher frequencies. In the circuit shown in Figure 2 the regenerative repeater at New York reduces the coefficient by enough to make the overall coefficient for the Los Angeles-Bangor circuit equal to that of the New York-Bangor portion. Regenerative repeaters are required only at important switching centers because a multi-switch call includes one or more of these points. These repeaters are either connected to a particular cord in the operating position or appear in the multiple so that an operator may quickly include one in a connection.

*RECORD, *July*, 1936, *p.* 355.

The TWX system has proved to be a valuable new form of communication service and it has made a commendable record, as evidenced by the more than 11,000 stations now connected to it. The average speed of service, that is, the average elapsed time after a subscriber calls until the calling and called subscribers are communicating, is 1.4 minutes. Developments will no doubt lead to further improvements in this new and important communication service.



The No. 3A Switchboard which is now installed in about 30 *centers, provides capacity for about* 1400 *subscriber lines and* 240 *inter-toll trunks*

The No. 5 Teletypewriter Switchboard

By P. V. KOOS
Equipment Development

IN providing a new communication service, there are always a number of factors that cannot be accurately known until a certain amount of actual operating experience has accumulated. When teletypewriter exchange service was inaugurated late in 1931, therefore, it was decided to employ existing facilities and designs as far as possible, and to design new boards only when the requirements were such that existing arrangements could not be made to serve economically. Only the No. 1 board,* suitable for the larger cities, was developed at first. Where only a few lines were needed, certain of the telegraph testboards were modified to give the required service, and for offices of intermediate size the non-multiple 65B1 teletypewriter PBX was used. With further experience the 3A multiple board† was developed for these intermediate-size offices. The facilities available about this time were reviewed in an article in the RECORD for September, 1936.

Since then, the 1A board‡ has been developed to supplement the No. 1 in very large offices. The large and medium-size offices were thus adequately provided for, but the small offices had available only switchboards consisting of modified telegraph test boards. The modified test board was not as satisfactory as would be equipment specifically designed for this purpose, and did not lend itself readily to further economical modification to incorporate improvements that were being applied throughout the teletypewriter exchange service system. In addition, the growth in private-line telegraph service and TWX toll circuits created a need for the telegraph test boards for their normal use and it became desirable, therefore, to provide a small non-multiple tele-

*RECORD, *January*, 1932, *p.* 145.
†RECORD, *January*, 1936, *p.* 146.
‡RECORD, *October*, 1937, *p.* 34.

typewriter switchboard that could be used in those offices where the traffic did not warrant the installation of a 3A board.

The new board developed, known as the No. 5, is shown in the photograph at the head of this article as installed at Charleston, West Virginia. It has an all-metal construction, with a neutral gray finish, and is about seven feet high, twenty-five inches wide, and twelve inches deep. As with all the new teletypewriter boards, the teletypewriter rests on a table beneath a sloping key shelf, and the top of the table is sloped to bring the operator nearer the jack field. It provides terminations for sixty local subscriber lines, for fifteen toll subscriber lines—used where the subscribers are at a considerable distance from the central office—and for eighteen intertoll trunks. Ten cord circuits are furnished for making the connections,

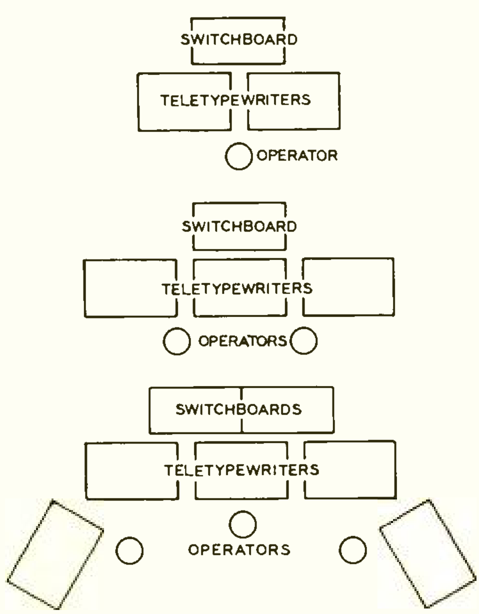


Fig. 1—Typical groupings of switchboard sections, position teletypewriters, and operators for the No. 5 teletypewriter switchboard

and three position-circuits, so that three teletypewriters may be used.

When the traffic is heavier than can be satisfactorily handled with ten cords and three position-circuits, a second section may be placed beside the first to provide ten additional cord circuits and two additional position circuits. The jack field will not be equipped in this second section—all connections being made between jacks on the original section but with cords on either section.

While a total of five position-circuits is thus provided, there will not be more than three operators employed, and with the single-section installation, not more than two. In establishing a TWX connection, a position teletypewriter must be connected to the circuit from the time the call first comes in until the connection has been completed and teletypewriter communication started between the two subscribers. The operator, however, will not be busy all the time during this period, so that if another position teletypewriter is available, she has time to be controlling more than one call during the same interval. Typical arrangements of switchboard sections, teletypewriters, and operators for various traffic conditions are indicated in Figure 1.

Each line jack has a lamp associated with it that lights on incoming calls. Each cord circuit is equipped with two lamps to give disconnect and recall signals. One of these lamps is associated with the answering cord and one with the calling cord and each is located just below its plug on the sloping key shelf. Below these lamps is a row of keys, two for each cord circuit. One of each pair is a ringing key, and the other is used to connect the cord to a position-circuit, including a teletypewriter. The latter keys may be operated up or down to allow the cord to be connected to either of two teletypewriters. The division of the various teletypewriters among the various cords is guided by local conditions, and is changed as required.

A feature that has contributed appreciably to the reduction in cost of the new board is the incorporation of the equipment to provide recall and disconnect signals in the cord circuit, instead of in the line circuits as has been the usual practice with multiple-type teletypewriter boards. This is accomplished by employing the sleeve connections of the jacks to differentiate between trunks and subscriber lines, since with a non-multiple board the sleeves are not required for a busy test or for out-of-order signals.

Besides the equipment in the switchboard there is a considerable amount of relay and miscellaneous equipment required, which is mounted on standard relay-rack bays. Ordinarily there are two of these bays, as shown in Figure 2, but under exceptional conditions, where a large number of toll subscriber lines are used, a third bay may be required. This auxiliary equipment has been designed to reduce engineering for individual installations as much as possible. The positions of the various types of equipment on the bays, and the amount of miscellaneous equipment provided, have been standardized. Only the main equipment items, such as the number of line and cord circuits, vary for different installations. The unit and bay wiring and assembling is done in the shop so that a minimum amount of work is required by the installer. Certain testing equipment is also provided on the relay bays, and a meter for transmission measurements is installed on the front of the section above the jack field.

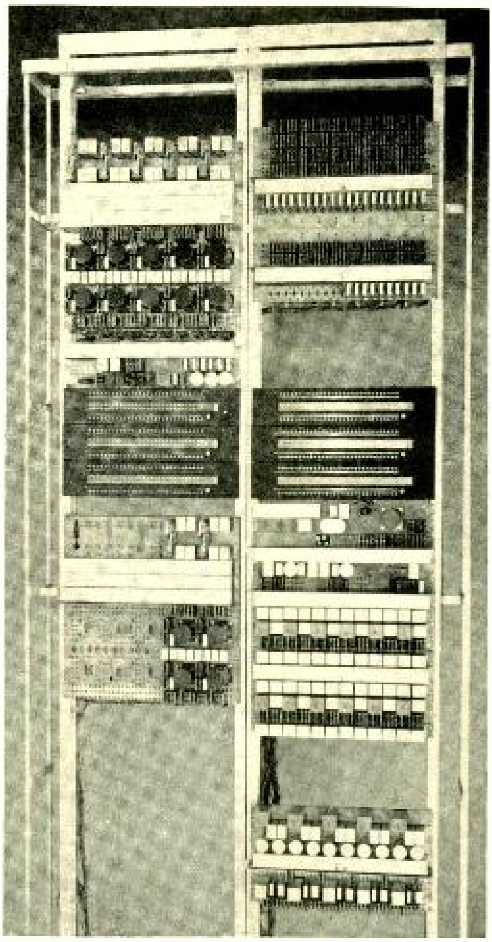


Fig. 2—From one to three bays of relay rack may be required for the No. 5 board

Testing of this equipment is done at a position of the telegraph test board and at the switchboard itself. These facilities permit usual maintenance work to be conducted by one man aided only by the operator at the switchboard, who establishes the test trunk connections. The operating and testing procedures that are involved, together with the supervisory arrangements incorporated in this new teletypewriter switchboard, provide for the smallest office facilities that are high in quality and at the same time low in cost per line.

Higher Volumes Without Overloading

By S. DOBA, Jr.
Circuit Research Department

FOR many years, a major problem in radio broadcasting has been how to utilize as effectively as possible the available power of a broadcast transmitter so as to render the best service to the maximum number of listeners. As one moves outward from a transmitter, a point will finally be reached where the signals received by the listener become so weak that the softer parts of the program are masked by static and other electrical noise, and beyond that point noise prevents good reception. Anything that increases the signal strength of the softer parts of the program being transmitted, therefore, extends the area throughout which good reception is possible.

For a given transmitter the strength of the loudest portions of the program is limited by the maximum level that can be applied to the transmitter without overloading it. With the maximum level thus limited, it follows that the narrower the volume range of a program the stronger will be the soft parts of the program and the farther from the transmitter is good reception possible. Most programs have a fairly narrow volume range, the loud and soft portions rarely differing by more than 30 or 40 db, but occasional programs such as symphony orchestral music may have volume ranges exceeding 60 db. It would be desirable to transmit to the listener the full volume range of a program, but in the interest of the best service to the most listeners, it is the practice to effect a compromise between volume range and noise interference at the receivers by reducing the volume range of those programs having initially the wider ranges before applying them to the transmitter. A further factor justifying limitation of the volume range is that under average conditions in a home, the transmission of a very wide range of volume would result in the soft portion of the program being submerged and lost in the room noise or set noise, even when static and other electrical noise is negligible.

In practice the volume range of the programs is controlled by having an operator at the studio monitor the program and make manual adjustments to keep the program levels within certain limits. The operator listens to the program and watches a

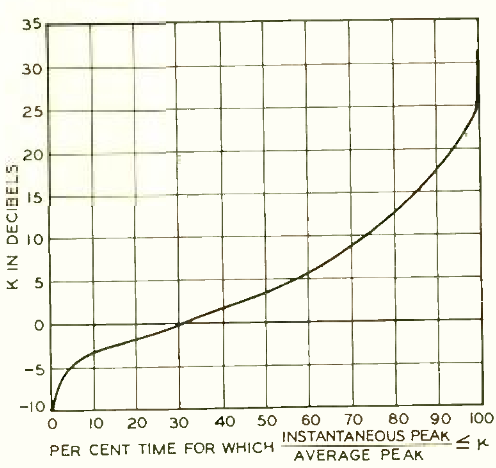


Fig. 1—Time distribution of peak power of a representative 75-piece orchestra

volume indicator, and makes adjustments to reduce the levels of the louder portions and to raise the levels of the weaker portions of the program, keeping the general levels as high as possible without overloading the transmitter. Very prompt action on his part is required, and he must become familiar with the most rapid and extensive changes in program loudness during rehearsals so that he can slightly anticipate them at the actual performance.

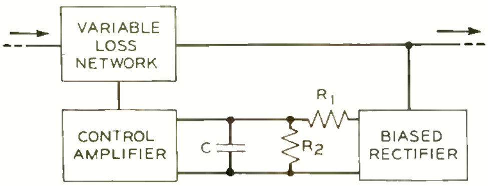


Fig. 2—Simplified block schematic of the volume control circuit

The situation is further complicated by the presence of sudden peaks of short duration that are too rapid for him to control. In raising the gain to give full modulation of the transmitter, therefore, he must consider these sudden peaks of power that would overload the transmitter and introduce distortion. Occasional overloads of short duration are not particularly objectionable, and the monitoring operator determines by trial some point below full modulation, perhaps 7 or 8 db, to which he may safely raise the gain for the higher amplitude portions of the program. This 7 or 8 db leeway that he allows is enough to insure, with careful monitoring, that only an occasional peak will actually overload the transmitter.

A typical variation in volume for a 75-piece orchestra is shown in Figure 1, where the ordinate gives the ratio in db of the instantaneous to the average peak power, and the abscissa, the percentage of time that this energy ratio of the program is equal to or below that indicated by the ordinate. Thus, for example, the instantaneous peak power is at or below the average for 31 per cent of the time, and it is not more than 25 db above the average during 99 per cent of the time. It may go 25 to 32 db above average, but this occurs only 1.0 per cent of the time. Other programs would have somewhat different curves but their general shape would be similar.

The volume at which the monitoring operator can permit the program to be transmitted depends upon the magnitude and duration of these short peaks. Obviously his work would be lightened, and a higher average signal strength could be maintained, if some arrangement could be provided for automatically limiting the amplitude of these peaks without causing serious distortion, or materially affecting the dramatic effect of the musical passage. Because of its importance, this requirement was carefully studied, and various ways of accomplishing it were considered. As a result a gain-regulating circuit was developed that seemed suitable from the standpoint of theoretical considerations, and also proved satisfactory in actual trials. In simplified block form, its circuit is shown in Figure 2. There are a variable loss network in the transmission path, a

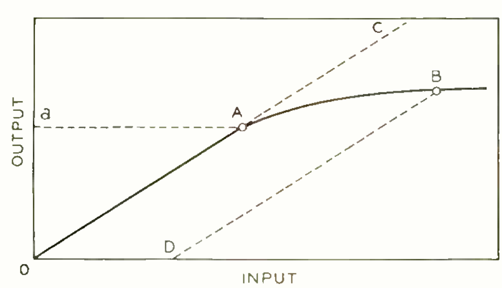


Fig. 3—Input-output characteristics of the controlled network

biased rectifier to rectify a portion of the output beyond the loss network, a timing circuit consisting of a condenser and resistances, and an amplifier to control the loss introduced by the network.

The action of the circuit is quite simple. Up to a predetermined output of the signal, the bias on the rectifier is such that the control circuit is essentially inactive, and the loss inserted by the network remains constant at its minimum value. When the signal output exceeds this predetermined value, however, the rectifier provides a negative voltage on the grid of the control amplifier, and the decreasing current of the amplifier increases the loss in the network, and thus decreases the output. It is essential that the change in loss be slow

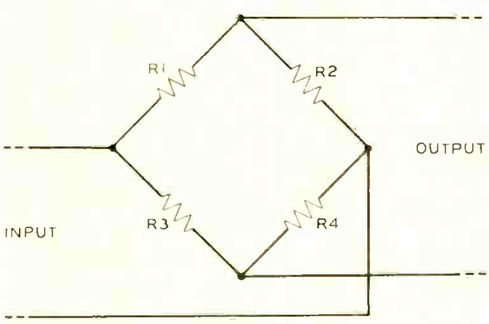


Fig. 4—The four resistors are arranged in a bridge network, with provision (not shown) made for passing direct current through R_1R_4 and R_2R_3

compared to the periods of the component frequencies of the signal, but fast compared to the normal changes in amplitude of the program. It must be fast enough to follow the increases in amplitude of the program but not so fast as to follow the wave form of the lower program frequencies, since this would result in a flattening of the waves of the component frequencies, and cause distortion. The timing circuit consists of the condenser C, the shunt resistance R2, and the series resistance R1, which is the effective resistance of the rectifier. The condenser must charge through the resistance R1 before the effect of the increased signal can increase the loss, and it must discharge through resistance R2 before the effect of a decreasing signal can decrease the loss. The two times may thus be controlled independently by properly selecting the values of R1 and R2.

The effect of such a device on transmission is indicated by Figure 3, on which the input to the variable loss network is represented along the abscissa axis, and the output on the ordinate axis. With minimum loss in the network the input-output curve would be line OC. The point A on this curve represents the signal strength at which the bias of the rectifier is overcome and the loss in the network begins to change. For all outputs between O and *a*, therefore, there is no change in the network, and OA is the input-output curve. As the output rises above *a*, however, the loss in the network is increased, and the gain is reduced, the output following the curve AB. At the point B, for example, the loss inserted by the network is such that the input-output curve becomes the line DB. If no further change were made in the loss network after the point B was reached, the input-output curve would be DB. The curve AB thus represents the upper limits of a series of input-output curves parallel to OA, the particular curve on which the circuit is operating at any moment depending on the loss inserted by the network.

The loss network consists of four varistors arranged in a bridge network and inserted in the circuit as indicated by Figure 4. The ratio of the output signal to the input signal of such a circuit is proportional to the expression ($R_1R_4 - R_2R_3$). When used as a Wheatstone bridge R_1R_4 is made equal to R_2R_3 for the balanced condition, and the output is zero. As used for volume control, however, R_1R_4 is always considerably greater than R_2R_3, and the output of the circuit is a function of their difference.

The resistance of these varistor units varies inversely with the current flowing through them, so that it is possible to control the output of the network by controlling the direct current through R_2R_3 and R_1R_4. This is done by sending current from a constant source of potential through a parallel-series circuit with R_1 and R_2 in one branch and R_3 and R_4 in the other. Another circuit, through the control amplifier, sends current through R_1 and R_4 in a direction opposite to, and a current through R_2 and R_3 in a direction the same as that due to the constant potential. Up to the critical value of output, the control amplifier has a minimum grid bias and its plate current is a maximum, with the result that R_1R_4 is large compared to R_2R_3, and the loss inserted by the network is a minimum. As the critical output is exceeded, the bias on the control amplifier becomes negative, and its output decreases. This results in increasing the value of R_2R_3 and decreasing the value of R_1R_4, so that the loss that has been inserted by the network increases.

These resistors and their supply circuits are connected into the circuit as shown in Figure 5. The network is coupled to the input and output circuits through impedance-matching transformers T_1 and T_2, and the d-c control current is fed to it through mid-taps on these transformers so that the current flows in opposite directions in the two halves of the winding and produces no net effect on the flux in the core. Current from the battery E_2 divides at the

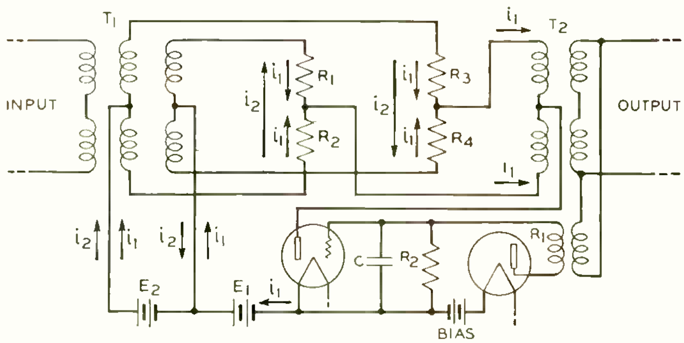
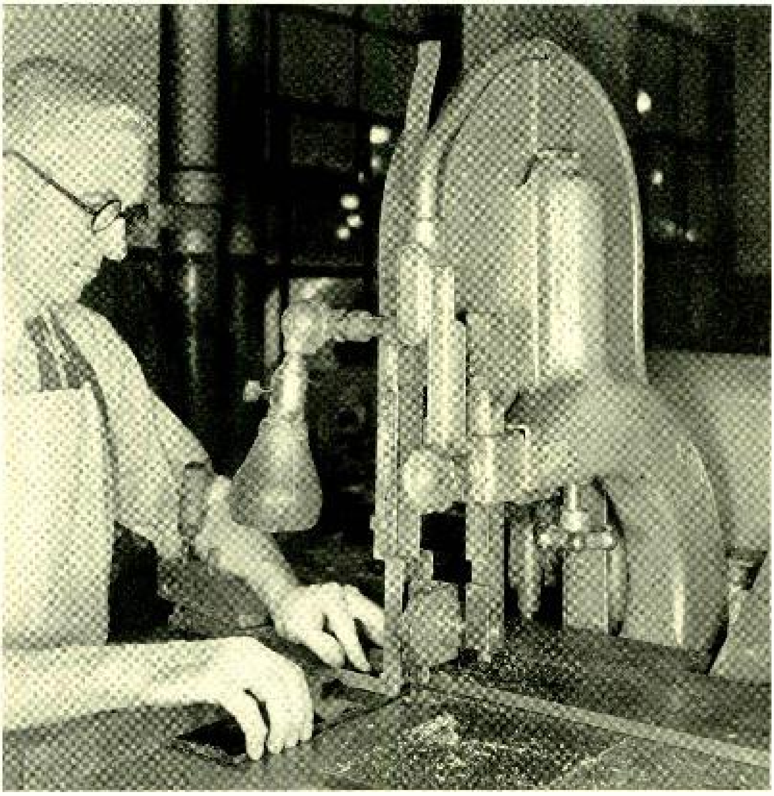


Fig. 5—Arrangement of variable-loss network in the transmission circuit

mid-point of a winding on T_1 into two parallel paths—one through R_3 and R_4 in series and the other through R_1 and R_2 in series. These currents, i_2, and their directions are indicated by the arrows on the diagram. Current from the control amplifier follows two paths, one leading to the mid-point of each secondary winding of T_1. One part of the control current thus passes through R_2 and R_3, and the other part through R_1 and R_4. These components of current passing through the control amplifier are marked i_1 on Figure 5, and from the directions indicated, it will be seen that i_1 opposes i_2 in R_1 and R_4 and assists i_1 in R_2 and R_3. The relative values of R_2R_3 and R_1R_4 thus depend on the current from the control amplifier, and the greater the control current, the larger will be R_1R_4 and the smaller will be R_2R_3.

For a volume control device to be

used at voice frequencies, it is essential to prevent the control current from passing into the output where it would appear as an audible disturbance. The circuit described above provides the accurate balance needed for this purpose. In addition it maintains a constant impedance for the circuit regardless of the loss it introduces. Furthermore, the bridge type circuit insures that the inherent shunt capacitances across the varistor units have a fixed effect on the loss, and their influence on the circuit can be allowed for in the original design. As a further advantage the varistors are very stable—maintaining the same values over very long periods of time. In view of its expected wide application, later models of this circuit have been designed for operation entirely on alternating current supply.



In the Laboratories Development Shop: Joseph Kelly at a band saw

A Volume-Limiting Amplifier

By O. M. HOVGAARD
Radio Development

PROBABLY no single factor is of greater economic importance to radio broadcasters than the level of modulation of their radiated program. For a given carrier power, it is the level of modulation that determines the area over which a program is heard, and thus approximately the population reached. More listeners, of course, mean a greater response to the advertising appeal and thus a greater potential income, so that the economic importance of a higher modulation level is obvious. On the other hand, distortion is caused by overmodulation, and increases rapidly as the program level is raised. Program peaks which exceed the level for complete modulation generate harmonics and cause interference with other programs on adjacent channels as well as distortion of their own program. As a result one of the important functions of a monitoring operator in maintaining the highest practicable program level is the manipulation of the circuit gain so as to prevent overmodulation during program peaks. In this he is guided by a level-indicating device, and frequently has the benefit of program rehearsals, but human limitations rather than the level-indicating means usually determine the maximum general program level that can be maintained by the utilization of this method.

To obtain maximum level with greater assurance of freedom from overmodulation, a new volume control device has recently been developed. It is known as the Western Electric 110A program amplifier, and is based on a circuit developed by the research department and described in an accompanying article. The original circuit was modified, however, to permit operation from the usual 110-volt, fifty- or sixty-cycle a-c power supply, and was arranged to be completely contained in a relay-rack mounting cabinet as shown in the lower panel in the photograph at the head of this article. The terminating impedances are six hundred ohms, and the overall gain is fifty-five db. The transmission-frequency characteristic is held flat to within one db from thirty to ten thousand cycles. This new volume-control device can be used with input levels in the range from −35 to +5 db, and output levels from −7.5 to +20 db can be obtained. These levels are for a single-frequency steady-state tone referred to six milliwatts, and adjustments are effected through fixed pads supplemented by input and output gain controls, each of these controls having nineteen one-db steps.

Figure 1 is a simplified semi-block schematic of the 110A program amplifier, and shows the volume-control network interposed between the input and output amplifiers, and their associated pads and gain controls. A portion of the output from the volume-control network is amplified and applied to a biased full-wave rectifier. Whenever the applied signal exceeds the bias, a d-c potential appears across the condenser c of a time-constant network formed by c and R. This is applied to the grid of a d-c amplifier, acting as a control tube, and the plate current of this tube, in turn, flows through the volume-control network, and determines the loss through it. As long as the signal level remains below that necessary to overcome the bias on the rectifier, the grid potential of the control tube will remain zero, and the control current, and hence the loss through the volume-control network, will remain constant. If the level rises above the bias on the rectifier, however, the bias on the control tube will become negative. This causes the control current to decrease, thereby inserting loss in the program circuit.

For program levels sufficient to overcome the rectifier bias, the growth of potential across the condenser c will lag behind the growth of the corresponding signal potential. Similarly a decrease of potential across c will lag behind the corresponding decrease in the program level. These time lags are determined by the constants selected for the time-control network. During periods of signal growth, the condenser c is charged through the resistance of the rectifier and voltage source in series; during periods of signal drop it discharges through the

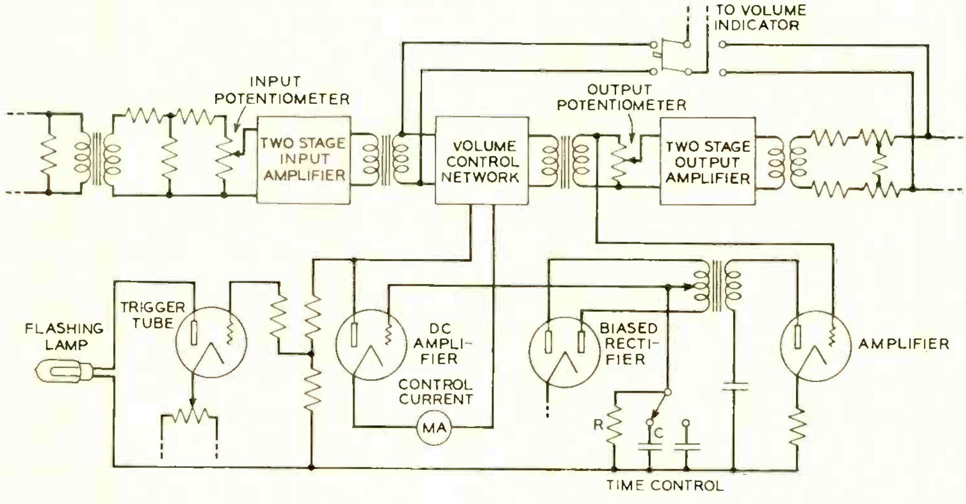


Fig. 1—Simplified schematic of the 110A program amplifier circuit

resistor R. Figure 2 shows the voltage-time relationship for a condenser charged through a resistor. The applied voltage is assumed to be a constant potential, and the time for complete charge is taken as that necessary to bring the potential across the condenser to 99 per cent of the applied voltage. The same curve also gives the conditions during the discharging cycle, in which case the ordinates indicate the percentage of the initial potential which has been removed, on the assumption that the charging potential was shorted at time $t=0$. The curve is for static conditions with a constant applied potential, and thus represents a limiting case, but it is convenient for the purpose in hand. With increasing or decreasing potentials, curves of different shapes would be obtained, but all of them would lie below and to the right of the one shown. C and R have been selected so that if a steady-state single-frequency tone is applied to the rectifier, the potential across C will reach a value corresponding to the peak value of the signal wave, and will remain at this value as long as the signal remains. This bias will cause a corresponding change in the plate current of the control tube, and thus cause the insertion of a fixed amount of loss.

An input-output characteristic of a 110A program amplifier, obtained by varying the input level of a steady-state single-frequency tone, is shown by the curve ABD on Figure 3. B is the input level necessary to overcome the rectifier bias, and BC is the extension of the linear portion AB of the characteristic. At any input level greater than B, the vertical distance between BC and BD is the amount of loss which has been inserted. If for instance a steady-state tone of peak value +12 had been applied, about 5.5 db of loss would have been inserted. Since the potential across the condenser C remains at a steady value, the loss remains fixed and the operating characteristic for the cyclic variations of the tone will be the straight line MN. The curve BD is therefore the locus for the end points of a series of linear

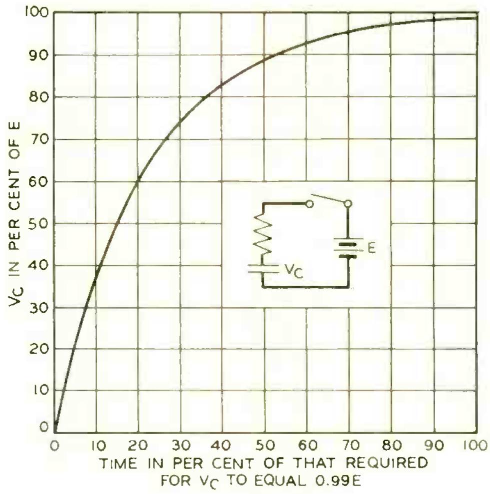


Fig. 2—Charging curve for the time-constant circuit

input-output characteristics whose location depends upon the peak value of the applied signal. With voice or music, where the signal varies rapidly in intensity, the location of the input-output characteristic will depend upon the magnitude of the signal peak, its duration, the wave shape, and upon the constants of the time-control network. These must be selected with due regard for the application for which the amplifier is intended.

Since the primary purpose of the device is to prevent over-modulation by program peaks, the time required for the insertion of loss must be sufficiently short to permit these peaks to be materially reduced. On the other hand, it must not be so short that the sudden stoppage in signal growth becomes noticeable to those listening to the program. The time needed for removal of loss must be made long enough so that the loss-control network will not follow cyclic variations in the program at the lowest frequencies which it is desired to transmit, and short enough so that there will be no noticeable growth in the background noise as the program circuit gain is restored during a silent period immediately following a crescendo. Obviously, the selection of constants for the time-control circuit is a compromise. In the 110A program amplifier these are chosen so that, in the limiting case of Figure 2, twenty milliseconds are required to insert, and 250 milliseconds to remove, 99 per cent of the loss. Means are provided for selecting either of two values for C; one giving the above values, and the other giving transient periods approximately half the above. Distortion due to the action of the control circuit is limited to those portions of the program peaks which exceed the rectifier bias, and then occurs only during the rapid insertion of loss. Even though the removal of loss may take place at levels below that corresponding to the rectifier bias, the distortion that results will be unnoticeable due to the slow rate of removal.

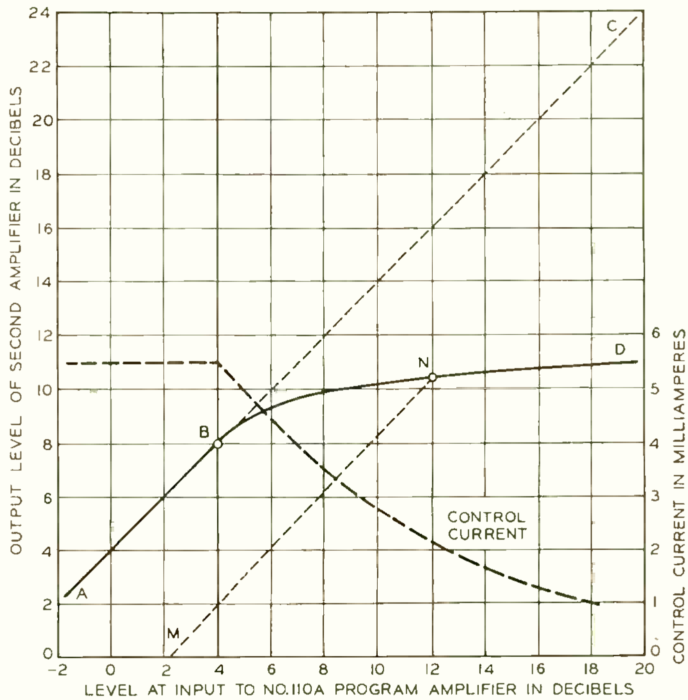


Fig. 3—A typical input-output characteristic of the program amplifier with a plot of the central current

In applying the 110A program amplifier to a broadcast transmitter for preventing overmodulation, its location in the program circuit and its adjustment are important factors in determining the benefits to be derived. Since the level at which the volume-control network commences to vary the circuit gain is fixed by the design, it is desirable to insert the amplifier at a point where the transmission levels are essentially constant regardless of their character or origin. This suggests associating the amplifier with the transmitter, and with this in mind, sufficient gain and flexibility have been provided so that it may serve as the line amplifier connecting the incoming program circuit to the radio transmitter.

The proper adjustment of the operating levels of the amplifier requires a consideration of the characteristics of the volume-control network. From Figure 3 it will be seen that as the input is raised beyond the level B, the output will continue to rise as shown by the portion BD of the characteristic. This characteristic is for a steady-state single-frequency tone, however, and the dynamic characteristic will lie instead somewhere in the region between BC and BD, its shape and location being determined by the magnitude of the peak, its duration, the wave shape, and the constants of the time control network. If, therefore, the instrument is to prevent serious overmodulation, it must commence to insert loss at levels below that required for complete modulation.

Figure 4 shows a possible adjustment. An output level of +10 is assumed to modulate the transmitter completely, and the dotted line EF is the input-output characteristic of a conventional line amplifier. ABD is the characteristic of a 110A program amplifier adjusted so that line inputs which gave complete modulation with the conventional amplifier will also give complete modulation with the 110A program amplifier. For the particular conditions shown, loss will

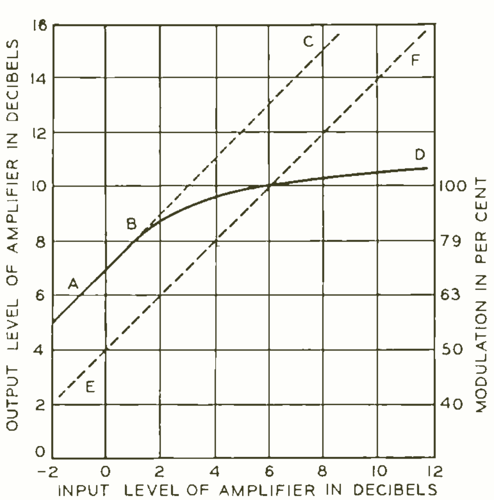


Fig. 4—With the program amplifier in the circuit the general program level is raised by an amount equal to the loss that is inserted at full modulation

be inserted for all levels in excess of that required for about eighty per cent modulation. For steady-state single-frequency tone about three db will have been inserted at one hundred per cent modulation, and the curve BD flattens out so that a modulation of 108 per cent is about the highest that can be reached regardless of what the input level may be.

As compared with the conventional line amplifier, the use of the 110A program amplifier results in an increase in the general program level somewhat less than the loss inserted at complete modulation. For the conditions assumed for Figure 4, it is evident that the output level is three db higher than it would be with a conventional line amplifier up to the point B. From this point to an input level of six db, where the two curves cross, the increase in general level decreases from three db to zero. Since the volume control network does not act instantaneously, however, the removal of loss is delayed by a period which may be long compared to the duration of the peak that caused its insertion, and as a result the increase that is obtainable in the general program level cannot be realized during the intervals of loss removal.

The portion of the total time during which an increase can be obtained depends upon the number and distribution of peaks and their duration, which factors are in turn determined by the character of the program and the level at which it is applied to the input of the amplifier. Other factors remaining fixed, the greater the loss inserted at complete modulation, the shorter will be the time during which a corresponding increase will be realized at the lower program levels. Furthermore, the ratio of maximum to average peak levels of the program is reduced by the action of the amplifier, and when the volume range of the program is less than that which the transmitter can accommodate, the volume range is reduced by an amount corresponding to the loss inserted at the one hundred per cent modulation level.

Based upon the experience obtained to date, the amplifier may be lined up so that for a steady-state single-frequency tone it will insert about three db of loss at the one hundred per cent modulation level without introducing any noticeable distortion or loss of fidelity in the program. Since, with this adjustment, peaks of modulation high enough to insert loss are relatively infrequent, a corresponding improvement of three db will be realized in the general program level. An improvement of this order is of course equivalent to doubling the rated carrier power of the transmitter, and is therefore decidedly worth while, particularly since it involves no change in the operating technique required for the station.

Contributors to This Issue

O. M. Hovgaard brought to the Laboratories a varied radio experience when he joined the Radio Apparatus Development group in 1928. After leaving Massachusetts Institute of Technology in 1919 after his freshman year, he worked as a radiotelegraph operator; returning to the Institute, he received the B.S. degree in electrical engineering in 1926, then worked for various manufacturers on the design of transformers and chokes and on power-supply apparatus for radio receivers.

During his first year with the Laboratories, he worked on broadcasting antenna problems and the development of frequency controls for use in aircraft transmitters. From 1929 until recently, he supervised the development and manufacture of frequency controls for radio apparatus and the design of antennas for broadcast stations, as well as conducting radio transmission studies. He is now in charge of a group engaged in fundamental studies of switching contacts and contact devices.

O. M. Hovgaard

C. B. Feldman received from the University of Minnesota the degree of B.S. in 1926, and the degree of M.S. two years later. He came at once to the Laboratories and has been conducting studies of wave propagation, in the course of which he has had a large part in developing coaxial conductors for use as transmission lines between radio receivers and their associated antennas.

W. M. Sharpless graduated from the University of Minnesota in 1928 with the degree of B.Sc. in Electrical Engineering. Coming at once to New York, he joined the Technical Staff of these Laboratories, becoming a member of the Radio Research group, then located at Cliffwood, New Jersey. He has since participated in many phases of radio transmission

C. B. Feldman

D. Mitchell

studies at the Holmdel Station. In the past years he has been active in the investigations of short-wave radio problems especially where ground effects and angle of arrival of signals have been concerned. These studies have resulted in the receivers described in this issue.

D. Mitchell joined the Department of Development and Research of the American Telephone and Telegraph Company immediately after graduating from Princeton University with the degree of B.S. in 1925. He transferred to the Laboratories in 1934. His time has been largely devoted to problems involved in interconnecting radio and wire telephone circuits. More recently he has worked mainly on the application of voice-operated devices to wire lines with a brief interval spent on developing special testing apparatus for telephotograph circuits.

W. W. Werring graduated from Cornell with the degree of M.E. in 1922 and joined the Laboratories that year as a member of the Apparatus Analysis and Materials group. Later he was assigned exclusively to materials engineering where he specialized on insulating materials. For several years he was in charge of the development work on plastic moulding and the application of moulded design to telephone apparatus. Recently he was placed in charge of the Precision Measurements and Standards Laboratory, and the development work on welding and studies of the mechanics of materials.

In August, 1922, F. J. Singer joined the Department of Development and Research of the American Telephone and Telegraph Company and, with that organization, became associated with the Equipment Development group. For a number of years he was engaged in the development of the first carrier-telegraph systems used in cables and of d-c grounded telegraph systems. In 1929 he was placed in charge of a group of engineers engaged in the development of telegraph switching systems and telegraph test boards. The switching arrangements included manual and dial systems for use by private-wire customers of the Bell System and the switchboards and associated arrangements now in use in the teletypewriter

W. M. Sharpless

W. W. Werring

F. J. Singer

S. Doba, Jr.

network. Since the transfer of the Development and Research Department to the Laboratories in 1934, Mr. Singer has continued the same type of work as Telegraph Switching Engineer of the Facilities group. He is a graduate in electrical engineering of the University of Washington and of the University of Wisconsin.

After graduating from Pratt Institute in 1922 W. J. Farmer joined the Specifications group of the Laboratories. He transferred to the Materials Engineering group in 1924 when it was organized and spent several years as consultant for other groups on problems relating to aluminum and its alloys. This included the selection and heat treatment of diaphragm material for microphones and transmitters and the development of the aluminum alloys used in light valves for sound picture recording. From 1931 to 1933 he was with the Apparatus Analysis group. He is now engaged in studies relating to aerial cable sheathing materials.

S. Doba, Jr., joined the Laboratories in 1926, and for a brief time was engaged in low-frequency telegraph studies. For the past ten years, however, his work has been with the Research Department in connection with voice-operated devices. These include vogads and compandors for radio telephone circuits and echo suppressors for long toll systems.

Paul V. Koos was graduated from the University of Wisconsin in June, 1927, with the degree of B.S. in E.E., and became a member of the Laboratories directly afterwards. As a member of the Systems Development Department he spent his first two years in job engineering work on initial and trial installations of new equipment, including that used in transatlantic radio-telephone systems. The following four years he was associated with a group which analyzes special or new problems in connection with orders placed on the Western Electric Company. He also edited equipment questionnaires covering panel and step-by-step central offices and toll and telegraph terminal room equipments. Since March, 1933, he has been engaged in the design and development of telegraph equipment.

W. J. Farmer

P. V. Koos