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Chemically Stabilized Paper Capacitors

By D. A. McLEAN
Chemical Laboratories

PAPER-insulated capacitors are used extensively in military equipment and frequently under more severe temperature and voltage conditions than they encounter in telephone use. Long before the war the problem of extending the service life of these capacitors had been under investigation by the Laboratories. One development, the addition of a small amount of anthraquinone to the impregnant with which the paper is treated, has greatly extended the life of capacitors.

Among the impregnants suitable for saturating the paper, chlorinated diphenyl and chlorinated naphthalene have been used extensively. They resist oxidation and thermal decomposition, have high dielectric constant, compared with mineral oil, and good electrical properties. When operated at room temperatures, capacitors with paper dielectrics impregnated with these chemicals have a satisfactory life. At high direct-current potentials, however, and at temperatures from 50 to 100 degrees C., which are common in much modern equipment for our Armed Forces, rapid degradation of the dielectric material results.

The Laboratories discovered that there are a number of compounds which substantially increase the life of capacitors on accelerated direct-current tests, when added in small amounts to the chlorinated im-

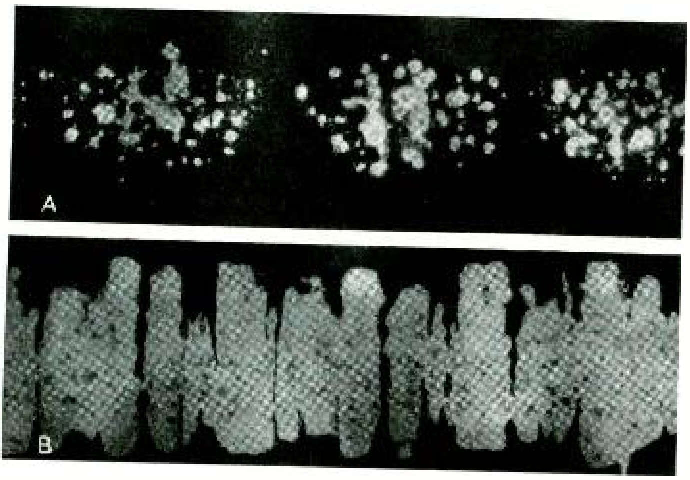


Fig. 1—Fluorescent areas in paper taken from capacitors next to the cathode after accelerated aging tests using chlorinated naphthalene impregnant and two layers of 0.4-mil unbleached linen paper. (A) No Stabilizer. Aged at 100 degrees C., 120 volts direct-current, for 245 hours. (B) No Stabilizer. Aged at 100 degrees C., 120 volts direct-current, for 670 hours

pregnant. These stabilizers also maintain the leakage current during tests at low and relatively stable values in contrast with the rapidly increasing leakage current in unstabilized capacitors. Among the stabilizers used, the quinones were the most satisfactory and of them, anthraquinone was chosen for commercial use owing to its high effectiveness, ready availability in pure form, low volatility and lack of toxicity.

Although kraft wood pulp is used almost exclusively for capacitor paper in this country, linen paper has been used in many of the experiments on stabilizers because its very poor performance with unstabilized impregnants makes it a very sensitive indicator of the effectiveness of a stabilizer. Figure 1, for example, illustrates the effect of anthraquinone on the deterioration of linen paper in capacitors subjected to direct-current voltage at high temperatures. These photographs were taken with ultraviolet light, previous experiments having shown that it causes decomposed areas in capacitor paper to fluoresce. Following the continuous application of voltage for the periods indicated, the pieces of paper shown were freed of impregnant by solvent extraction, mounted on a card and photographed simultaneously on one film. The photographs show the marked deterioration which occurred under the conditions of test when unstabilized chlorinated naphthalene was used. Paper from a capacitor stabilized with 0.5 per cent by weight of anthraquinone in the impregnant showed no visible deterioration, even though

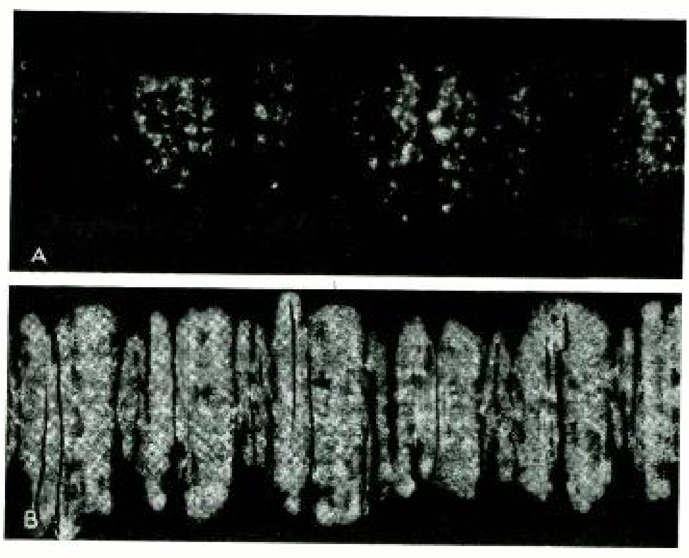


Fig. 2—Corrosion pattern on aluminum anodes taken from capacitors after test. Same capacitors as A and B of Figure 1. Taken with artificial light which struck the aluminum at a glancing angle. These showed marked corrosion while those from a stabilized sample showed only a slight haze despite the greater severity of the test

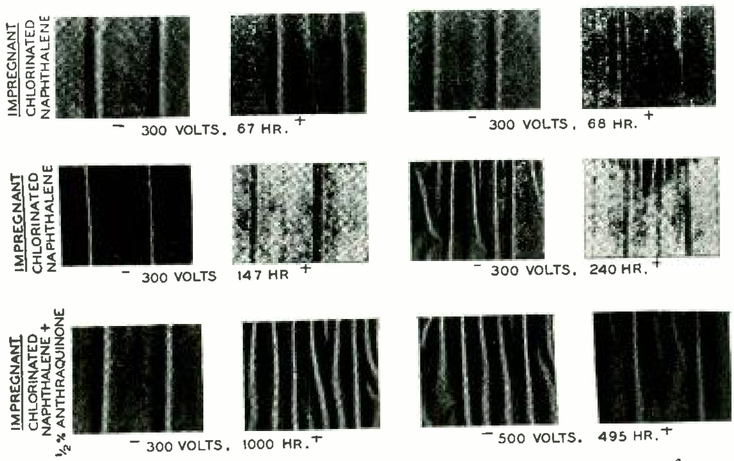


Fig. 3—Prevention of deterioration of evaporated aluminum electrodes by anthraquinone. Photographed by transmitted light. The electrodes are intact in stabilized samples, despite the greater severity of the tests

the voltage was twice as high and the time much longer. The two papers illustrated in the photographs were visibly browned and embrittled in the fluorescent areas, whereas the one treated with anthraquinone was not obviously different in color and flexibility from unused paper.

Corrosion of the positive electrode from the same unstabilized test capacitors is shown in Figure 2. Whereas these were markedly corroded, those from a stabilized sample showed only a slight haze despite the greater severity of the test. These photographs were taken with artificial light which struck the aluminum surface at a glancing angle.

Further evidence of the diminution of electrode corrosion by anthraquinone was obtained by using capacitors in which the electrodes consisted of thin aluminum films evaporated on kraft paper before the unit was wound. In these capacitors, a small amount of corrosion of the electrodes entirely consumed the aluminum. Capacitor windings made with this paper were dried and impregnated in the usual manner and subjected to voltage while held at 100 degrees C. The impregnating compound was then extracted and portions of the paper were photographed by transmitted light to show holes produced by the corrosion. The positive electrode, as shown in Figure 3, was rapidly attacked in the unstabilized capacitors and eventually even the negative electrode gave some evidence of deterioration. After testing for 240 hours at 300 volts, the anode was very largely destroyed. In contrast, the stabilized samples tested under the same conditions showed no detectable attack of either electrode in 1,000 hours, nor in 495 hours at 500 volts.

Suppression of degradation of the dielectric and corrosion of the electrodes through chemical stabilization with anthraquinone

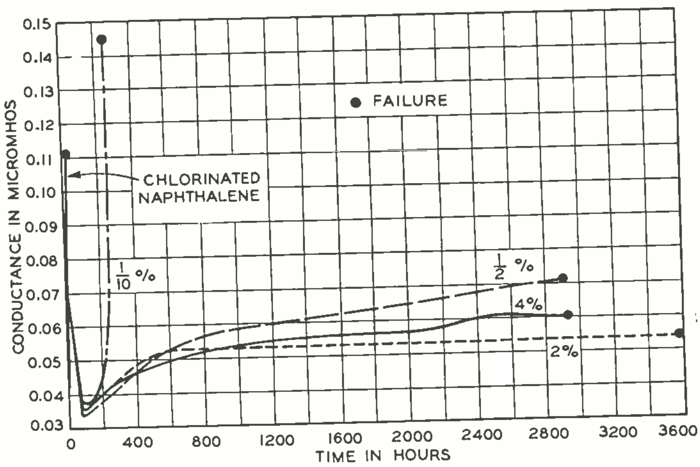


Fig. 4—Effect of various concentrations of anthraquinone on the leakage current and life of paper capacitors which contain chlorinated naphthalene. 100 degrees C., 350 volts direct-current, two layers of 0.4-mil linen paper

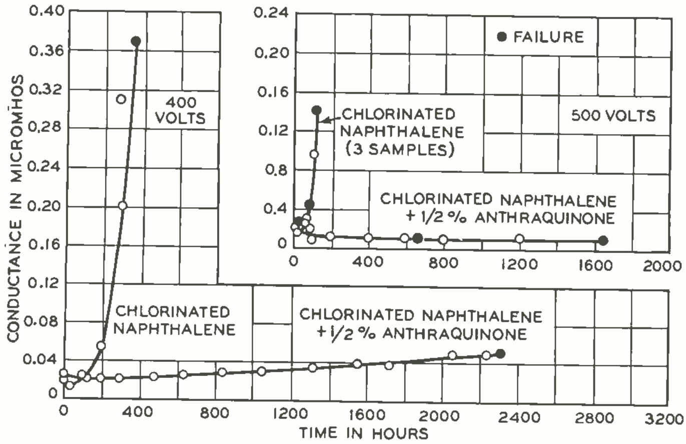


Fig. 5 — Conductance-time curves at constant direct-current potential at 100 degrees C. Lower graph, 400 volts direct-current, upper graph, 500 volts direct-current, two layers of 0.4-mil kraft paper. Kraft paper capacitors, when fortified with anthraquinone, are superior in performance to stabilized linen paper capacitors

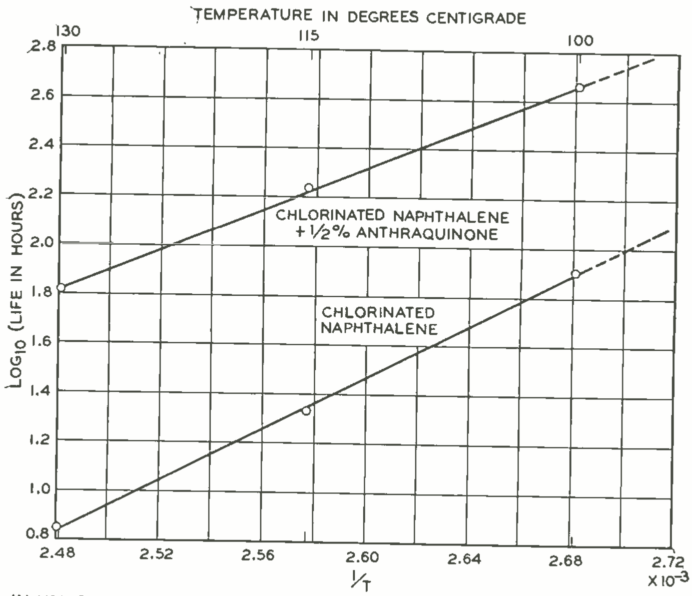


Fig. 6—Temperature-life relationship of stabilized and unstabilized capacitors at 400 volts direct-current, two layers of 0.4-mil kraft paper. T is absolute temperature. Improvement due to adding anthraquinone is somewhat greater the higher the temperature

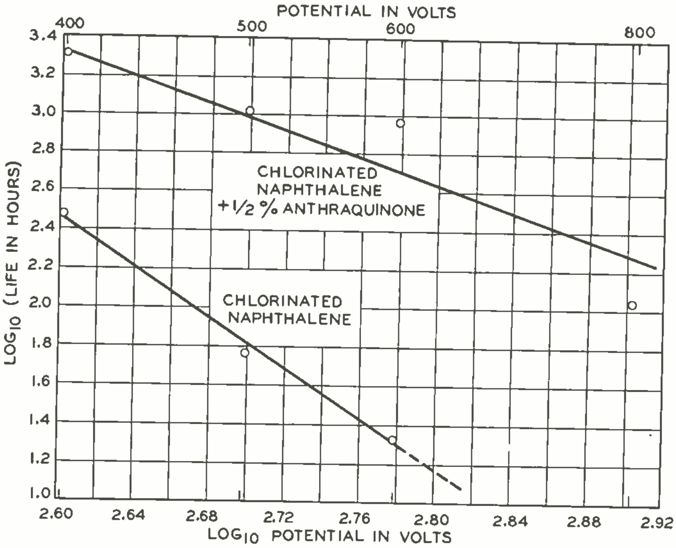


Fig. 7 — Voltage-life relationship at 100 degrees C. over the range 400 to 800 volts direct-current, two layers of 0.4-mil kraft paper. Dependence of the life of capacitors on voltage is as important to the design engineer as its dependence on temperature

is reflected in longer life and more stable leakage current, as is shown in Figure 4. When a linen paper capacitor impregnated with chlorinated naphthalene is subjected to continuous direct-current voltage at 100 degrees C., the leakage current rises rapidly. Within a very few hours a failure develops which completely short-circuits the electrodes at some point. With 0.1 per cent anthraquinone in the impregnant, the current rises less rapidly, and the life is increased by about tenfold. Increasing the amount of stabilizer to the range of one-half to four per cent produces a relatively stable leakage current. The life is then about one hundredfold as great as when no stabilizer is employed. On the basis of these and other results, a minimum of 0.5 per cent is recommended for commercial use.

Kraft paper exerts a stabilizing action of its own* and consequently kraft paper capacitors, when fortified with anthraquinone, are superior in performance to stabilized linen paper capacitors. The stabilizing action of anthraquinone on kraft paper capacitors is shown in Figure 5 for 100 degrees C. and two voltages, 400 volts and 500 volts.

An important consideration for the design engineer is the effect of temperature on the life of paper capacitors. This relation for stabilized and unstabilized paper capacitors with kraft paper dielectrics is shown in Figure 6. Improvement due to adding anthraquinone is somewhat greater the higher the temperature. A straight-line relationship on this plot is characteristic of chemical reactions. This and the fact that the slope is of the right order of magnitude constitute evidence that the deterioration and failure are predominantly chemical phenomena.

Dependence of the life of capacitors on voltage is as important to the design engineer as its dependence on temperature. To estimate the voltage effect, the equation, $\text{Life} = A/V^n$ where V is the voltage and A and n are constants, has been used. In Figure 7 are plotted data on the life of stabilized and unstabilized paper capacitors as a function of voltage. They fit the above relationship within the experimental error. The value of n is between 4 and 6.

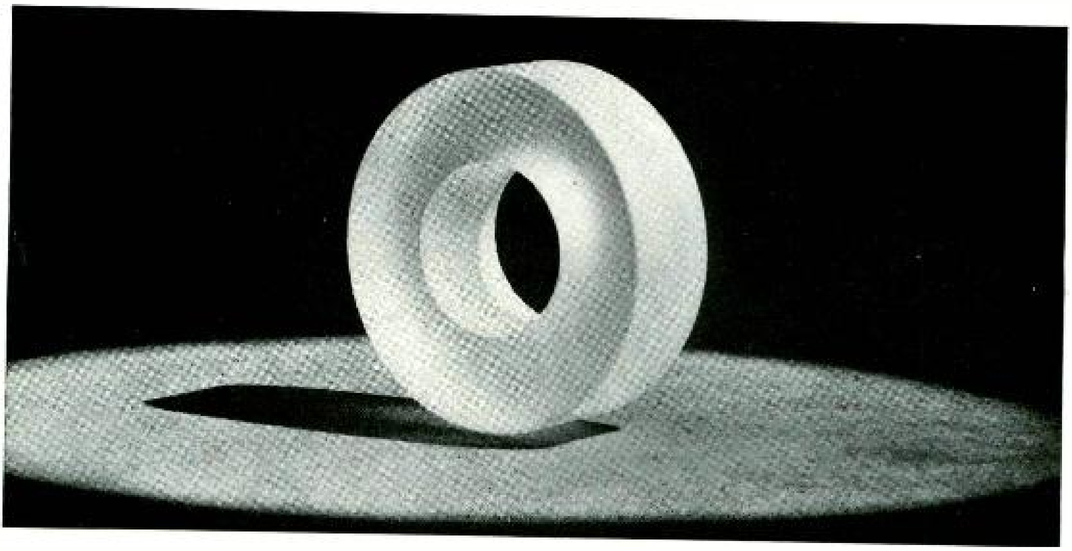
*Record, *February*, 1943, *p.* 136.

THE AUTHOR: D. A. McLEAN joined the Laboratories in 1929, the year he received his Bachelor of Science Degree in Chemical Engineering from the University of Colorado.

During the succeeding three years, problems in plasticity, viscosity, and the wetting of solids by liquids occupied his time and permitted him to contribute to the theory of capillary penetration of liquids into fibrous solids. Since then Mr. McLean has been concerned with investigations relating to the dielectric properties of materials used in capacitors.

The large stabilizing effect of anthraquinone in kraft paper capacitors which contain chlorinated impregnants is shown by Figures 6 and 7. The former indicates that the stabilized capacitors have an accelerated life performance equivalent to that shown by the unstabilized materials at 30 degrees C. lower temperature; the latter that stabilized samples at 700 volts d-c are about the equivalent in life of unstabilized samples at 400 volts d-c.

Anthraquinone has been used for several years to stabilize all Western Electric capacitors impregnated with chlorinated naphthalene and chlorinated diphenyl. As an aid in the prosecution of the war, the Western Electric Company has made its information on anthraquinone available to other capacitor manufacturers, several of whom have adopted this method of improving capacitor performance.



Historic Firsts

Zero-Temperature-Coefficient Quartz Crystals

Although quartz is stable compared to most substances, the natural frequency of vibration of a quartz plate varies slightly with a number of factors—chiefly temperature. Early studies showed that at any operating temperature, variation in frequency with departure from this temperature depended on the manner in which the crystal plate was cut with reference to the major axes of the original crystal, and also on the relative dimensions of the plate. For some directions of cut the temperature coefficient of frequency was usually positive and for others it was negative, and the magnitude as well as the sign of the coefficient varied. A particular frequency, moreover, may be the effect of two or more different modes of vibration, such as a longitudinal and a transverse, or a longitudinal and a flexure vibration.

Recognizing these facts, W. A. Marrison conceived the idea of so cutting the plate that at the desired temperature one mode of vibration would have a positive coefficient and the other a negative, and of then dimensioning the plate so that the effect of the positive coefficient of one mode was equal and opposite to that of the negative coefficient of the other, thus giving a net temperature coefficient of approximately zero in the vicinity of the operating temperature. He carried out a series of experiments in an effort to secure such a zero-temperature-coefficient crystal, and as a result obtained the crystal shown above. An application in December, 1928, resulted in Patents Nos. 1899163 and 1907425, 6, and 7. Over a small range of temperature, the crystal has a coefficient of less than one part in a million per degree Centigrade, and at one temperature the coefficient is zero. Such a crystal was at once incorporated in the Laboratories frequency standard,* replacing the original, which had a temperature coefficient of about four parts in a million per degree C.

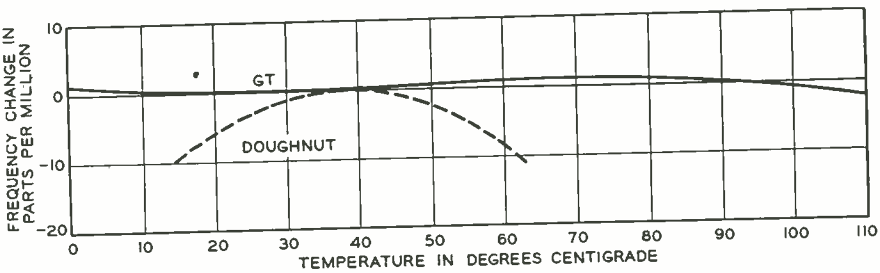
During the following years, other zero-temperature-coefficient crystals were obtained, and a number of them have been widely used for controlling the frequency of carrier telephone systems and radio transmitters. Although differing in many of their characteristics, all of these crystals were alike in having a zero temperature coefficient at only one temperature—both above and below this temperature the coefficient increased either positively or negatively. Temperature control was needed to maintain the crystal close to the temperature of zero coefficient for high precision.

Just how many of such zero-temperature-coefficient cuts were possible, what the

*Record, *March*, 1944, *p.* 355.

other characteristics of each such possible cuts would be, and whether or not a zero temperature coefficient could be obtained over a wide range of temperature, could be determined only by extensive experiment or by a mathematical study of the complete vibrational behavior of quartz. To express the temperature coefficient of a single mode of motion requires a set of equations involving some 12 constants and three angular variables. A general study of the temperature coefficients for all angular orientations was undertaken and successfully carried out by W. P. Mason. As one result of this work, he found that by cutting the plate in a way that corresponded to a double rotation around the crystal axes, and taking advantage of couplings between vibrations with positive and negative temperature coefficients, plates could be obtained with essentially zero temperature coefficients over a wide range of temperature. Such a plate that has proved very useful has since been called the GT cut. A patent application was filed in December, 1937, and Patent No. 2204762 was issued to Dr. Mason on June 18, 1940. For the temperature range from 0 to 100 degrees C., this crystal maintains its frequency constant to one part in a million, and over a range of 30 degrees C., in the neighborhood of ordinary room temperatures, the frequency does not change by more than one part in ten million. Such crystals are now used in the Laboratories' Frequency Standard, and in the National Bureau of Standards.

As a result of the studies of Dr. Mason and others in these Laboratories, the field of low-temperature-coefficient crystals has been widely explored, and the angle of cut and the dimensions required to secure zero temperature coefficients for a wide range of operating conditions are now known. Not only can zero temperature coefficients be secured over a wide range of both frequency and temperature, but the range in which the zero coefficient appears may be changed to meet a wide variety of applications.



Variation in frequency with temperature of the "doughnut" and GT crystals

"I urge that you sustain the high morale and fighting spirit of our personnel on the lonely islands and atolls of the Pacific and aboard ships at sea. If you could observe how eagerly all hands look forward to letters from home, or the cruel disappointment of those left out when mail is distributed, you would realize what a lift to the human spirit may be contained in a half-ounce envelope. Out here we regard mail as being of such help to morale that we establish post offices in LST's near the scene of amphibious operations, and try to get mail ashore even while beachhead fighting is still going on."

From a broadcast by

ADMIRAL CHESTER W. NIMITZ.

A Volume Limiter for Leased-Line Service

By J. A. WELLER
Transmission Engineering

A PAIR of wires carrying rapidly varying current radiates electro-magnetic energy that induces similarly varying current but with lesser intensity in all other circuits in the vicinity. This is the source of crosstalk that in all communications circuits must be kept below objectionable limits. To avoid it, a number of precautions must be taken. One preventive measure always employed is to maintain the current in all telephone circuits between fixed upper and lower limits. All Bell System circuits are designed with these limitations in view, but certain leased channels may have apparatus connected to them that is neither owned nor operated by the Bell System. The subscriber may maintain some form of volume control, but it may not prevent excessive current at times, and for certain types of circuits, such as those connected to police radio receivers, for example, the situation is inherently difficult. If the radio receiver is adjusted not to have too great a volume when the transmitter from which it is receiving is nearby, the speech may be inaudible from more distant transmitters, while if the volume is adjusted for the distant transmitter, it will be too high for a nearby transmitter.

With the inauguration of our national defense program, a large number of circuits were leased to the Army for connection to radio receivers used for airplane-to-ground communication. To permit these receivers to provide good transmission whether the planes are near or distant, it was very desirable to adjust the receiver for the weakest output signal and then to provide a volume limiting device that for stronger signals would limit the volumes to satisfactory values. To meet this need, a volume limiter was developed that holds the output level to a maximum of +8 vu* for all input levels up to +35 vu, and does not introduce noticeable distortion. It is directly operated by the power of the speech signal, and thus no outside source of power is required. This circuit introduces a small loss in the circuit for low input levels, and automatically increases this loss for high input levels, so that the output is never more than +8 vu. For inputs from +15 to +35 vu, this device provides practically constant output. It is thus evident that in addition to preventing excessive levels, the limiter will provide constant level on the line, and thus to the receiving end, for a large range in input levels.

This new volume limiter is essentially a hybrid coil arrangement as shown in the circuit schematic of Figure 1. Here the input line is connected to a transformer with balanced output windings. Thus the signal is divided into two paths, and then continues through these two paths to a similar transformer connected to the output line. It will be noticed that one of the secondary windings of the output transformer is reversed so that the currents of the two paths introduce opposing currents in the output line. If there were equal resistance in the two parts, there would be no output signal possible because of the equal and opposing currents in the line. At low volume levels, however, the resist-

*Record, *June*, 1940, *p.* 310.

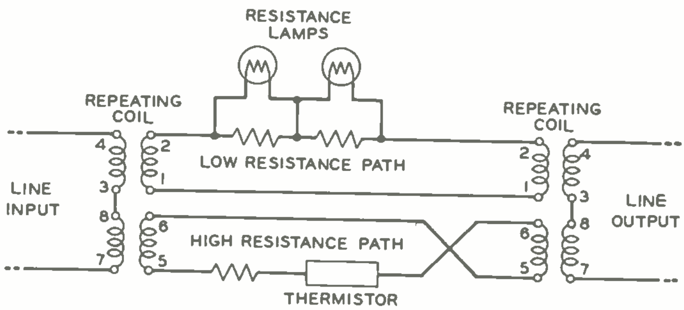


Fig. 1—Simplified circuit schematic of the volume limiter

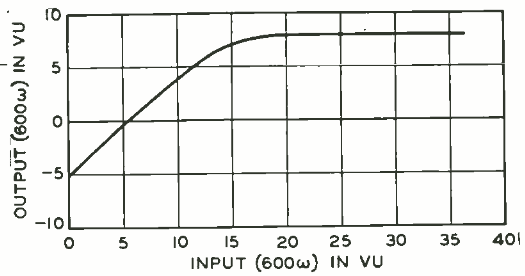


Fig. 2—Input-output characteristic of the volume limiter

ance in one path is very low and that in the other is very high. In this condition most of the signal current passes through the low-resistance path. The bridge arrangement is unbalanced, and the circuit introduces very little loss in the line. At input levels in the limiting range, the resistances in the two paths change to approach a common value. This tends to balance the bridge, and more loss is introduced into the line. The variation of resistance is so designed that the change in loss is approximately equal to the change in input level, which results in fairly constant output.

The elements responsible for the change in loss are non-linear resistances that vary in resistance with the input volume. A thermistor in one branch of the network, provides the high resistance, while two tungsten lamps in the second path furnish the low resistance. The resistance of the thermistor decreases rapidly with increasing current, while the resistance of the lamps increases with increasing current. For each input level in the limiting range, there is a particular equilibrium condition of resistances to which the circuit soon adjusts itself. The output is thus eventually brought to a common level regardless of the previous input level, whether it was above or below this new level.

The input-output characteristic for this device is shown in Figure 2, where it will be noticed that at low volumes, the insertion loss of the limiter is 5 db. At an output level of about +5 vu, the output starts to level off, and with higher inputs assumes a more or less constant volume of +8 vu. This output characteristic is slightly affected by ambient temperature in the limiting range of inputs up to +25 vu. Thus higher temperatures cause a lower level, and lower temperatures, a higher level in the output characteristic. This is due primarily to the thermistor resistance, which is actually dependent on the temperature. The current passing through the thermistor is the main source of energy to heat the element. At low current values, however, the ambient temperature modifies the current effect slightly. The lamps are not appreciably affected by ambient temperature, because the resistance changes only at high temperatures.

The action of the variable elements of the circuit, as the input level varies, is evident from Figure 3, which shows the change of resistance for each path and the output characteristic. A logarithmic ordinate scale is used to include the total range of the thermistor resistance, which is very wide—from 5,000 ohms to 20 ohms. It will be noticed that the resistances approach a common value of about 500 ohms at the maximum input level. The thermistor makes the greatest change and consequently is responsible for the major portion of the limiter action. The resistance values indi-

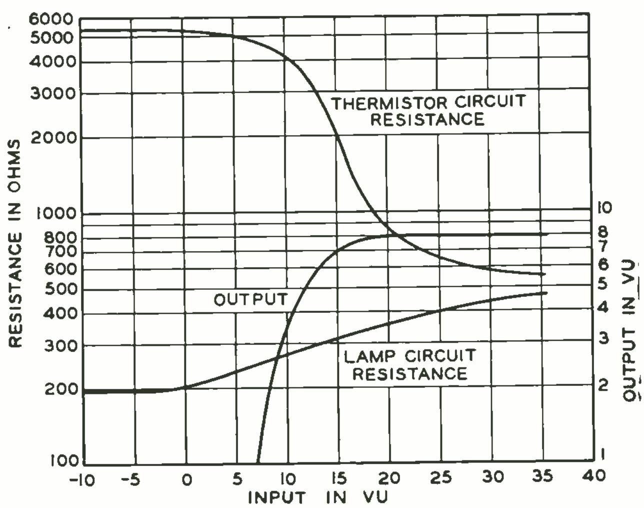


Fig. 3—Variation in resistance of the two branches of the limiter as the input varies, together with an output curve with the output in vu given at the right. Resistances approach a common value at maximum input level

cated are not those of the limiter and lamps themselves, but of the complete branches, which include also shunt and series resistances. These latter are selected so that the overall change in resistance will be such as to give the output desired.

An essential feature of this limiting device is that the loss it introduces in a circuit is

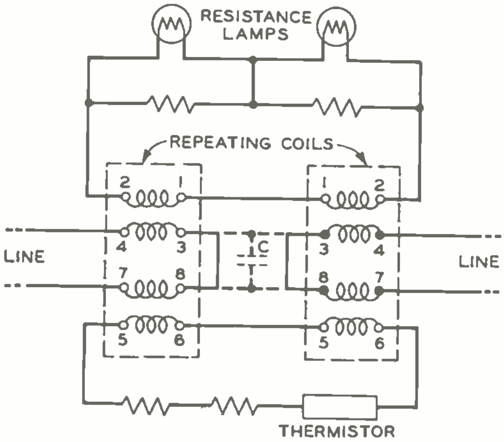


Fig. 4—Circuit of volume limiter drawn to show manner in which modifications may be made to pass direct-current or low-frequency signaling

not significantly affected by normal voice variations in the speech pattern, but follows the general level or average trend of speech volume. Such action is secured primarily by the delay characteristic built into the thermistor. As a result of this delay, the circuit does not immediately adjust its loss to changes in input level in the limiting range; the time for adjusting depends on the magnitude of change of the applied level. For a small increase in input level, the output first increases in proportion, but soon begins to drop, and approaches the limiting level. For the larger increases in input level, the rate of adjustment is faster, and the total time for adjustment is less. The rate of adjustment is also faster for high inputs, because the temperature of the thermistor element is higher then, and thus heat dissipation is faster. This adjustment characteristic is such that the device lags at the beginning of a change, then increases rapidly in rate of change, and finally slows down to gradually taper off to an equilibrium condition. When speech level is reduced, the loss of the circuit decreases at a somewhat slower rate because this is a cooling operation for the thermistor. The time for the device to adjust the output to within 1 db of steady condition varies on the average from 1 to 4 seconds—the longer adjustment time occurring for small changes in level. As the circuit is designed at the present time, it is not possible to attenuate high-level peaks of short duration.

A circuit that is too fast would follow the syllabic variations of the signal and would cause distortion, while one that is too slow could not follow sudden and extreme changes in level quickly enough to prevent overload or loss of signal in the output. Some compromise has been necessary. The circuit elements were selected and designed to provide as fast adjustment response as possible without introducing noticeable distortion from non-linear action in the high-input region of the limiting range.

The frequency response of the limiter is relatively flat, having less than 2 db variation from 200 to 8,000 cycles per second at low input levels. At higher input levels this characteristic is improved slightly because the coil losses are balanced out in the limiting range. The 1,000-cycle input and output impedances vary with input from 1,100 to 700 ohms. By using specially designed thermistor and lamps, it would be possible to have constant impedance, but, with the lamps available, the major operation is

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THE AUTHOR: JOHN A. WELLER received the B.S. degree in E.E. from the College of Engineering of the University of Michigan in 1940, and at once joined the Michigan Bell Telephone Company. After a period of general training in Detroit, he worked in various branches of the Plant Department of the Southern Division of the Michigan company, and later with the Toll Testing Department. In 1942 he transferred to the Laboratories for war work. Since then he has been with the Transmission Engineering Department, working on projects for the Armed Forces.

accomplished by the thermistors with the resulting impedance characteristic.

To show more readily certain modifications that may be made in the limiter, its circuit is drawn in slightly different form in Figure 4. Terminals 3 and 8 of each of the repeating coils are normally strapped together as indicated. If it is desired to pass d-c or low frequency signaling through the device, however, a number of alternative arrangements are possible. By removing the strap between 3 and 8 and by connecting the two No. 3 and the two No. 8 terminals together and bridging a condenser as indicated in dashed lines, the limiter will pass d-c and low frequency signals without limiting. This center tap circuit is also a convenient location for response-shaping networks, which are sometimes desirable. Other limiter circuits have since been designed which have slightly different network configurations and do not require transformers, but they all use thermistors as the basic operating element. The hybrid coil limiter operates on relatively high volumes, the design of which was facilitated by the development of non-linear elements of proper power sensitivity. More sensitive thermistors and lamps—that is, elements which change in resistance at lower power inputs—have permitted the design of volume limiters that find use in other audio circuits where constant volume is required but where the volume level is comparatively low. It is expected that the extension of volume limiter circuits will follow the development of non-linear elements of the thermistor and tungsten resistance lamp type.

International News Photo

This concentration of Spiral-4 and other field cable is representative of the enormous quantities of communications equipment which have poured across the English Channel since D-day. There are enough cables here to provide circuits for a good-sized town, if each of the Spiral-4 cables were equipped to handle its complement of three telephone and four telegraph circuits.

Excerpts From A. T. & T. Annual Report

COMMUNICATIONS requirements of the Nation continued in 1944 to match the forward march of America's war power and the amount of telephone service provided by the Bell System in the third full year of war stood at new high levels at each quarter of the year.

* * *

Bell Telephone Laboratories has continued to devote its efforts almost wholly to the needs of the fighting services. It now employs about 8,000 persons and has nearly 500 active military projects. About 55 per cent of its war work has been for the Army, about 35 per cent for the Navy, and about 10 per cent for the Office of Scientific Research and Development. Not only has the Laboratories developed war communications equipment, both wire and radio, but it has also made notable contributions in radar, submarine warfare, rocket design, electrical computers, electronic tube development and in other fields which cannot be divulged at present. . . . Devotion to the war effort has not left much opportunity for the Laboratories to work on post-war projects. However, it is possible now to do some forward looking in the light of fundamental developments that have been accelerated by the war. An outstanding instance is the progress made in utilizing very short radio waves. . . . While the communications possibilities of microwaves still await final proof and economic evaluation, they appear very promising and their use is being explored as a supplement or alternative to wires and cables for telephone and television transmission. For this purpose, the Bell System has obtained experimental licenses to test a radio relay system between New York and Boston.

* * *

Sales of the Western Electric Company, including its subsidiaries, largely exceeded in 1944 the sales of any previous year and amounted to $926,851,000, an increase of 30 per cent over 1943. Of these sales, $788,860,000 were to the United States Government and represented 85 per cent of the total, compared with $596,112,000, or 83 per cent in the previous year. At the close of the year, the backlog of unfilled Government orders was $747,000,000.

* * *

The intensive program for extending service to farm families, which was being carried on before the war, will be resumed as quickly as possible. Rural telephone service in this country is already more highly developed than in any other. Despite this, the telephone industry would like to see many more farms with telephones. To bring this about, the Bell System has developed important new facilities and methods. High-strength steel wire, permitting longer distances between poles, reduces the cost of extending lines into areas not previously covered. A method of sending telephone messages over rural electric power lines was under development by Bell Telephone Laboratories before the war and it is clear that a successful system can be produced.

* * *

The Bell System has pioneered in television and has made important contributions to this new art just as it has to sound broadcasting. It expects to play an active rôle in bringing television to the American public after the war by providing facilities over which television programs can be transmitted throughout the entire country. Standard telephone wires with suitable equipment are now used successfully for transmitting high-quality television pictures over short distances. Coaxial cables are also suitable for nation-wide television networks and the System is planning to construct several thousand miles of such cable. The projected radio relay system between New York and Boston will also be tested to determine the possibilities of this method for television transmission.

* * *

Present indications are that there will be a heavy increase in demand for overseas telephone service following the war, requiring new direct circuits as well as additional circuits over existing routes. . . .

Domestically, radio will probably be used in increasing amounts for bridging water barriers and reaching isolated communities. By using relay stations at intervals, microwave radio may also be employed for long distance transmission of telephone conversations, sound programs and television.

Other prospective new uses of radio by the Bell System include service to trucks, buses and other automotive vehicles, both in cities and on highways, to farmers and others in remote and sparsely settled areas and to moving trains and airplanes. Increased use of radio in furnishing ship service and to expedite restoration of wire service interrupted by storm or disaster is also likely.

* * *

During three years of war the Nation has needed, and has obtained, telephone communication far beyond any previous requirement. This is a telephone-run war from factory to foxhole and, as the struggle has increased in scale and intensity, the need for the vital services performed by the Bell System has increased accordingly. The System has met all war demands upon it and will continue to do so.

There is every likelihood that these demands will be even heavier in the future than they have been in the past. Fortunately, the System has the organization, experience and resources to perform whatever war service it may be called upon to render. Its physical plant is incomparable in size and quality. The men and women who provide the service are alert, competent and courteous. The management, which has risen from the ranks, is trained and experienced. Bell Telephone Laboratories and the Western Electric Company, research and manufacturing branches of the System, respectively, are able to design and produce great quantities of communication and electronic apparatus for war, just as, in normal times, they have steadily improved the telephone art and assured to the Bell Telephone Companies a continuous supply of standard equipment of the best quality.

The Bell System is able to meet all war demands promptly and to make an effective contribution to victory because it has had full freedom, under regulation, to develop its human and material resources in the public interest. Although earnings on investment in the war years have been low, on the average over a long period of time the System has been allowed to earn enough to pay good wages and a return on the money invested in the business sufficient to enable it to attract the new capital needed to expand and improve the service. The System's ability to render a more extensive and continuously improving service after the war will depend largely on regulatory authorities continuing to permit the telephone business to earn enough so that those with capital to invest will want to put it into this industry. The same factors that have operated to give this country in time of peace the best telephone service in the world have also created a communications system that has fully met the test of war. They will be no less important in the years ahead.

Today, and every day until the war is won, the people of American can rely on the Bell System to do everything in its power to speed the final victory.

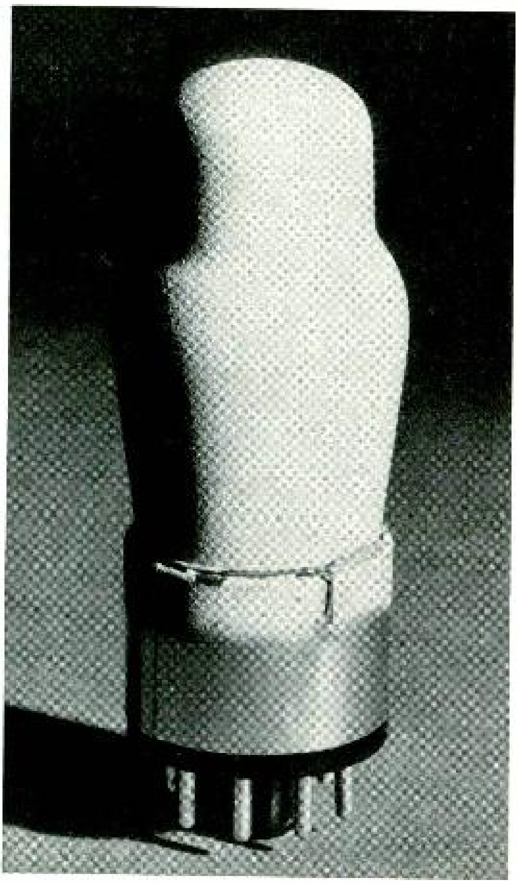
For the Board of Directors,

Walter S. Gifford, *President.*

American Physical Society

Harvey Fletcher, Director of Physical Research, has been elected President of the American Physical Society for the 1945 term.

One of the foremost authorities on speech and hearing, Dr. Fletcher directed the Laboratories' pioneering work in this field. His book "Speech and Hearing" is a classic, and he is author or co-author of numerous professional papers on various acoustical subjects. He is a member of the National Academy of Sciences and was the first president of the Acoustical Society of America.



A Pentode for the Battle Front in Three Days

ONE evening last December a messenger hurried into the Empire State Building and delivered a package to the local Office of Scientific Research and Development, meeting a deadline by less than five minutes. That night the package went to LaGuardia Field to be flown to Europe.

In this package were replicas of a foreign vacuum tube which had never before been made in this country. A cathode-type pentode, made by Siemens Halske, the original was different from any known American tube not only in electrical characteristics and in heater voltage but also in the dimensions of the bulb and base and in the disposition of the pins; moreover, as is common in Europe, the bulb was sprayed with metal for purposes of electrostatic shielding. Yet the Laboratories designed and the Western Electric Tube Shop made eight replicas of this tube in three days.

This tube is used in German-type repeaters in strategic telephone communications which the enemy abandoned during their retreat in France and Belgium. Except that nearly all the tubes had been removed, these repeaters were substantially intact and usable. So when an OSRD official returned from Europe, he brought a sample tube and an urgent request from one of the generals for 1,000 duplicates at once.

Late one afternoon the sample tube was brought to the Laboratories. The job appeared feasible. So working late that night, engineers roughed out the design of a tube which would duplicate the characteristics of the German tube and which could be made by combining a new grid with parts of our carrier-repeater tubes that were available in stock.

Other engineers obtained the nearest-size bulbs, redrilled the holes in available American bases, obtained proper sized pins, had grids made, and collected the necessary other parts. Next day the tube design was completed and the bases were ready. Two days later the assembled tubes started coming in from the Tube Shop for final processing and testing at the Laboratories. Electrically and mechanically the models substantially duplicated the German tube. The electrostatic shielding of the tube derives from a metal coating which is deposited by spraying molten particles of metal. The wire appearing on the outside connects the shield to the base and, internally, to one of the pins.

In the meantime, the Tube Shop started production of 1,000 tubes. The Westinghouse Electric and Manufacturing Company contributed by supplying the tube bases, which they made by utilizing an available mold quickly modified to meet the design requirements. Within three weeks the entire lot of pentodes had been delivered. Equipped with these tubes, the repeaters worked.

The following telegram, dated December 26, 1944, was received from Dr. Vannevar Bush, Director of the OSRD: "Your part in the spectacular job accomplished under our contract in providing the tube represents a record-breaking performance and merits the sincere praise and thanks of this organization and those who will use the equipment."

The engineering of this job was spearheaded by J. O. McNally, G. T. Ford, C. Depew, and W. Gronros. It would, however, have been impossible without the unstinted coöperation of many other individual specialists in electronics in the Western and at the Laboratories.

Red Cross War Fund

The cover of the RECORD this month depicts a Red Cross field worker giving coffee to our soldiers in the combat area—just one of the many services rendered in war areas and on the home front. March has been designated Red Cross month, when its 1945 War Fund of $200,000,000 will be raised.

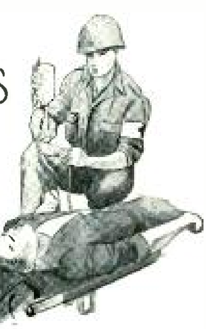
The Welfare Fund Committee of Bell Laboratories Club will send you a contribution card and ask for your subscription. If you wish, and so indicate on your pledge card, your contribution will be forwarded to the Red Cross chapter or branch in your home community so that you and your community will both receive credit for your gift. It is desirable that you contribute through the Laboratories so that our participation will compare favorably with other Bell System companies in the Metropolitan Area. You may also have your contribution deducted from your salary by the Payroll Department.

Military or Merchant Marine Leaves of Absence

The practices with respect to a member of the Laboratories upon reinstatement from a military or Merchant Marine leave of absence have recently been modified by action of the Board of Directors. The most important changes are:

1. *Reëmployment:* Effective December 8, 1944, the period within which an employee on military leave with the Armed Forces must make application for reëmployment was extended from 40 days after discharge to

Red Cross Blood Donors



C. A. Arnold
W. A. Arny
Jean Asbury
J. F. Ballard
A. Baltera
L. W. Bellevue
V. C. Belt
W. C. Bengraff
V. Bennett
T. O. Berthold
A. P. Besier
G. Bittrich, Jr.
Doris Boyajian
Ruth Boyajian
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H. W. Bryant
Marjorie Brydon
Ruth Brydon
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Lois Burford
R. Cooke
Anna Coughlan
R. H. Day
F. E. Dorlon
L. Dorrance
A. F. Duerr
Mary Ann Duffy
C. E. Ekman
Anna Falcone
Rose Faris
Valerie Feiss
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J. G. Fosdick
Herbert Gaestel
H. F. Gartner
Edith Gibbons
Harry Goedeke
C. B. Green
K. W. Hansen
J. B. Hays
M. Hoogstraat
W. F. Hoover
E. L. Housa
G. J. Huebner
C. J. Humphrey
J. H. Jezisek
Gloria Kirby
J. W. Kittner
G. W. Lees
A. F. Leyden
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R. M. Lux
D. J. Mahoney
Rose Mancuso
Jean Mater
J. G. Matthews
J. K. McKy
J. M. Meehan
K. W. Melick
A. Mendizza
M. Meyer
C. Miller
C. E. Mitchell
Mildred Molloy
J. S. Munies
Phyllis Nimmo
Lillian Norkin
M. Northup
J. J. Oestreicher
M. Olm
N. R. Pape
Elma Parker
Stella Patron
J. E. Phillips
R. P. L. Piltan
Theresa Potignano
J. F. Potter
J. R. Power
G. L. Prose
Molly Radtke
E. W. Rahn
P. Randolph
C. G. Reinschmidt
Mary Reynolds
M. Roland
D. J. Ryan
Harriet Rybka
H. P. Schoenfisch
Patricia Seymour
Dorothy Shaw
A. G. Shepherd
M. Sparks
L. Spiwak
A. L. Stillwell
W. S. Suydam
H. Sherwood Tiger
Ann Tingley
R. G. Treuting
Angela Vetrone
Ethel Walker
Anna Walsh
Anita Warwick
E. Watkinson
D. A. Weaver
E. G. White
H. A. White
R. W. Wickham
A. R. Winslow
E. Wintermantel
R. Wittkop
Eliz. Woodward
Sophie Wyka

90 days after being released from service or from hospitalization that has continued after discharge for a period of not more than one year.

2. *Service Credit:* Effective February 1, 1945, full service credit under the Benefit Plan will be allowed for all necessary absence in the Armed Forces or Merchant Marine provided the employee in such service is reinstated within the time specified.

3. *Pay Treatment Upon Reinstatement:* Effective February 1, 1945, an employee reinstated from military or Merchant Marine leave of absence within the required period will be restored to the payroll at the rate of pay he would have received had he been continuously on duty with the Laboratories during the period of absence in the job classification he was in at the time he left.

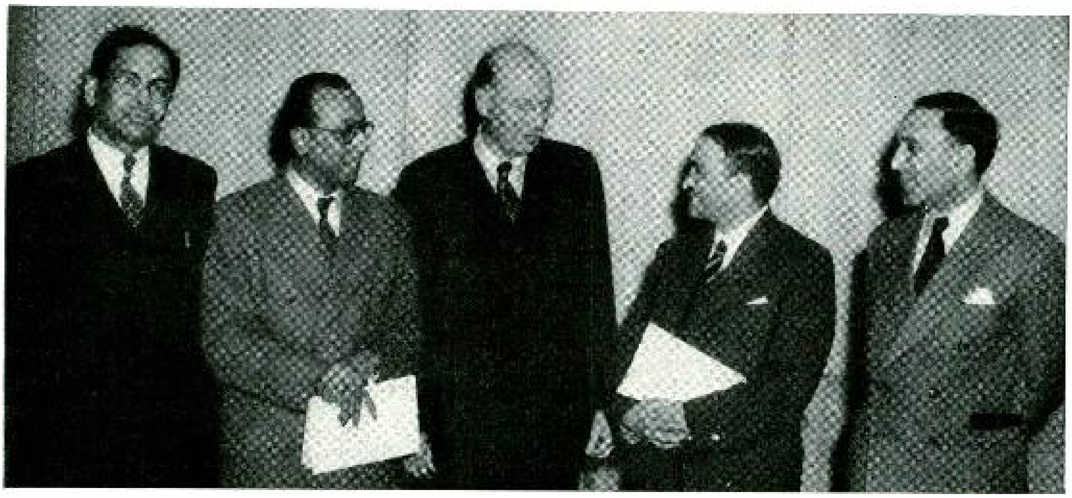
The provisions of paragraphs 2 and 3 will be applied retroactively to all who have been reinstated from such leaves in the Laboratories prior to February 1, 1945.

Scientists from India Visit Murray Hill

Research projects of Bell Telephone Laboratories were discussed by members of the staff with a delegation of scientists from India during their recent visit to the Laboratories' new buildings at Murray Hill. The guests were Dr. Nazir Ahmad, Director, Indian Central Cotton Committee; Sir Shanti Swarup Bhatnagar, Director, Scientific and Industrial Research Directorate, Government of India; Professor S. K. Mitra, Ghose Professor of Physics, Calcutta University, and Professor Meghand Saha, Palit Professor of Physics, Calcutta University. They were accompanied by Dr. P. C. Fine of the United States Office of Scientific Research and Development. Dr. Buckley, as host, outlined the purpose of the Laboratories' research and development program. Exhibits of apparatus and discussion accompanied the talks.

Investigations of quartz and synthetic piezo-electric crystals were described by S. O. Morgan. An automatic method of measuring the frequency response characteristics of loudspeakers was demonstrated by W. C. Jones. Problems relating to timber, the source of the millions of telephone poles and crossarms required to carry Bell System communications circuits were discussed by R. H. Colley. Characteristics and some of the applications of thermistors were described by J. A. Becker. F. J. Given explained how military demands for mica had been met by electrical tests which showed that much mica formerly rejected is usable.

This visit was made in connection with an inspection tour of laboratories and industrial establishments of the United States by a group of distinguished scientists and technologists from India.



Visit of Delegation of Scientists From India to Murray Hill
Left to right: Professor Meghand Saha, Professor S. K. Mitra, Dr. O. E. Buckley, Sir Shanti Swarup Bhatnagar, Dr. Nazir Ahmad

Dig Yourself a Share in Victory

Again Victory Gardeners are responding to Uncle Sam's roll call. The patriots who last year tended some 20,000,000 gardens have been asked to help increase the Nation's food supply by just as vigorous and successful a program as they carried on in 1943 and 1944.

Besides adding to the country's larder and releasing food shipping facilities for other war uses, gardeners have helped themselves and their families to better food, better health and recreation at no cost. In fact, even a medium-good Victory Garden will show a profit. If you really want some fun this year, keep a record of your produce. Charge yourself current market prices for those juicy, vitamin-chocked vegetables. Put the cash in a jar on the third kitchen shelf. Maybe you'll need *two* jars! In October take out what your adventure in farming has cost—and if you aren't entitled to blow in the rest on War Bonds, we don't know who is!

This is the month to start if you want to join the ranks of those who will harvest the most food, fun and fitness. To do this is as easy as *ABC*.

A—Ask for information. Seed catalogs making their colorful appearance on the scene are a cheerful reminder that now is the time to "study up" on the latest garden material. New vegetable varieties, fertilizers, spraying methods may have been developed by your state agricultural college; the information is yours for the asking. Your local seed store, your neighborhood Victory Garden headquarters, or a local garden club will have other garden material. Whether you're a novice or a veteran, you'll want the latest information available. Then . . .

B—Be sure to plan. Whether large or small, a garden needs a plan. After you've made a chart of the plot, you can engineer the crop planning so that you can get a second and possibly a third crop from some of your garden rows. Varying last year's garden plan and rotating crops to different sections will help insure good use of the soil. And there are some who say this fools the bugs so they have a hard time setting up housekeeping. After you've charted your garden, then . . .

C—Choose your seed and order it—but quick! Latest reports indicate that there'll be no surplus of seed this year, so the wise seed shopper will make his selection early. Of course you'll want to take into account which vegetables the family likes and what was successful in your garden last year, but don't fail to try some of the less well-known vegetables. Broccoli, bush lima beans, edible soy beans and kohlrabi may prove welcome additions to the beans, peas, corn, carrots and tomatoes usually appearing on gardeners' tables.

New Weapon Visits Old Scene

F. C. Willis Completes a Circuit

When F. C. Willis roared out over the Atlantic bound for England as a guest of his Majesty's Government, he didn't know where he was headed. But when he arrived, no one had to tell him where he was because it was the exact spot where he had been born and bred!

Then came the thrill of racing in a plane over hills and valleys of childhood memories to demonstrate a secret device which he had helped to develop more than 3,000 miles away and which now would help protect his native land.

The old familiar scene hadn't changed much except where a wheat field had sprouted airplane runways or meadows had mushroomed enormous dumps of military equipment. And people automatically accepted him as a native which proved that he hadn't changed much either, despite the best part of a lifetime spent abroad.

What struck him most were the many signs of a lively determination to secure a fair deal for all. For instance, through rationing the privileged classes are getting less but many people have more. And the poor are enjoying a real share of milk which, strange to say, is being produced in larger quantities than ever before. Remarkable to relate, this aroused social conscience is notably active in the younger members of the privileged classes who, in wartime, suffer most from its consequences.

Radio equipment developed by the Laboratories and manufactured by Western Electric is now being fitted to British planes. Installation was proceeding smoothly under the guidance of J. Glen Turner of the Western. However, questions came up that only one with an intimate knowledge of the design could answer, hence Mr. Willis' trip.

Stamp Club Contributes to Hospital Visitation Plan

Last year the Telephone Pioneers of America launched a coördinated program of visiting telephone people in military service who are patients in Government hospitals in the United States and Canada. In connection with this program the Laboratories Stamp Club is providing albums and stamps to the visiting committees of the seven Pioneer Chapters in the Metropolitan area. The Stamp Club is preparing twenty-five albums and packets of stamps.

Recently H. A. Richardson visited the Halloran General Hospital on Staten Island in behalf of the Stamp Club and, with the coöperation of the Red Cross Field Director, distributed twenty-five pounds of stamps to hospitalized servicemen.

Members of the Laboratories who may have accumulations of stamps (any amount) can help in this work by forwarding them to E. von der Linden in Section 7H. Quantities of current issues are quite acceptable. These stamps are distributed by the Red Cross to patients who may not be interested in making a collection, but who pass their time by cutting and pasting these stamps to form seasonable designs on greeting cards.

Bell System Network Facilities for FM Broadcasters

Bell System Headquarters, Feb. 2, 1945—An emphatic "yes" came from the American

Governing Committee of Bell Laboratories Stamp Club presents first allotments of albums and stamps for distribution to hospitalized servicemen. Left to right, C. D. Hanscom, E. von der Linden, W. S. R. Smith, Hattie Bodenstein and R. J. Heffner

Useful in bridging many a storm break are the hundred portable radio stations owned by Bell System companies. Pictured above is one end of a 27-mile radio link set up near McConnellsville, Ohio, to bring the town of Marietta back into the telephone network. A development of the Laboratories, this equipment has 50 watts transmitter power

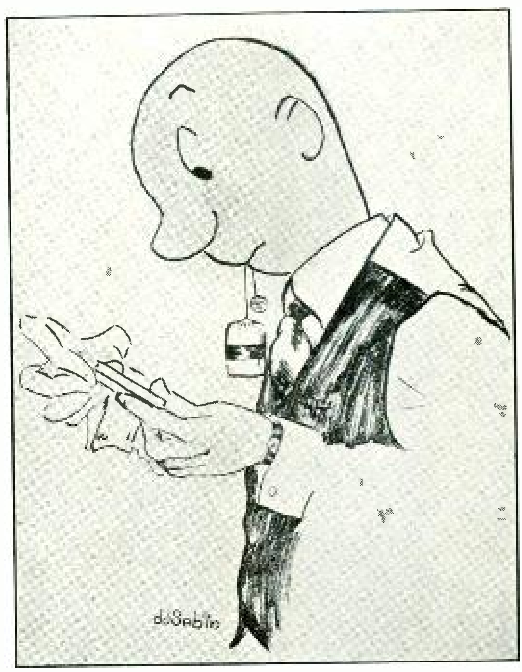
Telephone and Telegraph Company today in answer to the question of whether the Bell System can provide program transmission channels which will meet the present and future needs of FM broadcasters with respect to high fidelity and freedom from noise and distortion.

The statement is contained in a twelve-page brochure released today by the Company which points out that the Bell System already is furnishing studio-transmitter links to the majority of FM stations now in operation. These links transmit a frequency band of 15,000 cycles, as specified by the Federal Communications Commission. It was stated that present broad-band "carrier" telephone facilities can readily be adapted for 15,000-cycle program circuits by adding special terminal equipment.

For many years wide frequency bands have been transmitted over these carrier systems which make it possible to send many telephone and telegraph messages over a single pair of conductors. This network of wide-band channels, blanketing the entire country, already is capable of transmitting frequencies of 15,000 cycles or more for telephone purposes. There are thousands of miles of intermediary telephone routes which can be similarly equipped for wide-band transmission.

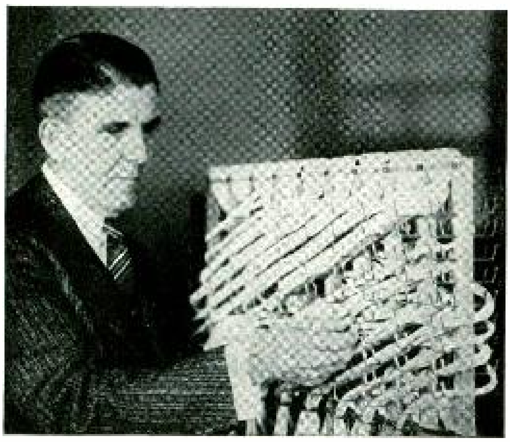
In view of the prospects for a big increase in the number of FM stations in the immediate post-war period, A T & T foresees the possibility that separate FM networks, with program sources of their own, may prove to be desirable. Whatever the broadcasting industry decides about grouping FM stations for separate networks and about the quality of channels desired, the Bell System will be able to furnish intercity circuits of the kind needed, including 15,000-cycle circuits if they are required.

If other means than wire circuits should prove better or more economical for FM program transmission, the Bell System will use them, citing as evidence of this the A T & T's projected microwave radio-relay system between New York and Boston. This trial installation is of a type which was under development by Bell Telephone Laboratories before the



war to test broad-band transmission by radio of various types of communications.

The announcement reveals that the Bell System now serves standard radio broadcasters with more than 130,000 miles of program transmission circuits.



F. H. Graham Retires

FRANK HEBER GRAHAM of the Equipment Development Department retired on January 31 with a Class A pension following a year's absence due to sickness. After Mr. Graham graduated from the University of Kentucky in 1908 with a B.M.E. degree, he immediately joined the power machinery division of the Western Electric Company at Hawthorne. A year later the Western Electric Company discontinued the manufacture of power machinery, and Mr. Graham moved to the telephone division, where, after two and a half years in the manufacturing, installation and merchandise groups, he joined the engineering organization. In 1917 he came to New York with several others to study the equipment phases of the panel dial system then being introduced into the metropolitan area and during this time he developed the equipment arrangements for key and call indicators. He has since been engaged in the design of central-office equipment for the panel and crossbar dial systems and for other systems, both in use and proposed. During the present war he had been concerned with the design of sheet metal casings and cabinets for housing equipment used by the Armed Forces. Mr. Graham contributed many ideas and inventions for telephone systems and some especially important ones in connection with dial cutovers such as the junctor group cutover arrangements described in the crossbar toll article on page 23 of the January issue of the RECORD.

Victory Depends on Good Communications

"Victory depends on good communications as well as guns and ammunition in the highly mobile warfare of today," declared Major General Harry Ingles, Chief, U. S. Army Signal Corps, recently, in stressing the urgent need for more communications equipment on all our fighting fronts.

Wire is the very lifeline of the soldier carrying on the offensive. Look at the following list of essential communications points in one Infantry Division of 15,000 men in one place and remember that wars are not won by standing still. This wire must move with the troops—often there is not time to disentangle it; the movement

U. S. Signal Corps Photo

Members of an infantry unit in France, using field telephones manufactured by the Western Electric Company, plot mortar fire from their advanced position must be speedy and it has to be left behind. The enemy makes it a point to disrupt and damage our communications lines and many miles of wire are lost in such action.

As soon as an Infantry Division command post is established, one or more wire circuits fan out as quickly as possible to:

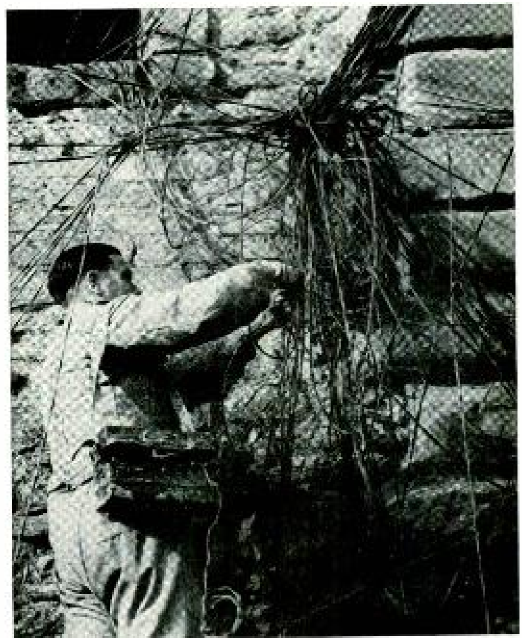
Each of the three Infantry Regiments, distance 5 to 20 miles each.
Division Artillery, distance 2 to 15 miles.
Division Observation Post, distance 5 to 20 miles.
Engineer Battalion, distance 5 to 20 miles.
Clearing Station, distance 5 to 20 miles.
Ammunition Control Station, distance 5 to 15 miles.
Division Reserve, distance 5 to 15 miles.
Rear Echelon, distance 5 to 40 miles.
Through Rear Echelon to Railhead, distance 5 to 20 miles.
Right Flank Division, distance 1½ to 4 miles.
Quartermaster Company.
Signal Company.
Ordnance Company.
Medical Battalion.
Traffic Control Stations.
Attached Tank Destroyer Battalion, distance 5 to 20 miles.
Attached Anti-Aircraft Battalion, distance 5 to 15 miles.
Other attached units.

The majority of these channels are trunk circuits terminating in switchboards from which there may be from four to forty extensions. An Infantry Division, including the usually attached units, has about 70 switchboards which serve more than 550 field telephones. A division's normal supply of wire exceeds 700 miles.

Beyond the above-listed lines, there are further ramifications. From Division Artillery, for instance, two lines must go to each of its four Field Division Artillery Battalions. In turn, each battalion must have wire communications with its three gun batteries, with forward observers, and with Infantry Regiments.

* * * * *

Signal Corps and other communications troops on the Western European front strung 330,000 miles of wire in the first five months after D-day and now are using approximately 2,200 miles of wire daily, according to a recent release from the War Department. As of late January, the communications network had utilized more than 200,000 tons of communications equipment and was serving 140 principal headquarters. One headquarters has 2,100 local telephones and handles 30,000 calls a day. Through principal switching centers more than 700 points can be reached. More than 100 headquarters have teletypewriter links.



Signal Corps Photo

Nerve Center—Over this maze of wire go vital messages that coördinate twenty units of an Infantry Division

Interim Research Body of Civilian and Military Scientists

Creation of a new board to develop weapons for any future conflict was announced recently by Secretary of War Henry L. Stimson, Secretary of the Navy James V. Forrestal and Dr. Frank B. Jewett, President of the National Academy of Sciences. The board, to be known as the Research Board for National Security, will serve in the interim between the expiration of the present Office of Scientific Research and Development, a wartime agency, and the establishment by Congress of an independent agency to carry on the work.

The board was set up by Dr. Jewett at the request of the Armed Services. Twenty civilian scientists, including Dr. Buckley, with an equal number from the Army and Navy, comprise its membership.

Measurement of Small Motions

By GORDON F. HULL, JR.
Physical Research

STUDIES of electrical contacts made between metals in telephone apparatus and between carbon granules in microphones require the measurement of extremely small motions. One way of doing this is to mount a contact pair between a fixed support and a cantilever bar so that the separation of the contact points depends on the deflection of the bar.* By applying a known amplitude of motion to the free end of the bar, the amplitude anywhere along it can be calculated, provided the bar's length is known and that it is rigidly clamped at the other end. The amplitude of the free end is relatively large and can usually be measured with a microscope. This device provides motions ranging from zero at the clamped end to a maximum at the free end. It is seldom, however, that a cantilever bar is clamped perfectly rigidly and the calculated and actual amplitudes at any point along it will in general not agree.

*Record, *September*, 1940, *p.* 130.

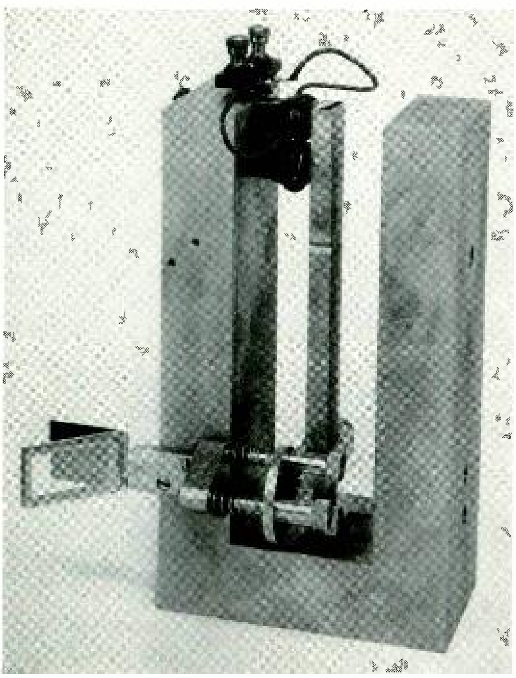


Fig. 1—Small motions, encountered in contact studies, can be measured with a cantilever bar which has been calibrated by an interferometer. The method is shown in Figure 2

A direct method of measuring precisely the deflection at any point along the length of the bar is to attach one of a pair of interferometer mirrors at the place in question, Figure 1, the other to the bar's fixed base and to measure the displacement of the interference fringes obtained when a beam of light is reflected from these two mirrors. The principle is illustrated in Figure 2 where M1 is a totally reflecting mirror attached to the bar, M2 a half-reflecting mirror fastened to the base of the bar and M3 is another half-reflecting mirror which permits observing the fringes at right angles to the direct beam of light. Monochromatic light is obtained by filtering, at F, the radiation from a mercury arc L. The light passes through the half-silvered mirrors M3 and M2 to M1 where it is reflected back through M2 and deflected to the observer's eye E by M3. At M2 some light is also reflected back to the eye and it is the two parts of the beam reflected from M2 and M1 that interfere and produce fringes.

Two methods of measurement were employed in these experiments. The first used continuous monochromatic light source which gave stationary interference fringes that had maximum visibility for particular amplitudes of oscillation. The second employed a stroboscope whose flashes of light were nearly synchronized with the oscillating bar, so that the fringes moved slowly back and forth in the field of view.

The cantilever bar and its base were cut from a solid block of steel to insure a rigid support. The bar was 15.0 cm. long and 1.6 x 0.6 cm. in cross section. An electromagnet which was connected to an oscillator vibrated the bar in its lowest mode, 275 cycles per second. Static displacements were also produced by passing direct current from a battery through this magnet.

The totally reflecting mirror M1 was cemented to a steel arm which was clamped to the bar at a point 2.54 cm. from its fixed end. The half-reflecting mirror M2 was attached to an adjustable mounting fastened to the base of the bar. The interferometer mirrors were aluminized.

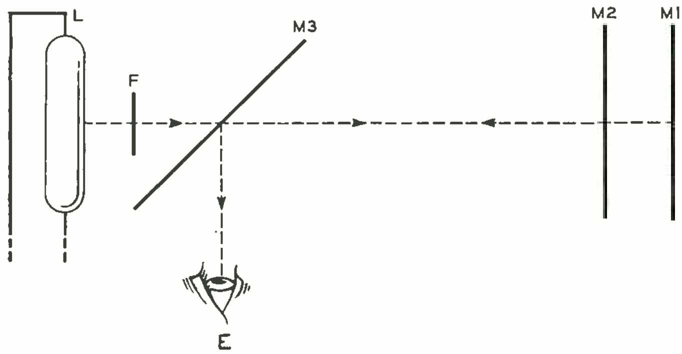


Fig. 2—The interferometer has a totally reflecting mirror M1 *attached to the cantilever bar, a half-reflecting mirror* M2 *fastened to the base of the instrument, and another half-reflecting mirror* M3 *to permit observing the interference fringes at right angles to the light from the source* L

By adjusting mirror M2, interference fringes were obtained as a series of nearly straight lines. When the cantilever bar vibrated, these fringes oscillated back and forth across the field of view in synchronism with the bar, but could only be seen when their amplitude was approximately $\lambda/4$ or a multiple of it. Then they became visible because the fringes were momentarily stationary at their position of maximum displacement, Figure 3, and were seen, by persistence of vision, when the fringes overlapped. Calculations show that the fringes are slightly displaced from the $\lambda/4$ position unless they are very narrow. A correction was applied for this difference.

In the measurements with continuous illumination, the interferometer was adjusted when the bar was at rest. Then the bar was vibrated with increasing amplitudes by gradually decreasing a series resistance in the oscillator and electromagnet circuit. This caused the fringes to disappear and then appear again. When they reappeared the amplitude of the bar at the point where the mirror was mounted was approximately $\lambda/4$; i.e., 1.37×10^{-5} cm. for the 5461A mercury line used. Exact calculations, allowing for the width of the fringes, show the value to be 1.67×10^{-5} cm. After the displacement of the top of the bar had been determined with a micrometer microscope, the amplitude of the bar was increased until the fringes disappeared and reappeared again. This was repeated and each time the fringes became visible the amplitude of the top of the bar was measured. By counting the number of times the fringes appeared and multiplying this by $\lambda/4$, corrected for fringe width, the displacement of the bar was obtained. For amplitudes greater than $10\lambda/4$ the fringes become too indistinct to observe because the vibrating mirror remained too short a time at the extremes of its motion.

Larger displacements, which involve the counting of more fringes, were measured by the stroboscopic method. The mercury light source was flashed intermittently on the vibrating interferometer mirror by applying some of the output from the oscillator to the grid of a thyratron tube in a trigger circuit.

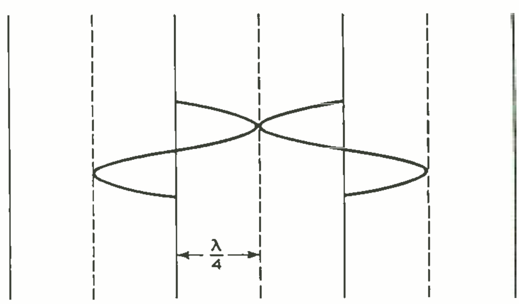


Fig. 3—When the cantilever bar vibrates, the fringes oscillate back and forth across the field of view but are visible only when two fringes overlap while they stop moving momentarily at their positions of maximum displacement, indicated by the dotted lines

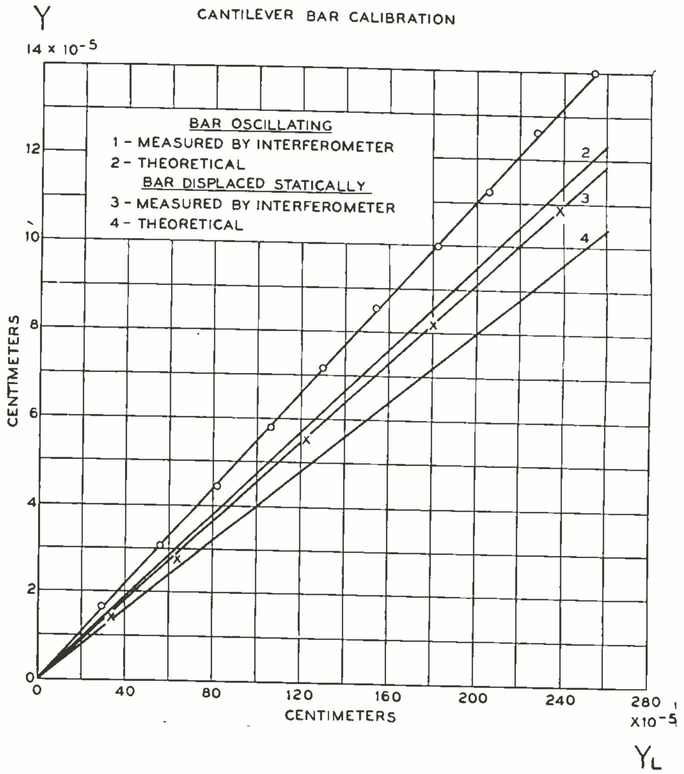


Fig. 4—Amplitudes of the bar where the interferometer was mounted compared with those of the end of the bar

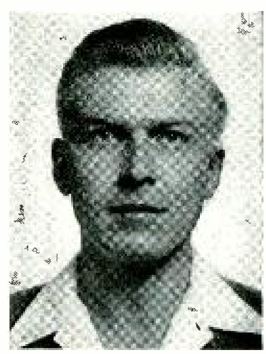
The fringes were made to move slowly back and forth across the field of view by adjusting the oscillator so that the flashes were not quite in synchronism with the bar. By counting the fringes as they passed the cross hairs in the field of view and multiplying that number by $\lambda/4$, the displacement of the bar was obtained. No correction for fringe width is required.

The results are shown in Figure 4, Curve 1, where the amplitude of the bar Y at a point 2.54 cm. from its fixed end, as measured by the interferometer, is plotted against the amplitude Y_L at the free end of the bar, as measured by the microscope. The experimental points do not depart from a straight line by more than two per cent. Curve 2 shows the corresponding theoretical values derived from Rayleigh's equations. The experimental curve differs from the theoretical one by fifteen per cent. This suggests that the cantilever bar was not attached rigidly. The results by the stroboscopic method also agreed with Curve 1 within the experimental error which was two per cent.

When the static measurements were made, by passing direct current through the electromagnet, the bar was held deflected by the amounts required to displace an integral number of fringes in the interferometer. The results are shown in Curve 3 together with the corresponding theoretical Curve 4. Again the experimental values differ by fifteen per cent from the theoretical ones. Since the difference between these curves is the same for both dynamic and static displacements of the bar, it must be due to elastic deformation of the bar's base.

From the experimental Curves 1 or 3, it is possible to calculate, by Rayleigh's equations, the length of the equivalent rigidly clamped cantilever bar. This calculation gives 15.2 cm. instead of the actual length 15.0 cm., which is an increase of 1.3 per cent. By using the equivalent length, the amplitude of motion at any point along the bar can be calculated correctly.

This interferometer method permits measuring amplitudes of the order of 10^{-5} cm. directly with high precision.



THE AUTHOR: GORDON F. HULL, JR., came to the Laboratories in the fall of 1937, the year in which he received his Ph.D. degree in Physics from Yale University. Previously he was graduated from Dartmouth College with the degrees of A.B. and A.M. and had studied in Germany. From 1937 to 1940 Dr. Hull worked on problems relating to contact noise in relays. Then his effort was diverted to war work which occupied his time until he was called, in 1944, to Dartmouth College, as Assistant Professor of Physics.

Impedance Bridge With a Billion-to-One Range

By H. T. WILHELM
Transmission Apparatus Engineering

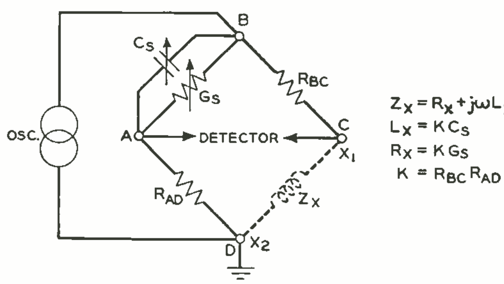
ELECTRONIC and communication apparatus is being manufactured for the Armed Services at an unprecedented rate. Every manufacturing facility has been strained to the utmost, and much new plant and equipment has had to be provided. One shortage that early appeared was in the bridges used for measuring the impedance of the wide variety of coils manufactured. Not only were there many more coils being produced than ever before, but the range in impedance values and in frequency was greater also. Heretofore, a number of different bridges had been used, each suitable for a limited range of impedance and frequency. It was realized, however, that greater flexibility and economy in production testing would result if it were possible to develop a single bridge having the combined range of several of the older bridges. Accordingly, the Laboratories designed the W-10135 wide-range audio-frequency bridge, and the W-10125 carrier-frequency bridge, and about 25 of these bridges have been constructed for the various manufacturing plants of the Western Electric Company.

The audio-frequency bridge, shown in Figure 1, will measure inductance from one microhenry to 1,000 henrys, and resistance from 0.001 ohm to 1 megohm—in both cases a ratio of a billion-to-one. How wide a range this is may perhaps be more readily grasped if it is expressed in terms of the more familiar measurement of lengths, when the range would extend from a thousandth of an inch to about 16 miles. In the new bridge, this extremely wide coverage is secured by providing six ranges, any one of which may be selected by operating a single range dial. Depending on the position of this dial, the normal reading of the bridge will be multiplied by 0.01, 0.1, 1.0, 10, 100, or 1,000. Although d-c bridges have been made with multiple ranges for many years, the application of so many ranges to an a-c bridge has not been simple. Many problems pertaining to the adjustment and compensation of phase angle have had to be solved, and the solution given practicable form in the new bridge.

The frequency range of this Maxwell type bridge* is from 20 to 10,000 cycles. The AB arm includes a conductance and a capacitance standard, each controlled by four dials. At the left of the upper row of dials of Figure 1 is the six-position range dial. In each position this dial selects resistors for the BC and AD arms that will result in the desired multiplying constant. Six resistors in the AD arm and three in the BC arm are used for this purpose. The inductance

*Record, *November*, 1940, *p.* 92.

Fig. 1—Maxwell type bridge used for measuring the resistance and inductance



component of the impedance under test is determined by the capacitance standard, and the four right-hand dials of the upper row, which control this standard, are marked directly in terms of inductance—ranging from steps of 0.1 henry at the left to 0.0001 henry at the right. The latter dial gives continuous control of the standard, and thus values may be estimated to one-tenth of a step, or 0.00001 henry.

Directly below the capacitance dials are the four conductance dials which measure the series resistance of the unknown. Since 1 micromho of conductance in the standard is equivalent to 1 ohm of series resistance, the dial designations are given directly in ohms instead of their actual micromho values. Steps on these dials run from 100 ohms to 0.1 ohm, the latter dial operating a 1-megohm potentiometer for continuous adjustment. The coil to be measured is connected to the two binding posts just below the lower left-hand dial. These posts are on 2¼-in. centers, and their central threaded studs are drilled so that standard impedances equipped with plugs on 2¼-in. centers may be plugged directly into them for checking the bridge. By drilling the studs instead of the screw caps of the binding post, a better connection is secured since the threaded contact is by-passed. Coaxial jacks are provided on the rear of the bridge for plugging in the oscillator and the detector. One of the unusual features of this bridge is that there is no zero position on the second dial from the right in both the upper and lower row. This is done to make the bridge direct reading. Since the capacitance and conduct-

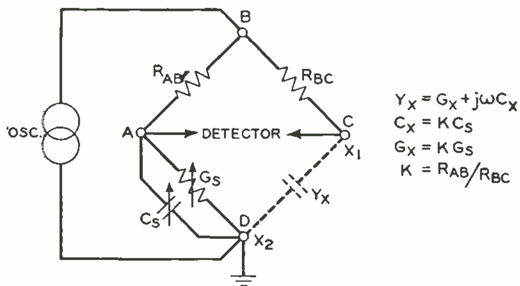
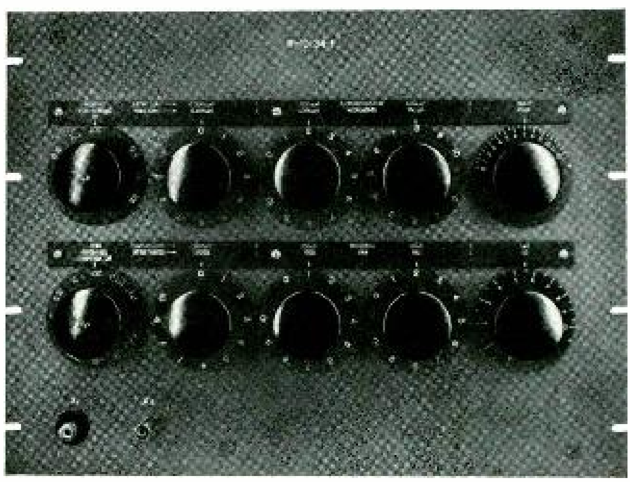


Fig. 2—The combined capacitance and inductance bridge for carrier frequencies



ance standards necessarily have some residual value with all dials set on a minimum, this residual has been increased to make it exactly equal to 0.001 μf, and 1 micromho, respectively. The zero positions of these dials are then marked 1 instead of 0, and all other positions are marked correspondingly high, and thus the dial markings run from 1 to 11 instead of from 0 to 10. With this provision the bridge is direct reading for all impedances with a resistance component greater than 0.01 ohm and an inductance component greater than 10 microhenrys. For measuring smaller values of impedance, or when it is desired to correct for the impedance of the test leads for any value of measured impedance, it is necessary to connect in a zero impedance compensator by operating the lower left-hand dial, and then to take two readings: one with the test leads connected to the unknown, and one with the test leads short-circuited. The correct net impedance of the unknown is then the difference of these two readings.

In measuring the inductance of ferromagnetic apparatus, it is usually found that the effective impedance depends upon the power level to which the apparatus is subjected. To permit measurements to be made under service conditions, either with or without superimposed direct current,* this resistance and inductance bridge has been designed for test potentials up to 300 volts and tests currents up to 2 amperes.

As shown in the photograph at the head

THE AUTHOR: H. T. WILHELM joined the electrical measurements group of the Laboratories in 1922. In 1924 he left to complete his studies at the Cooper Union Institute of Technology. After graduation in 1927 with a B.S. in Electrical Engineering, he resumed work with his former group. He has been engaged in the design of measurement apparatus including impedance bridges and standards, and in the development of test methods used by the Western Electric Company. In 1936 he received the E.E. degree from Cooper Union. More recently his work has been concerned with measurement problems arising in a number of war projects.

*RECORD, *December*, 1935, *p.* 131.

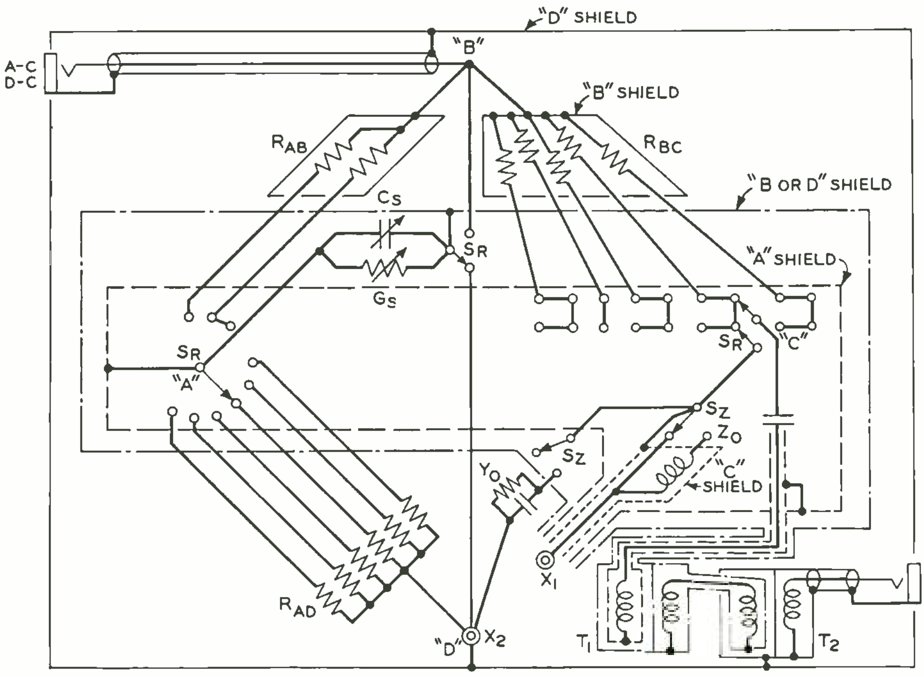


Fig. 3—Circuit of the W-10137 *audio-frequency combined bridge showing shielding*

of this article, the carrier-frequency bridge is almost identical in appearance with the audio-frequency bridge. It covers the frequency range from 200 to 150,000 cycles and differs from the audio-frequency bridge principally in the detector transformers, and in the capacitance and conductance standards. The carrier capacitance decade steps are one-tenth those of the audio bridge, and the carrier conductance decade steps are 10 times those of the audio bridge. It is designed for test potentials up to 100 volts and currents up to 0.2 ampere. A greater assortment of zero-impedance compensators is provided to permit zero balances to be made for all measurements.

The accuracy of measurement for both audio and carrier bridges is of the order of 0.25 per cent for the major component of the impedance, and a slightly wider limit of accuracy, depending on the Q, is attained for the minor component.

Without changing its size or general appearance, it was possible by the addition of a few circuit elements to adapt this bridge to measurements of capacitance as well as of inductance. Such a bridge was therefore developed and is shown in Figure 2. It, also, is available in both the audio-frequency and carrier-frequency range. Inductances are measured exactly as with the bridge described above, but for capacitance measurements, the circuit is changed to a ratio-arm comparison bridge.* Since for both types of measurements the standards are capacitance and conductance, the same two sets of four dials are used for all measurements, but the indicator plates are marked with two sets of units—the upper set being used for capacitance measurements and the lower for inductance. The change is accomplished by the range dial, which has one set of markings for use in inductance measurements and another for use in capacitance measurements. The zero-balance dial, at the lower left, also has two sets of markings, one switches an impedance in series with x_1x_2, and the other shunts a capacitance across them.

With such a wide range of impedance and frequency, these bridges require rather elaborate shielding. A circuit for the combined bridge indicating this shielding is shown in Figure 3. Switches marked s_R are controlled by the range dial, while those marked s_Z, by the zero-balance dial.

All of these bridges are mounted on a 14-in. x 19-in. panel and project 8 in. back of the panel. Figure 4 indicates graphically the size of the new bridges relative to typical previous ones. The new bridges use a cathode-ray null detector which is described in the next article.

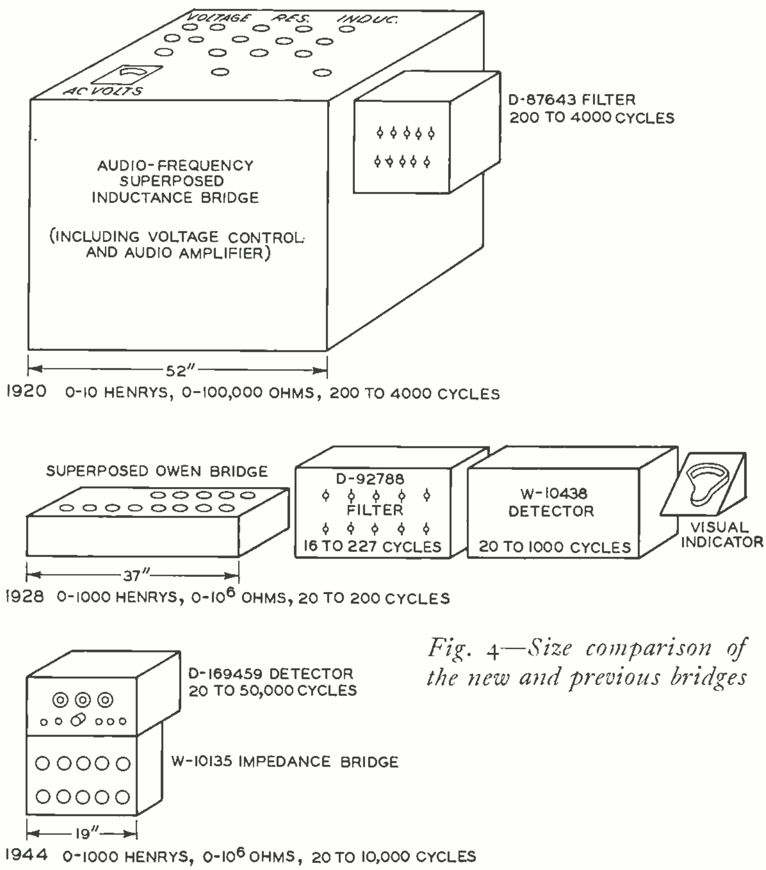


Fig. 4—Size comparison of the new and previous bridges

*Record, *June*, 1938, *p.* 341.

A Cathode-Ray Bridge Detector

By E. H. EVELAND
Transmission Measurements

IN DESIGNING the wide-range impedance bridge described in the preceding article, it was found that no detector was available that would operate over the wide range of frequency and give the high sensitivity needed, and still be suitable for use in manufacturing plants where size, ruggedness and easy manipulation are of prime importance. After a study of the various needs and requirements, it was decided to employ a cathode-ray detector, which has certain advantages where many similar units must be tested. It was decided also to incorporate an additional amplifier and detector tube connected to a meter jack to provide for situations where it might be desired to use a meter indication. To conform to the bridge design, two detectors were made: one for the audio range and one for the carrier range. These detectors are designated as D-169459 and D-170369, respectively.

With an a-c bridge, the signal delivered to the detector will in general contain a number of components in addition to the fundamental frequency of the oscillator. These may be harmonic frequencies of the oscillator, harmonics generated by the non-linear characteristics of the unknown, and noise picked up or generated by the system. The oscillator fundamental is balanced out by the bridge, but if a good null detection is to be obtained, provision must be made for eliminating or greatly decreasing the undesirable components. This has generally been accomplished by the use of filters, but with the wide frequency range required by the new detector, filters would be bulky and expensive. To avoid their use, therefore, feedback amplifiers are employed in the detector to reduce all components but the oscillator fundamental.

The circuit employed for the new detector is shown in block form in Figure 1, and in simplified schematic form in Figure 2. A buffer amplifier that receives the output from the bridge has sufficient feedback to prevent cross modulation of the harmonics that would generate the oscillator frequency as a component in its output. From this amplifier the signal passes through a three-stage amplifier with selective feedback that gives at least 40 db greater gain for the fundamental than for any other component

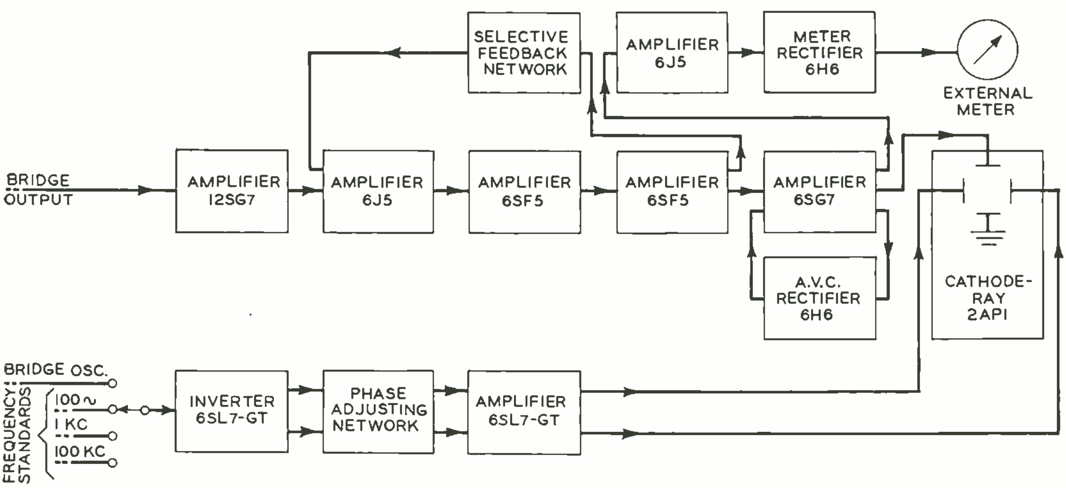


Fig. 1—Block diagram of the cathode-ray detector

present. From this feedback amplifier, the signal passes to a single-stage amplifier with automatic volume control, and thence to the vertical plates of the cathode-ray tube. A connection is also carried from the automatic volume controlled amplifier to another amplifier and a detector to supply an indicating meter when one is to be used instead of the cathode-ray tube.

To supply the horizontal plates of the cathode-ray tube, signal from the oscillator is first passed through an inverter to change the unbalanced output of the oscillator to the balanced input required by the cathode-ray tube. The output of the inverter is then carried through a phase-shifting network, and thence through an amplifier to the horizontal plates of the cathode-ray tube. The network permits the phase of the voltage applied to the horizontal plates to be shifted relative to that applied to the vertical plates so that an ellipse is obtained on the cathode-ray tube. The use of automatic volume control avoids the need of frequently adjusting the detector gain as the bridge is being balanced. It greatly expedites the work when not even the approximate value of the coil under test is known.

While the bridge is unbalanced, the image on the cathode-ray tube will be an ellipse with the shorter axis proportional to the resistance unbalance, and with the angle

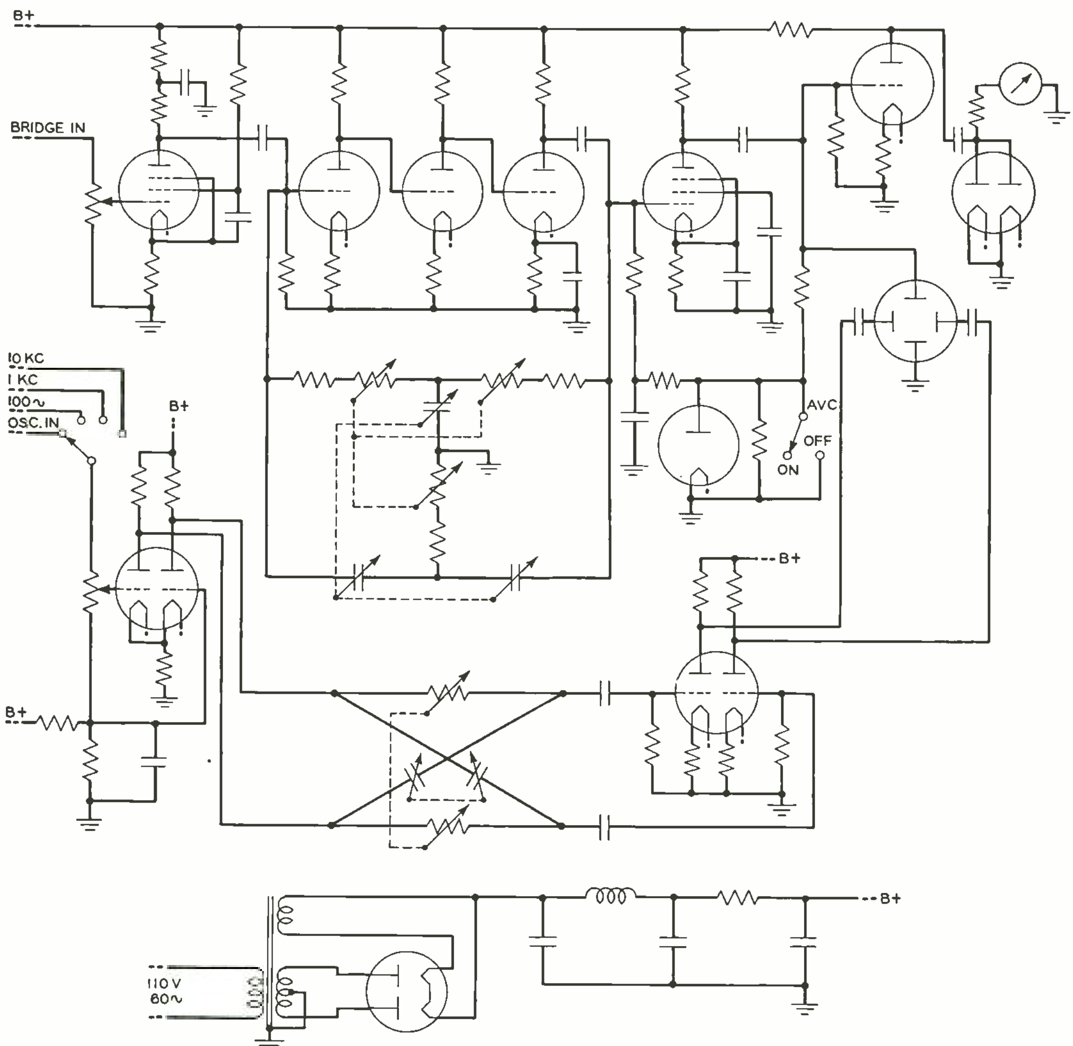


Fig. 2—Simplified circuit schematic of the detector

between the longer axis and the horizontal axis of the tube proportional to the inductance unbalance as indicated in Figure 3. The size of the angle made by the longer axis of the ellipse indicates the amount of the unbalance, while the direction of unbalance is indicated by this angle's being above or below the horizontal. At balance, the ellipse collapses to a horizontal line.

Both the feedback circuit of the three-stage amplifier and the phase-shifting network have to be adjusted for the frequency used. For this purpose, a nine-position dial is provided that adjusts condensers in both circuits for one of nine bands within the frequency range of the detector. Within each band, accurate tuning of the feedback circuit is accomplished by a tuning dial that adjusts resistances in the network. Similar adjustment of the phase-shifting network is made by a phase dial. These three dials occupy the center of the detector panel as shown in Figure 4. Directly below the tuning dial is the end of the cathode-ray tube on which the elliptical images are formed. On either side of the tube are the controls for adjusting the operation of the tube itself.

One of the purposes in designing the new detector was to permit rapid tests to be made of large numbers of similar coils at the manufacturing plant. These coils have nominal values of inductance and resistance that

THE AUTHOR: E. H. EVELAND received his E.E. degree from Polytechnic Institute of Brooklyn in 1930, and at once joined the New York Telephone Company as Outside Plant Engineer for the Long Island Area. Later he transferred to Commercial Sales and then to Dial Central Office Maintenance—both panel and crossbar. He has been on leave to the Laboratories since November, 1942, where he has worked on the development of oscillators and detectors used for war purposes.

they must meet within certain limits to be acceptable. To make it possible to determine quickly whether or not the coils meet their requirements, a thin cellulose acetate plate marked with limiting lines is placed over the end of the cathode-ray tube. When such an overlay is used, the bridge dials are set to the nominal values of inductance and resistance of the coils. Coils are then connected to the bridge, one after another, and if the ellipses appearing on the tube lie within the acceptance values as indicated, the coils are accepted. Ordinarily, the resistance values are well within the required limits and the coils may be judged by their inductance alone. Should it be desired to determine precisely the variation of the resistance component, the phase control dial may be adjusted so that resistance variations are indicated by angle in the same manner as the inductance variations normally are.

To extend the usefulness of the detector, it is arranged so that the output of a frequency standard, instead of the oscillator, may be supplied to the horizontal plates. The switch near the upper right corner is provided for this purpose. The bridge oscillator may then be accurately adjusted to the de-

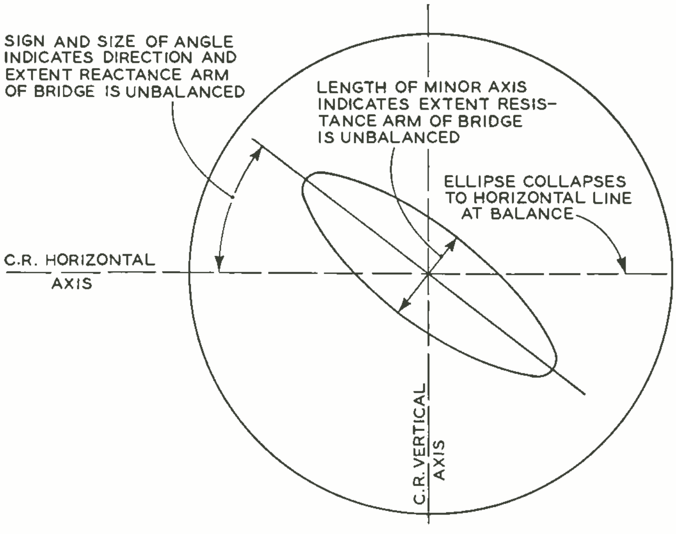


Fig. 3—The amount and direction of unbalance is indicated by the orientation and shape of the ellipse on the cathode-ray tube

sired test frequency by Lissajous figures* on the cathode-ray tube.

As evident in Figure 4, the mounting plate of the detector is the same width as the bridge. Its height is 10½ inches and it projects 13 inches to the rear of the panel. The two detectors available are similar in appearance and circuit arrangement, but one covers the frequency range from 20 to 20,000 cycles and the other, from 200 to 200,000 cycles. Twenty of these bridge-detector units are now in use testing coils in the various manufacturing plants of the Western Electric Company.

*Record, *April*, 1926, *p.* 57.

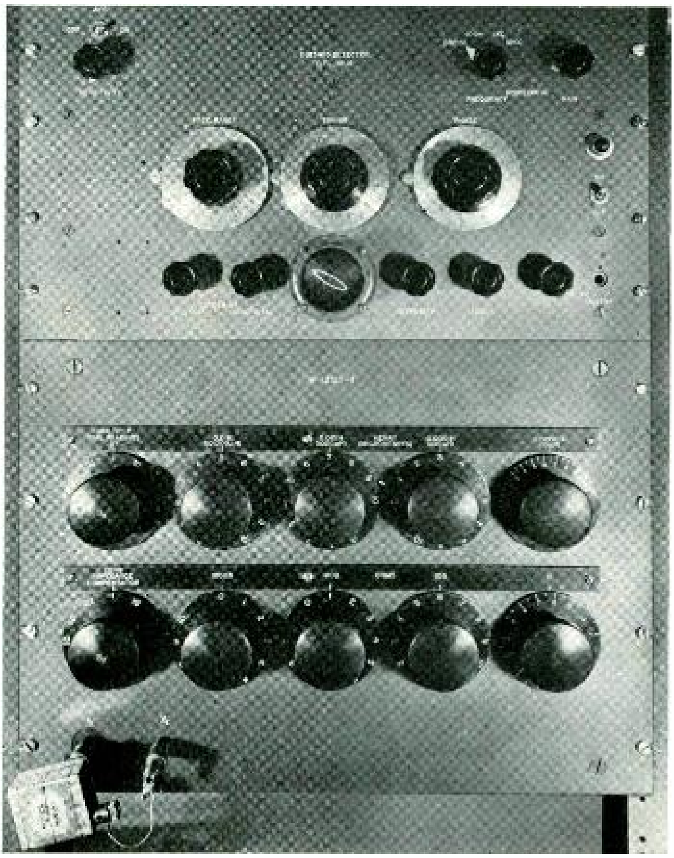


Fig. 4—The detector is designed to mount directly above the bridge at a height that will locate the cathode-ray tube on the level of the eye