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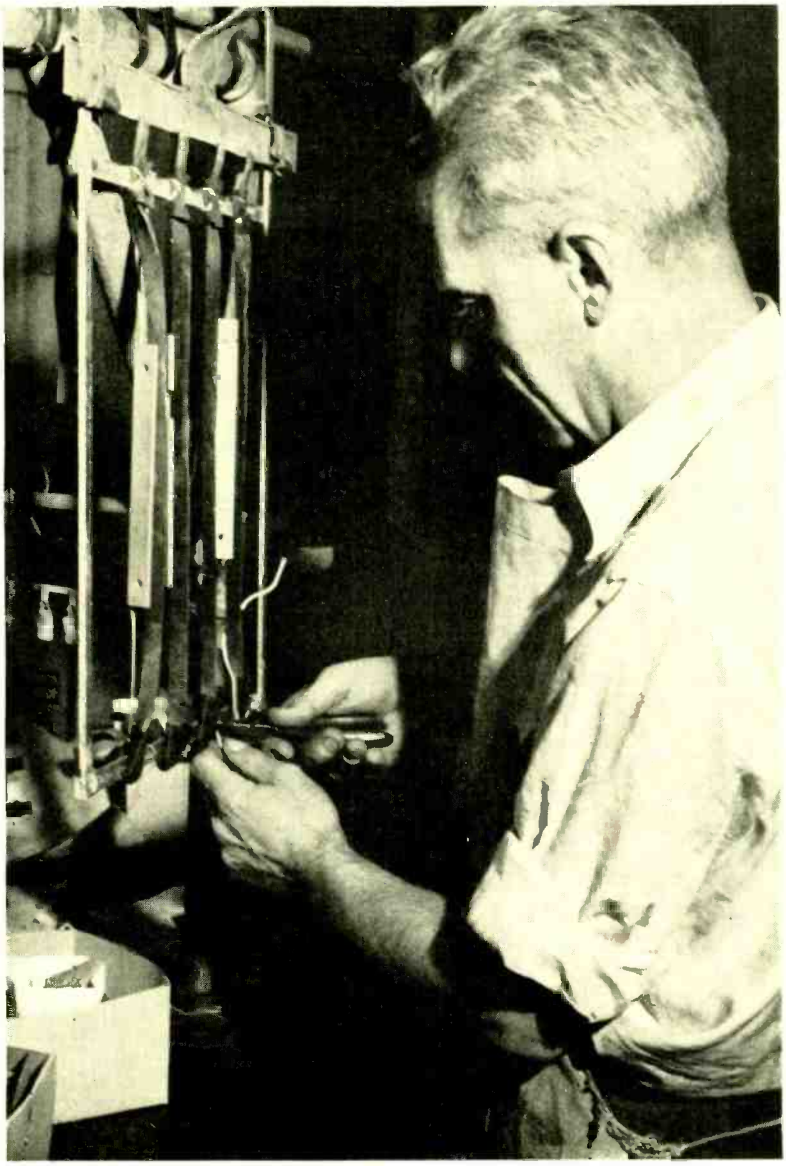
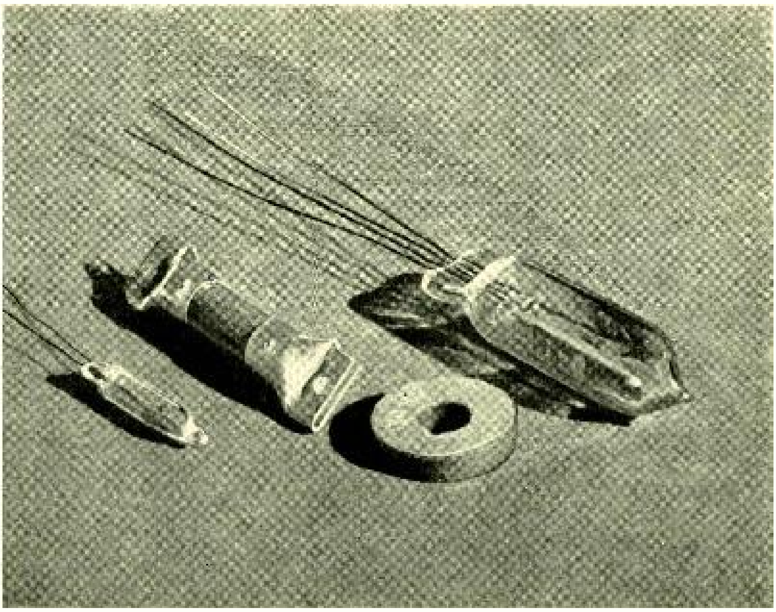


Racking experimental equipment in preparation for chromium plating.



Thermistors, Their Characteristics and Uses

By G. L. PEARSON
Physical Research

THERMISTOR is a contraction of the words "thermal resistor" and designates a new type of circuit element whose electrical resistance varies rapidly with change in temperature. In contrast with metals which have small positive temperature coefficients of resistance, thermistors are made from a class of materials known as semi-conductors which have relatively large negative coefficients.

The behavior of semi-conductors is not a new phenomenon; in fact, Michael Faraday, as early as 1834, reported measurements on the extremely high negative temperature coefficient of resistance of silver sulphide. Electric heating elements consisting of a mixture of rare earth oxides were developed by Nernst fifty years ago. These early devices, however, were not easily reproduced and did not have constant characteristics or long life.

The specific resistance versus temperature characteristics of three semi-conducting materials are shown in Figure 1. The upper curve is for uranium oxide (U_3O_8) which has a specific resistance of 50,000 ohm-cms at 0 degrees Centigrade. The specific resistance decreases rapidly with rise in temperature, being 2,800 ohm-cms at 100 degrees and 15 ohm-cms at 500 degrees Centigrade. The shape of this curve is typical of a large number of oxide semi-conductors. A mixture of nickel oxide (NiO) and manganese oxide (Mn_2O_3) shown in the next lower curve has a still larger negative temperature coefficient of resistance, the specific resistance values at 0 and 500 degrees Centigrade being respectively 10,000 and 0.8 ohm-cms. Silver sulphide (Ag_2S) exhibits a linear relationship between the logarithm of the specific resistance and the temperature below 179 degrees Centigrade. At this temperature a change in crystal structure occurs which decreases its specific resistance by a factor of about 70 and thereafter with increasing temperature the coefficient is slightly positive. The curve for platinum is plotted for comparison purposes; its temperature coefficient has a small positive value and the specific resistance is low, around 10^{-5} ohm-cms.

There are three common ways of using thermistors in electric circuits. In the first or externally heated method, the resistance of the thermistor is controlled by the ambient temperature. The second or directly heated method allows the electric current in the circuit to pass directly through the thermistor, thus heating it and changing the impedance in the circuit. The third or indirectly heated method uses a thermistor having a separate heating coil placed in a controlling circuit; the heat generated in it regulates the thermistor resistance. Thermistors suitable for each of these three circuit uses are shown in the headpiece. An ambient temperature-controlled thermistor is second from the right. The two units at the left are directly heated devices. The one enclosed in the insulating tube with metal electrodes at either end is a completed Western Electric 1A thermistor, while the other is the internal structure of the 1A. The unit farthest to the right with four lead wires is an indirectly heated thermistor.

The resistance versus power characteristics of a typical Western Electric 1A thermistor which is made of uranium oxide are shown in Figure 2. This is a static curve since for each point sufficient time is allowed so that the resistance attains its steady value. At room temperature and low power the resistance is 78,000 ohms. An increase in power, however, heats the unit and lowers its resistance until at ten milliwatts the value is approximately 30,000 ohms and at 100 milliwatts only 400 ohms.

The static voltage versus current curve for this same thermistor is shown by the solid curve in Figure 3. At low current where Ohm's law is obeyed the plot is a straight line, having a slope of forty-five degrees. As the current is increased, however, the slope decreases until at about one milliampere the voltage reaches a

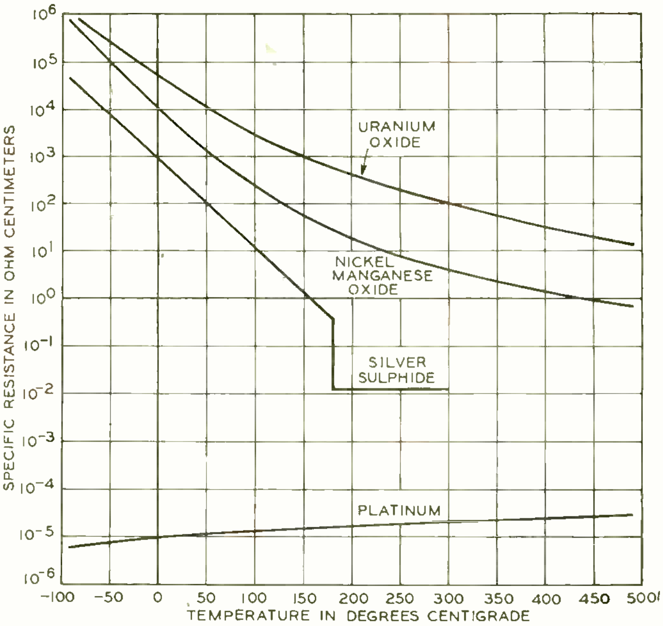


Fig. 1—Resistance versus temperature characteristics for three thermistor materials and for a metal

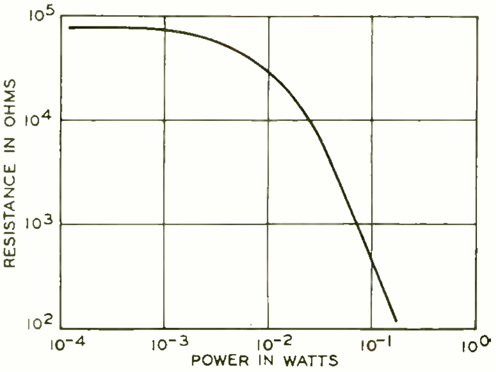


Fig. 2—Resistance versus power characteristic of directly heated thermistor

maximum and thereafter decreases as the current is increased. The falling portion of the curve, therefore, exhibits a negative resistance characteristic. At currents beyond 100 milliamperes the voltage drop in the semi-conductor as shown by the dotted line C has become so small that it is the same order of magnitude as the voltage drop in the metal lead wires, indicated by the dotted line D. The solid curve, which is the sum of these two voltages, thus has a second point of inflection and its slope becomes positive again. Although this curve is extended to ten amperes for analysis purposes, the 1A thermistor cannot carry currents greater than fifteen milliamperes continuously without impairing its life. It should be pointed out that thermistors made of silver sulphide or uranium oxide are usable only in alternating-current circuits since continued passage of direct current produces a polarization with an accompanying large increase in electrical resistance. Nickel manganese oxide does not polarize and is therefore equally stable in either a-c or d-c circuits.

In order to determine the life of 1A thermistors they have been placed in a circuit where an off-and-on current cycle of ten milliamperes a-c has been repeated every thirty seconds over an extended period of time. Resistance measurements were made on the units periodically in order to determine their stability with time. Figure 4 shows the results on a typical unit whose initial resistance at 76 degrees Fahrenheit is 62,000 ohms. The general trend is a rise in resistance during the first part of its life, after which it becomes quite constant. Over a period of fifteen months, during which time the thermistor was put through 650,000 heating cycles, the cold resistance did not vary more than seven per cent. The resistance of the thermistor when hot was found to be equally stable.

If a directly heated thermistor is placed in series with a source of voltage, key, milliammeter, and protecting resistance as shown in Figure 5, the meter will show a delayed building-up of the current following closure of the key due to the thermal capacity of the thermistor. This delay is illustrated by the current versus time curve for a typical 1A thermistor. The initial current, which is determined by the cold resistance of the thermistor, is small and rises slowly at first, then

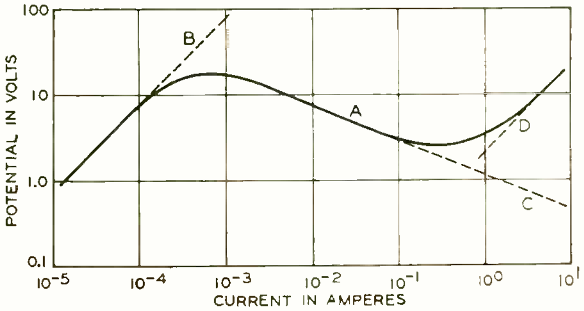


Fig. 3—Voltage versus current characteristic of directly heated thermistor

more rapidly as the thermistor becomes hot. The final current is limited by the circuit resistance. The magnitude of the time delay amounts to about one-half second for the particular circuit conditions shown in Figure 5; it increases with decrease in battery voltage. By a suitable design of the thermistor and choice of circuits it is possible to vary this time delay from a few milliseconds to several seconds. This time-delay property of thermistors is a distinct advantage in many applications since it provides an action which if obtained by other techniques would undoubtedly be much more cumbersome and costly.

Directly heated thermistors capable of carrying much larger currents than fifteen milliamperes, the maximum continuous current rating of the 1A thermistor, have been made by pressing semi-conducting materials into discs in much the same way that silicon carbide varistors are formed. These may also be made in the same shape as the ambient temperature-controlled unit shown in the headpiece. Such thermistors have characteristics of the same form as the 1A but can carry currents of several amperes. Due to their large thermal capacity they have longer heating and cooling periods when used as time-delay devices.

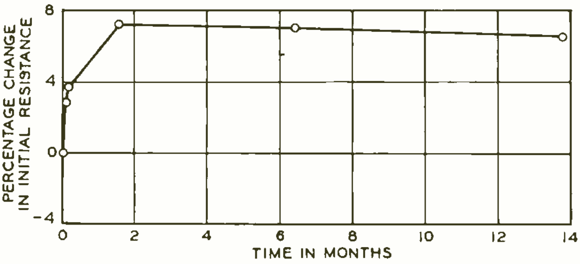


Fig. 4—Life characteristic of typical 1A thermistor

The thermistors which have been described have all been of the directly heated variety. By placing a heating coil around the thermistor in such a way that it is insulated electrically but in contact thermally, an indirectly heated device is obtained. The thermistor resistance as a function of heater current for a unit made of a silver sulphide semi-conductor with a 100-ohm heating coil is shown in Figure 6. With no current flowing the resistance is one megohm, at ten milliamperes it is 10,000 ohms, and at fourteen milliamperes the resistance is eight ohms. The curve flattens at this point because of the change in crystal structure of the silver sulphide. The thermistor resistance thus changes by a factor of 100,000 for a power dissipation of only twenty milliwatts. This curve is completely reversible. Indirectly heated units made of a mixture of nickel and manganese oxides have excellent life characteristics but do not cover such a wide resistance range with small heater powers.

The thermal and electrical characteristics of thermistors suggest a large number of circuit applications. One obvious use for devices having such high temperature coefficients of resistance is that of a resistance thermometer. In this application the measuring current is kept so low that it produces no appreciable heating and the thermistor resistance is dependent only on the ambient temperature. At 25 degrees Centigrade the changes in resistance of uranium oxide, nickel manganese oxide, and silver sulphide are respectively 3.0, 4.2 and 4.9 per cent per degree Centigrade change in temperature. This compares with 0.35 per cent per degree Centigrade for platinum. A second use for thermistors is that of compensating for changes in resistance due to ambient temperature in circuits having a positive temperature coefficient of resistance. This is accomplished by associating the thermistor with series or parallel circuit elements so that the change in resistance with temperature of the combination is equal and opposite to that of the remainder of the circuit which it is necessary to compensate.

The resistance versus power characteristics of thermistors make them useful as sensitive current and power-measuring devices. Due to the extremely small electrical capacity associated with these devices they are suitable for use in either low or ultra-high-frequency circuits. When placed in the proper bridge circuits thermistors may be used as flow meters, vacuum gauges, or to measure other physical quantities dependent on the flow of thermal energy from a hot body. High-sensitivity bolometers for the measurement of radiant energy have been constructed using directly heated thermistors for the temperature-sensitive element.

Thermistors may be used to stabilize the output voltage in circuits in which the input voltage varies over a considerable range. As shown by the voltage current plot in Figure 3, the thermistor voltage decreases with increase in current over the central portion of the curve. If a suitable chosen value of ohmic resistance is placed in series with the thermistor, the voltage across the combination may be held practically constant in this current range. The series combination of thermistor and resistance will therefore act as a variable current shunt if placed in parallel with the load and will tend to maintain the load voltage constant. Although changes in temperature limit the accuracy of regulation, these errors can be kept to a minimum by operating the thermistor at temperatures well above ambient.

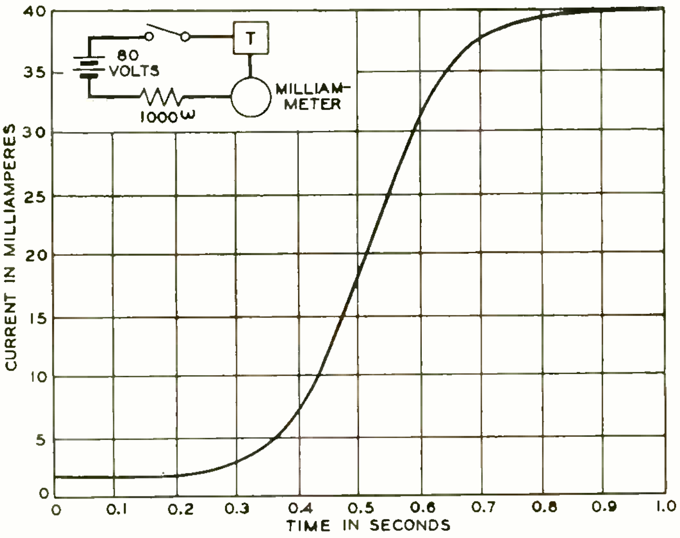


Fig. 5—Current versus time characteristic of a directly heated thermistor

The negative resistance characteristic exhibited by directly heated thermistors suggests their use as generators of alternating voltages. The inherent thermal capacity, however, limits their usefulness to relatively low frequencies. Tiny thermistors designed especially for this purpose have been made to oscillate, when placed in an appropriate resonant circuit, over the entire voice-frequency range. The output power is around one milliwatt and, although the characteristics are not extremely stable, these thermistors have been operating for over two years in a continuous life test circuit without serious signs of deterioration.

A standard relay may be made into a slow-acting device by putting a directly heated thermistor in series with its winding. The magnitude of the delay depends on the thermistor characteristics, the relay constants, and the circuit conditions. False operations of relays resulting from high voltage surges may be prevented in this manner. The thermal inertia of the thermistor, together with its high initial resistance, discriminates against voltage surges of short duration, but an application of voltage of greater duration, even though of lesser magnitude than the surge voltage, operates the relay after a small delay. This is the application for which the 1A thermistor was designed and a large number of these units have already been installed in the telephone plant, primarily in ringing circuits for private-branch exchanges.

Indirectly heated thermistors may be used as variable resistance devices which are operated by an electric current through the heating coil rather than by a sliding contact as in a standard rheostat. These devices have the advantage that their resistance change is continuously variable and that they may be operated electrically from a distant point. This type of thermistor has found important applications in automatic transmission-regulating networks.

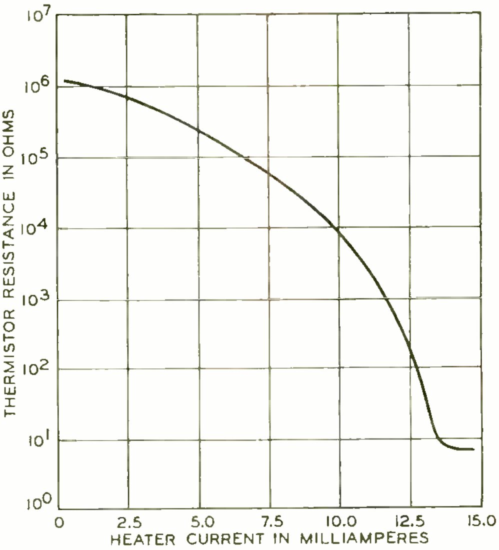


Fig. 6—Resistance versus heater-current characteristic of an indirectly heated thermistor which was made of silver sulphide

Thermistors have already found important applications as circuit elements. As time goes on, further uses will undoubtedly be found for these simple and inexpensive devices.

Devices for Combining DB Levels

By K. G. VAN WYNEN

Transmission Development

A FREQUENT operation in transmission studies is to total the contributions made by two or more sources when the quantities are expressed in decibels. Examples are finding the combined level of several noise sources or integrating the components of a complex tone. These computations are time-consuming by ordinary methods, if there are many components, and they are subject to inherent errors due to misplaced decimal points. The labor-saving devices described here have been developed to obtain results more quickly and to reduce errors when many computations have to be made.

The quantities involved in these examples are usually expressed in db with respect to a chosen reference power P_0 by the formula db = 10 $\log_{10}$ (P/P_0). If the components combine on a power basis, the resultant level in db is determined by the sum of the component powers. The mathematical process, therefore, consists in finding P/P_0 for each component, adding, and reconverting to the db scale. Suppose two components measure 53 db and 49 db above the reference level; then by the above equation 53 db corresponds to a power ratio of 2×10^5, and 49 db to 8×10^4, or 0.8×10^5. The sum is 2.8×10^5, which represents a level of 54.5 db. This requires, besides division and addition, the finding of both logs and antilogs. Whether the computations are done by log tables or slide rule, it is time-consuming and subject to error, particularly if the components are numerous and cover a wide range.

If two components are equal in magnitude their combined level is 3 db higher than the components whatever the original levels were. This follows from a fundamental property of the db scale; adding two equal powers is equivalent to multiplying by 2, which represents a 3-db increase in power. Similarly, adding two components which differ by 3 db is equivalent to multiplying the higher of the two powers by 1.5, or adding 1.8 db to the higher level, regardless of the absolute levels. Thus for any two components which combine on a power basis, there exists a unique increment which, added to the level of the higher component, gives the level of the combination. This increment is a function only of the difference between the two component levels; if the difference is 0, the increment is 3 db, and if more than 20 db, the increment becomes quite small. These increments are shown graphically in Figure 1 as a function of the difference of level.

This curve, or a table based on it, is a convenient method for combining two components. When three or more components are to be added, the operation is performed stepwise, by combining two components and then the third with the "sum,"* and similarly each additional component with the progressive "sum." It makes no difference in what order the components are added. When there are many components, this process becomes tedious because each succeeding component must be subtracted from the progressive "sum" to find the increment to be added.

This procedure can be mechanized readily in several ways, by using special slide rules. The one shown in Figure 2 is the closest analogue of the mathematical process just described. It has special linear scales on an ordinary 10-inch slide rule, and an indicator capable of crosswise as well as lengthwise motion. This indicator is made of transparent material, and has inscribed on it not only the usual vertical index line, but also a straight line inclined at 45 degrees, and a curved line like that of Figure 1 plotted in appropriate units along the vertical line. The origin is at the intersection of the two straight lines.

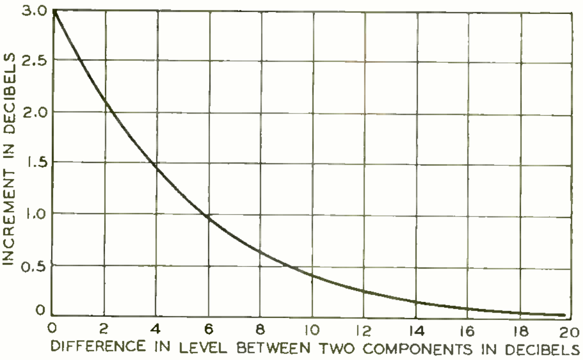


Fig. 1—This curve shows the amount in db by which the combined power level of two components exceeds the higher of the two

In one method of using the rule, the vertical line is set on the lower scale at the higher of the two components to be combined. By moving the transparent indicator vertically the 45-degree line can be made to intersect this scale at a point corresponding to the lower of the two components. The

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*The word "sum" will hereafter mean the db figure representing the level resulting from the combination of two or more components whose levels are also expressed in db.

increment will then be found added to the higher component where the curved line intersects this scale. For example the components shown in the photograph are 12 and 10, the increment is 2.1, and the "sum" is 14.1, which is the final answer for these two components. If other components are to be added, the vertical line is shifted to the "sum," and the operation repeated for each component. To avoid having to remember the "sum" while shifting the indicator, the arrow index on the otherwise blank slide is shifted to mark the "sum," and the vertical line is then shifted to the arrow. Both plus and minus scales have been provided to cover the complete range.

To avoid the cross-sliding indicator with its inscribed curve the device shown in Figure 3 was developed. This slide rule has the same scales as that in Figure 2 and a glass indicator with a single cross-hair. The increments in Figure 1 are inscribed on the slide by broken lines extending from the bottom to the top of the slide and numbered to correspond to the db difference between the components to be added. The indicator has been removed from the array of broken lines in Figure 3 to give a clear picture. If the components are −20 and −30 the glass indicator cross-hair is set at −20, and the zero of the lower part of the slide scale at −30, as shown. The broken line labeled 10 would be under the cross-hair, at its lower extremity. The cross-hair is then moved to the right until it is set on the upper extremity of the broken line numbered 10. The answer with the proper increment added is the scale reading under the cross-hair. This follows because the displacement of the upper end of each broken line is equal to the increment for the corresponding difference in level between the two components to be added. The broken lines to the left of zero on the slide are engraved in red instead of black and are used when components are to be subtracted instead of added.

The scale at the right of the slide permits the rapid combination of

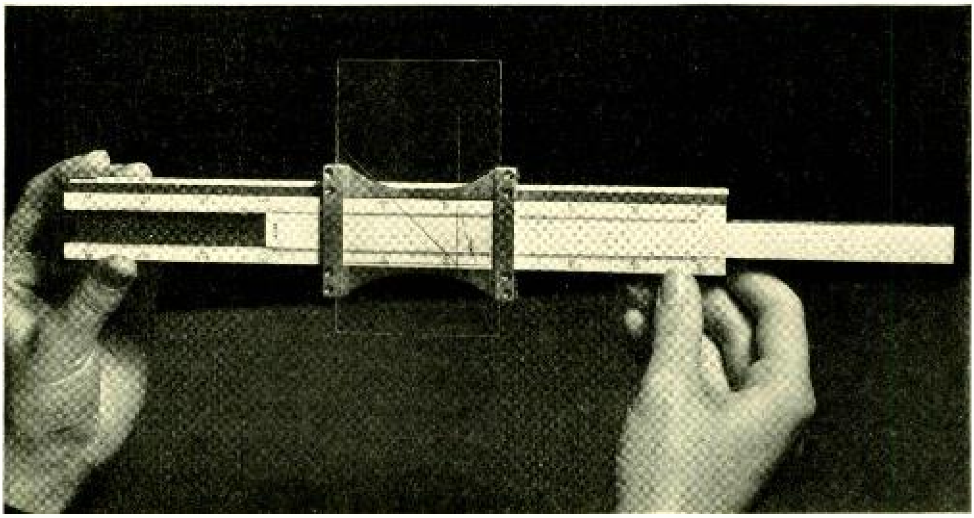


Fig. 2—Special slide rule, for combining db levels, which embodies the curve of Figure 1 directly on the indicator. The indicator slides both horizontally and vertically

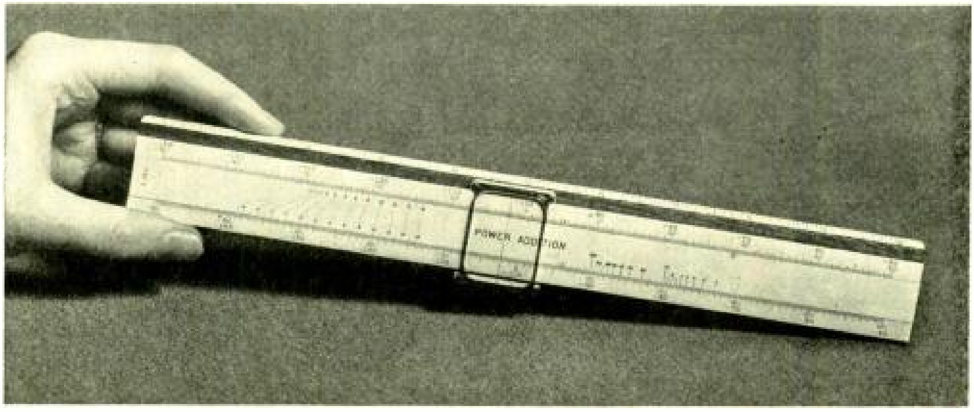


Fig. 3—Slide rule with the increments of Figure 1 shown by broken lines on the slide

many components which are equal in magnitude. As set in Figure 3 a level of 30 db on the lower scale under the index 1 on the slide is the result of the combination of 10 components each of 20 db, or 50 each of 13 db, etc.

A third device for adding the components is shown in the headpiece. It was designed by W. Koenig, Jr., specifically for computations of integrated spectra, each of which involves many components. The operator sets an index on each component in turn. The cumulative "sum" is available at all times. This device is based on the same principle as the others and is illustrated in Figure 4, with the cover removed. Two index lines are inscribed on a transparent disc of lucite; the outer is a circle and the inner a spiral. As seen through the window of the cover, the spiral looks like a slightly curved line which moves along the scale when the disc is rotated. By offsetting the center of the spiral from the scale, the spiral always intersects the scale at right angles, which makes it much easier to set accurately. The answer is read from the scale beneath the index line at the extreme right.

Pulling the thumb lever at the left actuates a friction clutch, which grasps the slide and moves it to the left until a small point on the arm above the slide strikes the edge of the disc. This edge is shaped to correspond to the curve of Figure 1. Releasing the thumb lever first releases the clutch, then allows the arm to resume its normal position against an adjustable back stop. The travel of the arm is 3 db along the scale when the spiral intersects the circle, which corresponds to adding two equal components. At the point of maximum separation between the circle and the spiral, which corresponds to about 18 db difference in level between two components, the arm almost touches the edge of the disc and consequently permits only a very small advance.

In using this device only that part of the lucite disc at the right of the shaft in Figure 4 is visible to the operator, as shown in the headpiece. The first component is set under the index line at the right by moving the slide through the apparatus by hand. The second, and each subsequent component, is set by turning the lucite disc which moves the left index line to the desired position on the scale. Operating the thumb lever to the limit of its motion after each setting automatically moves the slide by the appropriate increment. The progressive "sum" then appears under the index line at the operator's right. Operation is simplest when the largest component of the series is set first but thereafter they may be taken in any order that is desired.

These models all have approximately the same accuracy—about 0.1 db. Components so far below the cumulative sum that individually they do not add an appreciable increment are neglected. If there is a large number of these, the accuracy will be improved by totalling the low components separately and adding this sub-total to the sub-total of the high components.

These devices have been in use for about two years and have proved eminently practical. They are known by those who use them as "db adders." The particular scales shown in illustrating the several devices are those which apply when the components combine on a power basis. Similar scales can be provided for other laws such as those encountered with the addition of current or voltage.

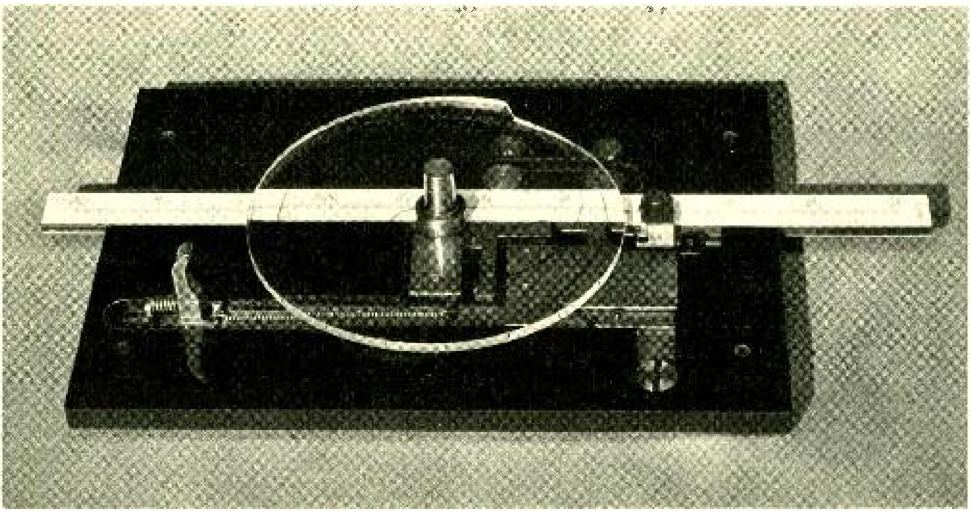


Fig. 4—Mechanized arrangement for adding db increments. The disc is shaped to conform to Figure 1 and acts as a stop to the clutch which advances the slide

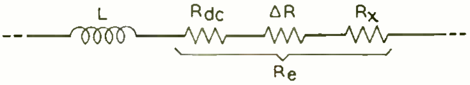
Analysis of Losses in Magnetic Cores

By C. D. OWENS
Transmission Apparatus Development

WHEN a ferromagnetic core is introduced into the field of a coil to increase its inductance, it exacts a compensation in energy for its contribution. This toll, which is dissipated in the magnetic material, is called core loss. The core of a transformer in a power-transmission system, for example, may become hot to the touch, providing tangible evidence of the dissipation of energy. In fact a measurement of the heat developed in such a core can be used to determine the magnitude of the core loss, commonly expressed in watts per unit weight of the core material. In the design of power apparatus, the core loss must be limited to prevent excessive waste of energy in overheating.

In a high-quality inductance, such as a loading coil or network coil used in communication circuits, where the energy levels are relatively very low, the power dissipation due to core loss is negligible so far as heating is concerned. The effects of core loss on the performance of these coils in transmission circuits are of such importance, however, that they govern the practical application of ferromagnetic core materials. The measurement and analysis of core loss consequently assume fundamental rôles in the development of ferromagnetic materials and the design of high-quality coils employing them.

Instead of a direct measurement of the heat developed in the core of a high-quality coil, the increase in series resistance due to core loss is determined from measurements on a-c bridges equipped with vacuum-tube amplifiers. The procedure is to measure the effective resistance R_e and subtract from it the winding resistance. The difference is the core loss resistance ΔR. The winding resistance consists of the direct-current resistance R_{dc} plus an alternating-current resistance R_x arising from eddy currents, dielectric loss, and distributed capacity in the winding. This latter resistance can be determined from measurements on the winding without the magnetic core. Figure 1 illustrates schematically these various resistances in series with the inductance.



$$\text{FIGURE OF MERIT, } Q = \frac{\text{REACTANCE}}{\text{EFFECTIVE RESISTANCE}} = \frac{2\pi f L}{R_{dc} + \Delta R + R_x}$$

Fig. 1—Core loss appears as one of the components of the effective resistance of a coil that has a magnetic core

The ratio of the inductive reactance to the effective resistance is commonly employed as a quality factor or figure of merit of the coil, termed "Q." To yield the highest value of "Q" for a given inductance, the core loss and winding resistance must be made as small as possible. A net gain in "Q" is realized from the use of a ferromagnetic core in place of a nonmagnetic core when the reduction in winding resistance due to the smaller number of turns required is greater than the resistance added by core loss.

Core loss, or the amount of energy dissipated, increases with both frequency and the magnitude of the induced flux. Hence, in a communication circuit, which has as its function the faithful transmission of a current of complex wave form, the core loss in the magnetic material acts to modify the shape of the transmitted wave and reduce the fidelity. Its effects are to attenuate the higher frequencies more than the lower and to introduce non-linear distortion. Since transmission requirements on most network and loading coils are severe in these respects, it is helpful not only to determine the total core loss, but to divide it into frequency and current components which can be related to the operating characteristics of the coils.

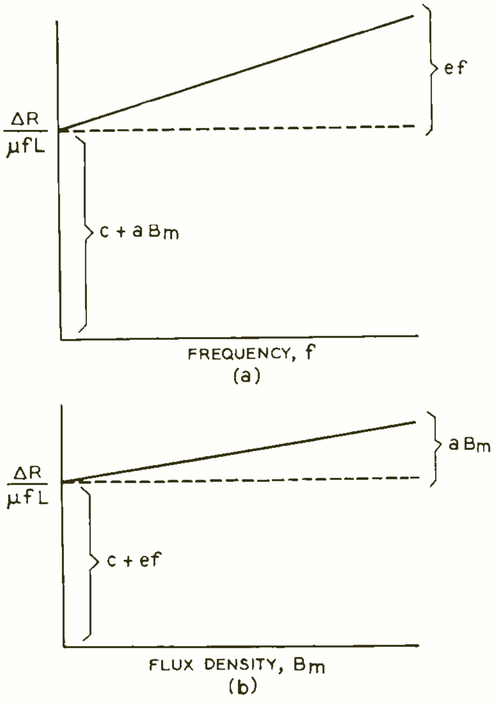


Fig. 2—With constant current, upper graph, the relationship between $\Delta R/\mu f L$ *and frequency is a straight line; and for constant frequency, lower graph, the relationship between* $\Delta R/\mu f L$ *and flux density is also a straight line for small values of flux density*

Investigation has shown that the total increase in resistance due to core loss may be divided into three components: one proportional to the square of the frequency, one to the product of frequency and the maximum flux density, and one to the first power of the frequency. The first of these components is called the eddy-current-loss resistance, the second the hysteresis-loss resistance, and the third the "residual"-loss resistance. An equation expressing them would be written:

$$\Delta R = e\mu f^2 L + a\mu B_m f L + c\mu f L \qquad (1)$$

Dividing through by $\mu f L$, this equation becomes

$$\Delta R/\mu f L = ef + aB_m + c.$$

In these equations e, a, and c are eddy current, hysteresis, and "residual" coefficients of the core material respectively, μ is the effective permeability of the core, f is the frequency, B_m the maximum flux density in the core, and L the inductance of the coil.

The coefficients e, a, and c may be evaluated by determining ΔR from a-c bridge measurements at two or more frequencies at constant current, and two or more currents at constant frequency, and solving the set of equations simultaneously. In practice this solution is obtained graphically as illustrated in Figures 2a and 2b. When values of $\Delta R/\mu f L$ are plotted for the same value of current (or flux density) at two or more frequencies, a straight line may be drawn through the points as shown in Figure 2a. The slope of this line is "e," and the ordinate intercept is $c + aB_m$. Similarly when points are plotted for different flux densities but at the same frequency, the line shown in Figure 2b is obtained. The slope of this line is

"a," and the ordinate intercept is $c+ef$. This determines both "e" and "a," and by substituting these values into the expressions for the ordinate intercepts, "c" is obtained.

Once these coefficients are known for a given core structure, the core-loss resistance can be calculated for other currents and frequencies and for other inductances by substituting in Equation 1. Furthermore, a knowledge of the relationship of these coefficients to the physical properties of the core material and to the electrical behavior of the coil is very helpful in developing improved core materials and in guiding their application.

The eddy-current coefficient "e" is an index to the energy dissipation arising from currents induced in the magnetic core material by variations in the current through the coil winding. The eddy currents flow in planes perpendicular to the paths of magnetic flux, and have magnitudes which depend on the value and rate of variation of the magnetic flux and on the resistance of the conducting paths available to the currents. This resistance is proportional to the resistivity of the magnetic material and the constriction of such paths. If the core is laminated parallel to the paths of the magnetic flux the eddy current losses can be shown to be proportional to the square of the lamination thickness. If the core material is subdivided into small particles insulated from each other, the eddy current losses are proportional to the square of the particle diameters. In high-quality coils such as filter or network coils, core rings made of insulated and compressed magnetic powder are commonly used because the eddy currents are minimized by the extremely fine size of the particles. Overall losses are limited by controlling the effective permeability through proper adjustment of the ratio of insulating and magnetic materials. The determination of "e" can be used in connection with the development and manufacture of such cores to indicate the uniformity of the various processes, such as grinding or the application of the insulation, or to indicate the effects of systematically controlled changes in these processes.

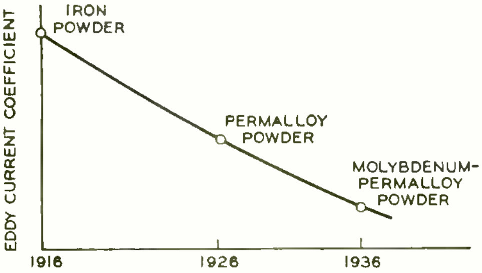


Fig. 3—Improvement in eddy current coefficient in cores used for voice-frequency loading and retardation coils over the last twenty-four years

The hysteresis-loss coefficient "a" depends upon the composition of the material and the heat treatment. Its magnitude is controlled therefore by selecting the most suitable material and employing the most favorable processing. The hysteresis loss is important not only because of its contribution to the effective resistance of the coil, but also as a source of distortion of the wave form in the circuits with which it is linked. This distortion arises from harmonics and new frequencies caused by the non-linear relation between the magnetizing force and the resulting magnetic flux. These new frequencies may cause not only distortion in the circuit containing the magnetic material, but may produce disturbances in adjoining channels of multi-channel circuits. It has been shown that these effects are proportional to the product $a\mu B_m$. The harmonic distortion, or modulation, is thus conveniently related to an intrinsic property of the magnetic material, and the relatively simple determination of the hysteresis coefficient "a" may be used in place of more involved modulation measurements for predicting and controlling this effect of the magnetic core. As in the case of the eddy current coefficient "e," a study of the change in the hysteresis coefficient "a" with variations in manufacturing processes may be used to determine directions for improvement of the core material.

The "residual" loss term in Equation 1 is a result of the observation that the total core loss as accurately measured on a-c bridges is larger than can be accounted for by the two eddy current and hysteresis components as conventionally determined. This additional component has been referred to also as "initial hysteresis" and "magnetic viscosity." Since the increase in resistance of a coil due to "residual" loss is a function of only the first power of the frequency, is independent of flux density, and does not contribute to harmonic distortion, it is not of as much consequence as the eddy current and hysteresis losses. Nevertheless it is desirable to keep the residual constant "c" as low as practicable. The physical basis of residual loss is still a matter of conjecture, but some control of the coefficient "c" is obtained through proper choice of composition and heat treatment of the material.

The utility of core loss determinations in development work and manufacturing control depends also upon means available for rapid and accurate measurements. As the quality of the core is improved, the ratio of core loss to the total effective resistance measured on the bridge decreases, requiring greater precision of measurement. Figure 3 presents, for example, a picture of improvements in the eddy current losses in cores used in voice-frequency loading and network coils during the past several years. To provide high speed and accuracy for the measurement of present-day materials, a new bridge has recently been designed and built and described in a previous article.* In the best quality cores, where highest accuracies are required, the test coils are prepared with a special standardized winding designed to minimize the a-c winding losses. The coils are thoroughly dried and then placed in hermetically sealed containers for measurement. The measuring equipment is maintained in air-conditioned rooms under practically constant conditions of temperature and humidity. Both alternating and direct-current measurements are made on the same circuit to avoid changing connections or handling the coils.

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*RECORD, *November*, 1940, *p.* 92.

"Information" in Less Space

By A. C. GILMORE
Manual Equipment Development

IN THE larger cities, where there are many central offices, "information" traffic is handled at one or more centralized information bureaus, where a group of "information" operators serve subscribers of a large number of offices. Some years ago the No. 3 information desk* was designed for this sort of service, and has come into fairly wide use. Since it was intended primarily for very large centers, such as New York and Chicago, it was designed to accommodate at each position four large local record binders open on reading shelves before the operators as well as a number of smaller toll and auxiliary record binders in directory racks. Although modified arrangements for two information binders were later made available, they did not permit as great a reduction in the space requirements as desired because of the basic section design of the information desk.

There are, however, many multi-office cities with centralized information service that require only one, or at most two, local record binders open before the operators, and such bureaus also require fewer toll and auxiliary binders. They have relatively small desks that do not contain many of the desirable features of the No. 3 desk. It is in these smaller centers that floor space requirements

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*Record, *March*, 1930, *p.* 328.

are more frequently a controlling factor, and even the modified No. 3 desk might be larger than could be conveniently accommodated. It seemed desirable, therefore, to design a new information desk framework to secure the floor space economies that the smaller number of records permits, and still retain the advantages of the circuits of the No. 3 desk. Such a desk could then be used to replace existing ones as occasion demanded. As a result the No. 6 type information desk has been developed. It uses the same key equipment and circuits as the No. 3, but provides a simpler and smaller desk framework, and permits easier installation procedures.

The new desk is designed on the basis of using one or two large local information binders per position. In the one-book form it is known as the 6A desk, and in the two-book form as the 6B, the latter requiring more floor space than the 6A but less than the two-book No. 3 desk. An installation of the 6A desk in Dallas, Texas, is shown in the photograph at the head of this article. Key and lamp equipment is mounted in the two opposite faces of a rectangular turret at one side of the position. This arrangement provides a double-sided desk with two operators. A sloping shelf on each side provides for the single information binder, and the level space between the key equipments may be used for a toll directory rack when required. In place of the wooden upright partitions formerly used between operators, a new transparent material is employed that has certain minor advantages over the wood.

The 6B section, shown in Figure 1, is like the 6A except that an additional sloping shelf is provided for each operator in the space between the key equipments, and it is for this reason that the 6B is somewhat larger than the 6A. Where toll and auxiliary records are required, they will be placed in a toll directory rack mounted on top of this added sloping section. When this is done, the lamps used to call the supervisor, shown on top of the key cabinets in the photograph at the head of this article, will be extended above the toll directory racks on pipe standards. The additional upper sloping shelf of the 6B desk provides room for a second local information binder.

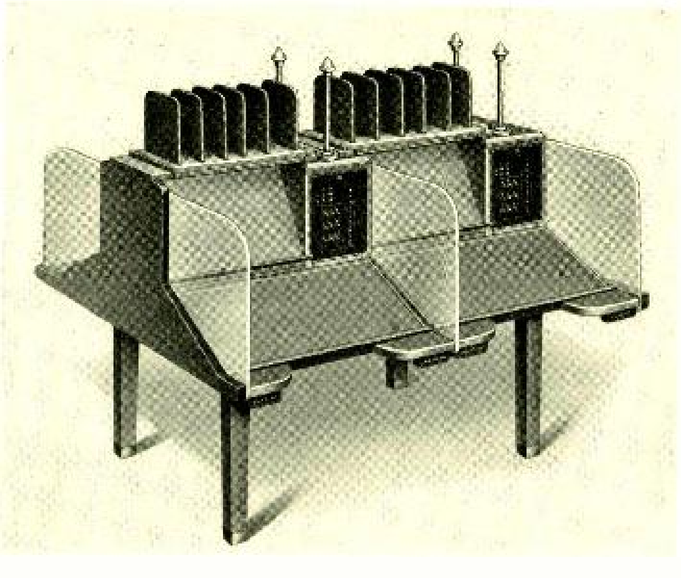

Fig. 1—The 6B information desk provides for two large local information binders by a sloping rack between the cabinets

The supporting structure for both of these desks is the framework and legs of a commercial flat-topped table. In a new installation, these lower units are all set in place first, and a metal cable rack is carried along them just below the top. The upper units are then put in place beginning at the end of a desk line-up farthest from where the cables enter. As each upper unit is put in place, the cables attached to the key panel are laid along the rack, as indicated in Figure 2. This simplifies the installation, since there is a minimum of work that must be done from underneath the desk top.

These new desks require less space than the corresponding No. 3 desks, and this fact, together with the simpler installation, reduced cost and the desirable operating and service features of the circuits of the No. 3 desk, makes them attractive for all but the largest multi-office cities.

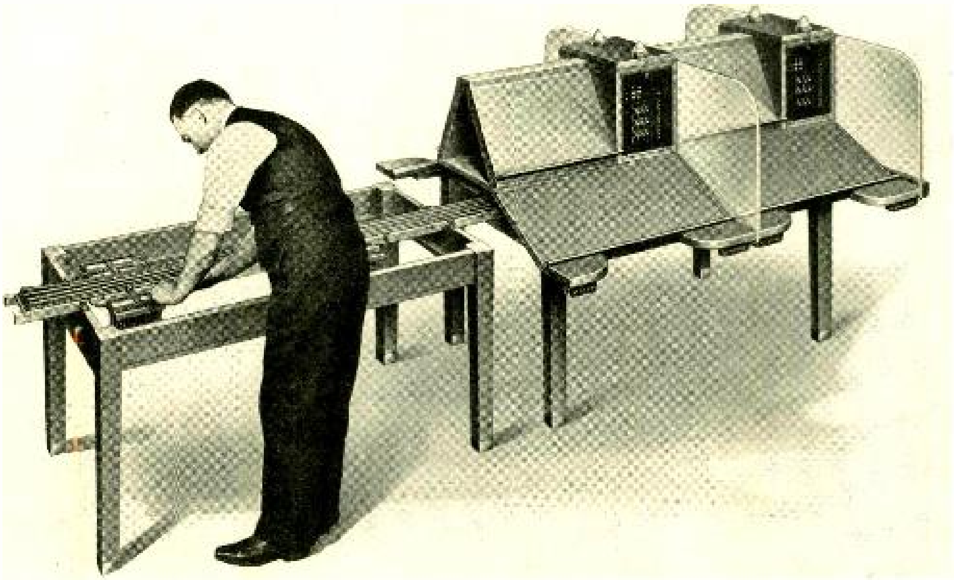

Fig. 2—In installing, the bases are all put in place first, and then the tops put on successively beginning at the end farthest from the cable entrance

Carrier and Pilot Supply for the J2 Carrier System

By L. R. COX

Carrier Telephone Development

THE J2 carrier system provides twelve voice channels in each direction in the frequency range between 36 and 143 kc. As with all the broad-band systems, twelve voice channels are modulated with twelve carriers at the transmitting terminal so as to lie between 60 and 108 kc, and then by two group modulations the 12-channel band is translated to the frequency position it will occupy on the line. To help in reducing cross-talk, four frequency allocations are provided so that when several systems are transmitted over the same pole line, the channels of various systems will be different from each other. The carrier supply system must provide not only the twelve carriers required for the basic channel modulations, but also those needed for the group modulations for each of the four line allocations. In addition each system employs two pilots to control the net transmission loss, and the carrier supply system must also provide the pilot frequencies needed.

The four frequency allocations are known as the NA, NB, SA, and SB. For the west-east direction, the NA and NB allocations are alike, as are the SA and SB; but for the east-west direction, all four are different. The frequency positions of these allocations and the modulating carriers required are graphically shown in Figure 1. Corresponding demodulations take place at the receiving terminal. All allocations use the same frequency, 340 kc, for the first stage of group modulation. For the second modulation, two carriers are required for the W-E allocations, and four for the east-west allocation. These are 364 and 484 kc for the west-east allocation and 306, 308, 541 and 543 kc for the east-west. Seven carriers are thus required for the group modulations in addition to the twelve required for the channel modulations. The positions of the sidebands with respect to the channel carriers are indicated in the conventional manner. In the basic group they are lower sidebands, and the first group modulation retains them in this position. The second group modulations employing carrier frequencies above 448 kc, however, in-

TABLE I

GROUP CARRIER FREQUENCY SOURCES

Harmonic of 4 kc	*Harmonic of 5 kc*	*Derivation*
79th	2nd	316 − 10 = 306 kc
77th	None	308 kc
85th	"	340 kc
91st	"	364 kc
121st	"	484 kc
67th×2	1st	2×268 + 5 = 541 kc
137th	1st	548 − 5 = 543 kc

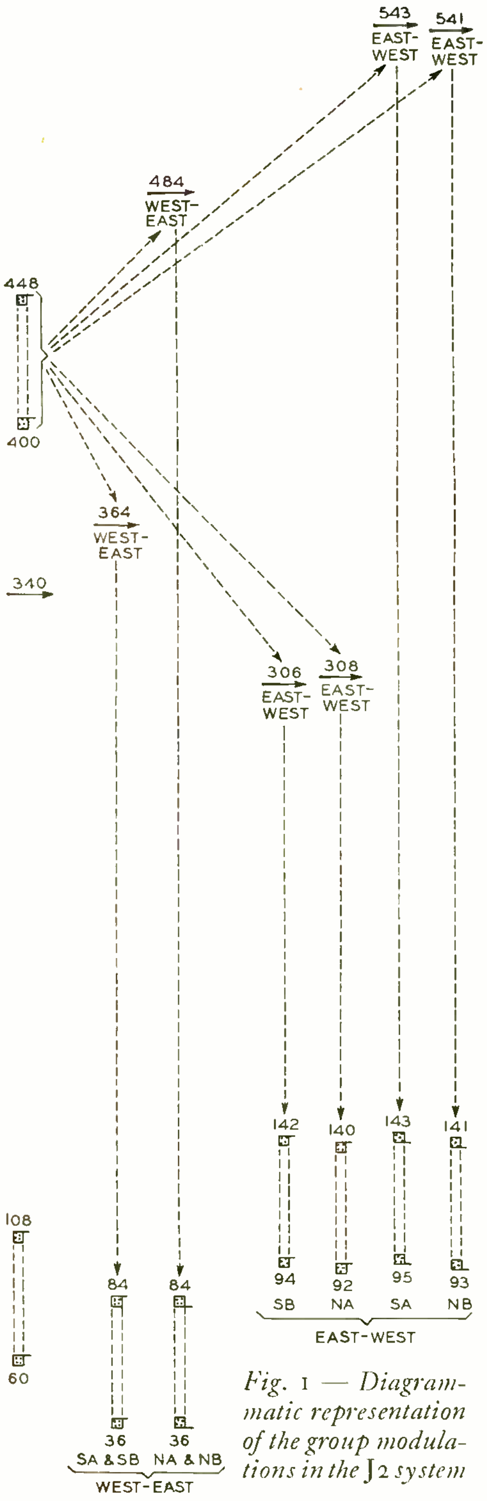

Fig. 1 — Diagrammatic representation of the group modulations in the J2 system

vert the position of the sidebands with respect to those employing carriers below 400 kc.

As with the type-K and other broad-band carrier systems,* most of the carriers are supplied by a 4-kc oscillator and a harmonic producer. From this source, filters pick out twelve frequencies at 4-kc intervals from 64 to 108 kc inclusive, and these are used to modulate twelve voice channels to form the basic group. This derivation of all the carriers from a single source is very advantageous because regardless of slight variations in the frequency of the basic source, all the channels retain the same harmonic relationship. Also, any variation in frequency can be corrected by an adjustment of one oscillator, while if a separate oscillator were used for each carrier frequency—a total of nineteen is required for the J2 system—each oscillator would have to be adjusted separately. The advantage of the harmonic generation of carriers from a single source is of particular importance in such a system as the J2, where the modulating frequencies are high with respect to the line frequencies. Under these conditions, and using independent oscillators for each carrier, the variations of all the oscillators may add up and thus give a net variation at the line frequency that is much larger than the variation of any one oscillator. With carriers all derived harmonically from a single source, however, the variation in the final line frequency, expressed in per cent, is always the same as that of the oscillator from which the carriers were derived.

The 308, 340, 364, and 484-kc carriers are all odd harmonics of 4 kc, and are selected by filters and suitably amplified. Filters, amplifiers, and

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*Record, *April*, 1937, *p.* 242.

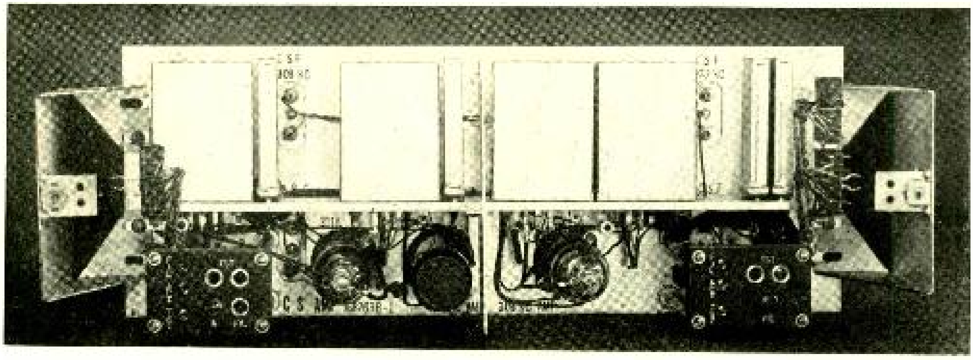

Fig. 2—Carrier-supply panel for 308 and 340 kc

other equipment for two carriers are mounted on a single panel as shown in Figure 2. The three other frequencies, 306, 541, and 543 kc, however, are not harmonics of 4 kc, and to secure them, a 5-kc oscillator is provided and used to modulate a harmonic of 4 kc. By modulating 548 kc, the 137th harmonic of 4 kc, with 5 kc, the difference frequency of 543 kc is readily obtained. For the 541-kc carrier, 268 kc—the 67th harmonic of 4 kc—is modulated with 5 kc. The products of any such modulation include, besides the sum and difference frequencies, the sums and differences between the multiples of 268 kc and the odd multiples of 5 kc. Twice 268 plus 5 gives the required 541 kc. To secure the 306-kc carrier, the connections of the 5 kc and of the 4-kc harmonic to the modulator are interchanged, so that an even harmonic of 5 kc will be available. The 79th harmonic of 4 kc—316 kc—minus twice 5 kc yields the desired 306 kc. The derivation of these various carriers is indicated in Table I.

A single-tube, fork-controlled oscillator is used to supply the 5 kc. This is quite similar to the 4-kc supply. The circuit arrangement is shown in Figure 3. A steel fork, operating in a vacuum in a sealed container, has an electromagnetic coil near each prong. One is connected to the plate and the other to the grid of the vacuum tube. The coils are shunted by condensers to tune their inductance, and the condenser shunting the grid coil is made adjustable to give control of frequency over a small range but it is not expected that adjustment will be needed except at long intervals. A varistor is connected across the plate coil to limit the voltage. The complete oscillator unit is mounted on a small panel, the front of which is shown in Figure 4; the fork unit and a few other elements are on the rear of the panel.

The modulating circuit with which this oscillator is used is shown in Figure 5. A copper-oxide varistor type

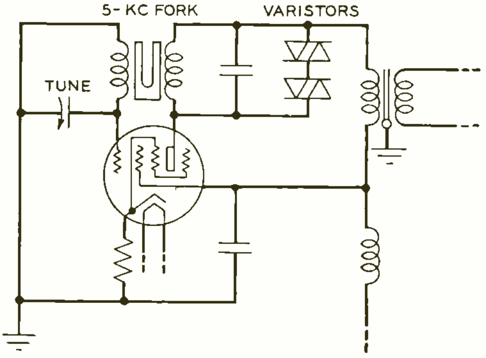

Fig. 3—Schematic of 5-kc oscillator used to modulate odd harmonics of 4 kc to obtain some of the group carriers

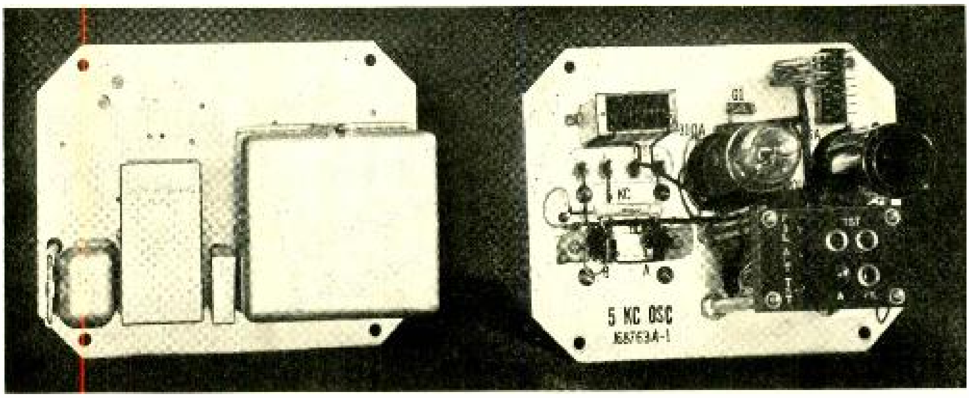

Fig. 4—The 5-kc oscillator panel used to secure group carriers

modulator is employed. The circuit connections are the same for both 541 and 543-kc carriers; only the filters are different. For the 306 kc, the arrangement is similar, but the connections of the 5-kc oscillator and the 4-kc harmonic are interchanged for reasons already stated. In all cases amplifiers follow the filters.

Besides these seven carriers required for the first and second group modulations, six other frequencies are needed to serve as pilots. For the west-east transmission, the pilots are at 40 and 80 kc on the line for all allocations, and for east-west transmission they are 92 and 143 kc for all allocations. For all west-east allocations, 40 and 80 kc are the positions that would be occupied by the channel carriers of 64 and 104 kc if they were transmitted. All carriers are suppressed in the channel modulating circuit, however, and these two frequencies are resupplied as pilots.

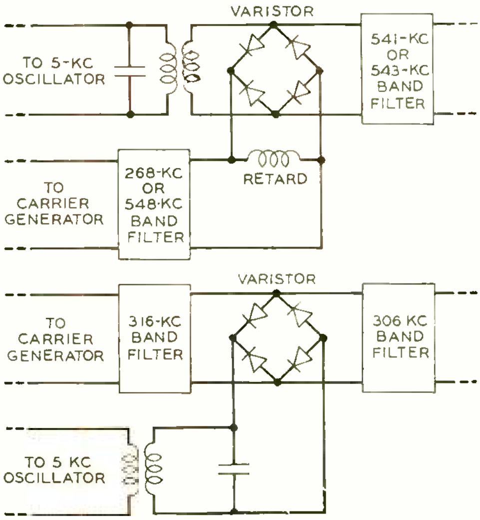

Fig. 5—Block schematics of the two modulating circuits used to obtain carriers of 306, 541, *and* 543 *kc*

Although the carriers are suppressed in the channel modulator, there is always a small amount of carrier leak. The effect of this leak on the level of the pilot could readily be allowed for, but if the frequency of pilot and carrier should differ somewhat, beat frequencies would result, and would be objectionable. Such beating is avoided by using the same 4 kc as source for both carrier and pilot. It is necessary, however, that the level of the pilot be accurately constant, while slight variations in the level of the carrier are unobjectionable. This constant level of the pilot is secured by using a second oscillator whose frequency is locked by the 4-kc harmonic and whose output is stabilized by a lamp-resistance bridge in the feedback path. The circuit in simplified form is shown in Figure 6. As the output increases, the lamps heat up, and the bridge approaches the balanced condition, decreasing the positive feedback. Equilibrium is reached when the loss in the lamp-resistance bridge equals the gain in the amplifier. In the vicinity of the balanced condition, the circuit is very sensitive and maintains a constant output with considerable accuracy. Variation in the level of the locking frequency or in the gain of the amplifier produces very little change in the output since a small change in the resistance of the lamps in the nearly balanced bridge produces a relatively large change in the loss. A 5-db change in the input or in the gain of the amplifier, for example, results in less than a 0.1-db change in output. One locked oscillator is used for the 64-kc and one for the 104-kc pilot, and their outputs are connected to a single bus that supplies the two west-east pilots for as many as ten systems.

It is desirable to have the pilots for one direction of transmission all at the same frequency on the line so that the same pilot filters used with the regulators can be employed for all frequency allocations. This is easily accomplished for west-east transmission by selecting two of the carrier positions for the pilots because these remain carrier positions for all four allocations. With east-west transmission, however, the carrier positions for the different allocations are staggered, so that if the same pilot frequencies are to be used for all allocations, they must fall outside the transmitted band.

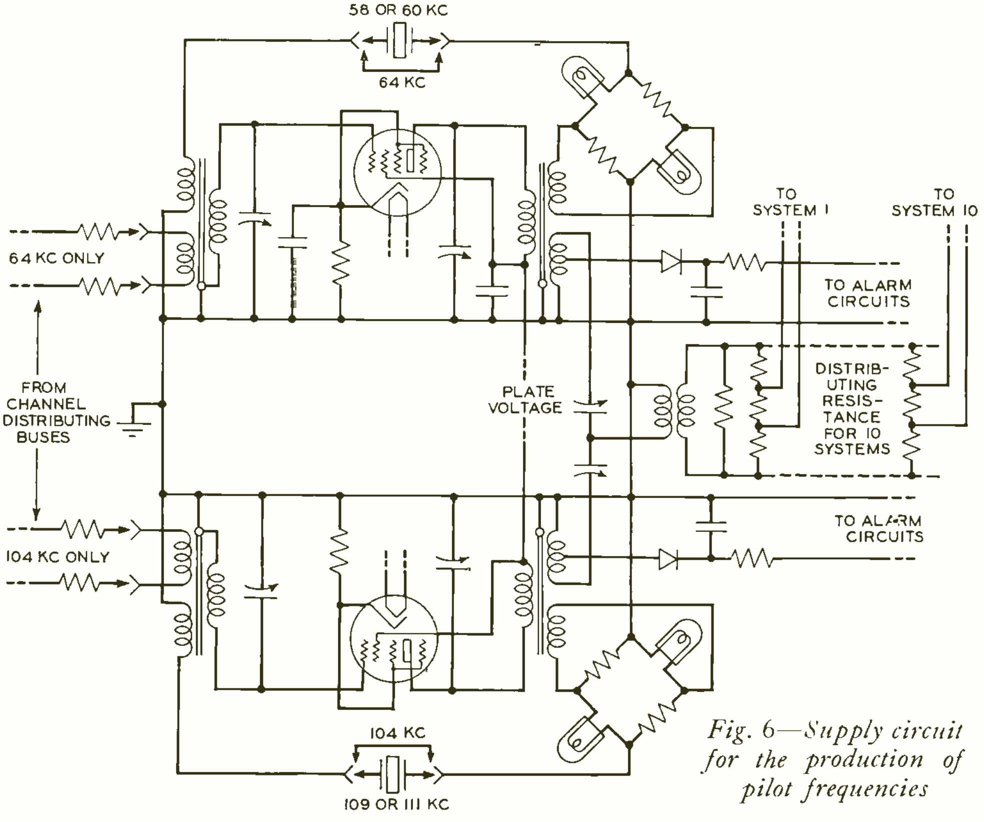

Fig. 6—Supply circuit for the production of pilot frequencies

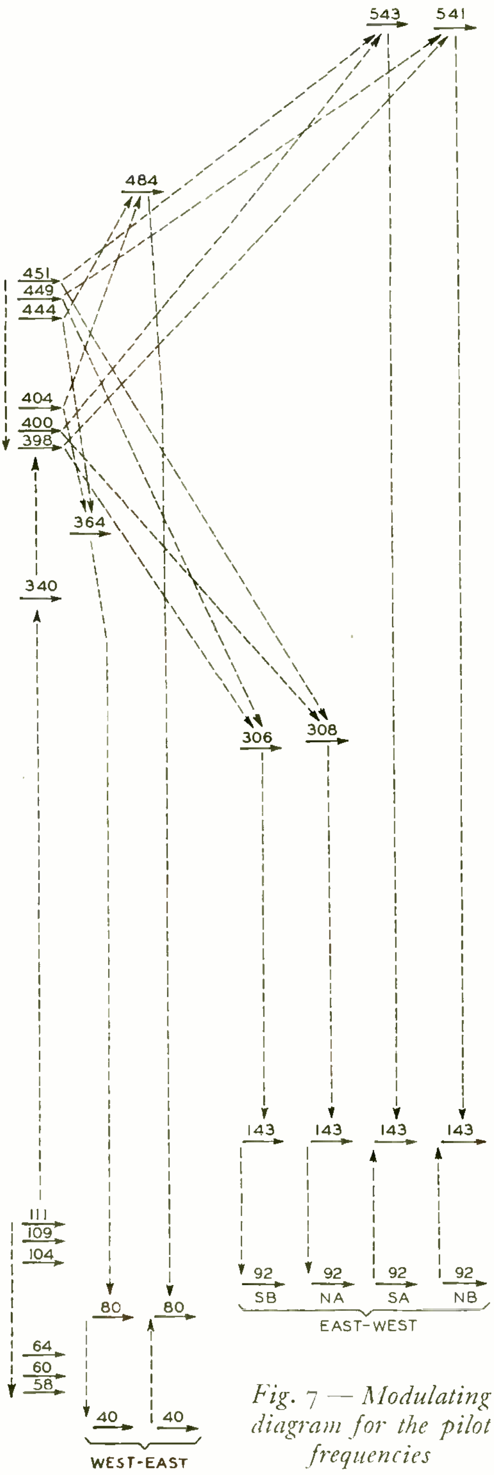

Fig. 7 — Modulating diagram for the pilot frequencies

By selecting pilot frequencies, on the line, of 92 and 143 kc, only two pairs of pilot frequencies before modulation are required. These are 58 and 109, and 60 and 111 kc. Since these frequencies are not normally furnished by the carrier supply, separate oscillators are used. The 58 and 109 are used for the NB and SB allocations and the 60 and 111 for the NA and SA allocations. The oscillators for these pilots are identical to those of Figure 5 except that there is no locking circuit, and instead, a crystal is placed in the feedback circuit to control the frequency, as indicated on the diagram. One such pair of oscillators supply the NA and SA allocations, and one the NB and SB allocations. All these pilots are generated at frequencies suitable for supply to the circuit before the group modulations, being at 58, 60, 64, 104, 109, and 111 kc. The effect of the two group modulations in bringing them to their line positions is shown in Figure 7.

The carrier supply equipment is provided in duplicate, and a transfer circuit is arranged to change to the second supply if the voltage on the first drops below a safe value. Transfer requires only a few milliseconds. An alarm is given whenever a transfer is made so that the cause of the transfer may be investigated, and a different alarm is given in the event of total failure of supply. The pilot supply is not provided in duplicate, but alarms are given whenever the level changes by as much as ½ db.

The arrangement of the carrier supply circuit is in general the same as that used for the type-K system.* Two bays are required for mounting the carrier supply equipment and these supply terminals for ten complete systems, or 120 talking channels.

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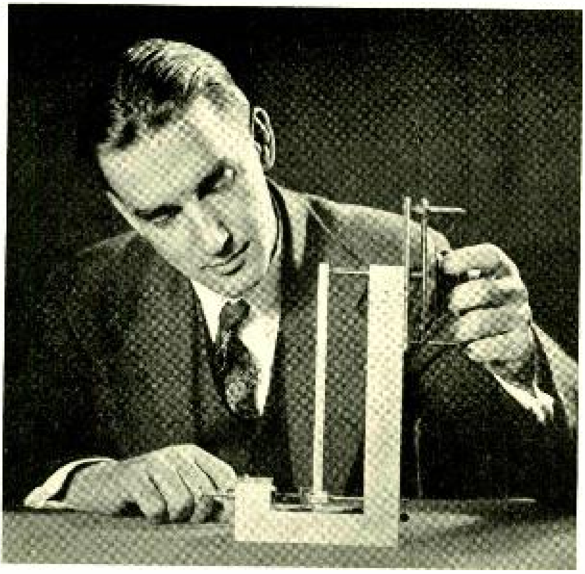
*Record, *July*, 1938, *p.* 365.

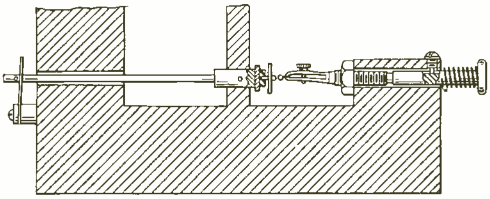


Metallic Bridges Between Contact Points

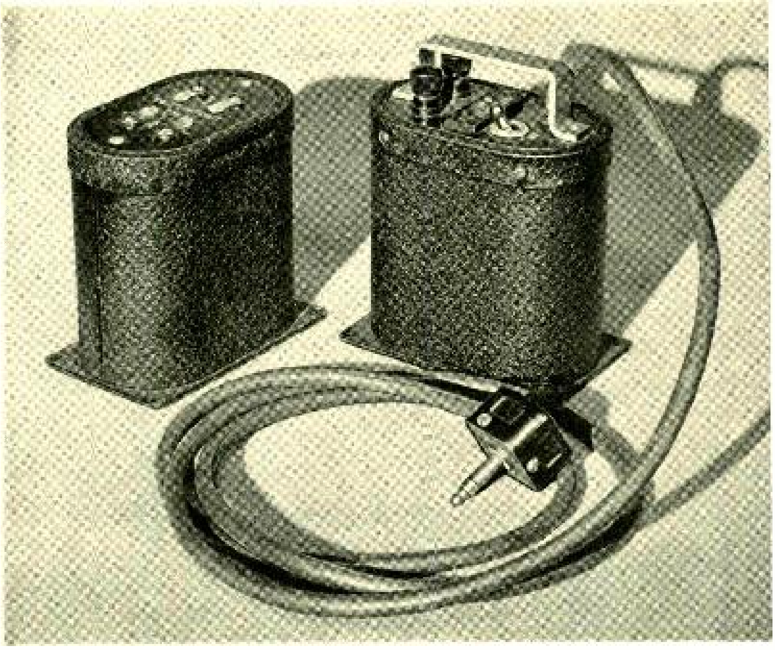
WHEN two electrodes are brought very close together, even under relatively low voltages, particles are torn from the electrodes and may establish a conducting bridge between them. These conducting filaments form at voltages less than the sparking potential and are produced by the large electrical forces which result from the very small separation of the electrodes.

In experiments by G. L. Pearson, bridges were formed between gold, steel and carbon electrodes when separated from 2 to 70 x 10^{-6} cm. The voltage gradients were about ten million volts per centimeter. To determine the point of zero displacement, electrical contact was made between the electrodes. They were then separated a known distance and the voltage between them slowly raised until the bridges formed. This occurred at voltages between 15 and 350 volts depending on the separation. The resistance dropped permanently to a low value at the same time.

Measurements of the temperature coefficient of resistance of the bridges identified them as consisting of the material of the electrodes and changes of their resistance when the electrodes were separated or brought together slightly showed that they can be pulled out and crushed. The separation of the electrodes was controlled very delicately by attaching one of them to a cantilever bar and adjusting it with a micrometer screw. The other electrode of the apparatus was mounted on a fixed support. To insure rigidity, the whole apparatus was cut from a solid block of steel.



Conducting bridges form between electrons when brought very close together even under relatively low voltages



A Coupling Unit for Telephotograph Transmission

By D. W. GRANT
Transmission Apparatus Development

WHEN an unusual event of wide interest occurs, news gatherers are alert to get the information to the newspaper offices as soon as possible. Since pictures are often a very important part of this information every effort is made by the reporter to obtain suitable ones and to send them in without delay. The promptness with which pictures can be supplied from distant points has been greatly increased in recent years by the development of satisfactory telephotograph equipment, and the provision of permanent transmission networks with fixed transmitting points in the more important cities of the country.

For transmitting pictures from other points, provision is made for the connection of telephotograph equipment to leased lines for semi-permanent installations or to regular toll lines for short intervals. In either case, it is necessary to have an arrangement for the connection between the telephotograph equipment and the telephone line which will permit the sending of satisfactory pictures, protect the telephone line from high voltages that may be present in the picture-sending apparatus, and prevent the sending of high signal levels which might cause noise and interference on neighboring telephone lines. Another function required of a satisfactory connection arrangement is a "holding-coil action," so that when the apparatus is connected across the line, it will draw sufficient current to "hold" the supervisory relay in the telephone office, thus permitting the handset or receiver to be replaced on the switch-hook without releasing the line. This is important because the telephone transmitter, which might pick up sufficient room noise to spoil the picture being transmitted, is thereby removed from the circuit.

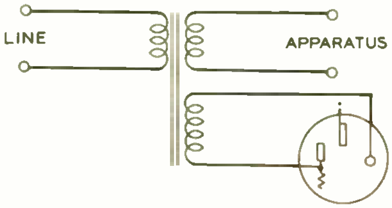


Fig. 1—Schematic of the 105A coupling unit for connecting telephotograph equipment to working telephone lines. The 104A differs from it only in the addition of a switch and plug in place of the line terminals

To meet the demands presented by the above requirements, two coupling units—the 104A and 105A—have been developed. These units, shown in the picture at the head of this article, provide a simple means for connecting telephotograph equipment to working telephone lines, provide the required holding coil action, and at the same time protect the lines from the possibility of excessive voltages and signal levels.

Electrically these units, shown schematically in Figure 1, are the same. They consist essentially of a transformer with two equal-impedance windings for coupling the transmission apparatus to the line, and a third high-impedance winding connected to a gas-filled tube.

The line winding has sufficiently low resistance to take the required supervisory relay current, and for the protection of the line is insulated from the other windings and from the case sufficiently to withstand surges of 2000 volts.

The gas-filled tube connected to the high-impedance winding is provided to protect the line from excessive signal levels. This tube has a nearly infinite resistance at potentials below about 75 volts. At approximately this voltage, however, the gas in the tube ionizes, and reduces the internal resistance to a very low value. The voltage ratio between the line and tube windings of the transformer is such that this ionizing potential corresponds to a peak voltage on the line of about 1.2 volts, which permits the transmission of slightly over one milliwatt of power into the line without distortion. If, due to improper adjustment of the sending apparatus, an input voltage corresponding to higher power than this is applied to the coupling unit, the voltage across the tube exceeds the ionizing potential and the tube, by virtue of the impedance-transforming action of the coil, imposes a low impedance shunt across the line, thereby limiting the voltage to approximately the critical

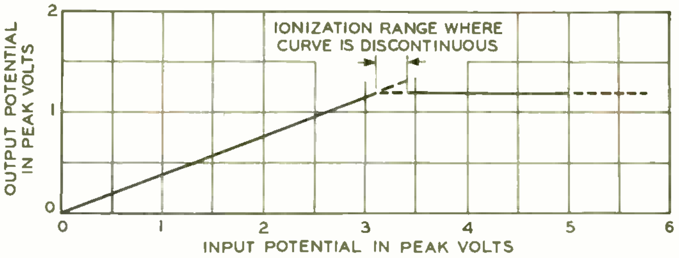


Fig. 2—Output-voltage characteristics of the new coupling unit

value. This characteristic is illustrated in Figure 2, which shows the relationship between generator voltage and line voltage. As may be seen, the output voltage increases linearly with generator voltage up to the point corresponding to the ionization of the tube. This indicates no distortion of the wave form. For higher generator voltages the output voltage increases only slightly. In this range the wave form becomes flat topped due to the peak-limiting effect of the tube.

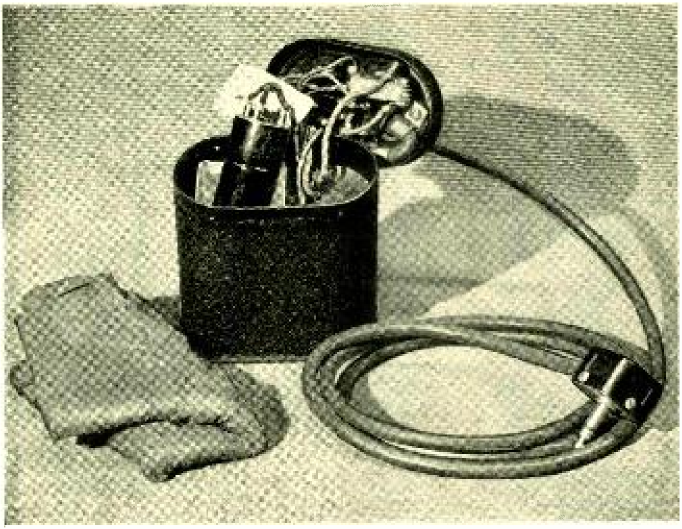


Fig. 3—The 104A coupling unit with cover removed to show the tube case at the left

Although the action of the two units is identical electrically, there is considerable difference physically as may be seen in the photograph. The 104A coupling unit is intended for temporary installations, and is therefore provided with a handle for carrying, a flexible cord terminated in a plug, and a switch in the cord circuit. The plug in conjunction with a jack installed in the line by the telephone company affords a ready means of connection to the line. The 105A coupling unit is intended for permanent or semi-permanent installations, and the line and apparatus windings are brought out to screw-type terminals that are mounted on the cover.

To insure long life, the transformer in both units is sealed to exclude moisture. The tube is mounted inside a small aluminum can which is, in turn, assembled in the larger case with the coil, and the connections between the coil and tube are made by means of the flexible leads with which this tube is provided. The cover of the 104A unit is readily removable so that if necessary the tube may be replaced. This unit with the cover removed is shown in Figure 3.

The development of these units has been a factor in increasing the usefulness of one of the newer types of service offered by the Bell System and available for the use of the press.

Measuring the Air Flow of Small Fans

THE ventilating fan in a telephone booth rotates slowly to assure quiet operation, and it is required to develop an air stream of such low velocity and low noise level that a special set-up had to be made in the Laboratories to measure it; also a stringent vibration requirement must be met.

In the tests a three-inch anemometer is mounted in front of the fan and twelve inches away from it. Measurements are made opposite the center of the fan and at one-inch intervals in four directions along a vertical and horizontal line which intersects the fan's axis. The anemometer is moved outward until the air velocity becomes too small to measure accurately.

The volume of air propelled by the fan per minute may be found from the anemometer readings by dividing the cross-section of the air stream into rings one inch wide and concentric with the axis of the fan. The area of each ring multiplied by the average of the four anemometer readings for that ring gives the air flow through it and the sum of these values the total air flow. The rate of rotation of the fan is measured with a stroboscope by determining how many flashes per minute make the blades of the fan appear to stand still. Ordinarily, the fans that are provided for telephone booths circulate from 175 to 350 cubic feet of air per minute.

To test for vibration the fan is mounted on a platform on which rests a vibrometer. By moving the vibrometer about on the platform the vibration in different directions is found.

Contributors to this Issue

Leslie R. Cox graduated from Purdue University in 1922 with the degree of B.S. in Electrical Engineering, and then joined the Western Electric Company at Hawthorne. After completing the students course he was engaged in writing installers' specifications for panel machine-switching exchanges. After a few years outside of the Bell System, he joined the toll development group of the Bell Telephone Laboratories in 1929. Since then he has been engaged in the development of carrier terminals for broad-band systems. His principal interest has been modulators and their carrier supply.

C. D. Owens received the degree of A.B. in Physics from Indiana University in June, 1928, and immediately joined the Technical Staff of the Bell Telephone Laboratories. As a member of the Transmission Apparatus Department he has been engaged in the development of condensers, loading coils, retardation coils, and compressed magnetic powder cores. During this period, he took part-time graduate work at Columbia University and received an M.A. degree in Physics from this university in 1936.

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 been engaged in the development of audio-frequency transformers for use in the telephone plant and in specialty products apparatus.

K. G. Van Wynen came to the Development and Research Department of the A. T. & T. Company after receiving the E.E. degree from Cornell University in 1925. Until 1927 he was associated with a group working on program transmission problems. From 1927 to 1929 his work was on inductive interference in connection with railway electrification. Since 1929 he has been concerned with the rating of transmission performance. During this interval he has been principally interested in the design and construction of circuit arrangements used in field and laboratory tests. Mr. Van Wynen also attended the Brooklyn Polytechnic Institute where he received the M.E.E. degree in 1933.

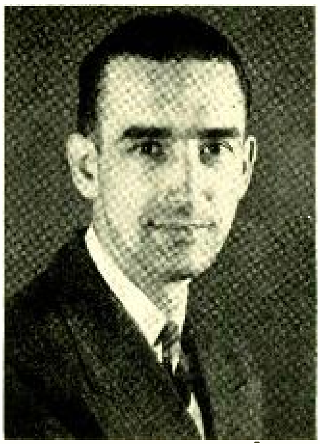
L. R. Cox

C. D. Owens

D. W. Grant

K. G. Van Wynen

A. C. Gilmore



G. L. Pearson

A. C. Gilmore joined the Laboratories in 1916 and became associated with the Materials Inspection group. Shortly after, however, he transferred to the Systems Department and for a number of years was engaged in equipment drafting. In 1923 he joined the Equipment Development group where he was first concerned with the analyzation of Hawthorne orders and later with trial installations. At the present time he is engaged in the development of equipment for central offices such as that he describes in this issue.

Gerald L. Pearson, who describes thermistors in this issue of the Record, began the Laboratories' study of these devices some five years ago. Entering our Physical Research organization in 1929, he had behind him undergraduate work at Willamette (A.B. 1926) and graduate study at Stanford (M.A. 1929). His initial assignment was to study thermal noise in conductors, shot noise in vacuum tubes and carbon noise in microphones. One of these studies has been accepted by Columbia University as a thesis for the doctorate of philosophy. A collateral investigation of thermo-sensitive materials grew eventually into a project under Mr. Pearson's direction, from which have come a number of present and prospective uses for thermistors in the Bell System.