BELL LABORATORIES RECORD

LOW-HUM VACUUM TUBE

J. O. McNally

IMPROVED BRIDGE FOR TOLL TESTING

A. J. Pascarella

ATMOSPHERES OF KNOWN HUMIDITY

A. C. Walker

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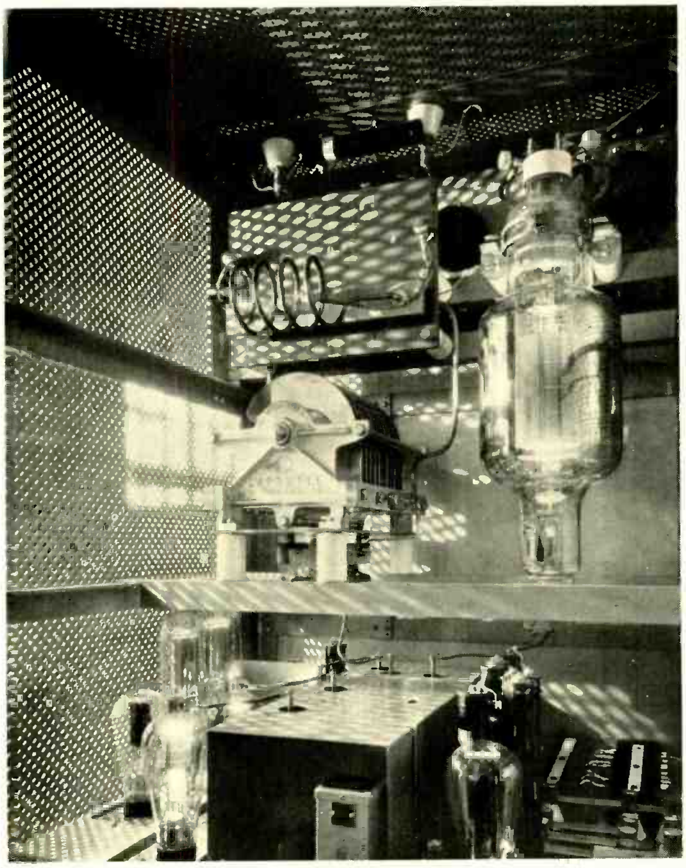

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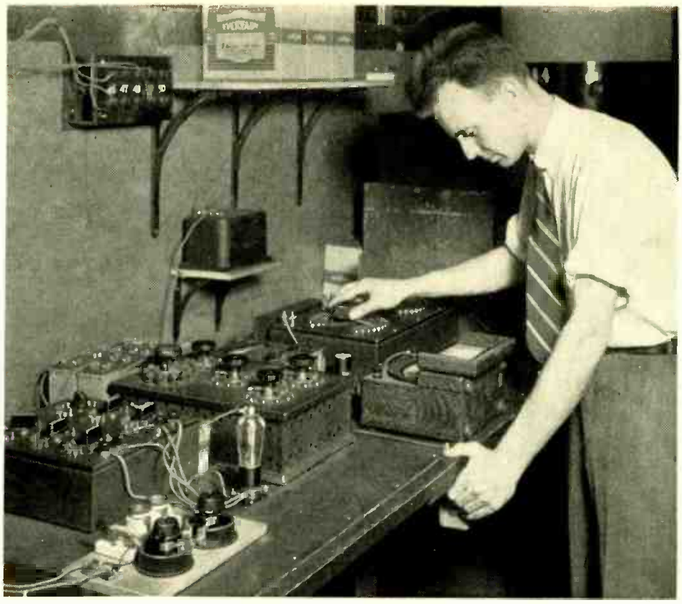


A "Low-Hum" Vacuum Tube

By J. O. McNALLY
Vacuum Tube Development

WHEN the filament of a vacuum tube carries an alternating current, disturbance currents of the frequencies of the power supply and its harmonics are found in the plate circuit. In voice frequency amplifiers, with sufficient gain following a vacuum tube so operated, these disturbance currents produce an undesirable or even intolerable hum in the amplifier output. In tubes where the electron emission is obtained directly from the filament they are so great that such tubes can be employed only in amplifiers giving very low gains. Tubes with indirectly heated, or equipotential type, cathodes may be employed for certain radio receiver and general amplifier uses, although they cannot be employed in the early stages of high-gain amplifiers. To provide for the need of an all a-c operated audio-frequency amplifier of high gain, such as are used in public address and announcing systems, sound picture projection, and speech input equipment for radio broadcasting, the Laboratories have developed a low-hum tube known as the Western Electric No. 262-A vacuum tube.

Before undertaking the direct development of a low-hum tube, it was necessary to study the various ways by which disturbances enter the plate circuit, and to evaluate the contributions from each source. Equipment was assembled with which it was possible to measure separately the disturbance currents of different frequencies. Such a measurement is shown being made by G. T. Papineau at the head of this article, where the shielding is removed. Output currents as much as 120 db below one milliampere, or .001 microampere, could be measured with satisfactory accuracy. With this measuring equipment available, numerous experimental tubes of the indirectly-heated-cathode type were made and tested. From the results it was found that disturbance currents are introduced into the plate circuit in three ways: through the electric field due to the potential of the heater, through the magnetic field due to the current flowing through the heater, and through leakage current flowing through the resistance and capacitance between heater and grid, and heater and plate. Disturbances introduced through induction between parts of the circuit external to the tube are not considered because they are not a part of the tube problem.

The electric field due to the potential of the cathode heater acts on the plate current in a manner similar to that of the field of the grid. Since the electric field due to the filament varies with the frequency of the heater supply, a corresponding disturbance current is introduced into the plate circuit. The space between cathode and plate in any indirectly heated cathode tube is partially shielded from the electric field of the heater by the cathode cylinder. Below the cathode cylinder, however, there is an unshielded section of heater conductor. Experimental tubes were made therefore in which various forms of shielding were applied to this lower section. It was found that commercially practical amounts of shielding would reduce the disturbance from this source by very appreciable amounts. In some of the experimental tubes the disturbance current produced by the electric field in shielded tubes was only about a hundredth of that from similar tubes not shielded.

The shield employed in the 262-A tube may be seen in Figure 1. It is in the form of a flattened bell covering the section of the heater wires below the cathode cylinder, and is supported by two short mount wires projecting upward from the glass press. Although not in contact with the cathode cylinder, it is connected to it electrically by a small wire.

A component of the disturbance current in the plate circuit arises from a deflection of the electron stream from cathode to plate—and a conse-

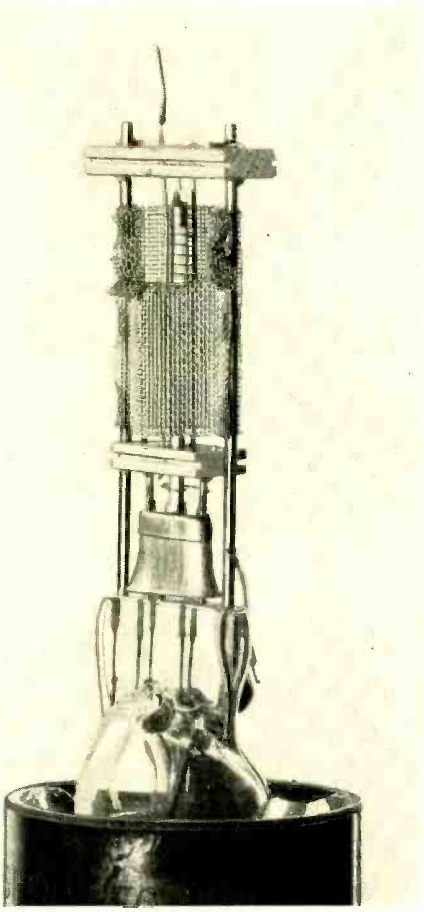


Fig. 1—Assembled 262-A tube without bulb and with part of plate cut away to show the grid construction

quent reduction in current—by the magnetic field produced by current flowing in the heater conductor. These reductions in plate current occur twice for every cycle of heating current, and thus produce a double frequency component—120 cycle for the usual 60 cycle supply—in the output. If, because of possible asymmetries in the tube, the two reductions of one cycle of heater current are unequal, a fundamental or 60 cycle component, is present. The level of such a fundamental output is generally less than that of the second harmonic, and because the human ear is 18 or 20 db less sensitive at 60 cycles than at 120, the disturbance of fundamental frequency due to the magnetic field usually is relatively unimportant.

In the 262-A tube the effects of the magnetic field of the heater have been reduced by employing a filament of comparatively high voltage, and thus low current, and by arranging it in a closely spaced "U" so that the field due to the current passing up one side of the "U" partially counteracts that due to the current flowing down the other side. The heater conductor is wound in a spiral and then threaded up and back through two longitudinal holes in a small ceramic cylinder. The two holes are made as close together as is mechanically possible so that the neutralization of the field due to current in one leg by that due to current in the other will be as great as possible. This ceramic cylinder is mounted within the nickel cathode which is coated with the thermionically active material. The heater is operated at ten volts and .32 amperes, appreciably less current than is normally used for tubes of this class, and the combined effect of the reduction in current and the arrangement of the filament is to minimize the disturbance currents due to magnetic fields.

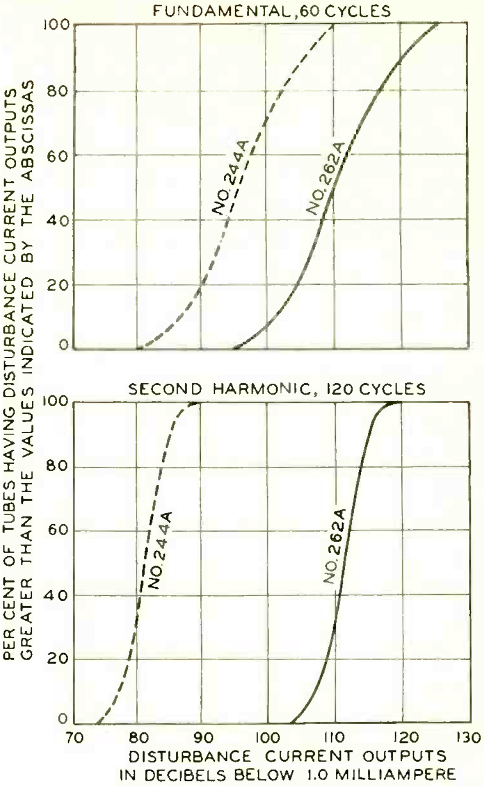


Fig. 3—Distribution curves for disturbance currents at 60 cycles, above, and 120 cycles, below

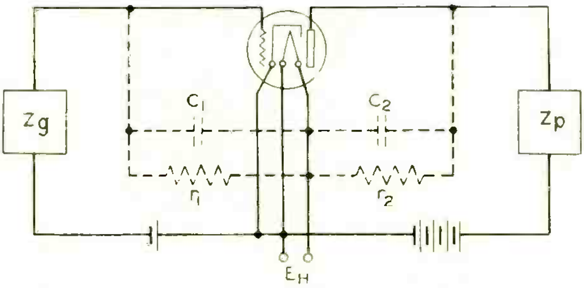


Fig. 2—Possible disturbance currents in a vacuum tube flow from the heater to plate and grid through the interelectrode capacitance and conductance

The third form of disturbance current occurs because of the conductance and capacitance between heater and grid, and heater and plate. The effect may be better understood by reference to Figure 2, where the resistance and capacity between heater and grid, and heater and plate are shown in dotted lines. The heater voltage causes a current to flow through the impedance Zg, of the grid circuit, and through the capacity C_1 and resistance r_1 in parallel, back to the other side of the heater. The voltage drop across Zg due to this current appears on the grid of the tube and produces a corresponding current in the plate circuit. In a similar way the resistance and capacity between the heater and plate are responsible for a disturbance current entering the plate circuit directly. In the actual operation of these tubes, the cathode—instead of being connected to one end of the heater winding—is connected effectively to the midpoint. Under these conditions capacities and resistances exist between both ends of the heater, and the grid and plate, but the action is essentially the same.

To reduce the disturbance currents introduced in this manner, the grid-heater conductance and capacitance has been made lower than for the usual indirectly heated tubes. This reduction has been brought about by supporting the grid between two lavite blocks, evident in Figure 1, and in making connection to the grid through the top of the bulb. In this way both the capacity and conductance between heater and grid leads, usually existing in the common glass supporting press, have been eliminated. The only effective leakage path over glass in the new tube is down the stem and over the entire length of the bulb. This resistance is held greater than 100,000 megohms, and the grid to heater capacity is only about a thousandth of that of the more usual types of indirectly heated cathode tubes. Such values permit the use of resistances of several megohms in the grid circuit without materially increasing the disturbance output.

Plate to heater capacities are not sufficiently large to contribute materially to the disturbance outputs, and insulation leakage between plate and heater sufficient to cause appreciable current is prevented by the

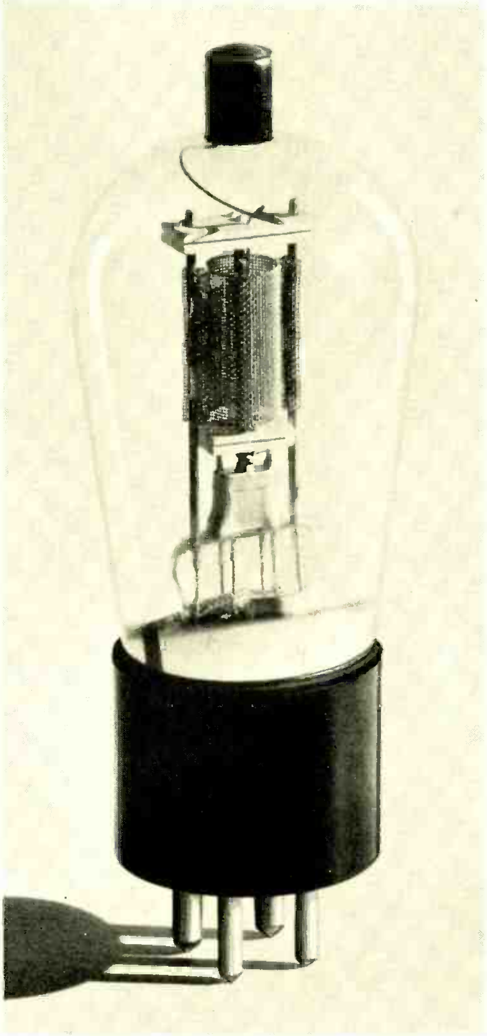
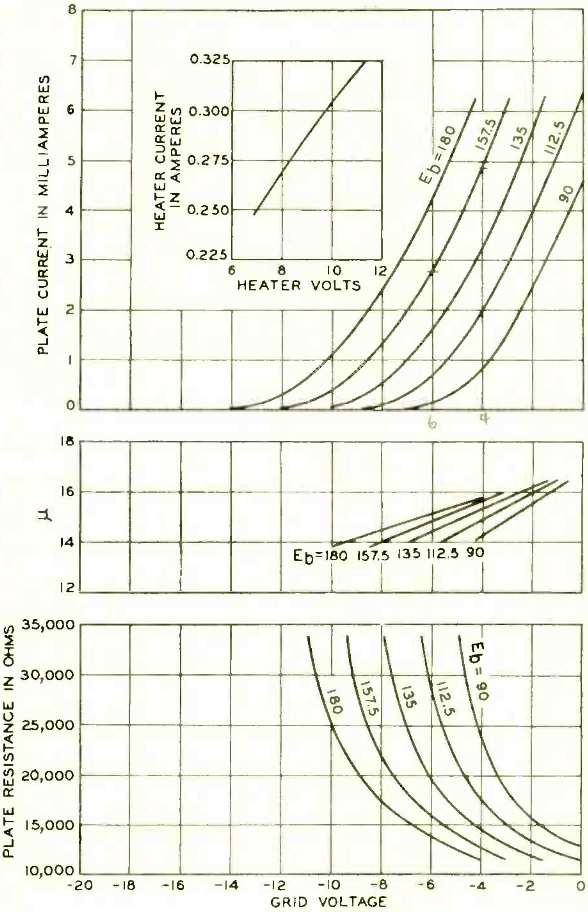


Fig. 4—The 262-A vacuum tube

electrostatic shield already described. This shield bells out over the glass press where the heater leads enter it, and prevents the deposition of material vaporized from the hot surface of the cathode. It is this deposited material that usually forms the conducting path between plate and heater support wires.

The extent to which disturbance currents have been reduced in the new tube is shown in Figure 3. Here the distribution of the disturbance outputs is given for a large number of 262-A tubes picked at random from the Tube Shop production. The abscissas represent the disturbance currents in decibels below one milliampere, and the ordinates the percentage of the total number of tubes that had disturbance outputs below the abscissa value for any corresponding point of the curve. For these tests the cathode was effectively connected to the midpoint of the heater. It may be noted from the curves that for the 60 cycle or fundamental output, one half of the tubes had disturbances not less than 110 db below one milliampere, and for the 120 cycle output, not less than 112 db below. Dotted curves show the corresponding data for the 244-A tube. The disturbances for the 262-A tube are distinctly less—amounting to 30 db for the second harmonic.

In addition to the disturbance currents discussed here, there are certain low level sources of noise, such as the shot effect, and the thermal noises* due to the resistances. The level of these unavoidable disturbances forms a natural lower limit by which other disturbances may be judged. Measurements made of disturbance currents in the 262-A tube due to these causes show them to be from 118 to 127 db below 1 milliampere for the shot effect, and about 105 db for the thermal noise with 2.0 megohms in the grid circuit. Disturbance currents in the 262-A tube due to the alternating current supply of the heater are somewhat greater than the shot effect and slightly less than the thermal noise. They have thus been reduced until they no longer exist as factors limiting the application of the tube.



Characteristics of the 262-A vacuum tube

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2.7
2.1
1/2

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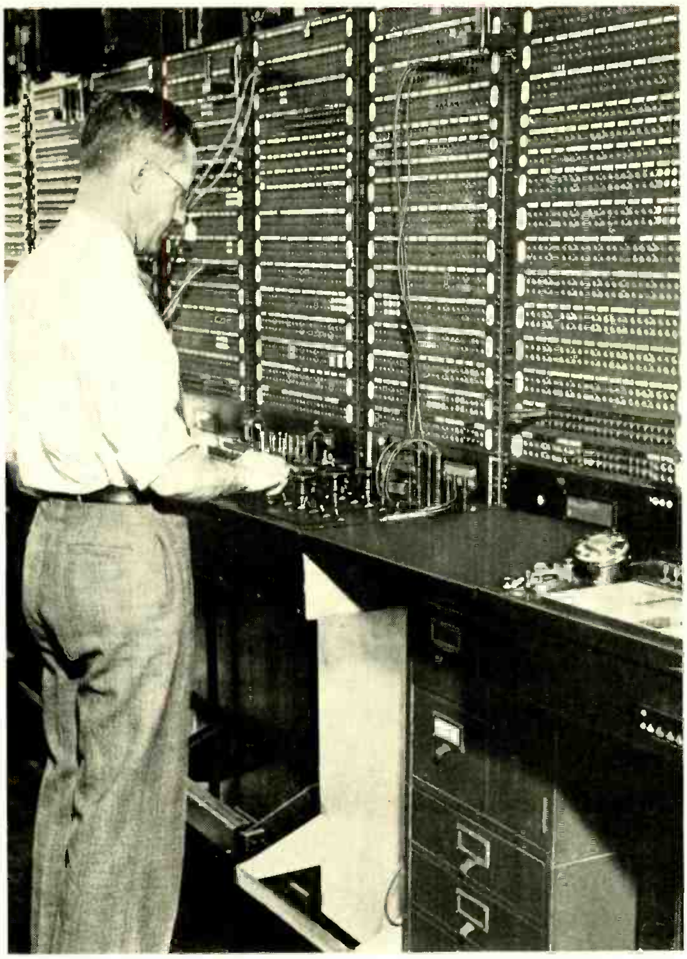
*Record, *February*, 1927, *p.* 185.



An Improved Wheatstone Bridge for Toll Test Boards

By A. J. PASCARELLA
Equipment Development

In maintaining high grade communication service over long toll lines, it is necessary to discover faults, such as leakages to ground or high resistance contacts, before they have become serious enough to disturb conversations or programs being transmitted, and to locate them accurately and quickly so that they may be promptly removed. An outline of the methods employed for line testing has already been given in the Record.* In general some form of "bridge" measurement is required, and the accuracy with which the fault

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*Record, *December*, 1928, *p.* 161.

may be located depends on the precision of the resistances of the bridge, on the sensitivity of the galvanometer, on the insulation of the testing equipment, and on the conditions of the line. A low resistance ground or short circuit is easily located within a very short distance if good cable records are available, but a high resistance fault, such as occurs when moisture first begins to enter a cable, requires very accurate tests for its location.

For the location of insulation faults up to about 100,000 ohms, a bridge of average insulation and sensitivity may be sufficient, but for locating faults with resistances of the order of several megohms, a more highly insulated bridge and a more sensitive galvanometer are required. To meet the requirements for this type of measurement, the Laboratories have recently developed a new bridge unit and associated testing equipment. In addition to the facilities for locating high-resistance faults, this bridge provides a number of improved features which are advantageous for other types of fault-location measurements. It may be employed as required in place of the earlier type bridge in the No. 5 Toll Test board.

Fig. 1—Front view, with front panel and foot rail removed, showing the associated battery consisting of twelve 22½-volt units, behind which is located the galvanometer

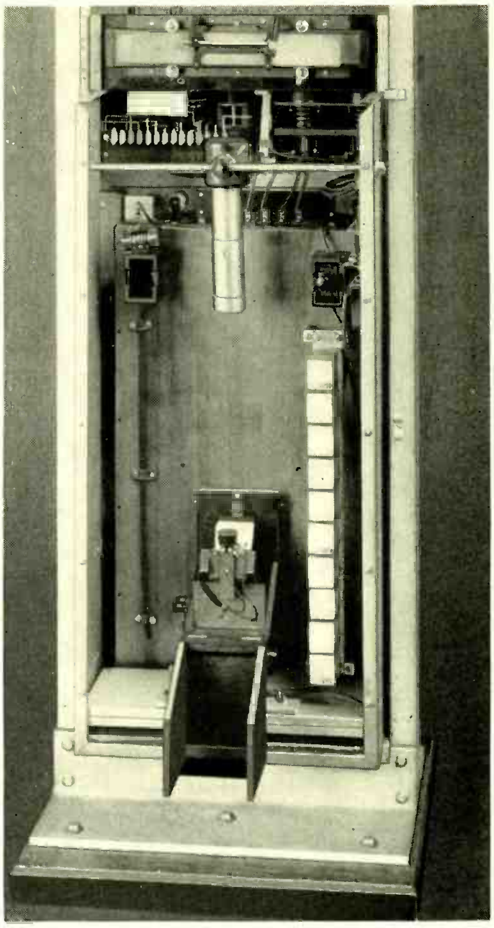


Fig. 2—Exposed view of rear of bridge section showing lamp unit and galvanometer

The increased accuracy and range of

the new bridge is secured by employing precision type equipment and adapting it for use in a standard toll test board section. An 85 cm light beam from the galvanometer is employed instead of the 20 cm beam formerly used. This greater distance is obtained by mounting the galvanometer in the lower part of the frame and, by a suitable arrangement of mirrors, prisms, and lenses, throwing the image of a hair line reflected from the galvanometer mirror upon a long translucent scale mounted in the piling rail, as may be seen in Figure 1. Other unusual features of the new set, which also were necessary because of the increased accuracy required, are the high insulation provided for all resistances and parts of the circuit, and the extensive "guard" system which prevents any leaks over the insulation from appreciably affecting the reading of the galvanometer.

The galvanometer is of the double-suspension D'Arsonval type and does not require accurate leveling. It rests on a weighted base which in turn rests on sponge rubber: an arrangement that acts as a mechanical filter to eliminate all vibrations except those of very low frequency. The arrangement of the optical system is shown in Figure 3. A lamp assembly, consisting of an automobile type lamp, a hair-line sweated across a flat annulus, and a lens for condensing the rays from the lamp on the mirror of the galvanometer, is mounted just behind the key shelf. Rays from this unit are reflected by a prism in the lower part of the section, through a lens, onto the galvanometer mirror. From this mirror the rays are reflected back

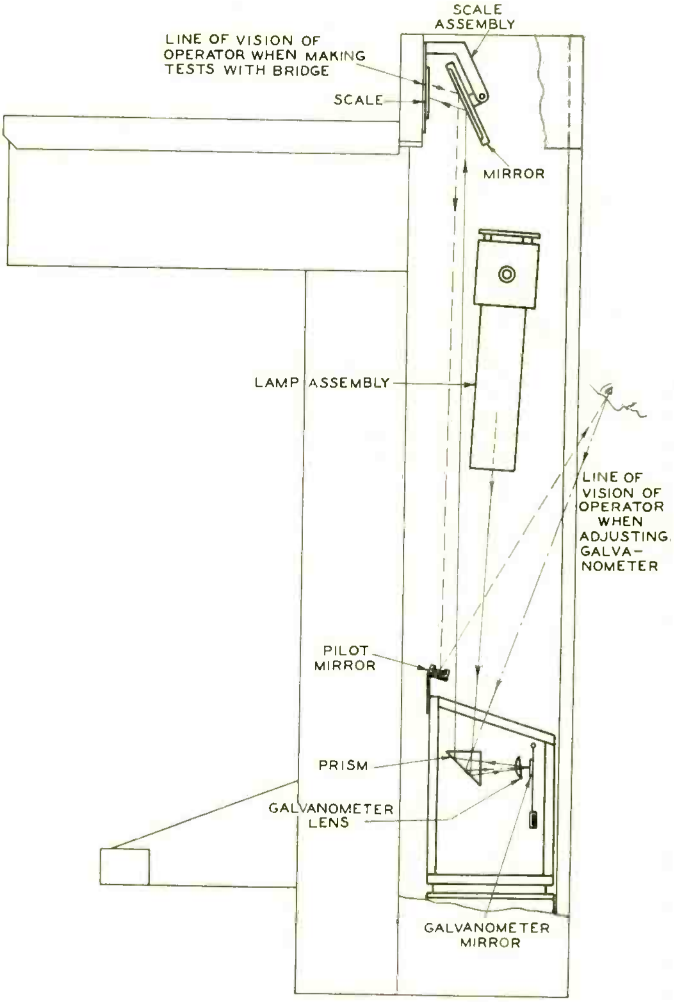


Fig. 3—The sensitivity of the Wheatstone Bridge is increased by mounting the galvanometer in the lower part of the section, which permits a light beam more than 4 times longer than that of the earlier equipment

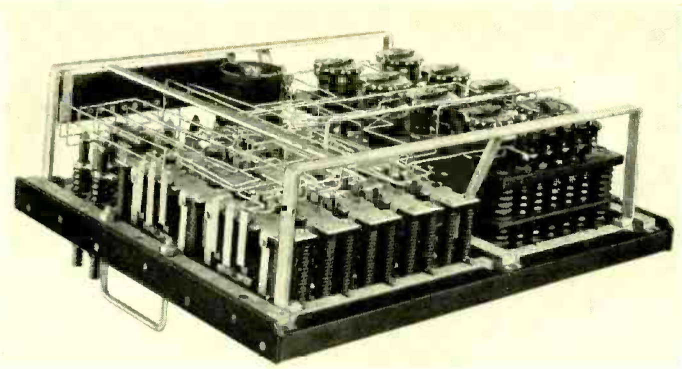


Fig. 4—View of under side of bridge showing high insulation and guard plates used on all component parts of unit

through the same lens and prism to a mirror just behind the piling rail, which reflects them onto the scale. The zero position of the galvanometer and the position of the prism may be adjusted from the rear of the section by a lever and a screw projecting through the galvanometer housing. A pilot mirror affords a view of the scale in the piling rail while this adjustment is being made. Small adjustments of the zero of the scale are made from the front of the section by an adjusting knob, which moves the scale to the left or right. The sensitivity of the galvanometer is such that with one volt impressed across the galvanometer in series with 200 megohms, a deflection of one millimeter is obtained.

Ideal conditions for the location of grounds require that all the current flowing into the test circuit and line pass through the two arms of the bridge, the two line conductors, and to ground through the fault. Leakage of current from the circuit at any point except the fault or the bridge apex tends to destroy the accuracy of the measurement obtained. Where the normal line insulation is not sufficiently high so that the effect of leakage through it can be neglected, it can, in general, be compensated by making two measurements, one from each end of the line. Leakages within the bridge cannot be compensated in this manner.

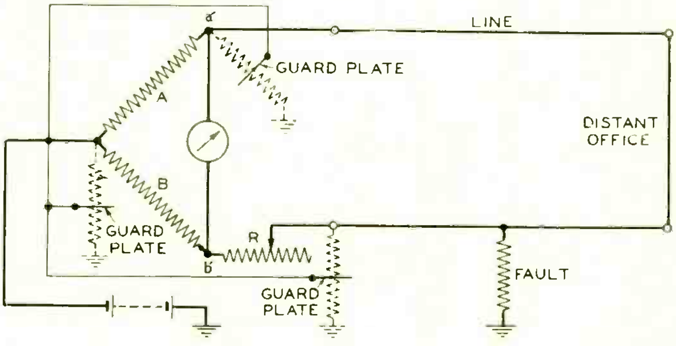


Fig. 5—Simplified schematic arrangement of bridge and guard plates

The accuracy of a fault-locating measurement is influenced by the leakage resistance of the bridge as a whole in a manner indicated by the curves of Figure 7. It is seen from these curves that with a two megohm fault an error of about 100 feet may occur when the effective insulation resistance to ground of the bridge (if located at the point shown in the figure) is 10,000 megohms.

To keep errors small, it is necessary therefore either to make the insulation resistance of all parts of the bridge very high or to provide other means of compensation. To secure high insulation resistance within the confines of a bridge small enough to fit into a toll test board was found to be impracticable. An equivalent sensitiveness may be obtained, however, by a suitable system of "guarding."

Such a guarding system is incorporated in the new bridge, and is secured by dividing the insulating supports of all parts of the bridge into two sections by a common metallic guard connected to the apex of the bridge. Such an arrangement reduces the flow of leakage current from the insulated parts back to the battery over the first half of the insulation, since the metal plate at the mid point of the insulation is at the same or a slightly higher potential than the part itself. Leakage current that flows from the metal plates back to the battery over the second half of the insulation cannot affect the balance of the bridge because it is not current that has passed through the bridge resistances or the galvanometer. With this guarding arrangement the effective insulation resistance of the bridge can be greatly reduced without materially affecting the accuracy of fault-locating measurements.

The arrangement of the metal guard plates is shown in Figure 4, and the general scheme of electrical connections in Figure 5. If guard plates were not employed, leakage current would flow, for example, from points "a" and "b" to ground over the insulation. If the two leakage currents were of the same value, and the ratio arms of the bridge were 1 to 1, these currents would balance each other and the galvanometer would be unaffected. If one were greater than the other, which is always the case in practice, the balance would be destroyed and the location found for the fault would not be correct. When guard plates are employed, however, no leakage can flow to ground from "a" or "b" because the guard plates are at slightly higher potential than these points as already noted. There are leakage currents flowing from the guard plates toward "a" and "b," which if unbalanced would tend to affect the galvanometer deflection, but because of the small voltage across the insulation between the guard plates and the points "a" and "b," the unbalanced current is too small to be appreciable.

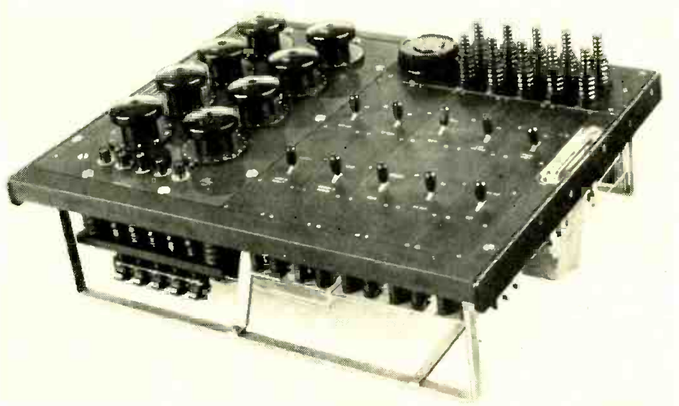


Fig. 6—Keyshelf assembly of highly insulated Wheatstone Bridge unit

Dials for operating the various resistances, keys for performing the switching operations required, and jacks for connection to the lines under test are mounted in the top of the bridge unit which mounts in the keyshelf of the test board. Its arrangement is shown in Figure 6. The group of jacks at the back of the bridge unit on the right are those employed for connecting to the line under test.

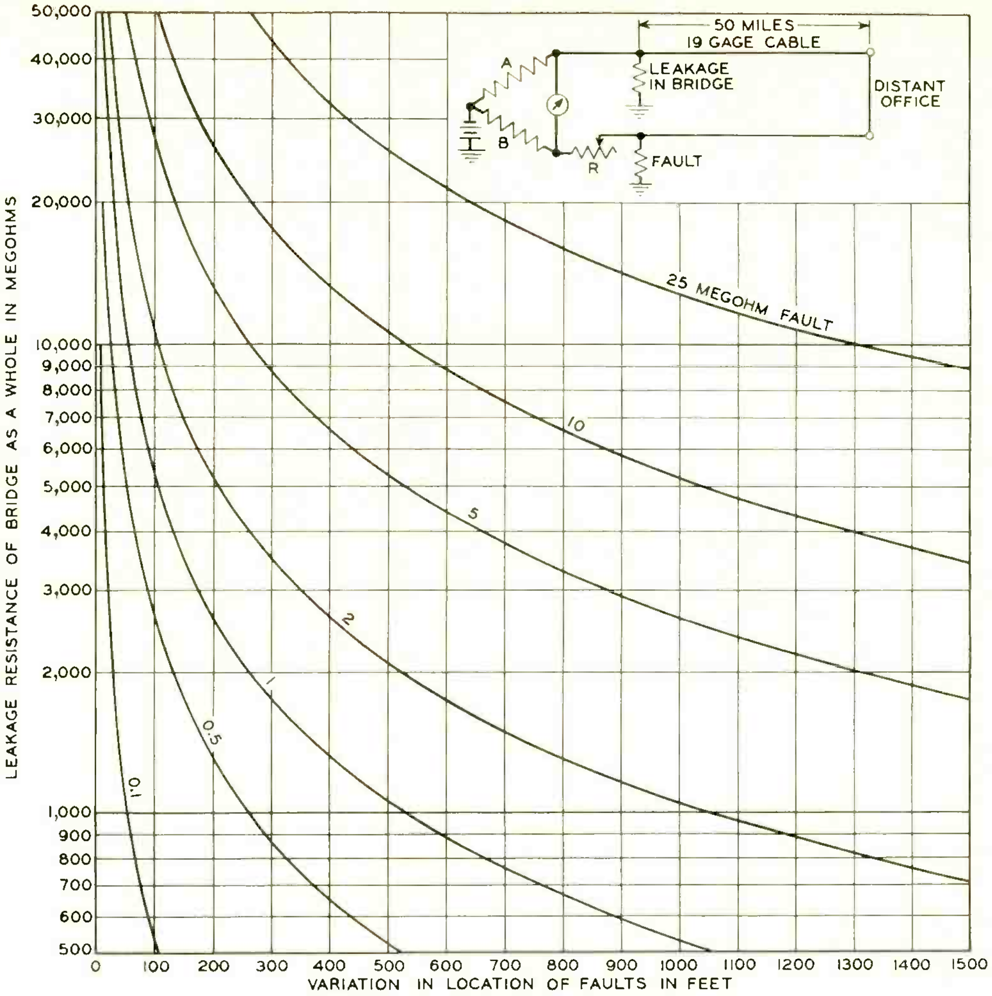
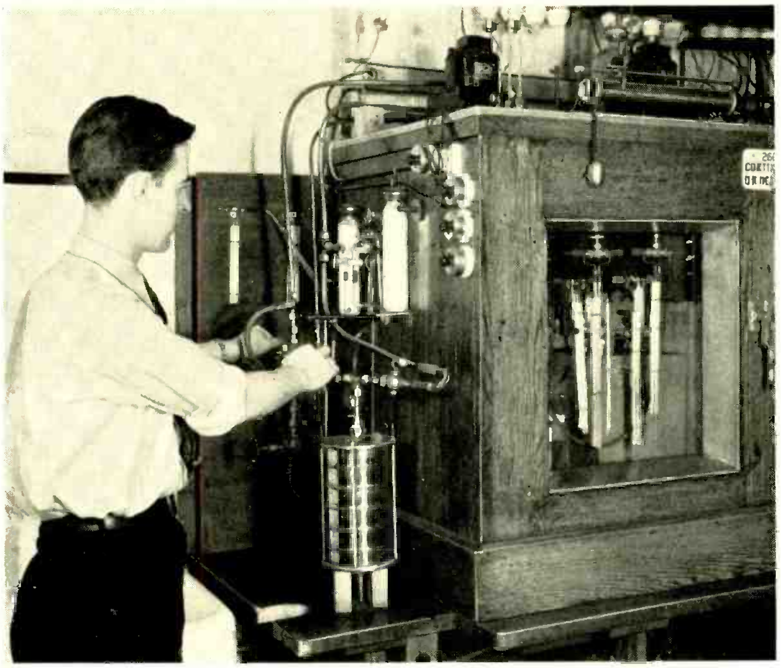


Fig. 7—The accuracy with which a fault may be located depends on the effective leakage resistance of the Wheatstone Bridge equipment

Highly insulated trunks run directly from one group of these jacks to the protector frame, and another group of jacks serves as terminals of the bridge. Short patching cords are used to connect from one set of jacks to the other. Any of several different battery voltages may be employed—depending on the type of fault—by operation of certain of the keys. Other keys are employed to set up rapidly the various connections required for the type of test being made. The same high insulation and guarding that has been described in connection with the bridge resistances is also applied to the keys, jacks, and all parts of the set.



Supplying Atmospheres of Known Humidity

By A. C. WALKER
Telephone Apparatus Development

THERE are many purposes for which it is useful to have apparatus which will continuously supply an atmosphere of a constant known humidity, variable at will. In these Laboratories such apparatus has been employed in calibrating a continuous humidity recorder of high sensitivity, and in the study of the properties of textile and paper insulation under different atmospheric conditions.

The apparatus in use supplies an atmosphere of constant absolute humidity: that is, containing a constant percentage of water vapor by volume. The relative humidity of the supplied atmosphere depends on the temperature at which it is used. This quantity is the ratio of the volume of water vapor which the atmosphere contains to the amount it would contain if saturated at that temperature. By reference to tables of the vapor pressure of water, the relative humidity can be found from the absolute humidity and the temperature.

Briefly, the apparatus provides two streams of air: one thoroughly dried, and the other nearly saturated with water vapor at constant temperature. It then mixes these streams in continuously controlled proportions. The control is exercised roughly by valves where the stream is divided, and precisely by controlling the relative pressure differentials which drive the dry and the moist streams past the mixing point.

The functioning of the apparatus

in detail can be seen from Figure 1. Air is taken at high pressure, and the pressure is diminished to a pound or two above atmospheric through reducing valves. This air is then dried very completely by passage at low velocity over a comparatively large surface area of concentrated sulphuric acid contained in a 20-liter carboy B. The acid serves to remove oil impurities as well as water vapor. Part of this air goes through a control valve V_1 to a water tower C, contained in the constant-temperature oil bath D, where the air is nearly saturated with water vapor at the temperature of D. The remainder passes through a valve V_2 and a flowmeter G, and then is mixed with the humidified air from C, which has been metered through a flowmeter F. The mixture passes to a mixing bottle H, thence through a flowmeter J and a valve V_3, and so to the apparatus in which it is desired.

To secure accurate control of the flowing gas mixtures it is essential that the pressures, and pressure differentials, in all parts of the system be constant. Constancy is secured by means of constant-pressure overflow tubes, N, O and P, at essential points. Tube O permits a small amount of the wet air, emerging from the saturator C and trap E, to bubble to waste, and thus compensates for small fluctuations in the pressure. Tube N fulfills the same function for the air supplied to the dry air flowmeter.

This arrangement is well recognized practice in securing relatively constant pressures in flowing gas mixtures, but the addition of a tube P to control the pressure of the mixture is a distinct innovation, and makes it possible to secure remarkably constant control of the compositions of gas mixtures. So long as small amounts of air bubble to waste from these three tubes, the composition of the mixture is fixed. Furthermore, by placing the tubes N, O and P in a single bath D, any change in the level of liquid in the bath does not alter the relations between the pressures, and the ultimate composition is unaffected.

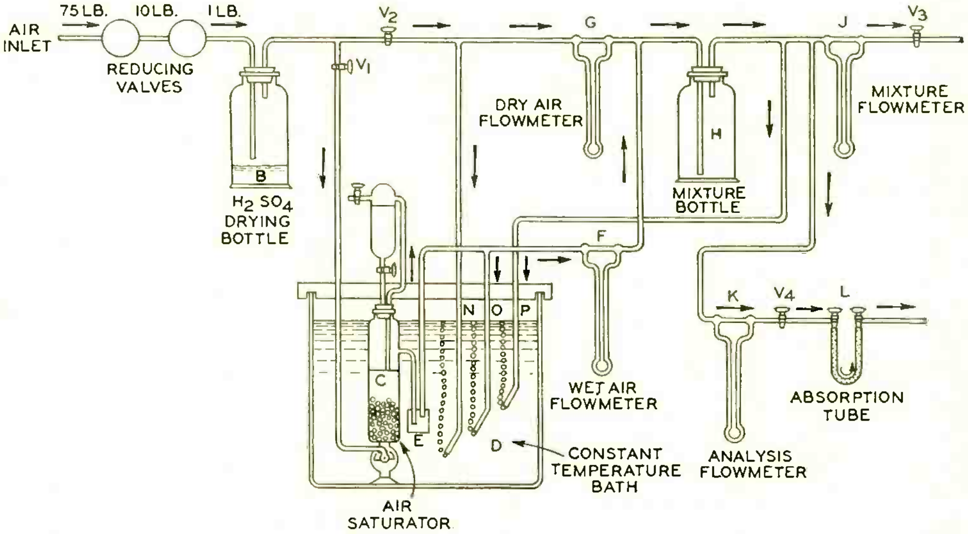


Fig. 1—An atmosphere of constant humidity is supplied by mixing in controlled proportions two streams of air: one thoroughly dried, the other nearly saturated

These overflow tubes are also used to vary the composition. Their depths below the liquid level in D determine the quantities of air flowing through the several flowmeters: the difference in depth of N and P determines the difference in pressure on the two sides of the flowmeter G, and similarly, the levels of O and P determine the difference in pressure through F, and thus control the quantities of dry air and wet air, respectively, fixing the composition. Tubes N, O and P are connected to their supply tubes by flexible rubber tubes, and their depths in the bath D may be readily adjusted.

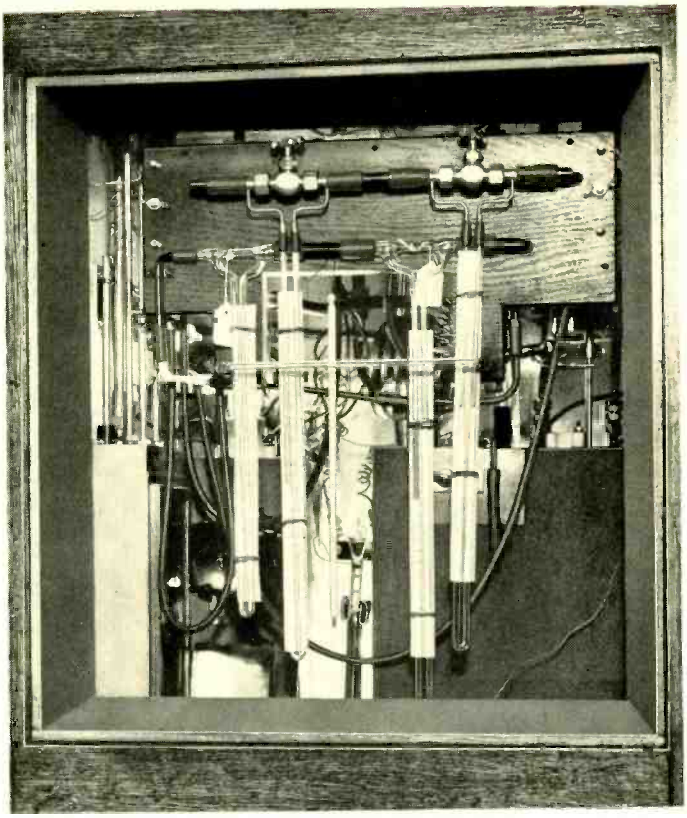
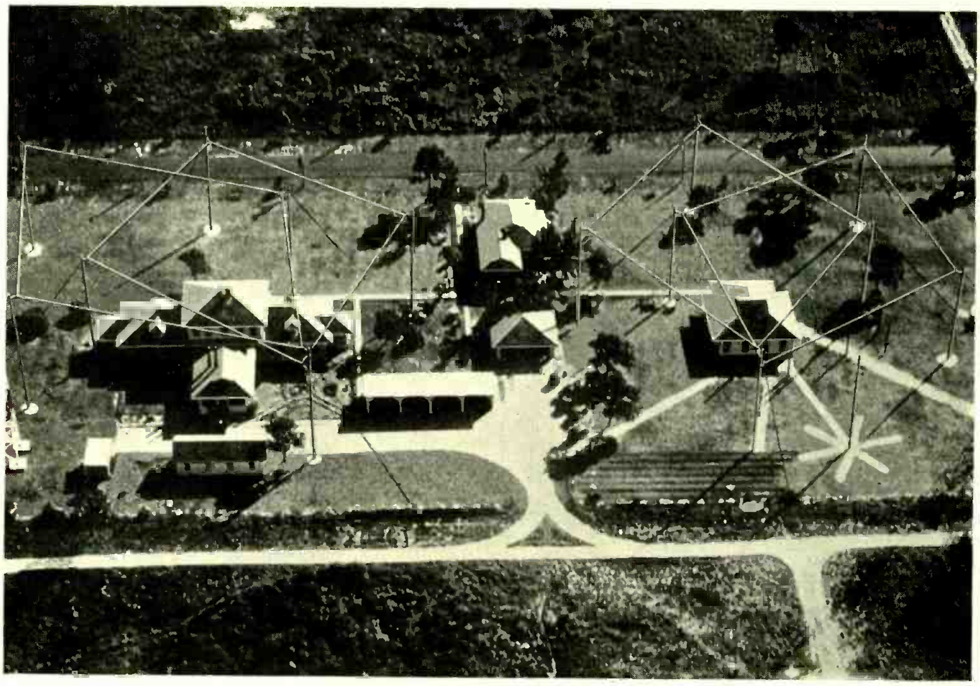


Fig. 2—Much of the constant humidity apparatus is in a temperature-controlled box. The flowmeters appear in front

The air passing through C is incompletely saturated due to the expansion of the air bubbles in their passage upwards through the tower. Complete saturation would occur only if the hydrostatic head in C were zero. But by maintaining the water level constant through a continuous automatic siphon, the degree of saturation (about 96 per cent) is fixed with remarkable constancy. Since the temperature of the bath surrounding the saturator is held to within ±0.01 degree Centigrade, this constant degree of saturation can be translated as a constant absolute humidity.

The water-vapor content of the delivered mixture may be analyzed by weighing the amount of water contained in a given volume of the mixture. The apparatus for the analysis consists of an accurately calibrated flowmeter K, and chemical absorption tube L, containing an efficient agent for absorbing water vapor, called "Dehydrite," which is magnesium perchlorate-trihydrate. Because of its granular structure, this substance is much more suitable than the phosphorus pentoxide more generally used, and it is quite as efficient for this purpose. The accuracy of an analysis depends upon the length of time of absorption required to secure sufficient weight of water, and since the apparatus is capable of giving constant mixtures for many days running, the analysis can be made as accurate as desired.



Telephone Links to Colombia and Venezuela

The Bell System was linked with Venezuela on December 18, and with Colombia four days later, by short-wave radio stations near Miami, Florida, and in the South American countries. The cost of a call between New York and either Caracas or Bogota is $24.00 for the first three minutes and $8.00 for each additional minute. North America now has direct telephone connections with seven South American countries; other links are giving service to Argentina, Brazil, Chile, Peru, and Uruguay. The Miami receiving station and rhombic antennas for the new tropical services are shown in the photograph above.

Light-Weight Transformers for Aircraft

By D. W. GRANT
Telephone Apparatus Development

THE development of radio equipment for use in aircraft communication created a demand for apparatus which would occupy a minimum of space and impose a minimum load on an airplane. Notably, there was need for audio frequency transformers very light in weight and small in size. Though reduction in these particulars is always a desideratum of transformer design, the aircraft radio demand furnished the first major problems in which this reduction, here a paramount concern, justified special design.

Some measure of the lightness of weight which has been achieved in the new designs can be seen in Figure 1. This figure compares the aircraft transformers with standard transformers electrically equivalent to them. The areas in the sketch have been made proportional to the weights of the apparatus.

Four transformers and two retardation coils were required in early aircraft radio equipment*: a retardation coil and a transformer in each of the two

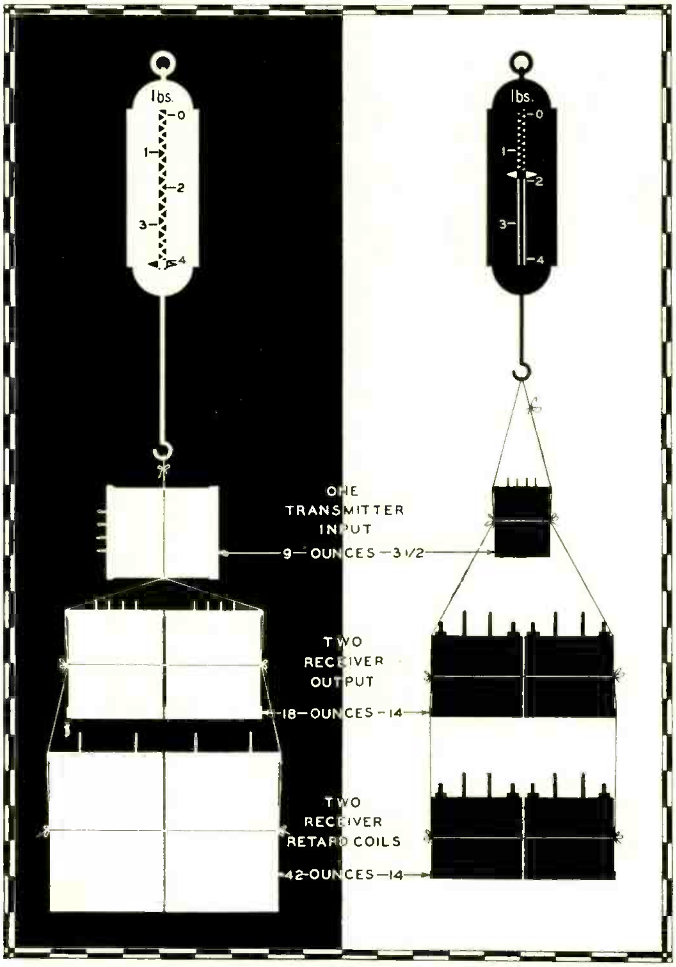


Fig. 1—Newly designed aircraft-radio transformers have considerably lightened the load on airplanes. Areas in the figure are proportional to weights of the apparatus

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*Record, *October*, 1930.

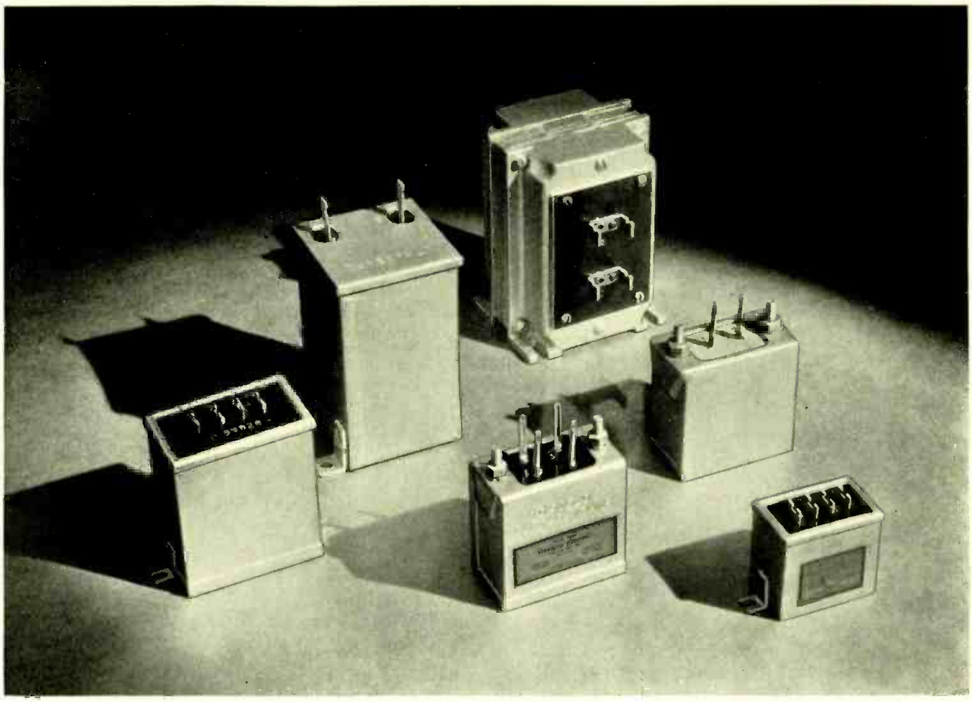


Fig. 2—The transmitter contains the largest and smallest of the aircraft-radio transformers. Input transformer (front right) has a closed permalloy core; output transformer (rear) silicon steel core. The receiver output transformer (front center) and retardation coil (middle right) employing permalloy cores, and the electrically equivalent silicon core coils (at their left), show considerable difference in size

receivers which are used in each completely equipped plane, and two transformers in the transmitter. The transformer in the receiving set is in the output circuit of the audio amplifier, and the retardation coil is in a filter which smooths out commutator ripple in the power supply to the vacuum tube plates. The transformers in the transmitter are used in the output and input circuits of the speech amplifier. Forming circuit elements whose proper performance is quite important and which necessarily incorporate considerable material, these six pieces of apparatus are responsible for an appreciable part of the size and weight of aircraft equipment. Figure 1 shows that this equipment had its weight reduced by 2⅓ pounds as a result of this development alone.

In detail it is noteworthy from Figure 1 that the weight reduction in the various types of transformers differs considerably. This implies that reduction in weight is not a simple thing to achieve, and that how and to what extent it can be accomplished varies with the function of the transformer. A glance at the factors determining the weight of a transformer will serve to show why reducing weight is not a simple task.

The size and weight of such a transformer are largely determined by the dimensions of its core. Theoretically it might seem possible, since an amplifier transformer is usually required to transmit relatively small amounts of power, to build one with a very great number of turns of very fine wire, thus reducing the weight of core required. There is a practical limit, however, to the fineness of wire that can be handled.

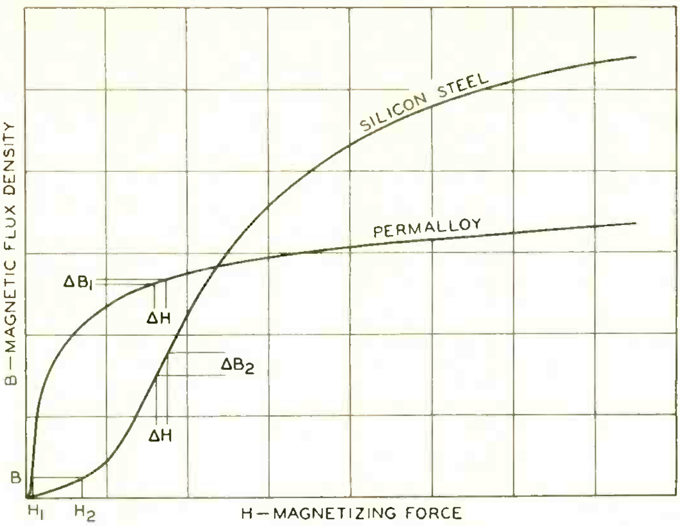


Fig. 3—Whereas permalloy has a higher initial permeability (B/H_1) *than silicon steel* (B/H_2), *its differential permeability* ($\Delta B_1/\Delta H$) *at high magnetizing forces becomes less than that of silicon steel* ($\Delta B_2/\Delta H$)

For a given magnetizing force the magnetic flux which will exist in a core is proportional to its cross-section and to the permeability of its core material. Thus to obtain the same actuating flux with equal magnetizing forces a transformer embodying a core material of relatively low permeability will have to be much larger than one using a core material of high permeability. Now the amplitudes of flux density variations in amplifier transformers are generally small. Since the permalloys are characterized by their high permeability at low flux densities their use offers possibilities of size reduction in transformer designs. However, a simple substitution for silicon steel, the usual core material, will not give this result unless accompanied by appropriate design technique.

The actuating flux is of course continually varying and in terms of flux density the amplitudes of these variations are generally small. If one or more windings of the transformers must carry direct current, the resulting steady magnetizing force will cause a steady flux in the core, which may be relatively much greater than the actuating flux. Under these conditions the magnetizing force required to produce the small variations in actuating flux may be radically different from that required when no such steady flux is present. The ratio of a small change in flux density to the small change in unit magnetizing force necessary to produce it is called the "differential permeability."

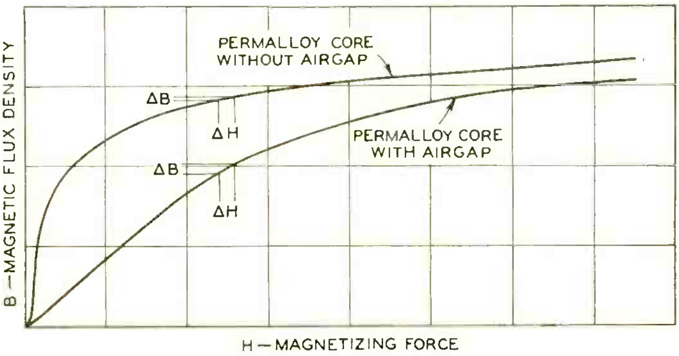


Fig. 4—While an airgap in a permalloy core decreases the effective permeability, it may increase the differential permeability at high magnetizing forces

By reference to Figure 3 it will be noted that the differential permeability of permalloy diminishes considerably as the steady magnetizing force is increased, becoming lower than that of silicon steel at high values of magnetizing force. As transformers used in vacuum tube circuits frequently must operate under conditions of high DC magnetizing force, it is the problem of the engineer to retain the advantages of permalloy under such conditions. This advantage can be retained by the use of a properly proportioned airgap or its equivalent in the magnetic circuit. The effect of such an airgap is shown in Figures 4 and 5. It will be noted from these figures that, although the initial effective permeability of the core is reduced by this means, the rate of decrease in effective differential permeability with increasing steady magnetizing forces is much less, and for large steady magnetizing forces the effective differential permeability is greater with the airgap than without.

While amplifier transformers are generally not required to transmit much power, there are certain exceptions such as the transformers which are used in the output circuits of large power tubes. In such cases, in order to obtain a transformer of economical size, the core and winding space are designed with such proportions that the transformer operates at high flux densities. At high flux densities, however, the relative advantage of permalloy over silicon steel becomes smaller and the higher cost of permalloy may preclude its use. An example of this case occurred in the output transformer of the transmitter in which a silicon steel core was used. For this transformer, however, a new type of mounting was designed, consisting of cast aluminum end-housings light in weight and having a high thermal conductivity which facilitates the dissipation of heat developed under severe operating conditions.

The input transformer for the transmitter, on the other hand, operates at low power levels and is required to carry no superimposed direct current. It is possible, therefore, to take full advantage of the high permeability of permalloy, and this transformer is accordingly the smallest of all those in the aircraft equipment, weighing only 3½ ounces. This piece of apparatus steps up the voltage generated in the microphone circuit forty times and applies it to the grids of three vacuum tubes operating in parallel. The transformer operates in this circuit as efficiently as would a standard transformer weighing nine ounces and employing silicon steel. In this design also the importance of

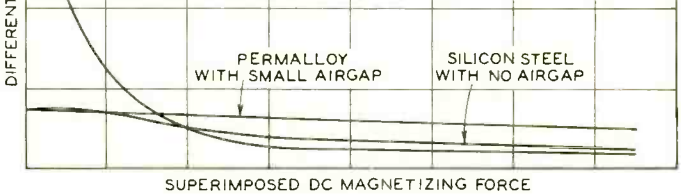


Fig. 5—With a large direct magnetizing force, a permalloy core with a small airgap has a higher differential permeability than a closed core of either permalloy or silicon steel

properly proportioning winding space to core area, and of designing a core shape to give a compact coil with an efficient mounting arrangement, were not overlooked.

Considerable advantage was also gained by the use of permalloy in the design of the output transformer for the receiver, although one winding was required to carry a direct current of about five milliamperes. In this design, therefore, in addition to other considerations, it was necessary to determine the best airgap for the operating conditions. By so doing, there were secured a considerable reduction in size and weight and an appreciable gain in transmitting efficiency over the transformer of standard size previously built for this purpose. The transformer weighs only seven ounces, and occupies only four cubic inches. Its transmission characteristic (Figure 6, Curve B) is considerably better than that of its predecessor (Figure 6, Curve A), particularly at the frequencies between 60 and 80 cycles per second which are used for beacon signals.

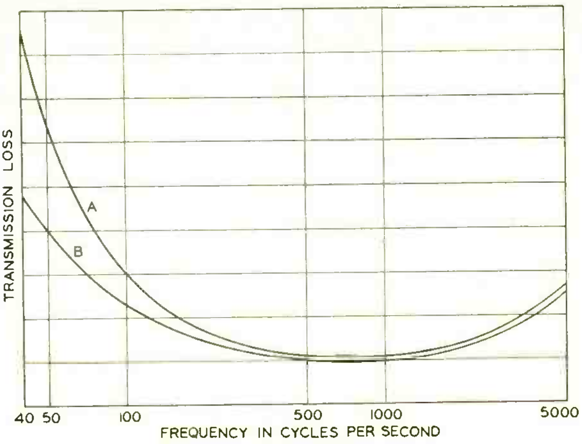
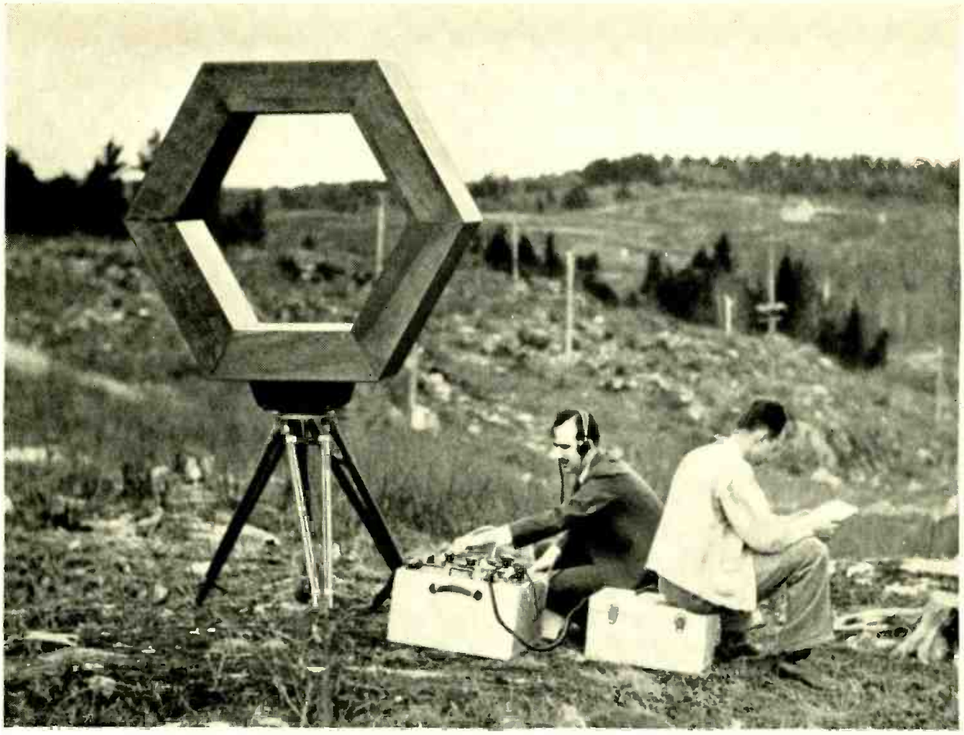


Fig. 6—The receiver output transformer, though smaller, transmits more efficiently (*Curve B*) *than the No.* 116 *type output transformer* (*Curve A*), *previously the smallest standard design*

The retardation coil for the receiver is used as a filter retardation coil in the plate supply and therefore must carry the direct current for several vacuum tubes. A coil designed to meet this requirement employing the smallest possible standard core of silicon steel would weigh 21 ounces. Here also the use of permalloy effected a large reduction in weight, the actual design weighing only seven ounces.

The large reduction in weight and size of these new coils has contributed materially to making possible the complete receiving set weighing only 17 pounds. The materials and construction employed in these transformers are, moreover, such as to achieve this lightness at no sacrifice in the life and durability of the apparatus.



Portable Long Wave Testing Apparatus

By G. C. DE COUTOULY
Radio Development

THE success of the transatlantic radio telephone service of the Bell System is based to a large extent upon countless and painstaking mathematical and experimental investigations, not the least of which is a systematic set of transmission measurements taken over a period of years. One of the most important of these measurements is the accurate determination of the intensity of the electromagnetic field at various distances from the transmitter. Such measurements not only play an important part in the selection of receiving and transmitting sites, but also permit continuous statistical study, a valuable guide in development work seeking to render radio telephony as reliable as good wire service.

Electromagnetic field intensity can be determined from the radio frequency current or voltage it induces in a wave collector, preferably a loop antenna, oriented to furnish the optimum response in the receiver. Theoretically the simplest measuring apparatus would be a loop antenna accurately tuned to the incoming signal, with a sensitive radio frequency galvanometer in its circuit. With such a device, the field intensity could be calculated from the loop current, the effective height of the loop, and the effective radio frequency resistance of the entire circuit.

Because of the high attenuation the field suffers in crossing the Atlantic, however, a high-gain amplifier must be inserted between the wave collector and the galvanometer. The value of the field determined would thus depend on the accuracy with which the gain of the amplifier was known, and since the gain varies, it would have to be determined for each reading. The determination of the gain of an amplifier requires elaborate and bulky apparatus, not well suited to measurements in the field. In actual field measuring equipment, therefore, the voltage established across the receiver input terminals by the local signal generator is made equal to that established by the emf induced in the loop by the incoming signal. The voltage established by the signal generator is adjusted by an attenuator network. In this way a passive network—the attenuator—is employed instead of an active one, and the measurement of amplifier gain is avoided.

The arrangement of the equipment is shown in the block diagram of Figure 1. The loop antenna is first accurately tuned and oriented for maximum reception, and then the coupling between the antenna circuit and the receiver, as well as the receiver tuning, and the amplifier gain, are adjusted until a satisfactory deflection is obtained on the detector galvanometer, or—when the signals are too weak for visual observation—until a distinct tone of satisfactory volume is heard on the telephone by the aid of the heterodyne oscillator.

The transmitting station is then shut down, or the loop oriented for zero reception, and the local signal generator turned on. Its output, tuned to the frequency of the signal, is then adjusted until the same deflection is obtained on the receiver meter, or the same sound heard in the telephone. Knowing the output current of the local signal generator, and the setting

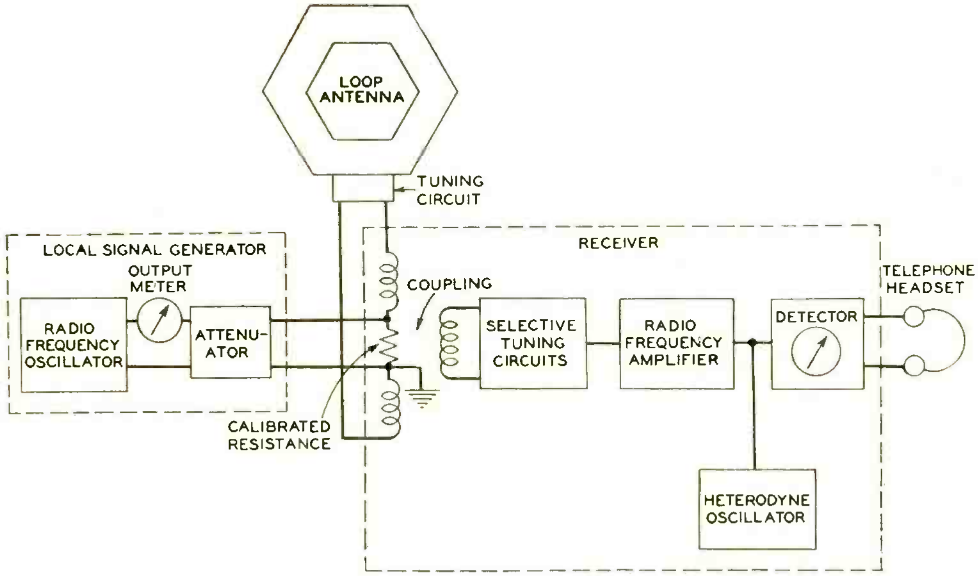


Fig. 1—Block schematic of the long-wave, field-intensity, measuring set

of the attenuator in series with it, it is then possible to evaluate the field intensity of the incoming signal.

For accurate field intensity measurements, it is usual practice to have the transmitting station send carrier-wave dashes of fifteen seconds' duration alternating with equal periods of silence. Loop and receiver tuning, and gain control dials are adjusted during the transmission periods, and the local signal output is introduced into the circuit by the operation of a non-locking key and properly adjusted during the periods of silence. Equipment of this type was constructed as early as 1923 by Bell System engineers and employed extensively in the frequency range from 20 to 1,500 kilocycles in connection with the development of the long-wave transatlantic telephone system.

The American Telephone and Telegraph Company and the Laboratories have since constructed a number of similar equipments, which have been extensively used in connection with various transoceanic radio-telephone activities, and have successively improved them to incorporate the latest developments in the radio art. Since these sets were primarily designed for use in fixed locations, they were not entirely suitable for field surveys conducted over rough country. A need for a more portable set has been felt for some time by the department of Development and Research and since field measuring equipment was also required by the Long Lines Department when it assumed responsibility for the operation and maintenance of the transatlantic channels, the Laboratories were asked to develop and construct two portable sets for use in the frequency range from 40 to 80 kilocycles.

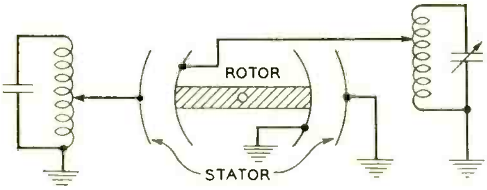


Fig. 2—Schematic arrangement of continuously variable capacity coupling

In agreement with the American Telephone and Telegraph Company it was decided to separate the various circuit elements into five units so as to obtain maximum portability and flexibility. One of the units is an impedance bridge used for measuring the characteristic impedances of both transmitting and receiving antennas and the other four are the antenna unit, the receiver unit, the local signal generator, and the battery supply unit. Each unit has been designed for minimum weight without sacrificing accuracy and electrical performance. With this equipment data may be obtained for determining many of the high frequency transmission characteristics of the transatlantic radio telephone system. The selectivity of the receiver is great enough to allow the measurement of weak signals from England without interference from nearby transmitters, and sufficient range of amplification is provided to permit measurement of intensities from a few microvolts per meter to a few tenths of a volt per meter.

The complete equipment is shown in the photograph at the head of the article. The battery box, furnishing the power supply, is designed to serve as a seat for the operator. The containing boxes for all units except the antenna are made of ply wood covered on both sides with aluminum sheet, a material which has recently come into use for the construction of light wardrobe trunks.

One of the most important undertakings was the design and construction of a portable loop antenna capable of withstanding reasonably rough usage in the field, and at the same time of meeting all necessary electrical requirements. The area within the outer periphery of the loop appears in the formula used for calculating field intensity, and so cannot be allowed to vary. At the same time the loop should have as few points of support as possible to minimize leakage, and should approximate a circle in form to secure the most efficient reception. To meet these various requirements it was made dodecagonal and supported at the twelve apexes. The winding is covered with a strip of muslin and both winding and muslin are thoroughly impregnated with cellulose acetate. For further mechanical protection, the winding is surrounded by a hexagonal wooden box of a special strutted ply wood construction, and forty-six inches across the vertexes. The loop tuning condensers are mounted in a small box at the base of the loop and are remotely controlled by a unit similar to that used with airplane receivers. This arrangement permits adjustment without having the body of the operator affect the sensitive tuning of the loop. At the base of the condenser box is a graduated azimuth scale so that the antenna may be used as a radio compass.

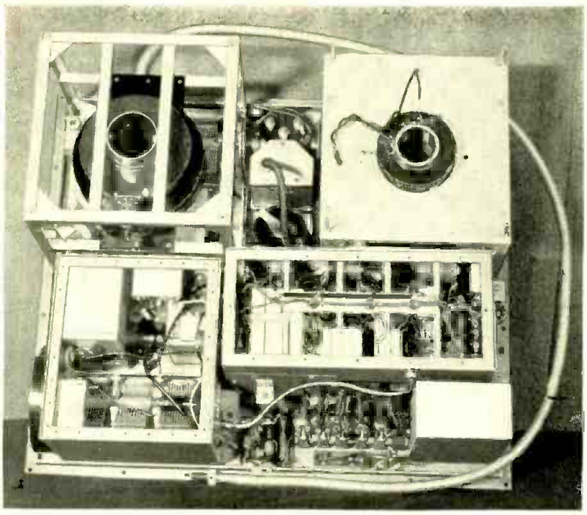


Fig. 3—The receiver unit is characterized by the extreme compactness of its arrangement

Three tuned circuits provide the necessary selectivity. The first is the loop and its associated condensers, and the other two are in the receiver unit, and are ganged to facilitate the tuning procedure. To avoid overloading the receivers when measuring high signal intensities, some type of coupling control between the tuned circuits is required to reduce the voltage applied to the first amplifier tube. Variable inductance coupling requires much space, and variable resistance coupling is undesirable because of the possibility of bad contacts and thus erroneous readings. Considerable time was therefore spent in the design of a novel attenuator system employing a continuously variable capacity, which would permit approximately 75 decibels coupling variation between the two tuned circuits in the receiver.

This attenuator, shown diagrammatically in Figure 2, has two sets of rotor plates, insulated from one another, and two sets of stator plates. One set of stator plates is connected to the coils of one of the two tuned circuits, and the other set of stator plates is grounded. One set of rotor plates is connected to the other tuned circuit, and the other set is grounded to the shaft. With the rotor in the position shown in the illustration, maximum coupling is obtained, and

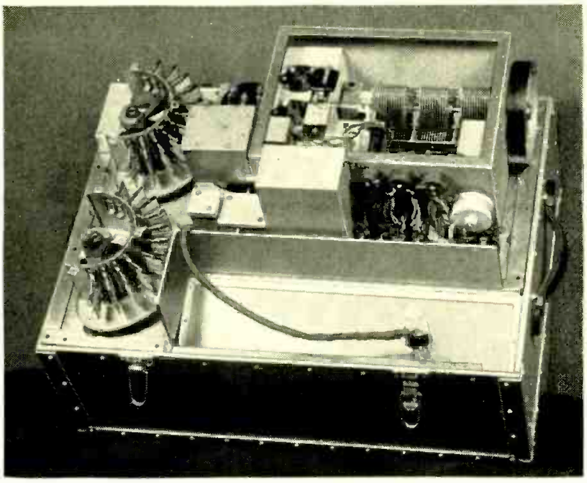


Fig. 4—The covers of the attenuator units are shown removed in the photograph of the generator unit

with the rotor turned 180 degrees both tuned circuits are in mesh with ground, and the coupling between them is then only that carried by the very small capacity between the two sets of rotor plates.

Another important item in the development work was the design of a compact and stable amplifier with a practically uniform gain of the order of a hundred decibels throughout the 40 to 80 kilocycle range. The interstage coupling transformers were designed to give the desired band pass characteristic with small, lightweight, interstage coils.

The complete receiver unit, shown removed from its case and inverted in Figure 3, also includes a heterodyne oscillator for use when the headset is employed as an indicator, and a 1,500 cycle filter between the detector and the headset. This single frequency filter increases the overall selectivity and thus greatly reduces the objectionable noise when the aural method of measurement is used.

Even at the relatively low radio frequency at which the set is operated, adequate shielding for the local signal generator was difficult to obtain. The accuracy of measurement depends to a large extent on the absence of direct pick-up between the generator and the loop winding, and it was finally necessary to triple-shield the main radio frequency coils to reduce the parasitic coupling to a level that would not detract from the accuracy of measurement. In addition it was necessary to silver-plate all shields where they come in contact with others to eliminate completely all possibility of leakage caused by eventual corrosion of the materials employed, and thus to preserve good contacts at all times. The principle of using a single ground to prevent parasitic coupling through ground currents was strictly adhered to in the design of the circuit of the signal generator.

Errors in field intensity measurements may also arise from a difference in wave form between the incoming signal and the output of the local comparison generator. A low-pass harmonic filter is therefore incorporated in the circuit of the signal generator to insure that the output will be a pure sine wave and will thus correspond to the wave form of the incoming signal. A simple key operation changes the cut-off of this filter from 60 to 80 kilocycles.

The total attenuation of 110 decibels, provided in the generator unit, is obtained in two sections. One—of 100 db—is variable in ten decibel steps, and the other—of 10 db—is variable in steps of one decibel. Although the electrical circuit of each attenuator section is of the conventional lattice type, the mechanical design is novel—particularly in the method of shielding adjacent sections. Copper fins are fastened to the cover of the attenuator and fit into grooves of the main attenuator frame when the cover is in place. Two attenuator dials indicate the field intensity directly in decibels above one microvolt per meter, thus greatly reducing the time formerly spent in making field intensity calculations. The disposition of the elements of the generator unit appears in Figure 4, where the attenuator covers are removed.

Suitable key systems in the signal generator and receiver units make it possible to measure filament, plate, and grid voltages of all vacuum tubes by meters mounted on the panels. This is of great importance in such equipment since it enables the operator to check his apparatus continually and insures maximum operating efficiency. Many innovations in the mechanical layout are due to the ingenuity of C. C. Graves, who assumed responsibility for the mechanical design. F. W. Boesche, who assisted in the electrical development throughout, also took an active part in the extensive field and laboratory tests, and is responsible for many of the novel features.

Two of these complete equipments have been delivered to the American Telephone and Telegraph Company. One is used for transmission tests by the Long Lines department at Houlton, Maine, and the other will be used by the department of Development and Research.

"*Modern Communication*"

This volume, recently published by Houghton Mifflin Company, comprises a series of seven lectures given before the Lowell Institute of Boston by representatives of the Bell System. The general title of the series was "The Application of Science in Electrical Communication," and the authors were Arthur W. Page, Frank B. Jewett, and Ralph Bown of the American Telephone and Telegraph Company, J. E. Otterson of Electrical Research Products, Inc., and Mr. Arnold, Mr. Fletcher, and Mr. Ives of these Laboratories.

A Circuit for Measuring Longitudinal-Circuit Unbalance at High Frequencies

By J. S. ELLIOTT, JR.
Transmission Apparatus Development

TELEPHONE lines that include long stretches of open wire are susceptible to electrical induction from adjacent power lines, electric railways, or lightning. These sources will induce voltages on each side of an exposed telephone pair. In general, the voltages induced on each side of a circuit are slightly different in magnitude and so can be resolved into two sets of components. One is a voltage component between the two wires, which acts in series around the circuit. This component sets up circulating currents which are manifested as noise. Such effects are known as direct metallic-circuit induction. The other is a component between each wire and ground, both being equal and in phase. These voltages cause currents which are equal and in phase to flow along each conductor of the circuit. This is known as longitudinal-circuit induction. The longitudinal-circuit currents acting on any inequality or lack of balance between the series impedance or the admittance to ground of each wire or of apparatus connected in the line will result in a voltage which will cause a current to flow in the metallic circuit. This current is in addition to the component from direct metallic-circuit induction, and its effects will also appear as noise. The unbalances which are responsible for this component of metallic-circuit current are known as longitudinal-circuit unbalances.

No design of apparatus will eliminate the direct metallic-circuit induction, but by care in the design and construction of apparatus inserted in the line, such as repeaters, filters, and loading coils, metallic circuit noise arising from longitudinal-circuit unbalance in such apparatus can be minimized. It is necessary therefore to measure the unbalance of all such apparatus while it is undergoing development so that the unbalance of the final product will be within satisfactory limits.

Circuits have been available for many years for measuring longitudinal-circuit unbalances. No convenient assembly of apparatus, however, has been available for covering both the complete voice and carrier frequency ranges. To provide for this type of measurement, the Laboratories have recently designed, for laboratory use, a set which will measure longitudinal unbalances at frequencies from 200 to 50,000 cycles.

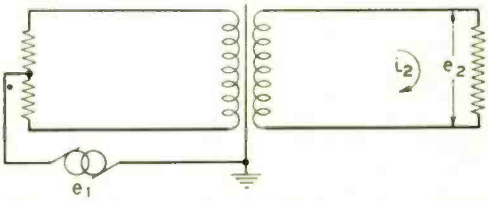


Fig. 1—Longitudinal unbalance is usually measured as the ratio of the circulating current to the impressed voltage

ts simplest form, a circuit for ne uring longitudinal-circuit unbalance would be as shown in Figure 1, which illustrates the arrangement for a measurement on a repeating coil. With a perfectly balanced coil, the impressed voltage e_1 would cause only longitudinal-circuit currents, but any condition of unbalance will produce an output voltage e_2 across the line, and a circulating current i_2. The ratio of e_2 to e_1 is thus a measure of the unbalance, and may be expressed in decibels, although the more common measure is the ratio of i_2 to e_1 expressed in micro-amperes per volt.

The new measuring set built by the Laboratories employs the circuit shown in simplified form in Figure 2. With this arrangement, the output voltage, e_2 of Figure 1, is measured by comparison with a voltage obtained by attenuating e_1. The unbalance is thus measured in decibels, but the result may be converted to microamperes per volt by a chart furnished with the set. To provide for the various types of apparatus to be measured, and the various ways in which the disturbance may be caused in the field, many switches and pieces of apparatus not shown on the diagram are included in the actual set shown in Figure 3.

It will be noted that the apparatus under test is terminated by longitudinal-circuit impedances at both ends. These simulate the impedances to ground through which the longitudinally induced current circulates. In order to simulate field conditions it is necessary that the metallic- and longitudinal-circuit impedances be adjusted independently. To provide this adjustment, a retardation coil in conjunction with a variable resistance is used. By this means the longitudinal-circuit impedance may be varied from practically zero to 900 ohms. This coil is designed to have a high metallic-circuit impedance over the entire frequency range, but a low longitudinal-circuit impedance, and to be well balanced both for capacitance and conductance to ground. It was found however, that one coil would not meet the requirements for the full frequency range, and so two were provided: one for frequencies up to 4,000 cycles, and the other for frequencies from 4,000 to 50,000 cycles. With this combination of coils and resistances it is possible to vary the terminating longitudinal-circuit impedances from 50 to 2,000 ohms.

Balancing condensers are provided to correct the capacity unbalance in the terminating coils. The residual unbalances in the set, due to conductance unbalances, are low enough to permit the measurement of unbalances in 600-ohm apparatus of .002 microampere per volt at 1,000 cycles and .25 microampere, at 50,000 cycles.

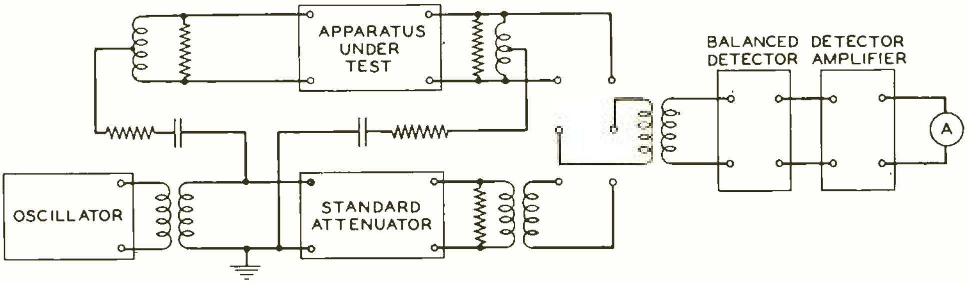


Fig. 2—Simplified schematic of the Laboratories measuring set for high frequencies

The set is arranged to measure unbalances from these lower limits to an upper limit of 50 microamperes per volt.

For measuring certain types of apparatus, such as input transformers, it is necessary to terminate the apparatus in very high impedances. The switching equipment is therefore arranged to terminate the apparatus under test directly in the grids of the vacuum tubes of the detector when desired, thus eliminating the terminating resistances and transformers of the circuit. Although the grid circuit itself is of low capacity, the switches and wiring connected to it insert a shunt capacity which may be relatively high. To keep the combined capacity low at all frequencies, keys have been developed for which the mutual capacity between contacts in the operated position is only 1.9 mmf as compared to 7.4 for the more usual type of key.

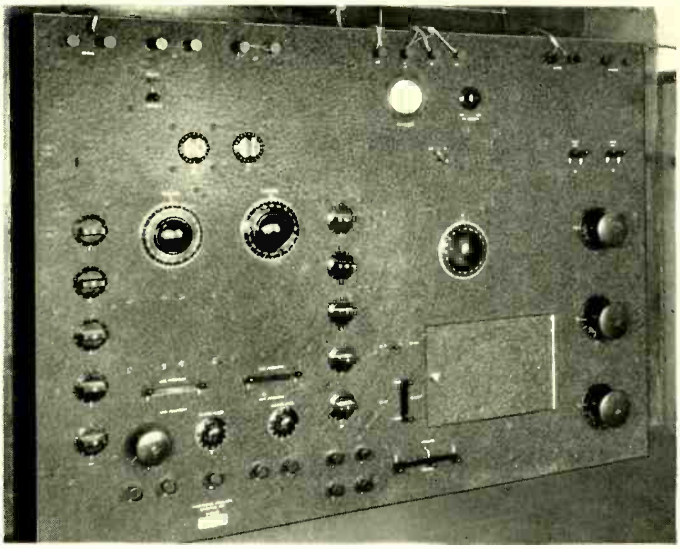


Fig. 3—The new longitudinal-unbalance measuring set mounts vertically on a bench, and a milliampere meter, connected externally, is employed as an indicator

The arrangement of the set, shown in Figure 3, presents a departure from earlier forms of similar apparatus. A panel, approximately forty inches square, is mounted vertically to bring the keys and meters within easy reach of the operator and to give easy access to all parts from the rear while it is being assembled and adjusted. More usual practice has mounted such sets as the top panel of a metal-lined box: an arrangement necessitating that the set be removed and inverted when adjustments are to be made. A framework of brass angle supports the aluminum panel and the outer shielding of the new set. All parts are copper shielded from each other and the spacing is made greatest between those parts having the greatest difference in potential. The various elements are placed to obtain the shortest possible wiring distances, and the keys and dials, which are within easy reach and sight of the operator, are so placed that their position indicates, to some extent, their function in the equipment.

Contributors to This Issue

After two years at the University of Colorado, A. C. **Walker** went to Massachusetts Institute of Technology, where he received the B.S. degree in Chemical Engineering in 1918. After a year in the chemical warfare service, and two in chemical research for a paper mill and a firearms plant, he went to Yale University for graduate study in physical chemistry, and received the Ph.D. degree in 1923. Coming to these Laboratories in that year, he has since been concerned with research on paper and textiles, first with the Chemical Laboratories, and since 1929 with the telephone apparatus development group. He has had a large part in developing and applying methods of purifying textile insulation, and methods for the inspection control of commercially purified textiles for telephone apparatus.

After graduating from Columbia University in 1916 with the degree of E.E., A. J. **Pascarella** entered the student course of the General Electric Company at Schenectady. Following our entrance into the war, he joined the Navy, and for two years was in charge of the electrical laboratory of the U. S. Navy Gas Engine School at Columbia. After this school was put on a peace-time basis, he spent some time on miscellaneous engineering work with a firm of consulting engineers, and in 1921 he joined the Technical Staff of Bell Laboratories. Here, with the Systems Department, he has been concerned with the development of toll signalling, telegraph, and miscellaneous testing equipment, and particularly of equipment for detecting and locating faults on toll cables.

J. O. **McNally** received the B.S. degree from the University of New Brunswick, Canada, in 1924, and immediately joined the Technical Staff of the Laboratories. With the research department his work has been entirely devoted to the design and development of vacuum tubes and to the study and analysis of vacuum tube problems in general.

J. S. **Elliott** received a B.S. degree from Pennsylvania State College in 1922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J. O. McNally

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G. C. De Coutouly

D. W. Grant

and at once joined the technical staff of the Laboratories. With the apparatus development department he was first engaged with routine tests and in making measurements of the electrical constants of apparatus. He then transferred to the condenser design group where he remained until 1927. Following this he engaged in the design of circuits and equipment for measuring the constants of transmission apparatus.

G. C. De Coutouly graduated from the Ecole de Physique et Chimie at Paris as a physicist-engineer in 1914, and at once entered military service in the French army, serving in a radio company of the 8th Regiment of engineers, which corresponds to the signal corps in the U. S. Army. In 1917 he came to this country with the French Military Mission. He was a liaison instructor, as radio specialist in communications, at Camps Dix, Sherman, Plattsburg, and Beauregard until the armistice, when he joined the French High Commission in New York City. Early in 1920 he joined the Technical Staff of Bell Telephone Laboratories, then the engineering department of the Western Electric Company, and later became an American citizen. With the radio group he worked on the Catalina-Los Angeles radio telephone system and on the development of a series of Navy radio telegraph transmitters and on the 5 KW radio telegraph transmitter for the S. S. Leviathan. More recently he has worked on field strength measuring sets, and at present is engaged in special receiver studies and in the development of radio frequency measuring equipment such as he describes in this issue.

D. W. Grant received the degree of B.S. in electrical engineering from Kansas State College in 1928. Coming at once to these Laboratories, he joined the transformer group in the Apparatus Development Department, where he has participated in the development of audio-frequency transformers for use in the telephone plant in repeaters and elsewhere, and in various special systems such as the aircraft radio system.