BELL LABORATORIES RECORD

MATHEMATICS AND COMMUNICATION
J. R. CARSON

DOWSING FOR CABLE
R. I. CRISFIELD

NEW CARRIER SYSTEM TYPE G-1
H. G. JORDAN

AUGUST 1936 Vol. XIV No. 12

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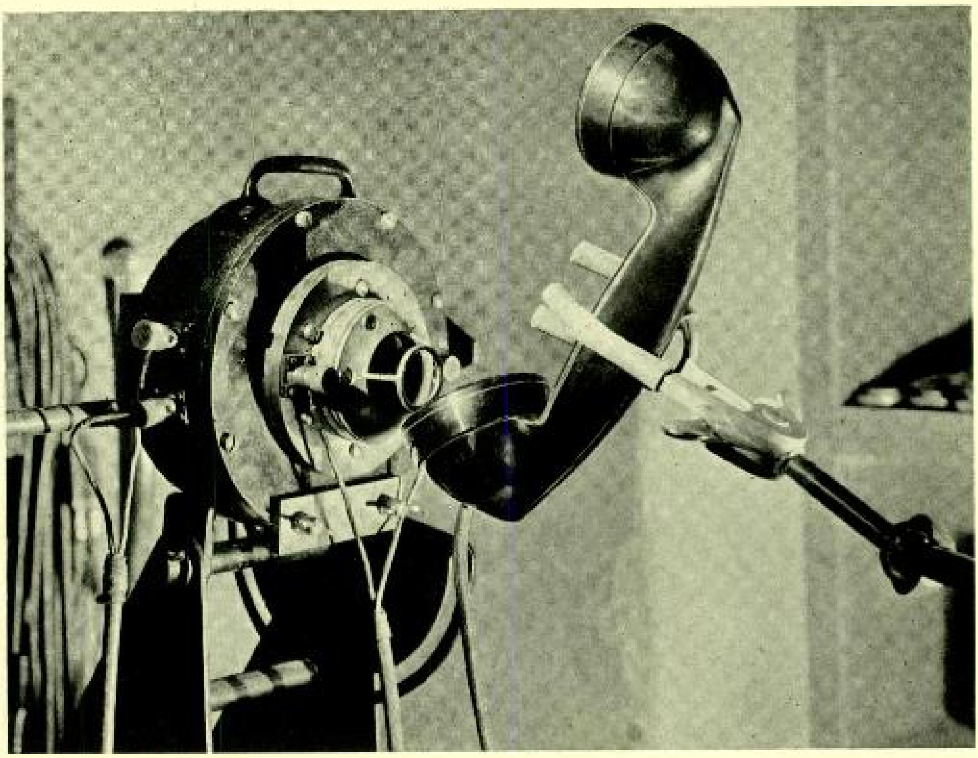


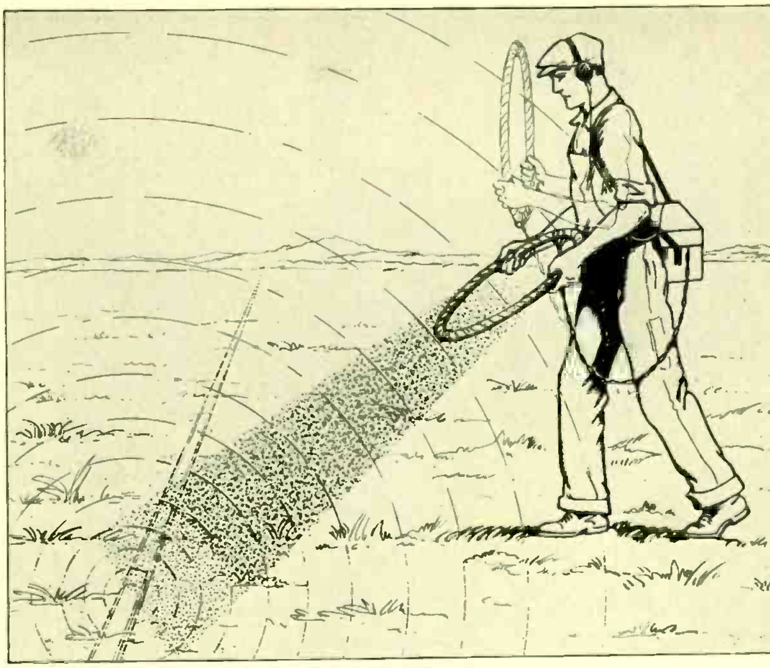
Testing a handset transmitter with the "artificial mouth"

AUGUST, 1936

VOLUME FOURTEEN—NUMBER TWELVE

DOWSING, *or searching with a divining rod for some hidden material, is an art of great antiquity. The "virgula divina" was described by Cicero and Tacitus. The illustration above shows the "virgula furcata" (forked twig) used in prospecting for metals. This illustration was reproduced, through the courtesy of the New York Public Library, from Agricola's famous "De Re Metallica," printed in 1556.*

The modern professional dowser is a water-finder. He walks about holding a forked twig of hazel or willow, until suddenly the twig twitches. "There," says the dowser, "water will be found." Professor Sir William Barrett, who made the classic study of the subject, ascribed the phenomenon to "motor-automatism," an obscure reflex action somewhat similar to the homing instinct of a pigeon. The cable-dowsing method described in the following pages, however, depends upon electromagnetism rather than upon motor-automatism.



Dowsing for Cable

By R. I. CRISFIELD
Outside Plant Development

WITH any cable system the route followed must be known so that the position of any fault that may develop in the cable, which will be located by bridge measurement, may be reached with a minimum of delay. Aerial cable is visible, of course, and its path can readily be followed by the test man. Because of more or less closely spaced manholes, the path of underground cable in duct can also be easily traced. Where armored* or other cable buried directly in the ground is employed, its exact course is not so definitely fixed. When such cable is laid, its path is indicated by substantial markers placed at road crossings, fence lines, loading points, or where the direction of path is changed. It has been found, however, that these markers may deteriorate, be removed, or become covered with snow, so that in many sections the route of the cable may be known only in a general way. The need for an accurate method of following the path of such a cable is therefore evident.

The recent development of a method for locating and tracing the path of buried cable from above ground has greatly simplified the problem of maintaining such cable. The method devised involves the use of a tracer current flowing along the sheath, and an exploring coil with an amplifier and telephone receivers. The exploring coil is essentially a loop antenna and, serving somewhat as a radio compass,

*Record, *June*, 1930, *p.* 465.

may be employed to determine not only the path of the cable but its approximate depth beneath the surface. In this system, the tracer current does not produce any interfering effects in the circuits carried by the cable.

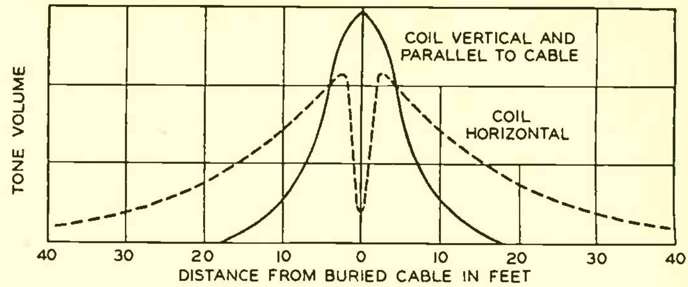


Fig. 2—Variation of tone with distance for a horizontal and vertical coil

To impress the tracer current on the sheath, two rods are driven into the ground as shown in Figure 1. These rods should be placed about fifty feet apart, as nearly as possible at right angles to the path of the cable, and both on the same side of it. In developing the method various positions were tried for the rods, but that shown in the illustration proved the most effective. A 20C test set, which is standard equipment with the maintenance forces, is connected to the two rods and provides an interrupted buzzer tone. The current enters the sheath from one of the rods, passes along the sheath in both directions, and ultimately leaves it to return to the other ground rod.

The exploring coil is made by winding a large number of turns of fine wire on the wood rim of a bicycle wheel. The ends of the wire are brought out to binding posts, and then the rim with its winding is wrapped with rubber and friction tape to protect the wire and keep out moisture. A 4B amplifier, also standard equipment, amplifies the current picked up, and the buzzer tone is heard through the ordinary headset receivers.

After the ground rods have been driven and connected to the test set, the exploring coil is carried to a point, such as X on Figure 1. To avoid interference from the field of the wire connected to the ground rods, this point should be at least 100 feet from the rods. The coil is then placed in a horizontal position, and is turned slowly around a horizontal axis approximately parallel to the cable, and the change in volume of the tone is noted. This volume will be greatest when the greatest number of the lines of force caused by the current in the sheath passes through the exploring coil. This will happen when the plane of the loop passes through the cable. By similarly rotating the loop about a vertical axis maximum tone will be heard when the plane of the coil is parallel to the direc-

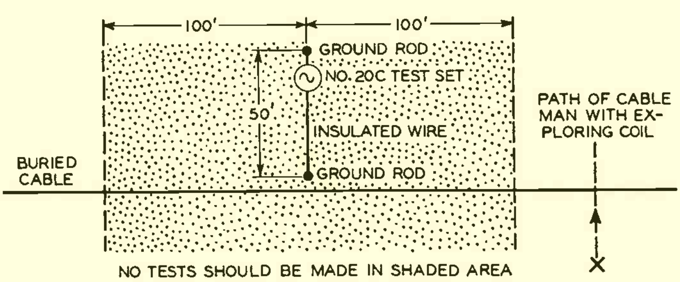


Fig. 1—Two rods, fifty feet apart, driven into the ground in a line at right angles to the cable, serve to lead the tracer current to the sheath. Tracer current is supplied by the 20C Test Set

tion of the cable. These conditions are indicated in the drawing at the head of this article.

After this preliminary location, the test man holds the coil in a horizontal position and walks toward the cable in a direction as nearly as can be determined at right angles to it. The tone will increase as the cable is approached until the coil is nearly over it, and will suddenly decrease when the cable is directly under the center of the coil. As an alternative method the coil may be held vertically with its plane approximately parallel to the cable. With the coil in this position, the tone increases steadily as the cable is approached and becomes a maximum when the cable is directly beneath the coil. Curves of tone volume and distance for the two methods are shown in Figure 2. The minimum tone position, with the coil horizontal, is very sensitive, and will locate the cable within a few inches.

After the cable has been located in this manner, its path may be readily followed by walking along with the coil in a horizontal position, and proceeding so as to maintain the tone at the minimum level. The path of the cable may usually be followed in this manner for a distance of about 500 feet each side of the ground rods—the actual distance depending on soil conductivity, noise conditions, and other factors. Having thus accurately located the path of the cable in the neighborhood of the fault, it is a comparatively simple matter to dig up a section for repair or further fault locating tests.

The exploring coil also provides a simple means of determining the depth of the cable, as indicated in Figure 3. The coil is held in a horizontal position directly over the cable, and a stake or stone is placed to indicate the spot. Then the test man, holding the coil with its plane parallel to the cable and at an angle of 45 degrees with the vertical, moves slowly away from the cable in a direction at right angles to its path. At the position of minimum tone, a line from the cable to the center of the coil will make a 45-degree angle with the horizontal as indicated in the illustration. A marker is placed directly beneath the center of the coil at this position. The two positions of the coil and the cable form a 45-degree right triangle, and the distance of the cable beneath the surface of the ground is equal to the distance between the two posi-

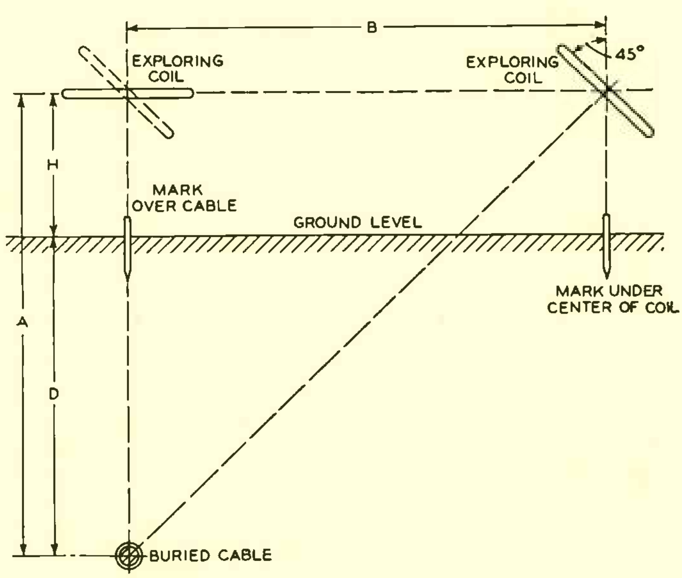
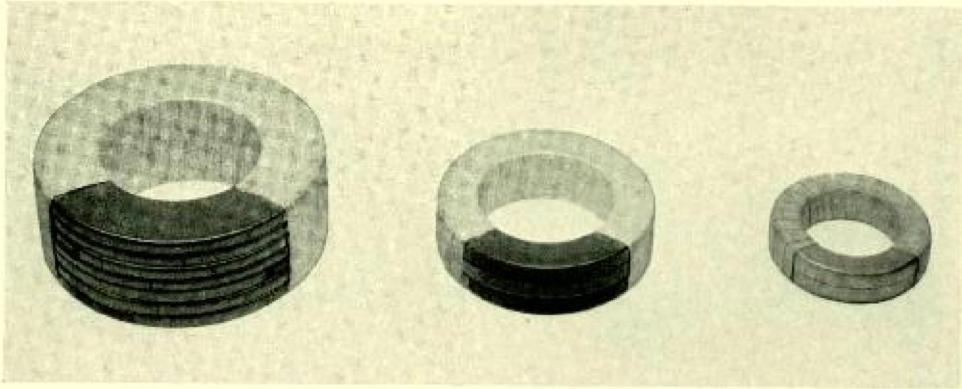


Fig. 3—The depth of the cable may be readily found by determining the position of minimum tone, first with the coil horizontal and then when it is held at an angle of 45 *degrees*

tions of the coil minus the height of the coil above the ground, since the two sides of the triangle, A and B in the diagram, are equal.

The simplicity of the apparatus required, and the ease with which a location can be made, makes the method widely applicable. The exploring coil is the only apparatus that needs to be added to the usual equipment, and it can be built of material readily and economically procured.

Molybdenum Permalloy Improves Loading Coils



The remarkable magnetic properties of the permalloys have made possible great savings in telephone plant construction. These alloys have had most extensive application as core material for loading coils, where they have replaced iron dust. The use of permalloys has resulted in a material decrease in the size of these coils. Recent development work indicates that a still further reduction in size will be practicable with new permalloys which contain a small percentage of molybdenum in addition to iron and nickel. The increased efficiency of the new material is strikingly illustrated in the photograph where magnetically equivalent loading coil cores of iron dust, permalloy dust and molybdenum permalloy dust are shown.

The Grounded Vertical Radiator

By J. F. MORRISON
Radio Development

VERTICAL broadcast antennas have heretofore been insulated from the ground at their base. Although this construction has been deemed necessary for the proper functioning of the antenna, it has introduced difficulties and complexities in both the electrical and mechanical features. Since insulating material is inherently weaker mechanically than structural steel, the insertion of an insulator at the base of the antenna, where the mechanical forces are the greatest, has generally required a modification of what would otherwise have been the most economical design. The electrical complications introduced by the insulator, however, are of greater importance, and lead to greater additional expense and complexity. The recent development of a new method of coupling to a vertical antenna, which completely eliminates this base insulation, is thus an achievement of considerable practical importance.

The ordinary base-insulated antenna is energized by a transmission line running from the radio transmitter, and between the end of this line and the antenna some form of coupling circuit must be provided to match the impedance of the antenna to the characteristic impedance of the transmission line. For any one type and size of transmission line, the characteristic impedance is more or less fixed, but the impedances of antennas vary widely, depending on height, configuration, and the operating frequency of the station. The coupling network, therefore, must either be especially designed for each installation, or a standardized coupling circuit must be provided which has sufficient flexibility to allow it to be adjusted to meet the wide range of antenna characteristics. One of the advantages of the new "shunt-excited" antenna arrangement is that the coupling circuit has been reduced to a single condenser and a connecting wire that becomes essentially an element of the antenna, and the normal adjustment of impedance involves only an adjustment of this condenser.

This simplification is brought out by Figure 1, where the upper sketch represents the usual arrangement of the insulated antenna, and the lower one the new shunt-excited antenna. A simplified schematic arrangement of the electrical elements comprising the insulated antenna and connecting circuit could be represented as shown in Figure 2. The radio transmitter, designated T, operates between the transmission line and ground. Z_o represents the characteristic impedance of the transmission line, and z_a, the impedance of the antenna; the insulator at the base of the antenna is indicated for contrast with the grounded antenna. The function of the coupling impedance, z_c, is to make the combination of z_a and z_c equal to z_o.

Contrasting with this, the arrangement of the shunt-excited antenna circuit is shown in Figure 3, where the base insulator of Figure 2 is replaced by a solid connection to ground. This arrangement divides the total antenna impedance into two parallel impedances, with the result that the antenna impedance may be varied within limits by changing the point of con-

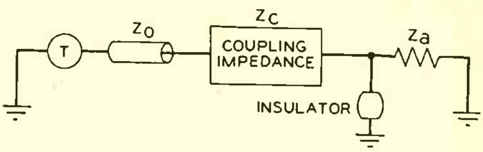


Fig. 2—Simplified schematic of an equivalent circuit of the series-excited antenna

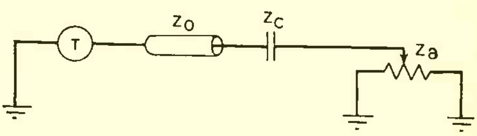


Fig. 3—Simplified schematic of an equivalent circuit of the shunt-excited antenna

nection of the coupling wire. Still further adjustment is possible by varying the distance "b" of Figure 1, which also modifies the impedance which must be matched with that of the transmission line. With the former method the entire antenna impedance was in series with the coupling circuit, while with the new method it is split into two parallel branches, and for this reason the new method is described as shunt excitation.

The simplification wrought by the shunt-excited antenna would be largely vitiated if the radiation from the antenna were adversely affected. Although mathematical analysis could give an approximate answer to this problem, there are always assumptions underlying such computations which may be open to question. It seemed desirable, therefore, to make field studies on an actual, full-size antenna. Such a study became possible through the courtesy of the

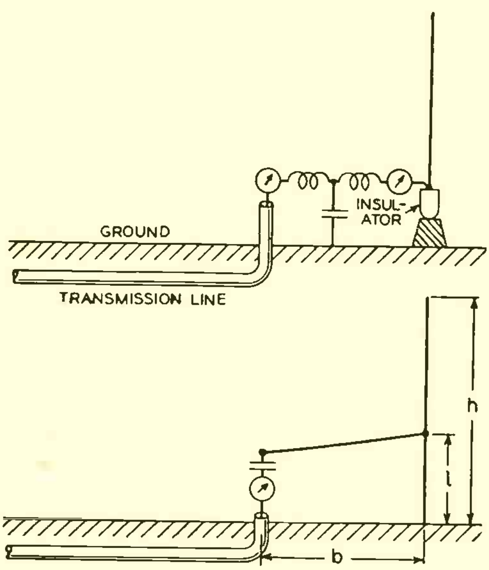


Fig. 1—Schematic representation of the series-excited antenna, above, and the new Western Electric shunt-excited antenna, below

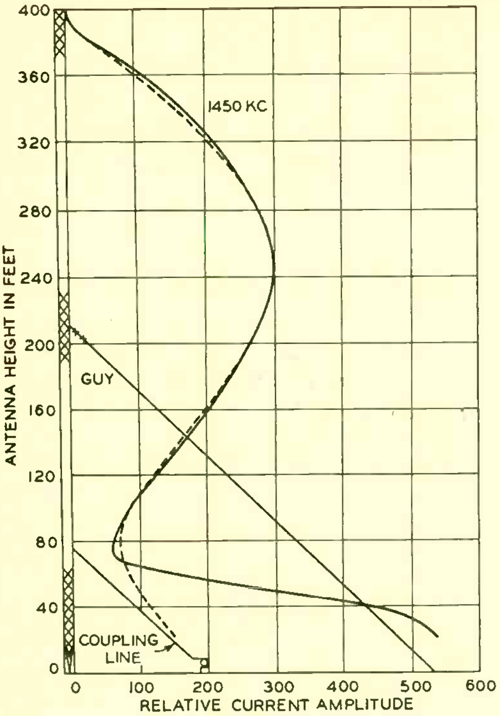


Fig. 4—Measured current distribution for the series-excited antenna, dotted curve, and the shunt-excited antenna, solid curve

Detroit Daily News, which made available its 400-foot vertical radiator at Station WWJ. This antenna is of uniform cross-section, 6½ feet square throughout its entire height except for the bottom 22 feet, which tapers to the dimensions of a single porcelain insulator. The antenna and its base construction are shown in the accompanying photographs. It offered the advantage of permitting comparative tests on grounded and ungrounded antennas, since the base insulator could be short-circuited for the grounded tests.

Although the current distribution in an antenna is commonly referred to as sinusoidal, such a distribution is only approximated in practice. To determine the actual current distribution, studies were made under both grounded and ungrounded conditions. A loop antenna from a Western Electric 44A Field Intensity Measuring Set was arranged so that it could be carried by a rope suspension up or down the full height of the tower. It was maintained firmly against one corner of the structure so as to be predominantly affected only by the current in the antenna at its own level. Current distributions for the series and shunt-excited antennas are shown in Figure 4. In neither case is the current strictly sinusoidal, but it is essentially alike for the two conditions except for that section of the antenna

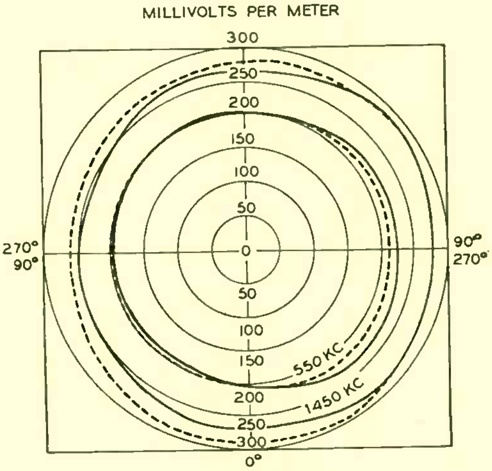


Fig. 5—Ground-wave field intensity for 1000 watts at one mile for both series and shunt-excited (solid curve) antennas

below the point where the coupling wire is connected. The measurements were taken on the side of the antenna opposite to the coupling point so as to eliminate the field from the coupling connection itself. Calculations indicated that for other positions around the antenna, the field caused by the current in the coupling wire would partially neutralize that due to the vertical radiator—making the distribution of the grounded antenna more closely approach that of the ungrounded antenna.

As a further check on the comparative effectiveness of the series and shunt methods of excitation, the ground-plane field intensity was investigated. A low-power oscillator was used to excite the antenna, but the data were corrected to correspond to a power level of 1000 watts and a distance of one mile. As shown in Figure 5, the two field intensity curves are substantially alike.

These field intensity measurements plotted against the height of the antenna in wavelengths are shown in Figure 10 for both the series and shunt-excited antennas. Here again, it will be observed, the two methods of excitation give very similar results. The slightly lower value of field strength in the vicinity of an antenna height of 0.3 wavelength for the shunt-excited condition was caused by known deficiencies in the ground system near the base of the antenna. These curves illustrate in addition the fact that with either series or shunt-excited antennas there is very little justification for increasing the an-

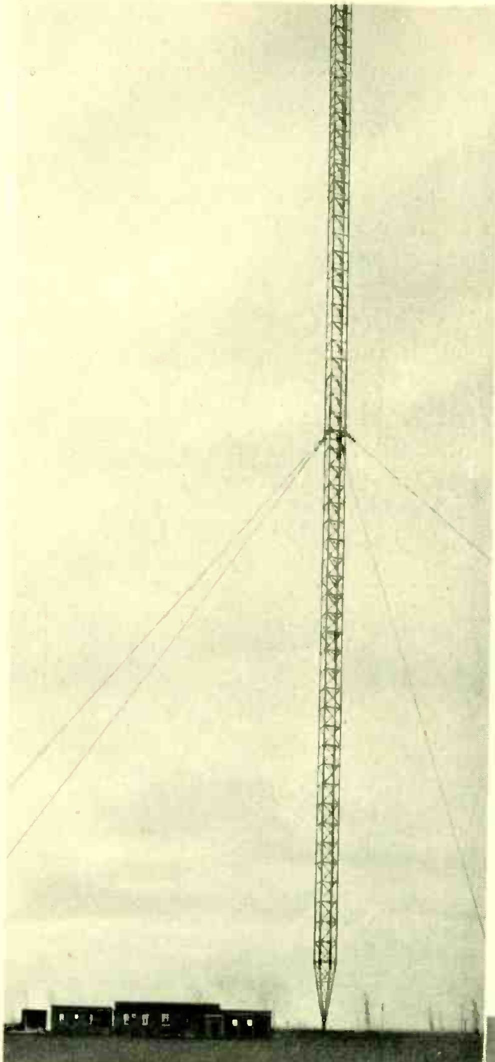


Fig. 6—The 400-foot vertical radiator of Station WWJ, *Detroit*

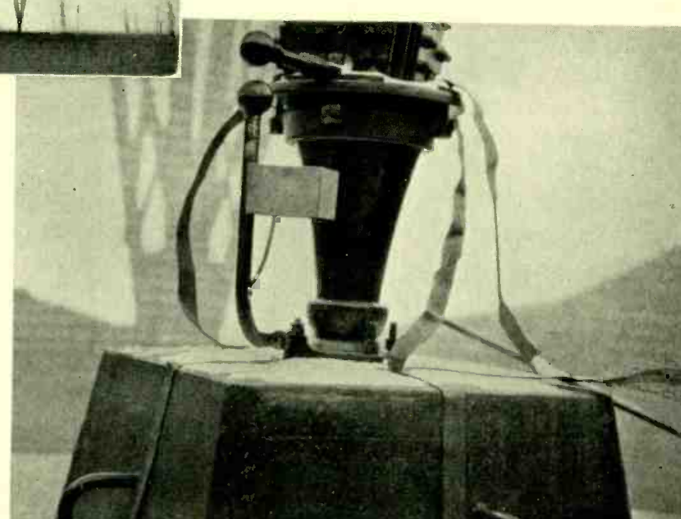


Fig. 7—The base of the WWJ *antenna rests on an insulating support and is enclosed in a brick wall as a safety precaution*

tenna height above about 0.25 wavelength unless it is increased to between 0.5 and 0.6 wavelength. The curves are fairly flat up to about 0.4 wavelength, and then begin to rise more rapidly, reaching a maximum value in the neighborhood of 0.6 wavelength.

These various curves show that the ground-wave radiation is not appreciably affected by the new method of excitation. To determine the effect on radiation at higher angles, field intensity measurements were made, through the courtesy of the National Life and Accident Insurance Company, at distances ranging from 35 to 110 miles in several directions from the 0.58 wavelength vertical radiator of Station WSM in Nashville. Automatic recording equipment was used, and the antenna was excited by the series and shunt methods alternately every hour from midnight to 8:00 A.M. over a period of three weeks. A typical chart is shown in Figure 11. No discernible difference in the fading characteristics for the two methods of excitation was noticeable.

Fig. 8—To measure current distribution, a small loop was carried vertically up and down one corner of the antenna

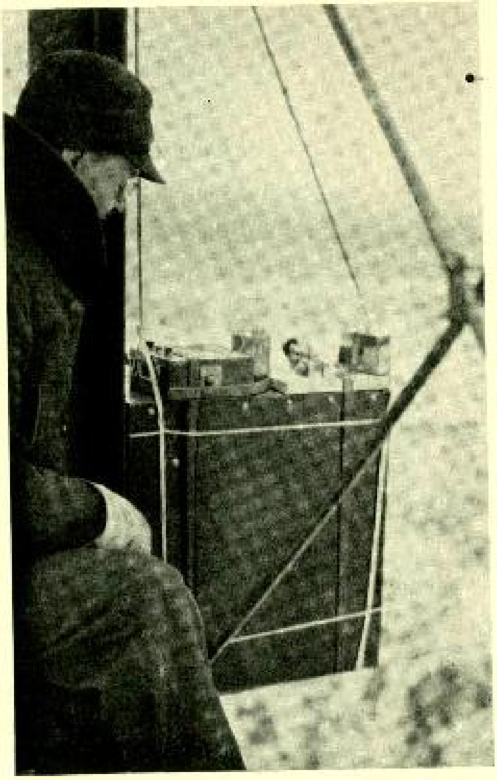


Fig. 9—Taking a reading of current distribution high up on the antenna

In so far as radiation characteristics are concerned, therefore, there is no important difference between the series and shunt-excited antennas. In respect to the cost and operation of the system, however, the shunt-excited antenna has a number of distinct advantages. The gain in the simplification of the coupling equipment has already been mentioned. With the shunt-excited antenna the weatherproof housing for the coupling equipment becomes smaller and less expensive, since the only equipment required is a series capacitance and a meter.

The circuit supplying antenna lighting is simplified to an even greater extent. Since the antenna is at ground potential at its base, filter circuits or coupling transformers are not required. The lighting circuit may be run directly to the base of the antenna and thence vertically up the structure. All forms of protection from lightning or other high voltages on the antenna structure also become unnecessary. With the base of the antenna at ground potential no precautionary measures need be taken either to eliminate high potentials or to keep people from coming in contact with the structure. The shunt-excited antenna also has the advantage of greatly reducing the interruptions of programs caused by lightning or static discharges. Although such interruptions are of short duration, they are annoying to the listeners, and their radical reduction will be welcome to broadcasters. Over and above these many advantages, the cost of the antenna itself is decreased, since no base insulators are required and the more rigid support of the direct steel connection to the foundation permits the use of smaller cross-sectional dimensions.

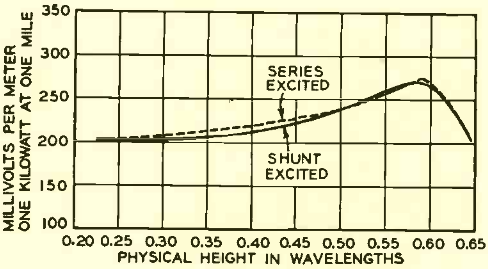


Fig. 10—Field intensity for various heights of antennas of both types; the solid curve is the shunt-excited antenna

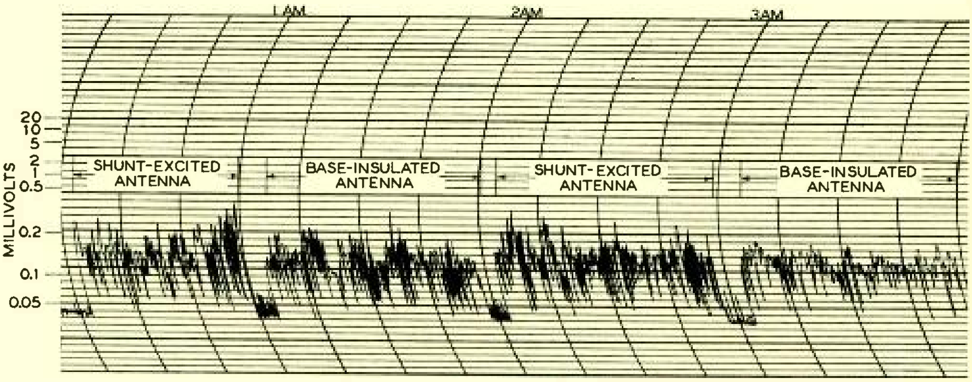


Fig. 11—Results of fading tests from station WSM *with the two types of operation*

A One-Tube Carrier System

By H. G. JORDAN
Toll Transmission Development

DURING the past fifteen years carrier telephone systems have provided a considerable part of the growth of toll circuits on routes served by open-wire lines. The use of carrier systems, however, has been limited in general to the medium and long haul circuits, because the oscillators, modulators, amplifiers, filters, and other equipment required at the terminals of such systems are comparatively expensive. The vacuum tubes employed as oscillators, modulators, and amplifiers must be provided with suitable power supply, which adds to the total cost. Where the distances are short it may be less expensive to provide the additional circuits by using more pairs of wires.

Two types of open-wire carrier systems are widely used at the present time. The type C provides three additional circuits, and is commonly used for distances as short as 100 miles. It is used also on some of the longest open-wire lines in the country, some systems being over 2000 miles in length. The type D system provides only a single additional telephone circuit, and is commonly used for distances down to 50 miles, with an upper limit at about 200 miles. The shorter distance is justified as a result of the simplification that goes with a single-channel system, and the restriction of the upper limit of transmission to about 200 miles.

Circuits less than 50 miles in length comprise a large portion of the toll plant, however, and attention has recently been directed to the provision of carrier facilities which could be used in this field. As a result a new carrier system, very simple and comparatively inexpensive, has been made available, which has been designated G-1. This system, which provides a single additional circuit, may, under certain conditions, be advantageously employed for distances as short as ten miles, or possibly less. The maximum distance depends on the gauge of wire, the amount of entrance cable, and the overall loss that can be allowed for the grade of service required. Twenty-five miles represents the normal upper limit of transmission.

The system has been designed primarily for use between two points only, and not as a link in a longer circuit. This permits somewhat higher losses than could otherwise be tolerated. It is also not designed for use on pole lines carrying other types of carrier systems. By thus limiting the scope of application, it has been possible to take advantage of certain economies in design which, together with recent developments in the art, have made it possible to provide a system that can be economically used over these very short distances. Notable among these are the transmission of both sidebands and the carrier, which permits the use of less expensive filters, the use of the copper-oxide modulators, and the use of a carrier supply arrangement that makes it necessary to provide an oscillator at only one terminal.

No amplifiers are employed in the G-1 system, and a single 10,300-cycle oscillator supplies the carrier for both directions of transmission. As already noted, after this carrier is modulated by the voice of the telephone user, substantially the whole resultant product, including the carrier and both sidebands, is transmitted over the line. The lower sideband extends from about 10,200 to 6,500 cycles and the upper sideband from about 10,400 to 14,100 cycles.

Power is required only at the oscillator terminal, which is called the active unit, while the other terminal, from its requiring no associated power supply, is called the inert unit. Both active and inert units are arranged on panels for mounting on a relay rack—the active unit requires a seven-inch panel and the inert unit a 3½-inch panel. The two units are shown in the photograph at the head of this article,

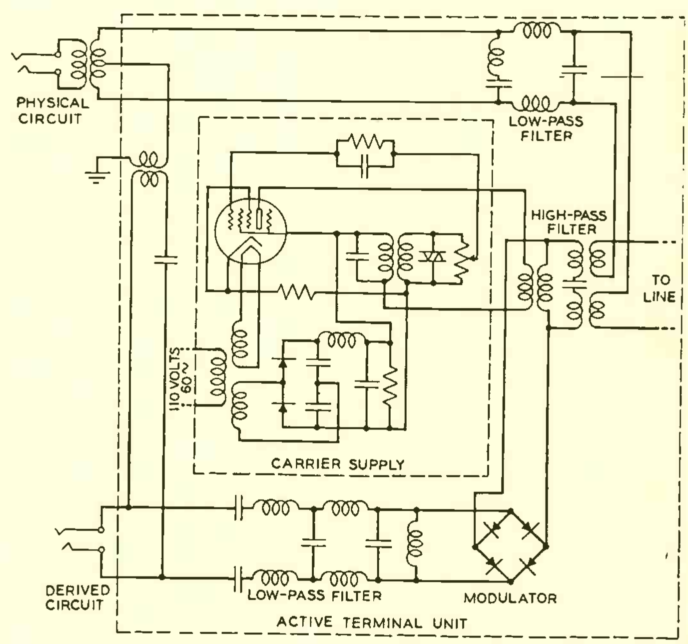
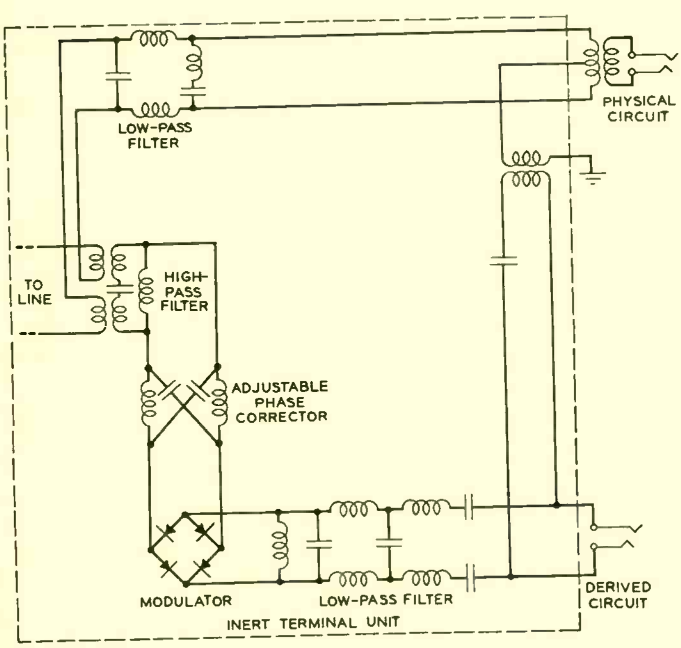


Fig. 1—How the G-1 carrier system

where the upper is the inert unit, and the center panel is the active unit. The lower panel is equipment required only when d-c. ringing is employed.

Since no amplifier is employed by the G-1 system, and since there is some loss in the modulators and filters, and somewhat higher line loss at the carrier frequencies than at voice frequencies, the overall loss is greater than for the voice-frequency circuit on which the system is superposed. To reduce the reflection and attenuation losses in entrance cables at carrier frequencies, an impedance equalizer has been designed for mounting on the pole at the junction of the open-wire section and the entrance cable. This will take care of cable lengths up to about one mile and is more economical than the conventional methods of loading. In addition a phase shifter is required because of the transmission of both sidebands and of the supplying of carrier at only one terminal. This phase shifter is located at the inert terminal.

The circuits to which this new carrier system will be commonly applied are arranged for 20-cycle ringing, which is applied across the line. The G-1 terminals are provided with a simplex circuit to provide this type of ringing so that the operator rings over the carrier channel in exactly the same way she does over the physical circuit. The general arrangement is indicated in Figure 1. With such a circuit ringing potential is applied across the line for the physical circuit, the current flowing around the circuit in the usual manner. For the carrier channel, the ringing is applied across the tip and ring conductor at the switchboard, as for the physical circuit, but a transformer across the derived, or carrier, drop imposes this ringing potential between the mid-point of the repeating coil and ground. Ringing on the carrier channel is thus transmitted over both sides of the physical line in parallel, and over a ground return. If the carrier is being applied to one side of a phantom circuit, the ringing arrangement is similar except that the signaling tap is made at the mid-point of the phantom repeating coil, and ringing current passes over the two sides of the phantom in parallel and thence to ground. Both active and inert terminals provide the equipment required when 20-cycle ringing is employed at the terminal offices.



provides an additional circuit

Occasionally, however, the G-1 system may be used in connection with community dial offices. Under these conditions an additional unit is required at each terminal—shown below the carrier units in the photograph at the head of this article. With this arrangement, which is known as composite signaling, the ringing path is from one side of the physical line to ground, and two identical signal paths are provided—one for the physical and one for the carrier circuit. Simplified coil and relay arrangements were employed to make the method economical.

When it is desired to operate more than one carrier system of this type on a given pole line, it is necessary to consider the possibility of crosstalk. Factors which affect the crosstalk unfavorably are (1) the transmission of the same frequencies in both directions, which brings in the effect of "near-end" crosstalk,* and (2) the employment of two sidebands, which doubles the frequency band required and thus increases the upper frequency at which crosstalk may occur. On the other hand, the short distances for which these systems are used make possible a larger crosstalk limit per unit length of line. Generally speaking, pole lines transposed for voice frequencies can carry several G-1 systems if the systems are kept apart by applying them to pairs on opposite ends of crossarms and only on alternate arms.

Two field trials of this system have been conducted. One was on a circuit between Ellenville and Woodridge, New York, spanning a distance of about twelve miles. This circuit employed 20-cycle signaling, and was in a resort territory where the demands for service vary considerably from season to season. The other trial was on an eighteen-mile circuit between the No. 3 toll switchboard at Richmond, Virginia, and the unattended dial office at Manakin, Virginia. In the latter case composite arrangements were provided for passing the dial pulses over both the physical and derived circuits.

Besides providing an inexpensive additional facility, the system is well adapted for use as portable equipment, since the active terminal weighs only 26 pounds and the inert terminal only 16 pounds. This new carrier system is particularly useful when an additional wire circuit is difficult to obtain either because the pole space is rented, the line is full, or because service is required too quickly to allow time for new construction.

In addition to the standard arrangement for mounting these units on relay racks, a cabinet is available for housing them where no relay rack is available. This cabinet is arranged for either floor, shelf, or wall mounting. An hour's time should be sufficient for connecting a terminal ready for service, and this readiness for use, combined with ease of transportation because of their small size and light weight, makes them suitable for holding in stock for emergency or temporary applications. When so available, and subject to the transmission limitations mentioned previously, the units are well suited to supply seasonal or peak-load business, or perhaps in the case of storms or other natural calamities.

*Record, *Nov.*, 1934, *p.* 66.

Mathematics and Electrical Communication

Excerpts from a dinner talk before the Corporation of the Polytechnic Institute of Brooklyn

By JOHN R. CARSON
Mathematical Research

SHORTLY before I entered upon my present work three great achievements had ushered in what may be called the Golden Age in the development of the art of electrical communication. I refer to the establishment of transcontinental communication and to two very great inventions, the vacuum-tube amplifier and the electric wave filter. In these days everyone has a radio set and knows the tremendous importance of the vacuum tube. Not everyone, however, knows of the importance of the wave filter or that it is well-nigh indispensable in modern communication circuits. In fact, it is so important that after more than twenty years we are still doing a large amount of experimental and theoretical work on it. These three achievements opened the way for an unprecedented development, and, fortunately for me and my kind, this development called for more advanced and rigorous mathematical theory to interpret new phenomena and to serve as a guide to further development.

Perhaps I can best give an idea of the place of mathematics by describing a specific problem with the solution of which I was associated.

The original transcontinental line was a loaded line with inductance coils inserted at regular intervals to reduce its attenuation. On this line, more than three thousand miles long, a peculiar and disconcerting noise could be heard at the receiving end. In laboratory slang this was called the "tweet-tweet" effect since that was the way it sounded. Oscillographic and other tests went to show that the effect depended in some involved way on the length of the line, on the inductance and spacing of the loading coils and on the frequency of the electric waves. It was also inferred that the "tweet-tweet" was some kind of transient phenomenon.

The effect, however, was so complicated, so many variables were involved, and the physical system was so vast, that a thoroughgoing experimental investigation was out of the question. The problem was, therefore, put up to us for a mathematical investigation—in a rather vague way in fact, with very little more information than I am giving you now.

I shall not attempt to trace the course of this investigation. It finally ended in enabling us to identify the phenomenon as a transient variable-frequency effect and to establish a formula for designing loaded lines so as to keep this effect within tolerable limits. The research involved three major steps. First the problem had to be rather drastically simplified and stripped of non-essential complications. Then it had to be precisely formulated and translated into mathematical terms. In the third place, it required considerable preliminary work in the way of selecting and adapting our mathematical tools; and finally, our results had to be put into shape for immediate engineering use.

The formulation of a problem and its translation into the shorthand of mathematics may be the most difficult phase of a whole research. I have in mind a problem which came up a number of years ago. Suppose we are transmitting by radio from a given station in America to a given station in Europe. Now suppose we reverse the direction of transmission by interchanging transmitter and receiver. What is the relation between the received signals in the two directions? The formulation of this problem was the hardest part of the whole job.

All of which brings me to the statement that the application of mathematics to electrotechnical research is as much an art as it is a science. The art consists in seeing how to go at the problem; in knowing what simplifications and approximations are permissible while leaving the essential problem intact, in precise formulation in mathematical terms, and finally, in reducing the solution to a form immediately interpretable in physical and engineering terms.

Now, I would like to say a few general words regarding the function and place of mathematics in electrotechnics. There are some who are contemptuous as regards the value of mathematics in the applied sciences. Their view is that you put mathematics into the problem and you get the same mathematics out, so that the mathematics contribute nothing. What these critics fail to see is that *the function of mathematics is to render explicit relations which are involved and implicit.*

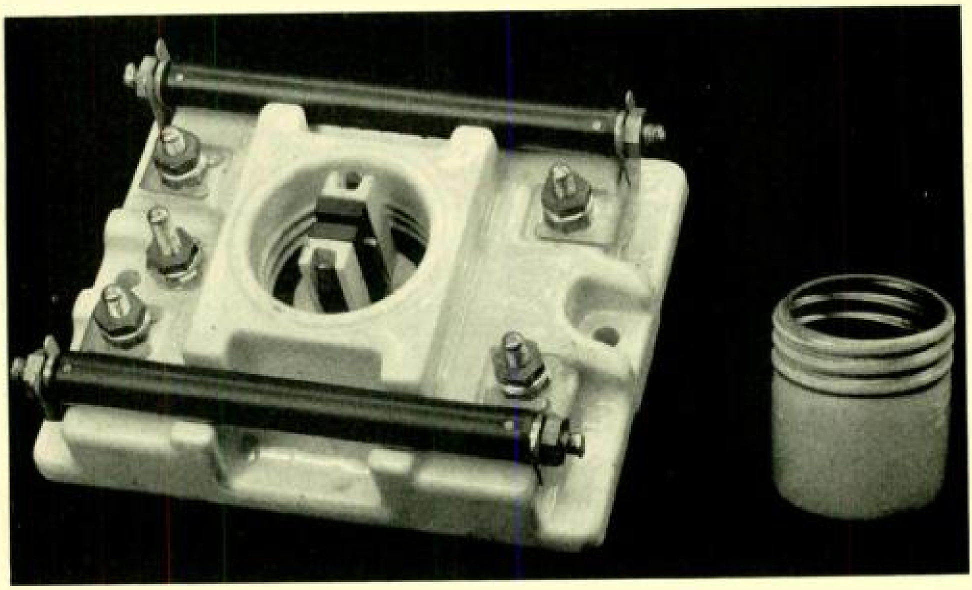
It is true that when we have correctly formulated a problem in words the answer lies in this very formulation, but it is latent and concealed. When we translate the formulation of a problem into mathematics—that is, express its physical relations in terms of symbols and equations—we are merely writing down the problem in shorthand. But having done so we are then in a position to forget the original problem and to solve the equations by the methods of mathematical analysis; and this mathematical analysis, as J. J. Thomson pointed out, is the greatest mental-labor-saving machine ever invented. Instead of having to keep in mind involved and complicated relations, we have in mathematics a tool that does this work for us, once the problem has been correctly formulated in equations which express the physical relationships.

In the applied mathematics of physics and of electrotechnics every symbol has a physical significance and every equation expresses in a symbolic term a physical relationship. In pure mathematics this is not the case—in fact, as Eddington remarked, a pure mathematician is never so happy as when he doesn't know what he is talking about. This remark is more than witty; it is really acute. Because the pure mathematician is dealing with abstract relations, the more general and vague his symbols are, the more general are his results.

Fundamentally then, the function of mathematics in electrotechnical research is to provide a guiding theory to interpret the results of experiment and to suggest future lines of development and research. As a by-product of such mathematical research in communication we now have a substantial body of inventions and patents which owe nothing immediately to the experimentalist.

Mathematics also has a negative function: that is, to show that certain inventions and schemes are unsound and inoperative. A theoretical analysis by a mathematician may show clearly the impossibility of a scheme, with present-day systems at least, and, therefore, be of value in saving time and in eliminating efforts which can only end in failure. In a large research organization this function may be rather inglorious, and is not conducive to popularity. We mathematicians are much in the position of the lawyer to whom a business man complained that he didn't want a lawyer to tell him what he couldn't do—he wanted a lawyer to tell him what he *could* do.

In this talk, however, I cannot hope to have given you more than a mere glimmering of the functions and use of mathematics in electrotechnics. Its scope is, of course, limited; but where it can be applied it is a powerful and valuable tool. I think it is destined to play an increasingly important rôle as the technique of electrical communication becomes more and more refined and imposes higher and higher standards. The ideal worker in this field should be a master of physics, of mathematics, and of electrical engineering. Unfortunately it is barely possible to be a master of one branch of learning, to say nothing of three; so most of us have to be jacks of three trades and carry on as best we can.



A New Station Protector

In keeping with the trend toward greater compactness, a new telephone station protector, coded No. 98A, has recently been made available to supersede the No. 58AP protector. Its dimensions permit it to be installed on the conventional six-inch wooden floor beam without projecting below the edge of the beam and without the use of a supplementary backboard

The 86 Type Amplifier

By V. M. COUSINS
Special Products Development

AMPLIFY: To enlarge or to increase in scope. As defined thus in the dictionary, the word amplify has ordinarily been used to describe the rhetorical process of enlarging an idea, or perhaps of expanding a description or discussion. Whatever the ordinary usage has been and to whatever extent the enlargement has been carried out, it is safe to say that the amplification involved has not even approached the amplification obtained in many types of vacuum tube amplifiers used in various forms of electrical communication and transmission. "To enlarge or increase in scope" is almost ludicrously inadequate to describe a process that increases the electrical energy in a circuit tens or hundreds of billions of times, values which are required of amplifiers in numerous circuits at the present time.

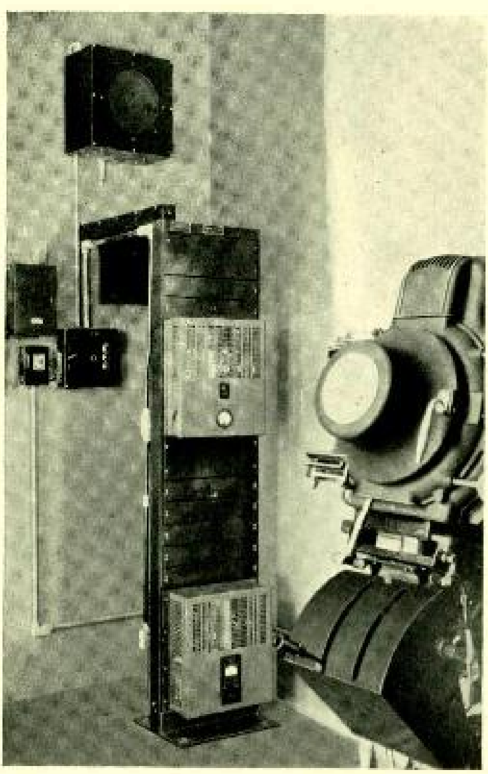


Fig. 1—An installation of a 1086A amplifier in a motion picture theatre in New York City. An 87A amplifier is mounted on the lower section of the rack

Sound picture and public address systems require amplifiers capable of providing energy increases of the order of ten billion times, or gains of 100 db, to increase the very small amount of energy received from the photoelectric cell, microphone, or phonograph reproducer to values capable of operating the loud speakers in a theatre or hall at the level required for proper sound reproduction. Besides providing this large amount of amplification for the signal currents, the amplifier must provide—if operated from alternating current—energy losses between the power and voice circuits of a similar order of magnitude, so that crosstalk from power circuit to voice circuit will be maintained at an inaudible level.

To make available an economical, high-quality amplifier for sound picture and public address systems, the Laboratories has recently developed the 86A, B, and C amplifiers. Incorporating the latest developments in vacuum tubes, transformers, and other

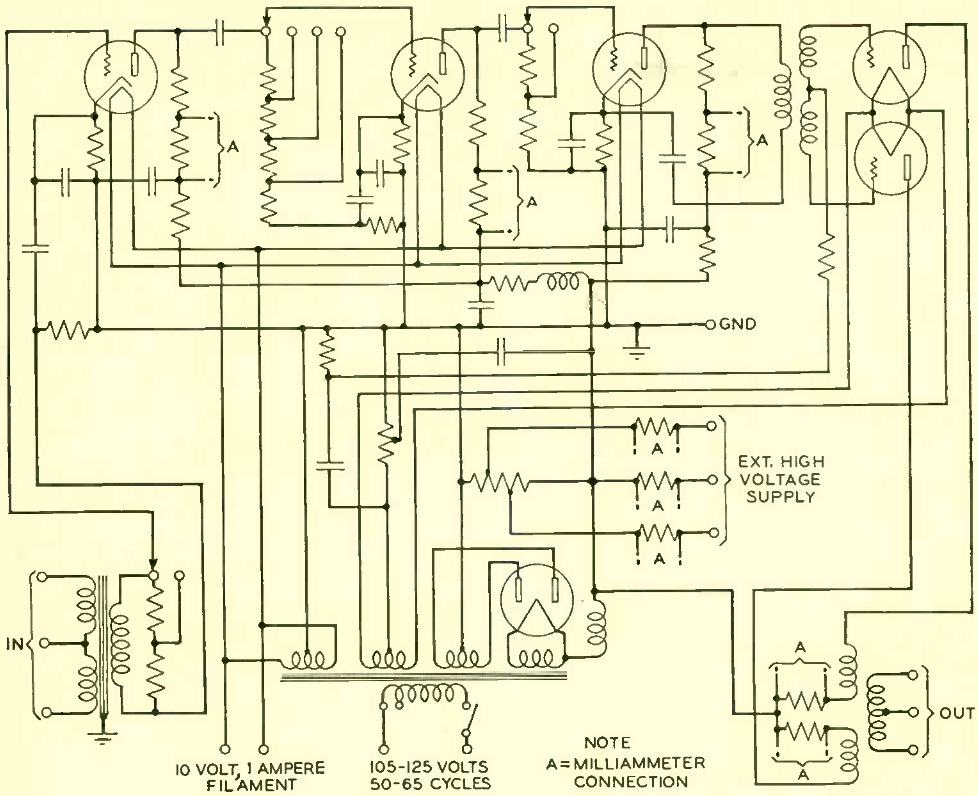


Fig. 2—Simplified schematic of the 86 type amplifier circuit

elements, these amplifiers provide a gain of 98.5 db and an output level of approximately fifteen watts. The circuits and mechanical arrangement of the three amplifiers are essentially the same; they differ chiefly in being arranged for different power supply frequencies and output impedances, in order that they may be adaptable to a wide range of uses.

As shown in the schematic of Figure 2, these amplifiers have four stages, the three preliminary stages employing 262A vacuum tubes* resistance-condenser coupled, and the power stage employing two 300A vacuum tubes† in a push-pull arrangement. Transformer coupling is used for the input to the first stage, and as input and output for the power stage. The amplifiers are entirely a-c operated: the plates being supplied from a 274A vacuum tube, which rectifies the high voltage supplied by the power transformer, and the filaments being operated on low voltage obtained from the same transformer. The power transformers of all three amplifiers are designed to operate from a primary supply voltage between 105 and 125 volts. The A and B amplifiers are designed for sixty-cycle circuits and the C amplifier for either 50 or 60 cycles. All three may be operated continuously at room temperatures as high as 110 degrees Fahrenheit.

In a considerable number of sound-reproducing systems, auxiliary amplifiers or circuits are used for which

*Record, *February*, 1933, *p.* 158.

†Record, *July*, 1936, *p.* 365.

small amounts of plate and filament energy are required. To make it possible to supply this energy, the 86 type amplifiers are provided with excess power capacity and suitable connections from which one ampere at ten volts may be obtained for filament supply, and rectified and partly filtered plate currents of 5, 7.5, or 10.5 milliamperes at 400, 190, or 85 volts respectively. This is sufficient to energize three Western Electric 80A or 62A amplifiers. Two small filter units, the 714A and 716A apparatus units, have also been designed for providing the additional filtering required by the high-voltage energy used for auxiliary amplifiers.

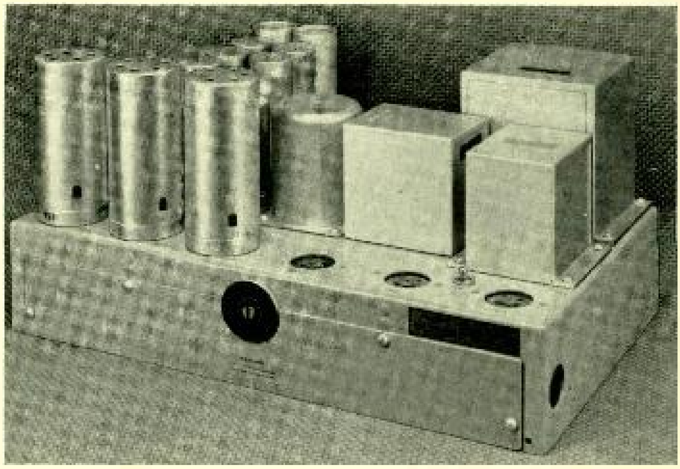


Fig. 4—The 86 type amplifiers have a metal chassis, on the front of which is mounted the meter switch

To aid in installation and servicing, means have been included in the amplifiers for measuring the space current of each vacuum tube and external "B" supply circuit. Current shunts have been soldered into each of these circuits and a rotary switch provided by which a special meter, known as the KS-7535, may be connected to any of the shunts.

All three amplifiers are designed to operate from a 200-ohm impedance, which is common practice for amplifiers of this type, but the output impedances differ. The 86A and 86C amplifiers operate into a load impedance of either 6 or 12 ohms, while the 86B operates into either 8 or 500 ohms. Continuous adjustment of gain is not provided, but fixed attenuators have been placed in the grid circuits of the three preliminary stages so that the gain may be adjusted over a wide range in steps of 5 db. These attenuators may be connected into the circuit by means of taps shown in the diagram. Five decibel attenuation is provided in the first stage, 10, 20, or 30 db in the second stage, and 10 db in the third stage. Connections from these taps

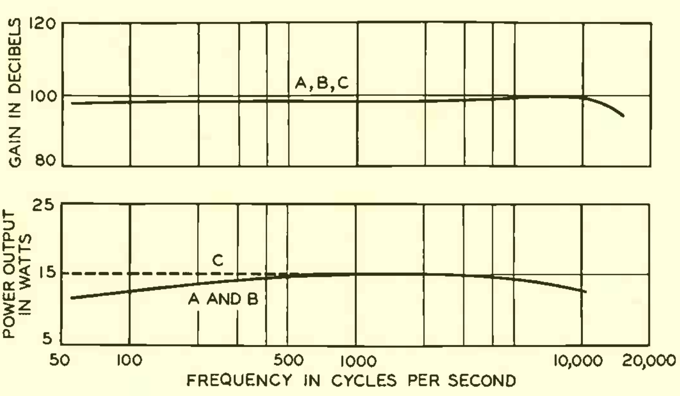


Fig. 3—Characteristic curves for the 86 type amplifiers: above—gain-frequency; below—power output

are brought to a terminal strip beneath the chassis where connections for the desired gain may be made. In addition, one or two of the preliminary stages may be cut out of the circuit. By these means the gain of the amplifiers may be adjusted in 5 db steps from 38.5 to 98.5 db.

Characteristics of the new amplifiers are shown in Figure 3. The gain-frequency characteristic is the same for all three types, and is essentially flat from 50 to 12,000 cycles. The power output characteristics of the 86A and B amplifiers are similar, showing an output level of 15 watts over the major portion of the frequency band, while the 86C amplifier characteristic is more uniform in the low frequency region.

The 300A vacuum tubes employed in the power stage of the amplifiers are highly efficient three-element tubes, with a plate-filament impedance of the order of 700 ohms. Two of these tubes in a suitable push-pull circuit are capable of closely approaching the theoretical limit of efficiency and harmonic generation for the ideal vacuum tube in Class A amplifier service—namely 50 per cent efficiency with no harmonic generation. In the 86 type amplifiers the plate-circuit efficiency of the power-stage vacuum tubes, with negative grids, is approximately 47 per cent over the frequency range where the harmonic generation is less than 1 per cent. By allowing 5 per cent harmonic generation, the efficiency of the vacuum tubes is increased to 57 per cent, and the output level to 18 watts—an increase of 20 per cent.

The use of an amplifier is frequently limited by the noise level in the output circuit—the maximum gain of high-gain amplifiers being frequently limited by the thermal noise generated in the input circuit. In addition to thermal noise, high-gain a-c operated amplifiers must contend with interaction, or crosstalk, between the power and voice circuits—the fundamental or harmonic frequencies of the power circuit being picked up in the circuit elements or wiring, or generated in the vacuum tubes due to their operation on alternating current. To keep such noise at a sufficiently low value, the 262A tube, which was designed particularly for low noise level, has been employed in the preliminary stages of the 86 type amplifiers, and in addition the shield of the first-stage vacuum tube is provided with a perm-

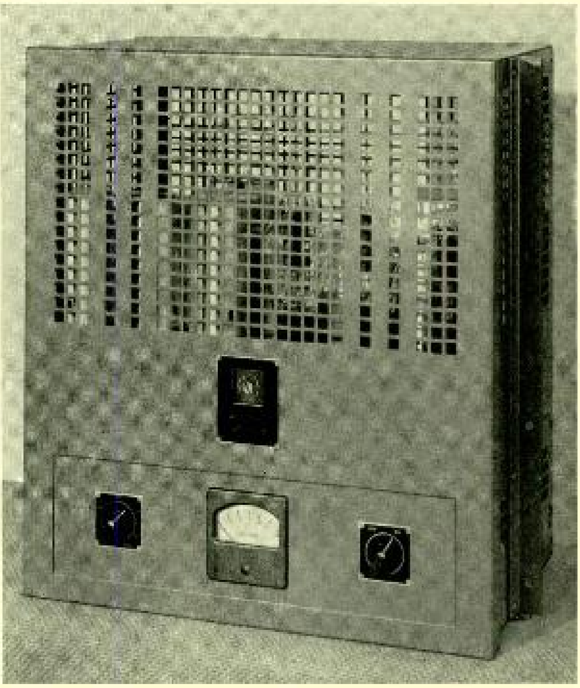


Fig. 5—The 1086 *type amplifier consists of one of the* 86 *type amplifiers mounted in a metal housing and including whatever auxiliary equipment is desired*

alloy liner. A common source of noise in high-gain amplifiers is induction between the power and input transformers. For this reason many amplifiers are not provided with input transformers; the users of these amplifiers being required to furnish their own input transformers and to take what precautions are necessary to prevent the introduction of noise. In the 86 type amplifiers, however, input transformers are incorporated in the amplifier, and the magnetic pick-up from the power transformers is minimized by providing the input transformer with internal and external permalloy shields. These provide an attenuation of 40 db to induced noise. In this way, the equivalent attenuation between power circuit and the plate circuit of the first stage is maintained at approximately 0.14 cross-talk units, or 137 db.

As a result of these various precautions, the noise level of the 86 type amplifiers is approximately 25 db below 6 milliwatts, unweighted, or 44 db when weighted for either the audibility threshold characteristic of the ear, or the Bell System program noise-weighting characteristic. The volume range of the amplifiers—the range between the noise level and the overload level of 15 watts—is thus 59 db unweighted and 78 db weighted.

The 86 type amplifiers employ the familiar inverted dish type of construction, with all component apparatus mounted on the chassis in such a manner that terminals and wiring are concealed. The chassis carries the meter switch as shown in Figure 4. As used in the field, however, they are usually mounted in a perforated metal cabinet, arranged for either wall or rack mounting and measuring about 19 inches high and 10½ inches deep. When so housed, the complete assembly is known as the 1086A, B, or C amplifier, one of which is shown in Figure 5. In the particular form shown a volume control, at the lower left, is connected in the 200-ohm input circuit ahead of the amplifier, a milliammeter is included for indicating plate currents, and an a-c power switch is installed at the lower right. Beneath the amplifier and behind the instrument plate, space is provided for auxiliary filters and other apparatus which may be a part of the sound system.

A Single-Sideband Short-Wave Receiver

By GEORGE RODWIN
Radio Research

THE desirability of employing single-sideband transmission for radio communication has long been realized, and such a system has been employed for some years in the long-wave transatlantic service. Studies showed that similar advantages would accrue from operating short-wave circuits by the single-sideband method, and preliminary tests indicated that the theoretical gains could be realized in practice. Maintenance of the correct adjustment of the resupplied carrier at the receiver, however, is difficult at these high frequencies, and so it seemed desirable to build a system with which several variations of single-sideband transmission could be studied. Through the coöperation of the British Post Office a transmitter was set up in England which radiated a single sideband and a carrier reduced to about one-sixth of its normal value. This small value of carrier does not detract from the advantages of a single-sideband system, and has the advantage of supplying a basis for the resupplied carrier at the receiver.

It was felt that a single-sideband receiver should be designed so as not to require any more attention in operation than an ordinary double-sideband type, and with this in mind the resupplied carrier adjusting features

Fig. 1—The complete single-sideband receiver is housed in a single steel cabinet which is about twenty inches in width

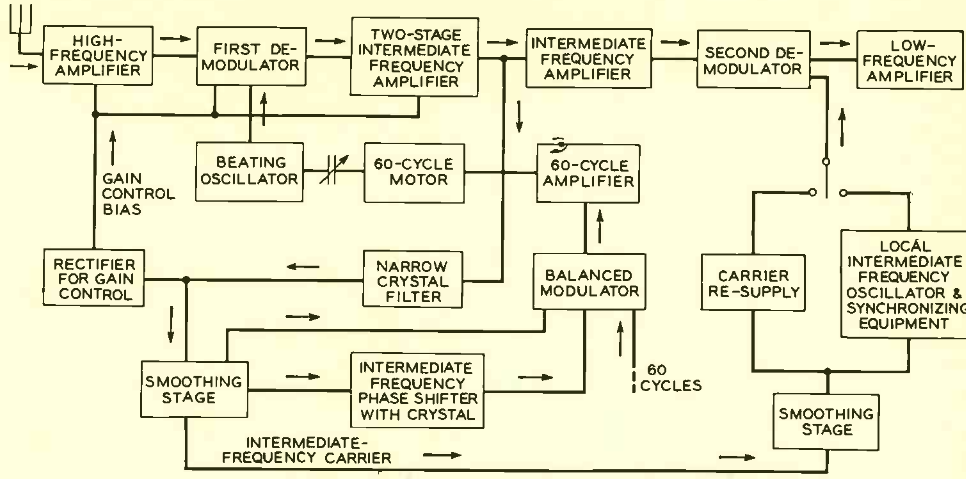


Fig. 2—Block schematic of the single-sideband receiver

were made automatic. The complete receiver, mounted in a steel cabinet seven feet high, is shown in Figure 1. It is of the double detection variety, and consists of a high-frequency amplifier stage, a balanced first demodulator, a three-stage intermediate-frequency amplifier, and a balanced second demodulator and low-frequency amplifier, with the addition of circuits and apparatus for resupplying the carrier. To widen the scope of the studies, two methods of carrier supply were provided. One utilized the transmitted carrier after it had been reconditioned, and the other employed a local oscillator for the carrier resupply, using the incoming carrier to control the frequency of the local oscillator.

A simplified block schematic of the system is shown in Figure 2. A beating oscillator supplying the first demodulator reduces the incoming signal and carrier to the intermediate frequency. A branch circuit from the grid of the third intermediate-frequency amplifier tube contains a narrow-band crystal filter, which selects the carrier without passing the sideband. This filtered carrier is used for gain control, for tuning the beating oscillator, and to supply carrier to the second demodulator, either directly or by controlling the frequency of a local beating oscillator.

For purposes of gain control, the filtered carrier is passed to the gain control rectifier, and the rectified output is then distributed to the high-frequency amplifier, the first demodulator, and the first two stages of the intermediate-frequency amplifier. The circuit has a time-constant of about a second so that the gain of the receiver is not affected by momentary fading of the carrier.

For purposes of resupply, the carrier from the crystal filter is passed through two smoothing stages which smooth out variations in the carrier amplitude, and pass the carrier to the second demodulator at a level about

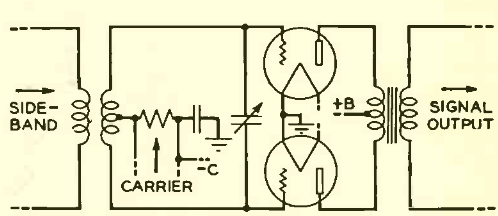


Fig. 3—Simplified schematic diagram of the second demodulator circuit

ten times that of the signal. The circuit of the second demodulator is shown in Figure 3. The sideband is put on the two grids in opposite phase while the carrier is put on the grids in the same phase. The outputs of the two tubes, due to beating of the carrier and signal frequencies, add in the output circuit, while beats between frequencies in the sideband itself will leave the tubes in opposite phase and thus will balance out. This balance cannot be made perfect in practice, and the resulting beat products of signal frequencies form the major source of distortion in the single-sideband receiver. By making the resupplied carrier large compared to the sideband, however, the desired signal can be made large with respect to these distortion products. As the result of the partial balancing of the distortion products, and of supplying the carrier some 20 db above the sideband, the receiver contributes no appreciable distortion to the overall circuit.

Since the carrier from the crystal filter is employed for all the various control purposes, it is essential that the intermediate frequency be at the correct value to pass through this very narrow filter. To secure this result, the beating oscillator must be controlled so that its frequency is always a definite amount above or below that of the incoming carrier, because the difference between the frequency of the incoming carrier and that of the beating oscillator determines the intermediate frequency. The general method of control employed is to tune the beating oscillator by an adjustable condenser driven by the rotating element of a watt-hour meter, which acts as a sixty-cycle motor. This arrangement is shown with copper shielding cover removed in Figure 4. The motor, in turn, is connected to a circuit which supplies no input when the frequency of the beating oscillator is the correct amount above or below that of the incoming carrier, and which supplies an input

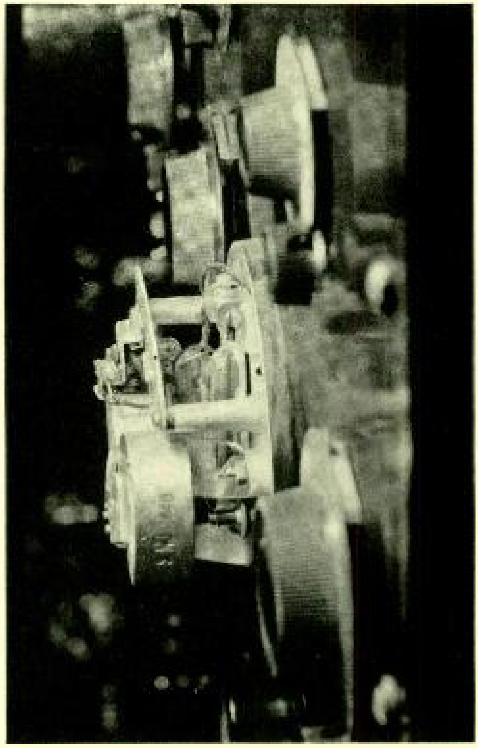


Fig. 4—A modified watt-hour meter serves as a motor to drive the vernier tuning condenser of the beating oscillator

tending to rotate the motor in a direction to bring the oscillator to the correct value when the difference-frequency varies. The input to the motor increases in proportion to the deviation of the difference frequency, so that the greater the error in the difference frequency, the greater will be the speed of correction.

A schematic of the balanced modulator circuit and associated phase-shifter with crystal, which supply the driving current for the motor, is shown in Figure 5. The carrier from the crystal filter passes through one smoothing stage and is then fed to the grids of the balanced modulator over two circuits. One circuit applies carrier to the grids through a coupling transformer, thus supplying the two

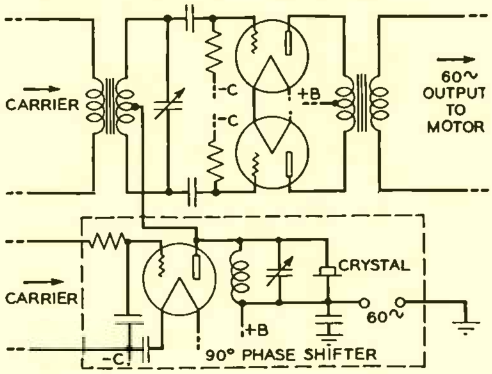


Fig. 5—Simplified schematic of the phase shifter, crystal, and balanced modulator used for tuning the beating oscillator

grids in phase opposition. The other circuit takes the same carrier but shifts it ninety degrees, amplifies it, and applies it to the two grids in the same phase. The phase relationships of the two carrier-frequency supplies to the modulator grids when the intermediate frequency is at the correct value are shown at the left of Figure 6. A and A_1 are the two direct feeds and are in opposition in the two tubes, while B and B_1 are the two quadrature components, and are in the same phase at the grids. The resultant voltages on the grids are C and C_1, each of which is the vector sum of the two components. These are of equal magnitude. A sixty-cycle supply is also connected to the two grids at the same point as the quadrature high-frequency current. The sixty-cycle component is in phase on the two grids, and the amount that will appear in the output circuits is a function of the high-frequency grid potentials C and C_1—equal amounts of the sixty-cycle components will appear in the output when C and C_1 are equal, and unequal amounts when they are unequal. When the intermediate frequency is at the correct value, C and C_1 are equal in magnitude, and as a result equal amounts of the sixty-cycle component will appear in the output of each tube where they will be balanced out because of the ninety-degree difference in phase.

Shunting the circuit of the quadrature component between the phase shifter and modulator is a crystal

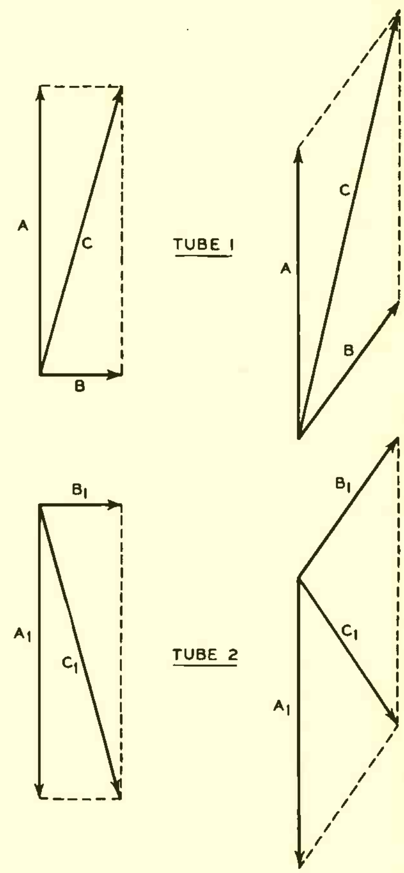


Fig. 6—Phase relationships of the two carrier frequencies supplied to the grids of the modulator. (Left) when the intermediate frequency is correct; (right) when the intermediate frequency is incorrect

sharply tuned to the desired intermediate frequency, which is also that of the narrow crystal filter. This crystal has no effect on the phase of this quadrature component as long as its frequency is at the correct value. When it deviates from this value, however, the crystal acts as a phase shifter, and shifts the phase and amplitude of this component by relatively large amounts for a small deviation from the correct value. The effect of this shift on the resultant voltage on the grids of the modulator tubes is shown at the right of Figure 6. A and A_1 are not changed because they do not pass through this crystal circuit, but B and B_1 are. The effect of the phase and amplitude shift of the B components is to give a large difference in the resultants C and C_1 as indicated. This unbalances the modulator with the result that the sixty-cycle component is no longer balanced out, but gives a sixty-cycle output to operate the tuning motor. As may be noted, the amplitude change in B and B_1 in the out-of-tune condition aids in unbalancing the modulator. Depending on whether the intermediate frequency was greater or less than the desired frequency, the C or C_1 resultant will be the larger. In one case the sixty-cycle output will drive the motor in one direction, and in the other, in the opposite direction. This circuit acts rapidly, and operates very effectively to hold the intermediate frequency at the correct value.

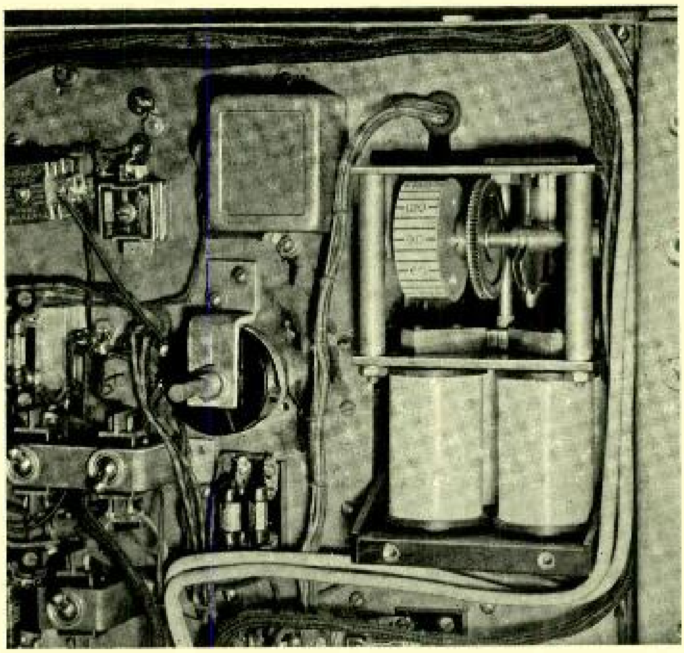


Fig. 8—A two-phase motor drives the vernier tuning condenser of the local oscillator through a worm gear

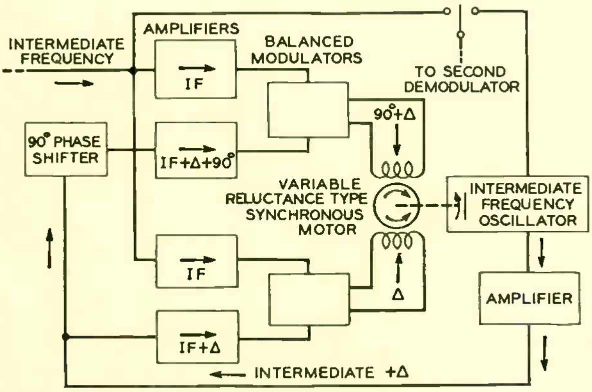


Fig. 7—Block schematic diagram of the synchronizing circuit which is employed for the local oscillator

To be able to compare reception using a reconditioned carrier with that when the carrier is supplied by a local oscillator, an optional arrangement was provided for furnishing carrier to the second demodulator. This arrangement requires a tuning control for the oscillator, but the problem differs from that encountered in tuning the beating oscillator in that the frequency for this resupply oscillator must be held to a value approximately the same as the intermediate frequency, while the frequency of the beating oscillator must be held at a frequency differing from it by a constant amount.

The tuning of the local oscillator is obtained by a circuit shown in the block diagram of Figure 7. It is similar to the equipment that has been used for synchronizing broadcast stations. The incoming carrier and the local oscillator are beat together in two modulators whose outputs are in quadrature. The resulting beat drives a two-phase motor, shown in Figure 8, that operates until the beat-frequency becomes zero. The speed of the motor varies directly with frequency, and so the larger the deviation in frequency, the more rapidly will the correction be made. The action of this synchronizing circuit is slower and more precise than that of the automatic tuning of the beating oscillator, so that when a change in the incoming carrier or the beating oscillator occurs the automatic tuning control of the beating oscillator will act to bring the intermediate frequency to the correct value to pass the crystal filter. The synchronizing apparatus will make what further adjustment is needed to hold the local oscillator at this value.

This single-sideband receiver has proven very satisfactory in preliminary tests, and from studies made with it a large amount of information has been gathered on single-sideband transmission, some of which was discussed in an article in the May issue, page 303. Tests on single-sideband operation on short waves are in progress, and although results so far have been favorable, there are still some unsettled points. Only one-direction transmission has been tested between England and New York, but two-way commercial tests are planned.

Contributors to this Issue

R. I. CRISFIELD received an M.E. degree from Cornell University in 1921 and joined the Department of Development and Research of the American Telephone and Telegraph Company the same year. Here he engaged in studies of loading-coil cases, cable terminals, cable conductor splicing, and other outside plant problems. In 1934 he transferred to the Outside Plant Development group of the Laboratories, where his work has been concerned with apparatus and methods for making electrical tests during the installation and service life of exchange, trunk, and toll cable.

V. M. COUSINS received the B.S. degree in Electrical Engineering from the University of Minnesota in 1925, and a few months later joined the Technical Staff of the Laboratories. Since then, with the Special Products Department, he has been engaged in the development of apparatus for sound picture and public address systems.

JOHN R. CARSON was graduated by Princeton University in 1907 and received the degrees of Electrical Engineer and Master of Science in 1909. The degree of Doctor of Science was conferred upon him this year by the Brooklyn Polytechnic Institute, in recognition of his contributions to the theory of electrical transmission.

Dr. Carson joined the engineering staff of the American Telephone and Telegraph Company in 1914, and transferred to the Laboratories in 1934. He is the inventor of the single-sideband, suppressed-carrier method of transmission, now widely used in wire and radio communication; for this and for his development of the theory of transients by means of the operational calculus he received the Morris Liebmann Prize of the I.R.E. in 1924. Dr. Carson is the author of about fifty professional papers and of the book *Electric Circuit Theory and the Operational Calculus*.

GEORGE RODWIN received an A.B. degree from Columbia University in 1923 and an E.E. degree in 1925. He then joined the Technical and Test Department of the Radio Corporation of America where he was engaged in radio research until the spring of 1929. During

R. I. Crisfield

V. M. Cousins

J. R. Carson

George Rodwin

J. F. Morrison

H. G. Jordan

the following year he was assistant chief engineer for the Earle Radio Corporation where he was in charge of the development of broadcast receivers. In 1930 he came to the Laboratories and has since been occupied with radio receiving research and development. During this period he has done considerable work on the development of the transatlantic radio receiving equipment. He worked on the design of the ultra-short-wave receivers now being used on the radio link between Green Harbor and Provincetown, Massachusetts. Lately he has been occupied principally with ultra-short-wave circuit and repeater design.

J. F. Morrison joined the Engineering Department of the Federal Telephone and Telegraph Company in 1923, where he engaged in the development and manufacture of the earlier broadcast receivers and transmitters. Previous to this time he had spent two years at the Electrical Vocational School, Buffalo, New York. In 1926 he left the Federal Company and joined the Long Lines Department of the American Telephone and Telegraph Company. The following year he was engaged as wireless operator by the Radio Corporation of America, and operated on Standard Oil Company ships between New York and South American ports. A year later he left to become Vice President and Technical Director of the Buffalo Broadcasting Corporation which operated Radio Broadcast stations WKBW, WGR, WMAK and WKEN. In 1929 Mr. Morrison joined the radio development department of these Laboratories. His work in that department has included the supervising of radio broadcast transmitter installations, radio transmission studies, and broadcast antenna design.

H. G. Jordan joined the Engineering Department of the Western Electric Company in 1917, where he worked on the drafting of floor plans and equipment layouts. He then served about two years in the Signal Corps of the U. S. Army, spending a year overseas with the 314th Field Battalion. In 1919 he returned to his former work with the Western Electric Company, but in the fall went to Northwestern University where he studied electrical engineering for two years, followed by one year at Purdue University. He returned to the Western Electric Company as equipment engineer in 1923. In 1931 he transferred to the American Telephone and Telegraph Company where with the D. & R. Department he worked on repeaters and pilot-wire regulating equipment. Two years later he transferred to the development of carrier systems, in which work he has also been engaged since the incorporation of the Development and Research Department with the Laboratories.