BELL LABORATORIES RECORD

INDEX

Volume 33
January 1955 to December 1955

Bell Laboratories Record

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LIST OF ISSUES IN VOLUME 33

The ancient belief that Nature abhors a vacuum was discredited by Torricelli's famous experiments, but Nature is still reluctant to yield the last few molecules from an enclosed volume. Nevertheless, the modern vacuum pumps described in this article can produce such nearly perfect vacua that only one molecule in 100,000,000,000,000 remains. The achievement and measurement of such ultra-high vacua have both contributed to the life and efficiency of electron tubes and provided research scientists with a more flexible range of accurately controlled experimental conditions.

Ultra-High Vacua

J. A. BECKER *Physical Research*

Electron tubes are today being used in very large numbers by the Bell System and by the communications industry in general. Since imperfect vacua have harmful effects on efficiency and tube life, it is desirable in nearly all cases to reduce the pressure in these tubes to as low a value as it is possible to attain economically. During the last decade, research work at Bell Telephone Laboratories and elsewhere has made it possible to produce and to measure lower pressures than ever before, and to determine the processes responsible for the gases that cannot be removed from an enclosure.

Of primary practical interest, of course, is the effect of this research on the production of better electron tubes. Beyond this, however, scientists in many areas of chemical, physical, and electronics research have found controlled and measurable vacua an invaluable condition for a variety of experiments. To mention just one example, the Research Department at the Laboratories is currently investigating electron emission from metal surfaces by the action of slowly moving positive ions — a process of special significance since it is responsible for the functioning of the glow-discharge gas tubes that are now finding ever-increasing use in electronic switching circuits. For these studies, an atomically clean metal surface is necessary, which requires the maintenance of the best vacuum that is obtainable.

Above — C. D. Hartman, left, points out to the author an improvement in nozzle design in a mercury diffusion pump.

In the early days of the vacuum art, pressures were measured by noting the difference in level of two columns of a liquid on the two sides of a U-shaped tube called a manometer. In time, liquid mercury (Hg) became the standard of comparison, and hence it became customary to express pressures in millimeters of mercury. This unit of pressure is still the most widely used today, even though the method of measuring low pressures no longer employs columns of a liquid.

Before 1950, pressure of 10^{-7} and 10^{-8}mm of Hg were considered high vacua. Pressures lower than these were very likely obtained, but it was impossible to measure them because the most sensitive gauges were no longer reliable at such low pressures. Today, however, it is possible to produce and to measure pressures between 10^{-9} and 10^{-11}mm of Hg. Such pressures are called ultra-high vacua. Furthermore, by a technique that will be described later, it is possible to estimate pressures as low as 10^{-12}mm. And finally, since for many experiments we are interested only in the chemically active gases in the space being evacuated, we have by another technique estimated partial pressures of these gases down to 10^{-14}mm of Hg.

It will perhaps be of some interest to review the various developments that have permitted the achievement of these low pressures. First, however, we must summarize briefly the operation of the basic pumping apparatus. An enclosed volume can be reduced from atmospheric pressure (760 mm of Hg) to about 10^{-3} or 10^{-4}mm of Hg by means of mechanical pumps. One type incorporates an eccentric cam revolving inside the body of the pump, with a movable vane separating the input and output volumes. This type is illustrated in the lower left of Figure 1, where it is called a "fore pump" – the terminology commonly used in vacuum work. With such mechanical pumps alone, the pressure cannot be reduced indefinitely because of leakage around the various parts of the apparatus. To reduce pressures below 10^{-4}mm of Hg by this method is a slow and expensive process.

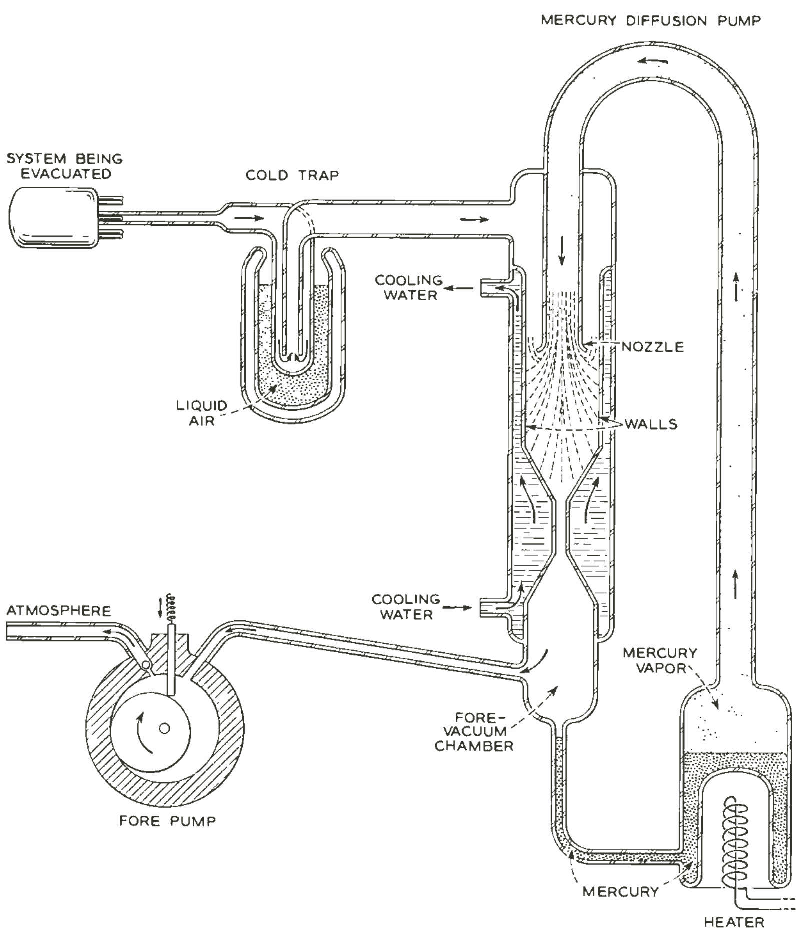

Fig. 1 — Simplified drawing of a mercury diffusion pump (right) and its associated equipment used for producing high vacua.

Much lower pressures can be obtained with a mercury diffusion pump, a device invented about 1916. A schematic cross section of such a pump is shown at the right in Figure 1. Mercury vapor is generated in the boiler and is directed through a nozzle, where the action is similar to the familiar aspirator or spray gun. The mercury vapor is ideally directed uniformly downward, and in passage, the mercury vapor molecules collide with gas molecules coming from the system to be evacuated. The gas molecules are thus driven into the "fore-vacuum chamber," and are expelled into the atmosphere by the fore pump. Most of the mercury vapor molecules condense on the water-cooled side walls of the pump and are returned to the boiler, but because the nozzle action is not perfect, a few molecules diffuse backward toward the system being evacuated. These are prevented from reaching the system by being condensed in the cold trap (upper part of the illustration). The backward diffusing mercury vapor molecules strike some of the gas molecules and knock them back into the system. When as many gas molecules diffuse through the mercury from the fore-vacuum as are evacuated, pumping action ceases. With this combination of cold trap, mercury diffusion pump, and fore pump, pressures well below 10^{-8}mm of Hg can be achieved.

The production of pressures several orders of magnitude below 10^{-8}mm of Hg is partly a story of new and improved pumping techniques, but very importantly it is also a story of the measurement of very low pressures. The most sensitive mercury-type manometer, the McLeod gauge, can only measure vacua down to about 10^{-6} mm, and before improved measuring devices were invented, lower pressures could not be verified.

Our former president, O. E. Buckley, introduced such an improvement in 1916. He noticed that in a triode in which the "grid" was operated at a positive potential, and the "plate" was operated at a negative potential, the positive ion current to the plate was directly proportional to the pressure readings on a McLeod gauge. When such a tube was once calibrated, it served as a convenient and useful means of measuring pressures. Furthermore, by

Fig. 2 — R. G. Brandes attaching the ion-collector lead to ion gauge, used here as pump for high-vacuum equipment.

extrapolating the calibration curve to lower pressures, it was possible to measure pressures below 10^{-6}mm of Hg. Between 1916 and 1950, the Buckley gauge, or modifications of it, was the most commonly used manometer.

As the vacuum art improved, however, people began to note that "pressures" below 10^{-8} were never found. It was suggested that in the Buckley gauge there were other currents besides the true ion current, and that these "spurious" currents were independent of pressure. They therefore increased the total apparent ion current and thus falsely recorded a pressure higher than the actual value. Specifically, it was thought that soft x-rays were produced and that these in striking the plate produced an electron current.

About 1950, this hypothesis was independently confirmed by J. J. Lander of Bell Laboratories, by R. T. Bayard and D. Alpert at Westinghouse, and by G. H. Metson in England. Since then, work at the Laboratories has shown that there are two other spurious "ion" currents, namely those caused by the emission of photoelectrons, and an electron current that reaches the "plate" even though it has a negative potential with respect to the cathode.

After these spurious currents were diagnosed, a way of minimizing them was soon found. The remedy proposed by Bayard and Alpert was to reduce the area of the "plate" by making it in the form of a fine wire. As illustrated in Figures 2 and 3, this wire, termed the "ion collector," is surrounded by a cylindrical grid or cage, which collects the electrons. The cathode filament is located outside the cage. In a sense, Bayard and Alpert turned the Buckley gauge inside out. This made it possible to measure true pressures down to about 10^{-11}mm of Hg, in the region of ultra-high vacua.

As pressures drop to such low values, we become increasingly interested in the small amount of gas still remaining in the system. To find ways of reducing the amount of this residual gas, it is of course useful and even necessary to know its sources. In some cases it is then possible to decrease the influx of these gases and in this manner produce the lower pressures that are desired.

One source of gas entering the system has already been mentioned, namely the gas molecules knocked back into the system by the backward diffusing mercury vapor molecules. This can be decreased by improved pump construction, and several advances in nozzle design and in other features have been made at the Laboratories. There are, however, four other important sources of gas that must be considered. The first is the release of gas from the cold trap — a factor not often fully appreciated. Mercury condenses in the trap, and, like most clean metal surfaces, quickly adsorbs gases. As more and more mercury condenses, the concentration of adsorbed gas can become quite high.

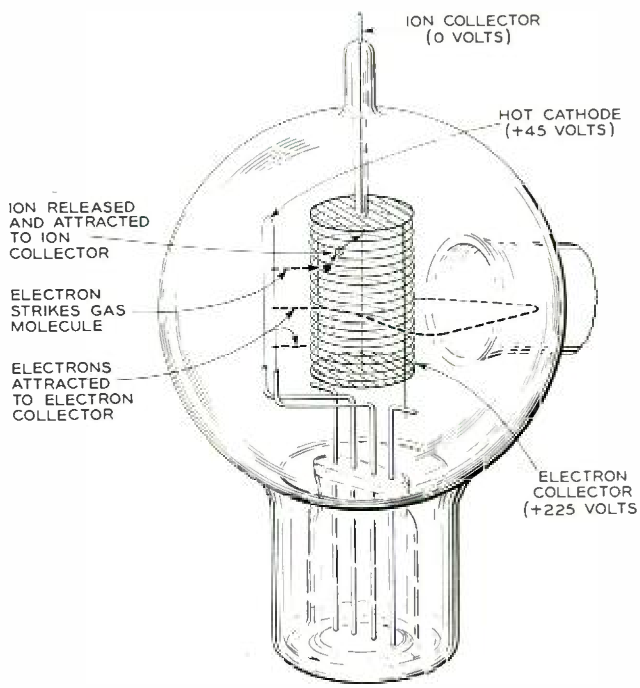

Fig. 3 — Ion gauge used both for the measurement of ultra-high vacua and for pumping.

Then, as the surrounding liquid air evaporates and the level of the liquid drops, large amounts of gas can return to the system. Our experience has shown that the liquid-air level must be kept low during the initial stages of pumping, and throughout must be carefully controlled. The cold trap then acts as a pump — adsorbing gas but not releasing it. It has been found, in fact, that in the later stages of pumping by the arrangement that is illustrated in Figure 1, almost all the pumping is due to the action of the cold trap.

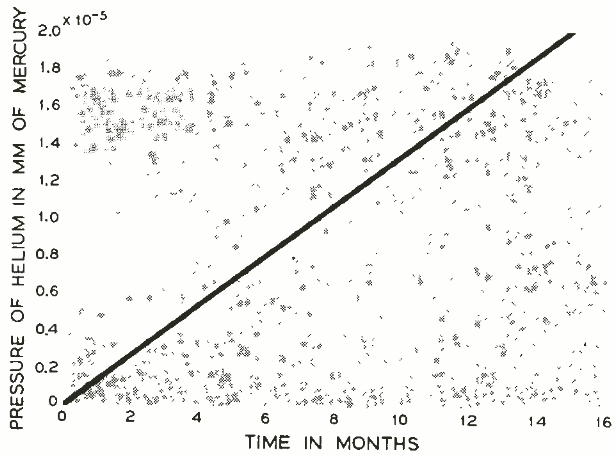

Fig. 4 — Graph showing constant rise of pressure in idle tubes because of diffusion of gas through glass walls.

Secondly, gases dissolved in the glass and metal parts of the system may diffuse into the volume and increase the pressure to an intolerable extent. And third, gases adsorbed on the surfaces of the parts can be released, which will also contribute to an increased pressure. The Laboratories has made considerable additions to the knowledge of the solubility of gases in metals and glass, and also to the knowledge of surface adsorption and desorption phenomena. As a result, careful processes have been worked out for the baking of glass tubes and for the "glowing" of metal parts. These processes reduce the amounts of dissolved and adsorbed gases, so that the later pumping operations result in lower pressures than could otherwise be obtained.

The fourth source of residual gases comes as a surprise to many people, for it is often assumed that idle electron tubes "on the shelf" maintain their original characteristics. Actually, work at the Laboratories by J. P. Molnar, R. G. Brandes, and the author has shown that the pressures in such tubes rise because gases diffuse through the glass from the atmosphere. As shown by the graph, Figure 4, the pressure in each of about thirty well pumped, sealed-off tubes rose about 2×10^{-9}mm of Hg for each hour of shelf life, and this rate was constant for at least a year. This increased pressure, of course, could have harmful effects when the tube is placed in service. It has been found that different gases vary in diffusion rates through the glass, with helium entering the tube most easily at room temperature. Additional information has been gathered on the diffusion rates at higher temperatures, with the result that we can improve our techniques to provide maximum selectivity against this source of gas during the periods when the tube is baked.

These facts are seen to have an important but indirect influence on ultra-high vacua, inasmuch as they do not contribute to the actual removal of gases. There remain to be discussed two sorts of pumping actions which are very necessary to the production of the lowest possible pressures.

It is commonly noticed in most electron tubes that a metal film has been deposited on the inside surfaces of the glass walls. Often a small filament of a metal with appropriate lead-in wires is assembled in the tube, so that when the filament is heated, the metal evaporates and the metal film is deposited. Such films, or "getters," are very efficient pumps. The rate at which molecules will be removed by the surface is the product of the rate at which they strike and the probability that they will stick. Considerable attention has therefore been paid to this phenomenon. For example, it has recently been found at these Laboratories, that an atomically clean tungsten surface at room temperature has a sticking probability for nitrogen of 0.5 to 0.2, depending upon which crystallographic planes are exposed to the gas. We have also studied tantalum and molybdenum and have found them to be very effective as getters in sealed-off tubes.

These studies of the gettering phenomena have led to the estimation of pressures below 10^{-11}mm of Hg, as mentioned at the beginning of this article. An atomically clean tungsten surface will adsorb gases at a rate determined by the pressure. At a pressure of 10^{-6}mm, a single layer of nitrogen atoms is adsorbed on the surface in one second; lower pressures will require longer periods of time for this monolayer to form. At a pressure of 10^{-12}, for instance, it should take 10^{6} seconds or ten days. At this pressure there would still be 3×10^{7} molecules in one liter; this should be compared with 2.3×10^{22} molecules at atmospheric pressure.

In our Laboratories we have also observed the effect of tantalum-film getters on the electron-emission currents in sealed-off tubes. In one such tube, the film kept the tungsten elements so "clean" that the emission current was maintained at a steady value for several months. From this it can be deduced that the pressure of chemically active gases in the tube was about 10^{-14}mm of Hg.

Evaporated films, however, do not pump rare gases like helium or argon. To remove these from the system, we turn again to the ion gauge which, besides its use as a manometer, is also important as a pump. The ion gauge ionizes many of the rare gas molecules and drives them into the glass or into an evaporated film that may also be present. Here they become so firmly imbedded that they can be removed only at temperatures above about 200 degrees C. About 10^{14} ions can be imbedded per square centimeter of surface. While the pump speed of an ion gauge is much smaller than that of a mercury diffusion pump and very much smaller than that of evaporated films, it has two distinct advantages besides its ability to pump rare gases: there is no low pressure limit to its pumping action, and it can be used in the tube being pumped.

This discussion of the many factors affecting vacua has not in all cases followed the actual experimental order of operations. The picture can therefore be brought into perspective by concluding with a brief summary of the step-by-step procedure often followed in laboratory work. To obtain ultra-high vacua it is customary first to bake and cool the tube and to "glow" the metal parts. The baking and glowing cycle is then repeated two or three times, because the glowing process releases gases which adsorb onto the glass, and because some of these gases are in turn released again when the tube is baked. With careful control of these steps, a well designed mercury diffusion pump can then reduce the pressure to 10^{-9} or 10^{-10}mm of Hg. To obtain still lower pressures, the tube is then sealed off and a tantalum or molybdenum film is deposited over a considerable portion of the glass walls. This reduces the pressure of the chemically active gases. To remove rare gases, an attached ion gauge is then operated over a period of several hours. These procedures reduce the total pressure to such a low value that it cannot be measured.

A closer approach to the perfect vacuum thus awaits still better measuring instruments, and with these will come better pumps. By using the results of continuing research and analysis, it will be possible to produce for the communications industry electron tubes with longer lives and more uniform and constant characteristics.

THE AUTHOR:

Joseph A. Becker received his B.A. degree in 1918 and his Ph.D. degree in 1922 from Cornell University. Following two years as a National Research Fellow at California Institute of Technology, Dr. Becker joined the Laboratories in 1924. His work has been concerned with thermionic emission and adsorption phenomena. This work led into the field of semiconductors where he made important contributions to the understanding of copper oxide and silicon carbide varistors. Dr. Becker also contributed to the development of thermistors and thermistor bolometers, and took part in the early work on transistors. He is now employing the field emission microscope in his research on surface phenomena in high vacuum. Dr. Becker has just completed a stay of three months as visiting professor at Notre Dame University during which time he conducted a seminar on surface phenomena. In 1942, Dr. Becker was awarded the Mendel Medal by Villanova College. For eleven years he was a consultant to the National Research Council and the O.S.R.D. He is a Fellow of the American Physical Society, the A.A.A.S., and the A.I.E.E., and a member of Sigma Xi.

The Condenser Microphone as an Acoustic Standard

M. S. HAWLEY *Station Apparatus Development*

Western Electric condenser microphones have been used for many years as acoustic standards in the Bell System and elsewhere. The current improved model, the 640AA, continues to serve in this capacity by acting as a precisely calibrated "ear" listening to and measuring both real speech and speech as reproduced by telephone instruments.

The accurate determination of sound pressure is required for precise acoustic studies and for the development and production of telephone instruments. Such measurements are based on standard microphones, which in turn are calibrated by a standardized technique. The first microphone permitting accurate measurements of sound was the condenser microphone developed in 1916 by E. C. Wente of Bell Laboratories.* Today the condenser microphone continues to be the preferred sound standard, and the Western Electric 640AA is the condenser microphone used by the Bell System. This microphone also finds use as a standard outside the Bell System in many laboratories, industries, and colleges in this country and abroad.

There are several reasons for using this type of microphone as a standard. It has a uniform and wide range response-frequency characteristic, it can be made small, and it is stable with atmospheric conditions and time. Also, the diaphragm has a high acoustic impedance — that is, a high resistance to motion caused by sound pressure. It is probably evident why these properties are needed in a standard, except perhaps for the high acoustic impedance. For measurements of sound in small chambers, a low impedance or yielding diaphragm effectively adds volume to the chamber and thereby reduces the sound pressure. Because such a reduction in sound pressure has a complex relationship to the diaphragm impedance, a microphone with a

Above — In Murray Hill Laboratory "dead room," R. T. Ferri spaces two Western Electric 640AA microphones as part of a reciprocity calibration.

* RECORD, *July*, 1943, *page* 394.

nearly rigid diaphragm reduces the number of computations required and increases the accuracy of the measurements.

For its operation, the condenser microphone depends upon the variation of its capacitance by the sound pressure to which it is exposed. The closely spaced diaphragm and stationary electrode form the two capacitor plates. The sound pressure produces a diaphragm deflection and thereby a change in the capacitance. In some applications, this capacitance forms an electrical impedance element in a resonant circuit, and the change in capacitance produces a shift in the resonant frequency. However, in its most common application, the microphone has a constant polarizing charge applied to its plates so that the change in separation produces a proportional change in the potential. Thus, the microphone generates a voltage which is a replica of the sound pressure striking its diaphragm.

The Western Electric 640AA microphone is shown in Figure 1. The grid at the left screws into the cavity in front of the diaphragm and acts as a protective barrier. Figure 2 is a simplified sectional view with labels identifying the parts. The diaphragm is made of 0.0003 inch stainless steel and is highly stretched to be resonant at a frequency of 8,500 cycles per second. The separation between the diaphragm and the stationary electrode or back plate is about 0.001 inch. The viscosity of the film of air between the diaphragm and back plate dampens the motion of the diaphragm in the region of its resonant frequency. As can be seen in Figure 2, the back plate is divided into three parts, a central disk and two annuli or concentric rings. The back plate is divided in this way to achieve the desired damping at a smaller separation between the plate and diaphragm — an arrangement that results in greater sensitivity. During assembly, the spacing between the diaphragm and back plate is adjusted to give the optimum damping for a uniform response-frequency characteristic.

Sensitivity to humidity and temperature in an earlier version of this microphone was reduced by design improvements in the 640AA. The effects of humidity were reduced by eliminating certain materials that swelled under humid conditions, thus changing critical dimensions and thereby the response level. Variations due to temperature changes in the previous microphone were caused in two ways: first, the diaphragm was made of aluminum and had a thermal coefficient of expansion differing from that of the steel supporting structure, so that changes in temperature resulted in changes in the diaphragm tension. Second, the damping of the air varied because the viscosity of air increases with temperature. The first variation was reduced in the 640AA by making the diaphragm of a material, stainless steel, having a thermal coefficient of expansion nearly equal to that of the diaphragm supporting structure; the variation due to the change in viscosity was reduced by making the back plate of nickel-chromium-iron alloy whose coefficient of expansion causes the spacing between it and the diaphragm to increase slightly with increasing temperature.

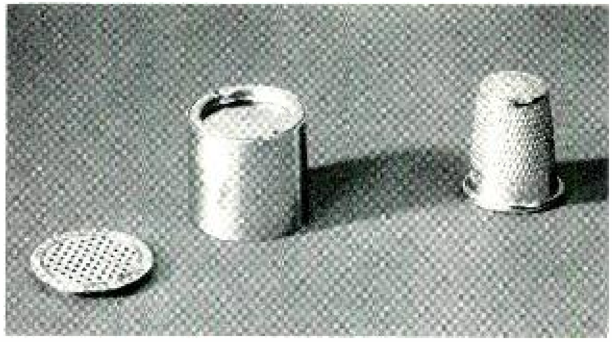

Fig. 1 — The Western Electric 640AA microphone with protecting grid removed. Thimble shows the relative size of the microphone.

It was also known that the earlier microphone was sensitive to changes in atmospheric pressure. However, for normal changes, the effect was so small that no compensating means were introduced into the 640AA microphone. The variations in sensitivity are due to changes in the acoustic stiffness of the air volume in back of the diaphragm. At a given location, the atmospheric pressure rarely differs more than ± 4 per cent from its average value.

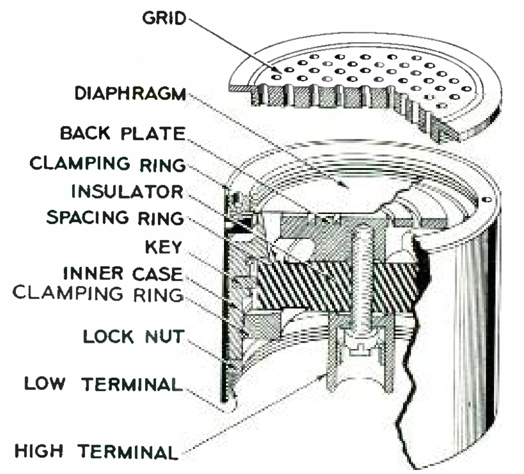

Fig. 2 — Sectional view of the Western Electric 640AA microphone, with parts identified.

Variations in pressure of this amount produce less than 1 per cent change in the microphone sensitivity. Changes due to altitude differences, however, may be greater than this. For example, the sensitivity of a 640AA microphone will be about 3 per cent higher when used in Denver, Colorado (about one mile above sea level) than when used in New York City.

Response-frequency characteristics of the 640AA microphone are shown in Figure 5. Two types of response are given – the pressure response and the free-field response. The pressure response is simply the ratio of the generated voltage to the sound pressure on the diaphragm, and is used to determine the pressures in small, confined spaces. This type of response applies, for example, when the 640AA is used as part of an artificial "ear" for testing telephone receivers. The artificial ear is a small volume of air whose acoustic load on a receiver under test simulates the load of a real ear. The free-field response, which is used for measuring pressures in open spaces, is a somewhat more involved concept. When a microphone is placed in a sound field – for example that from a loud speaker – it reflects the sound waves, resulting in a pressure build-up on the microphone diaphragm. For some conditions, this build-up pressure is several times as great as the undisturbed or free-field pressure. By means of the microphone's free-field response, it is possible to measure the undisturbed field pressure rather than the actual pressure on the microphone diaphragm. This response equals the ratio of the generated voltage to the undisturbed field pressure. Indoors a truly free field is not attained, but may be approximated by a so-called "dead room," the walls of which are sound-absorbent.

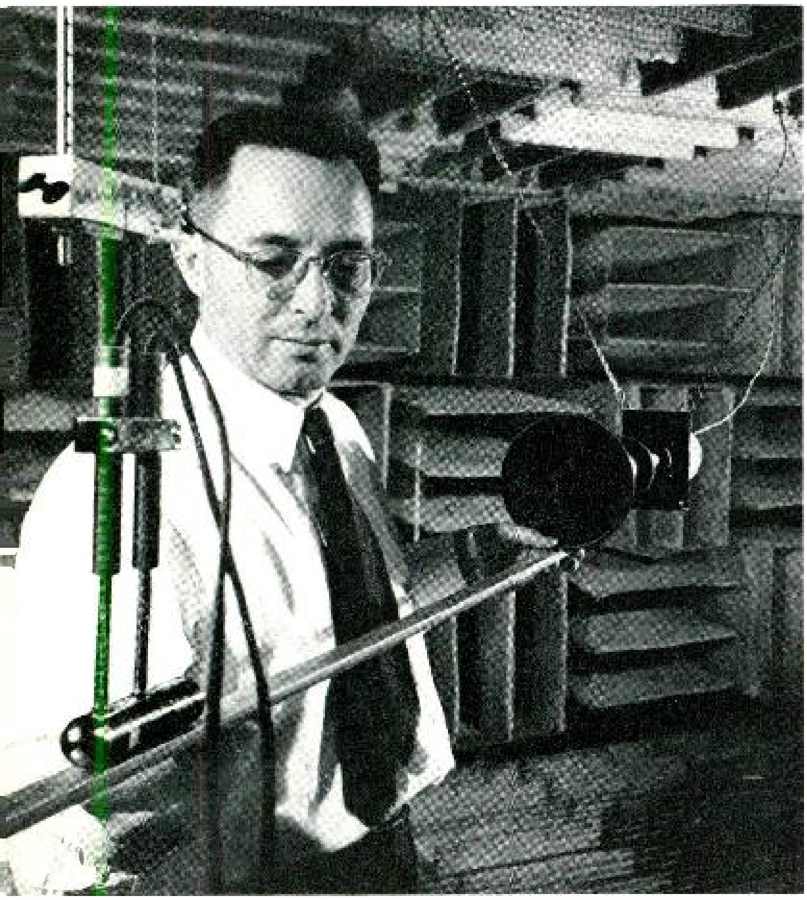

Fig. 3 — The author positioning Western Electric 640AA microphone for test of loud speaker.

Two of the many applications of the 640AA microphone in acoustic measurement are shown in Figures 3 and 4. In Figure 3 the 640AA is being positioned in front of a loud speaker in preparation for measuring its performance. In Figure 4 a telephone handset is being placed in position for test. The "artificial mouth" at the bottom "speaks" into the transmitter, and the 640AA at the top "listens" to the receiver. Prior to the test, the level of sound delivered by the artificial mouth is also established by means of a 640AA microphone. The microphone also is sometimes used in conjunction with a "search tube," a small tube leading from the microphone to the ear cavity.* This is done when the space where the pressure is to be measured is too small to receive the microphone. A search tube is also used when a sound field at the point of measurement must not be disturbed as much as would be the case if the microphone were placed there. The photograph on page 6 illustrates another procedure involving the 640AA; here, two microphones are being positioned a known distance from each other in preparation for their calibrations.

Although the 640AA microphone is used primarily for acoustic measurements, it is also used in radio broadcasting and other sound-reproducing systems where high quality is of prime consideration. In addition, although most of its applications are in the audio range of frequencies – that is, between 20 and 20,000 cycles per second – it is frequently used outside this range. In some studies it has been used to make measurements down to a fraction of a cycle per second, and in others it has been used up to frequencies several times the upper audio limit of 20,000 cycles per second. At these higher frequencies, it has also proved to be a useful calibrated source of sound.

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* Record, *August*, 1950, *page* 347.

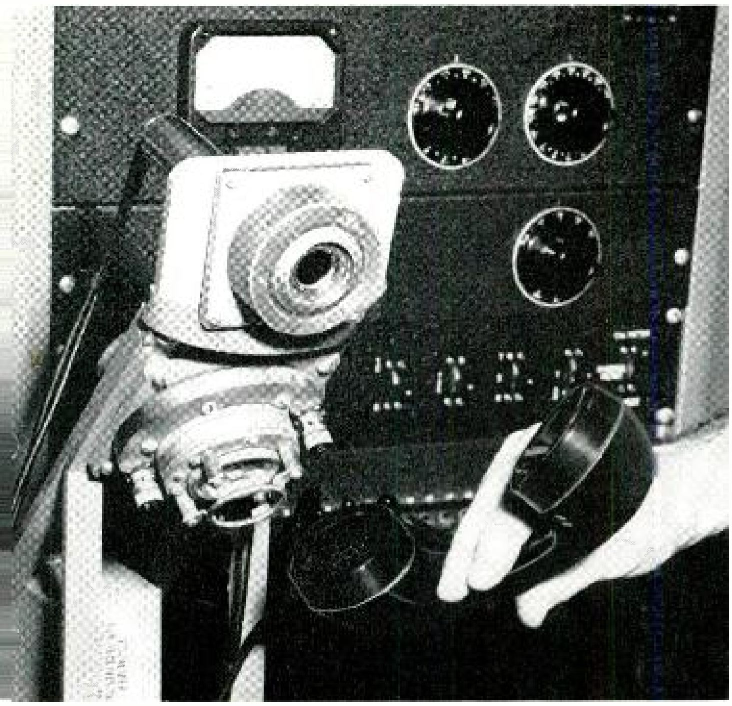


Fig. 4 — Western Electric 640AA microphone (in upper fixture) and "artificial mouth" being used in device for testing telephone handsets.

Like the ear, a microphone is limited in the intensity of sounds it can detect and tolerate. A microphone cannot detect very low pressures because of the masking effect of the thermal noise generated by the electrical resistance associated with it. At the higher levels it is limited by the amount of overloading acceptable to the user and by the possibility of damage.

The thermal noise appearing at the terminals of a condenser microphone comes primarily from the high resistance through which the polarizing charge is applied. A typical value of resistance used for this purpose with the 640AA microphone is 50 megohms. The amount of thermal noise appearing at the output of the electrical system following the microphone, besides being a function of the microphone polarizing resistance, is also a function of the frequency range transmitted by the system. For the audio range, a 50 megohm resistance across the 640AA microphone produces an effective thermal voltage of 10^{-5} volts. Since a sound pressure of 0.003 microbar * also produces this voltage in the microphone, this pressure is near the lower detectable limit. In contrast, the smallest sound pressure the normal ear can perceive is about 0.0002 microbar. Under these circumstances, the human ear is thus about fifteen times as sensitive as the 640AA microphone.

In single-frequency measurements, however, it is possible to reduce the noise by means of electrical filters that limit the frequency range to a very narrow region centered on the frequency of the signal being measured. If, for example, the transmitted band is reduced to a width of ten cycles per second and is centered at 1,000 cycles per second, the effective thermal pressure is 0.00006 microbar, or about one-third that of the smallest sound detectable by the ear. These noise levels pertain to microphone circuits that place a constant polarizing charge on the capacitor plates. When the microphone works as an impedance element in a high-frequency resonant circuit, however, the noise output can be reduced even further.

At the other extreme, the 640AA microphone can be exposed to sound pressures as great as 1,000 microbars with only a few per cent harmonic distortion, and may be used up to 10,000 microbars without possibility of damage. By comparison, the human ear suffers discomfort when exposed to sounds above 200 microbars.

It is of interest to consider the magnitudes of the effects produced in a 640AA microphone by a typical sound field. Assume the sound pressure to be one microbar. This is about the pressure to which the ear is exposed in ordinary conversation. This pressure moves the center of the diaphragm about four one hundred millionths of an inch, and this displacement in turn produces a voltage of 0.003 volt. This motion of the diaphragm is only three times the diameter of the air molecules pushing the diaphragm. Although these are very small quantities, we have seen that with a ten cycle per second bandwith, the 640AA microphone can be used down to 0.00006 microbar, where the dis-

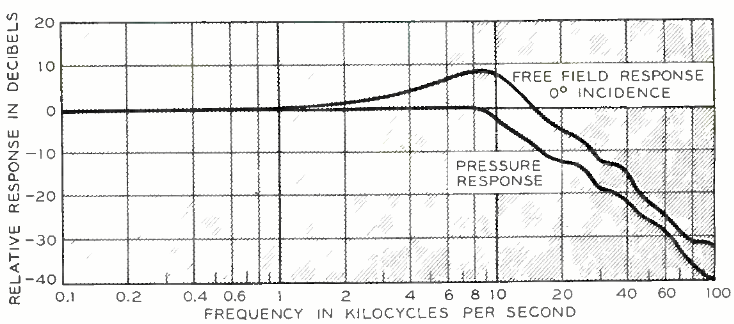


Fig. 5 — Free-field response and pressure response of the Western Electric 640AA microphone.

* A microbar (1 dyne per square centimeter) is approximately equal to one millionth of the normal atmospheric pressure at sea level.

placement and voltage are about one ten thousandth of those just described.

Before the output voltage from the microphone can be used to measure these sound pressures in absolute terms, the microphone must be calibrated. For many years, the standard calibration method at Bell Telephone Laboratories made use of the thermophone.* In this device, a current heats a thin metal ribbon; the heat expands the surrounding gas and thereby produces a sound pressure. The relationship between the applied current and the resulting pressure can be found from the properties of the ribbon and the properties of the gas.

A standard such as the thermophone is called a computable standard, since its performance is computed from its properties and its operating principles. However, the method used almost universally today, the reciprocity technique, does not use a computable standard. The reciprocity method was introduced in 1940 independently by W. R. MacLean of the Polytechnic Institute of Brooklyn and R. K. Cook of the National Bureau of Standards. It depends upon the reversibility of an electroacoustic transducer. A reversible transducer is one that operates with equal efficiency in both directions – that is, as a microphone to convert sound into electrical energy and as a sound source to convert electrical energy into sound. The ratio of the responses in the two directions is called the reciprocity constant. This constant is universal; its value is the same for all reversible transducers and is independent of operating principle and construction.

The reciprocity method requires a knowledge of only a few physical and electrical quantities, and these can be measured with great accuracy. It is primarily for this reason that the reciprocity method has replaced the other methods, and has permitted the very precise calibration of condenser microphones. To calibrate microphones by this technique it is merely necessary (1) to subject two microphones to the same unknown sound pressure and measure their resulting generated voltages, and then (2) to use one of the two microphones as a sound source to drive the second and measure the current applied to the first and the voltage generated by the second. The calibrations of both microphones are then completed merely by the use of the reciprocity constant and the few electrical quantities measured.

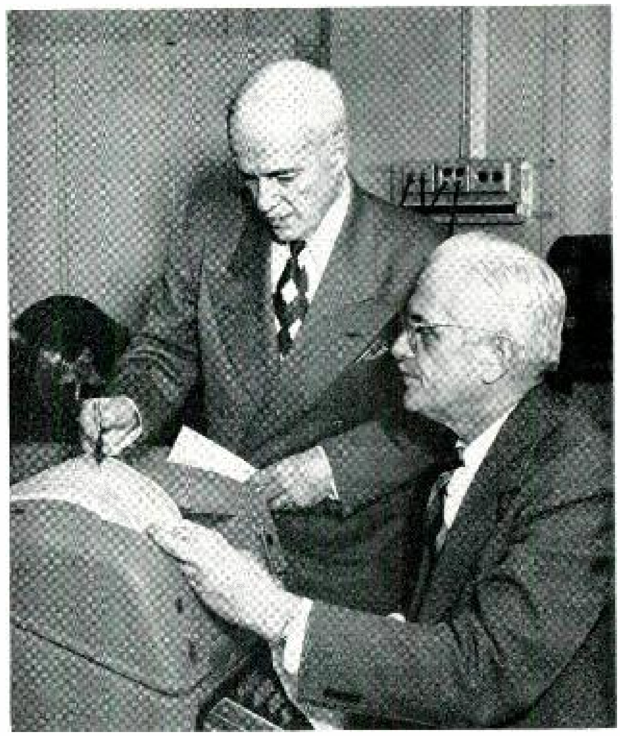
The early experimenters in acoustics worked without calibrated microphones and obtained their information by laborious processes. The introduction of the microphone into sound measurements, which was made possible by the advent of electronic apparatus, has greatly reduced the labor required, expanded the range, and increased the accuracy of these measurements. Of the electroacoustic instruments thus used, the condenser microphone has held the position of the sound standard. The Western Electric 640AA microphone, because of its characteristics and dependability, has played and probably will continue to play an important role as one of these standards.

* Record, *November*, 1943, *page* 105.

THE AUTHOR:

Melville S. Hawley was awarded a Bachelor of Science degree in Electrical Engineering from Union College in 1929, and joined the Laboratories in the Fall of the same year. As a member of the Station Apparatus Development Department he is engaged primarily in the development of telephone receivers. He is also concerned with the basic calibration of microphones, and serves as an instructor in electroacoustics in the Communications Development Training Program. His early work at the Laboratories included the development of hearing aids and other sound instruments.

Telegraph Transmission Coefficients



S. I. CORY *Telegraph Development*

With the aid of telegraph transmission coefficients — a simple, numerical means of grading circuits — complex telegraph networks are set up and maintained so that continuous, dependable service is provided for a large number of customers. Usually, the transmission quality to any customer is such that the circuit is responsible for not more than one error in several million teletypewriter characters.

A simple yet very useful method of expressing transmission impairments has been employed in telegraph work for a number of years. In this method a single number, between zero and ten, quoted to the first decimal, is assigned to each part of a telegraph network. This number, called a telegraph transmission coefficient, has two highly desirable characteristics. First, since it contains factors for all transmission degrading effects peculiar to the circuit part in question, it indicates the likely rate of occurrence of telegraph errors. Second, the numbers for the different parts of the circuit may be added together directly to indicate the transmission performance of the overall circuit. For example, a coefficient of 1.5 is used for a telegraph section of the highest grade, such as voice-frequency telegraph operated at 60 words-per-minute teletypewriter speed over a voice channel in cable or over a voice channel of K or L carrier. Some of the lower grade single sections, such as grounded telegraph to outlying points, have ratings of about 4 or 5.

These telegraph transmission coefficients find important use in circuit layout and maintenance in the field. Coefficient values for all the important types and lengths of line sections, loops, repeaters, switchboards, and other components are available to the circuit layout engineers and are used by them to indicate the transmission quality of proposed layouts. Even though the engineer has long experience on which to base his judgment of a suitable layout for a particular case, his work is simplified, and better results are secured, by the use of these coefficients. They are also used by maintenance forces to indicate expected transmission performance of a circuit. In addition, they find use in design work to indicate an objective to be met by a new telegraph system.

In layout work, the engineer is assured that a proposed circuit layout is likely to provide satisfac-

Above — H. B. Coxhead (left) and author compare distribution record with teletypewriter performance.

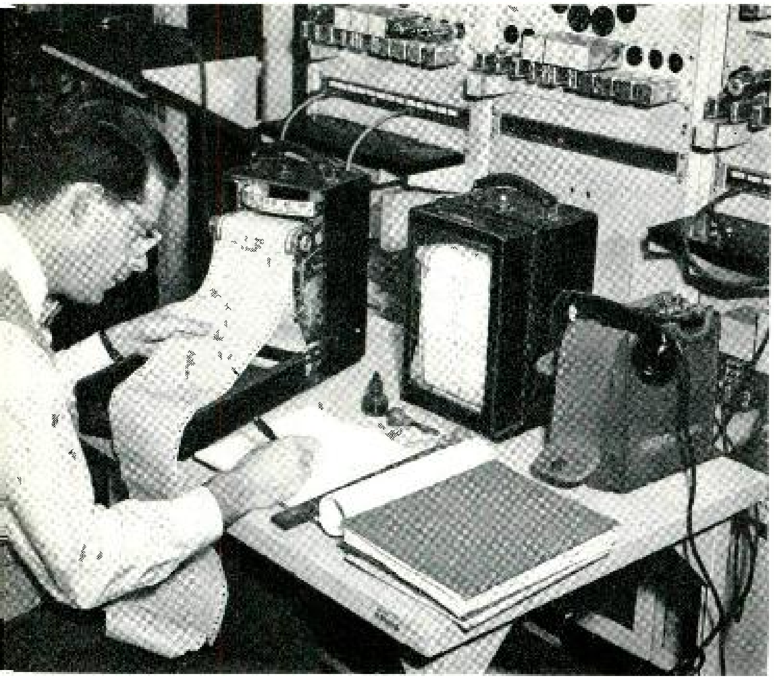


Fig. 1 — P. Rosenbaum obtaining coefficient data with 118C-3 measuring sets and recording meters.

tory service if the sum of the coefficients for the circuit links between customers is no more than 10. If the sum is materially greater than 10, it is necessary to provide better transmission facilities or to divide the circuit into parts by the insertion of one or more regenerative repeaters.* Such a repeater re-forms and re-times the signals so that the coefficient at its output is zero, the same as from a customer's transmitter. For instance, if the overall coefficient reached 14, it might be practicable to insert a regenerative repeater in a location that would result in a coefficient of 7 on either side.

A regenerative repeater, however, does not correct errors. If the distortion of the signals received by the regenerative repeater becomes excessive and the code combination is incorrectly interpreted, a perfectly timed but incorrect code will be transmitted. To provide margin against this possibility, it is the usual practice to limit the sum of the coefficients for the links between regenerative repeaters or between such a repeater and a terminal to about 7. In this way, the layout of circuit networks involving many line sections, loops, repeaters, and stations can be prepared quickly and with reasonable assurance that the transmission between any two stations will satisfy the high standard demanded.

* RECORD, *August*, 1930, *page* 570, *and April*, 1948, *page* 173.

The nationwide network provided for Press Associations, Inc., is a complex circuit layout that will serve to indicate the magnitude of some of the problems involved. This network serves about 900 cities and towns and about 1,500 customer stations. It requires a total of about 80,000 miles of circuit and 900 line sections. The circuit layout information on this network requires 41 maps of various sizes and 266 circuit layout cards.

Present layout practices are such that the mean coefficient for private-line service * is about 6.5, and for switched teletypewriter exchange connections †

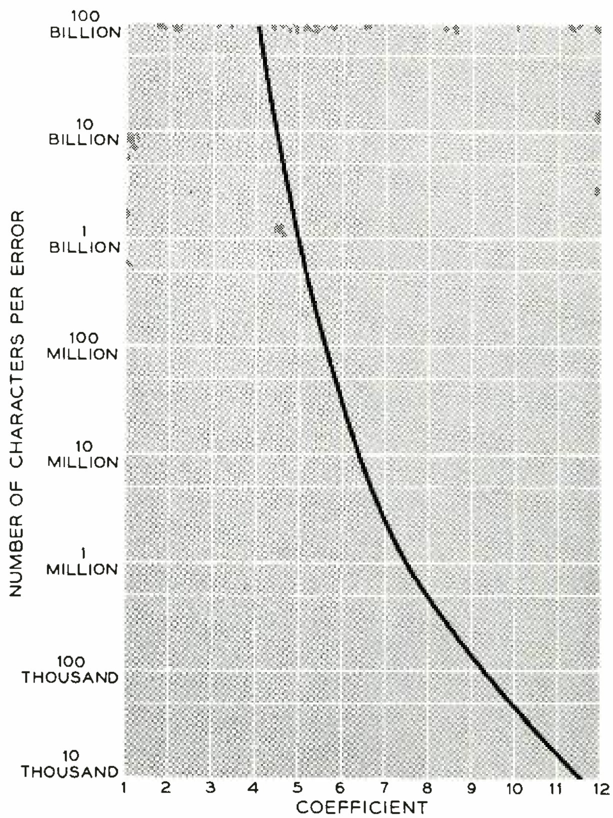


Fig. 2 — Relationship between telegraph transmission coefficients and accuracy of transmission.

it is about 3.5. This is shown in Figure 3, which gives recent information on the distribution of coefficients in the Long Lines plant. The mean coefficients are low because many circuits are short (average length of circuit in private-line service is about 400 miles) and because of the general availability of high-grade sections. The figure also shows that it is necessary to use circuits having coefficients greater than 10 in some cases because of circumstances — for example, because of the lack of suitable circuits

* RECORD, *January*, 1948, *page* 20.
† RECORD, *January*, 1938, *page* 167.

and regenerative repeaters in particular locations. In such cases, improved circuit layouts are provided as soon as practicable.

The transmission objective represented by the limiting coefficient of 10 is that, over a long period of time, the average error rate should not exceed one in 44,000 characters. This represents the performance of the circuit in its normal operating condition with the usual interference and adjustments. It does not include failures or interruptions. This transmission objective does not imply a "standard error rate" to which circuits are designed; it is merely a limiting condition. Some circuits that are especially critical of errors are "liberally engineered" for virtually errorless service insofar as the grade of transmission over the channels is concerned.

The limiting error rate of one in 44,000 characters is a result of experience in satisfying the exacting accuracy requirements of telegraph customers. It represents a very high grade of service – an average of only one error produced in about twelve 8½ x 11 pages of single-spaced typing, or one error in two hours of continuous typing at 60 words per minute. No effort is made to design telegraph circuits so that they will operate in this fashion uniformly, since this would be highly impracticable. In practice, errors are not evenly distributed but occur in bunches. That is, circuits operate for a number

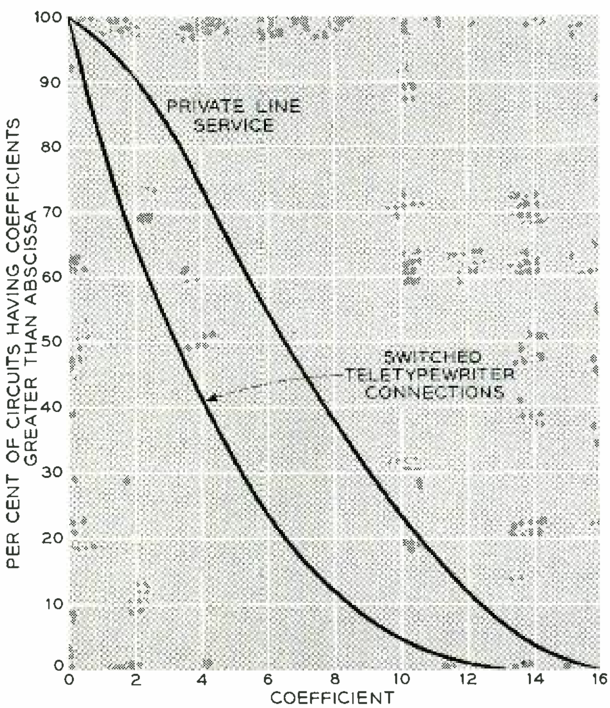


Fig. 3 — Recent distribution of telegraph transmission coefficients in the Long Lines plant.

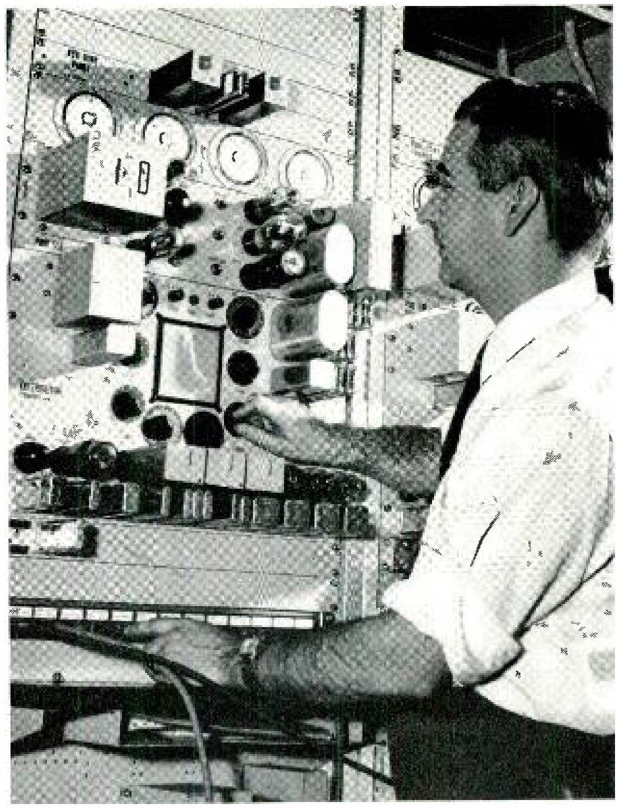


Fig. 4 — W. R. Grant calibrating 118C-3 telegraph transmission measuring set.

of days with few errors and then with more errors over a period of several minutes to an hour or so. When errors increase in this manner, steps are taken to improve transmission – by readjustment, by the substitution of better facilities, or by other changes in the circuit layout which reduce the coefficient. Accuracy improves rapidly as the coefficient is reduced. This is indicated by Figure 2, which shows the general relation between the coefficients and the rate of character errors. The mean private-line coefficient of 6.5, for instance, represents only one error in about 8,000,000 characters.

Now, what is the basis underlying this simple transmission rating system? Teletypewriter characters are transmitted by means of pulses, called "marks," separated by time-intervals called "spaces." In undistorted signals, the transitions from space to mark and from mark to space occupy definite positions in a time sequence. In distorted signals, the transitions are displaced from their proper positions; these displacements are called telegraph distortions. The first assumption underlying the use of transmission coefficients is that distortion greater than 35 per cent of the time required for a unit pulse will cause an error in the printed copy. This

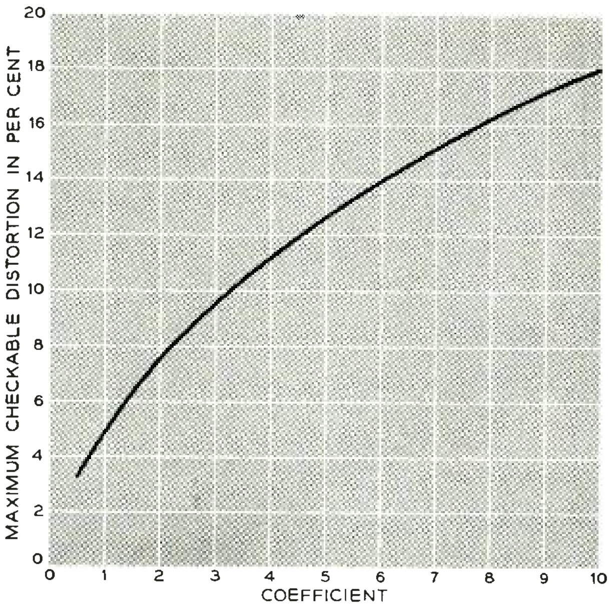


Fig. 5 — Distortion of telegraph signals versus coefficients, applicable to a short-term test in design work.

limiting value of distortion applies generally to teletypewriters and to regenerative repeaters, although the newer electronic regenerative repeaters* tolerate somewhat greater distortion.

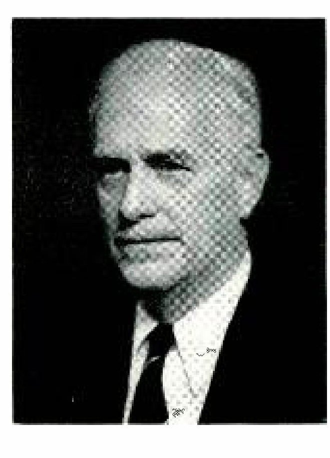
Secondly, the signal distortion in each link of a complete telegraph circuit, even one of comparatively simple make-up, is a result of contributions from a number of sources. Since any increment of distortion may have either a positive or a negative effect, and will vary in magnitude, it rarely happens that practically all of the contributing factors combine in the most unfavorable manner – that is, to cause the maximum distortion possible due to direct addition of all increments. Relative to the occurrence of smaller values, the occurrence of large values of distortion is therefore infrequent, the actual distribution being generally in accordance with the normal law of probability. Such a distribution is defined by its *rms* (root mean square or standard deviation) value. A number of such distributions may be added together by obtaining the square root of the sum of the squares of the individual *rms* values. In other words, the procedure is based primarily on the direct addition of mean-squared values.

Now assume that a telegraph circuit has a number of links or sections, each with a distortion distribution characterized by its *rms* value. The mean-squared value for each of these distributions may be added directly to obtain a value for the overall circuit. Accordingly, the mean-squared values could be used as coefficients. It is more convenient, however, to use simple numbers, zero to ten, proportional to these values. For the limiting coefficient of 10, the frequency of occurrence of errors is the transmission objective mentioned above, namely one error in 44,000 characters. Since only two of the four transitions in the average character are particularly susceptible to distortion, the probability for the limiting distortion of 35 per cent being exceeded becomes one in 88,000 transitions. From tables of the normal-law distribution, this probability determines a conversion factor of 0.155. The product of this factor and the mean-squared value thus gives the coefficient for any particular section.

The actual procedure in arriving at a coefficient for a given type of telegraph section is somewhat more complicated and laborious than is indicated

* Record, *December,* 1949, *page* 436.

THE AUTHOR



Samuel I. Cory was graduated from Ohio State University in 1916 with the degree of Bachelor of Electrical Engineering. He then joined the American Telephone and Telegraph Company and continued there in the Development and Research Department until 1934 when he transferred to the Laboratories. He has been engaged principally in transmission development problems, chiefly relating to telegraph systems and transmission measuring methods. During World War II, he was engaged almost exclusively in telegraph developments for the Armed Services, mainly in the application of teletypewriter techniques to radio circuits. In 1953, Mr. Cory transferred to the Military Communication Development Department. He is a member of A.I.E.E., Alpha Tau Omega, and Lambda Phi Omega.

by the above. First, long term tests are made of representative sections under normal operating conditions in the field. These tests give statistical information on the frequency of occurrence of different amounts of distortion. Then the data are analyzed to obtain the average and the mean-squared value indicative of the variations about the average. Isolated "hits" are also evaluated; these can be caused, for example, by lightning discharges on open wire lines. Because of the low rate of occurrence of hits, however, they are evaluated from an empirically derived curve instead of from a probability curve. Finally, the increments of coefficients thus obtained are added together to make up the coefficient for the telegraph section.

In design work and in other work where the objective is a certain grade of transmission, a large number of conditions of operation must be examined, and it is generally not practicable to go through the procedure outlined above to produce a coefficient. Instead short term tests must be made, and the design engineer must judge from the results whether the objective is being met. Computations have been made of the maximum checkable distortion to be expected in such short tests, say of five-minutes duration, using as a basis the distortion results expected over a long time. An example of a distortion objective, produced for use as a guide in design work, is given by Figure 5.

This transmission rating method has been used with very satisfactory results for over twenty years in the layout of telegraph circuits in the Bell System. Coefficient information is available to the field in the familiar Bell System Practice publications, which give a list of coefficients and describe their use in circuit layout work. Thus the engineer has a simple and workable method of arranging telegraph circuit layouts so that customers are practically guaranteed satisfactory transmission from any one station to any of the other stations.

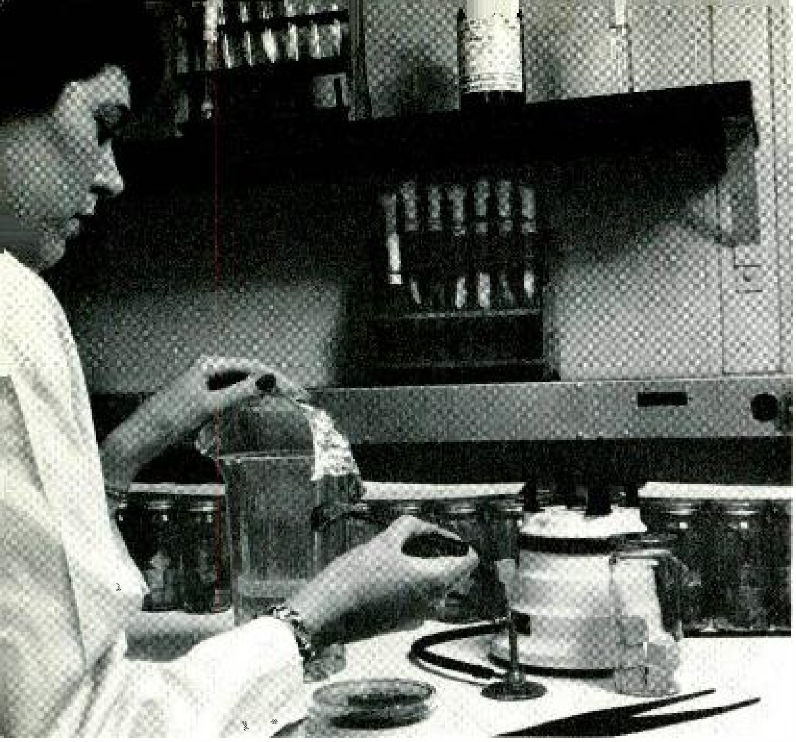
Dr. Buckley to Receive Edison Medal

Dr. Oliver E. Buckley, former President and Chairman of the Board of the Laboratories, now retired, has been awarded the 1954 Edison Medal by the American Institute of Electrical Engineers. The medal, one of engineering's major awards, will be presented to Dr. Buckley on February 2, 1955, at the Institute's winter general meeting in New York City.

Dr. Buckley, who has had a distinguished career as a scientist and administrator of industrial research, is cited by the A.I.E.E. for "his personal contributions to the science and art which have made possible a transatlantic telephone cable; for wise leadership of a great industrial laboratory; for outstanding services to the government of his country."

Dr. Buckley was President of the Laboratories from 1940 to 1951, and served as Chairman of the Board from 1951 until his retirement in 1952.

The Edison Medal, established in 1904, is awarded by the Edison Medal Committee of the American Institute of Electrical Engineers once each year to a resident of the United States of America and its Dependencies, or of the Dominion of Canada, for "Meritorious Achievement" in Electrical Science or Electrical Engineering, or the Electrical Arts. Dr. Buckley joins a number of other Bell System recipients – Alexander Graham Bell (1914), John J. Carty (1917), Frank B. Jewett (1928), Bancroft Gherardi (1932), George A. Campbell (1940), and Otto B. Blackwell (1950).



Many organisms that inhabit wood cause decay, but some have been found that increase the penetration of wood preservatives. Extensive laboratory and field studies of this new phenomenon have been made, and these have furnished valuable information about molds which may be useful in wood preservation.

JEAN E. PERRY *Outside Plant Development*

Molds Assist the Preservative Treatment of Poles

All poles being installed in the Bell System are treated with preservatives to protect them from wood-destroying organisms and insect attack. From an economic standpoint, pole preservation is very important. A southern pine pole if used untreated is apt to show advanced decay in five years or less, depending upon its location. A properly treated southern pine pole, however, can be expected to have a useful life of upwards of thirty-five years. The Bell System owns about 560,000 miles of pole line representing more than 20,000,000 poles, and it is purchasing about 800,000 poles every year. It is obvious that replacement costs resulting from attack by wood-destroying fungi would be exorbitant if untreated poles were used.

This article considers the possibility of using non-destructive wood-inhabiting organisms to assist in the treatment of poles to prevent attack by destructive organisms. The historical background for this method is provided by the work of Dr. Ralph M. Lindgren, Chief, Division of Forest Disease Research, Forest Products Laboratory, U. S. Department of Agriculture. Dr. Lindgren was concerned with the large losses of freshly cut pulpwood due to decay during storage. The moisture content of such wood is usually high, and conditions are ideal for the growth of fungi. However, when the common green mold *Trichoderma viride* was present on the pulpwood, the wood-destroyers were either absent or less abundant. Molds and wood-destroyers are both fungi, but in timber language the term "mold" is restricted to those lower-order fungi that do not cause the decay of wood, and the term "wood-destroyers" is reserved for those higher-order fungi that do cause decay.

Controlled studies by Dr. Lindgren in 1949 on southern pine pulpwood showed that *Trichoderma* grew on wood sprayed with sodium fluoride, a chemical generally toxic to fungi. Earlier work by the U. S. Department of Agriculture with "stain" organisms (other wood-inhabiting fungi) indicated that their development increased the penetration of liquids into air-dried southern pine wood. To

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Above — The author transfers mold culture to blender prior to inoculation of wood blocks.

see if the permeability was similarly increased by the development of *Trichoderma,* the pulpwood was immersed in a five per cent pentachlorophenol-oil solution. After a five-minute soaking period, the molded wood absorbed five to nine pounds of preservative per cubic foot, as compared with only about one pound absorptions for unmolded wood. Penetration was often complete – 2.5 to 3 inches deep – as compared to only about 0.1 inch in the unmolded wood.

To enable the reader to see how the cells of wood are arranged and to understand the growth pattern of the mold, a schematic drawing of a section of a log is shown in Figure 1. The faces of the wood have been magnified several hundred times. Microscopic investigations indicated that the mold develops in the "ray parenchyma"; these are the storehouses for the food supply of the tree. Development in the longitudinal tubes, called "tracheids," is sparse. In severe cases the end walls of the ray parenchyma cells are completely destroyed by the mold, forming a large hollow tube rather than a network of individual cells. An example of a hollowed-out ray is shown on the tangential face. Laboratory tests have indicated that *Trichoderma* causes no appreciable loss in structural strength of the wood. However, if the use of molds in the treatment of poles were to become a practical procedure, further data would have to be obtained on full-sized specimens.

The idea of using *Trichoderma* to reduce decay in wood during storage, and in particular to increase the penetration of preservatives, appeared to have possible application in pole seasoning and treatment. To investigate the effect of such treatment on southern pine poles, Bell Telephone Laboratories in 1950 initiated a preliminary field test at the Wiggins, Mississippi, storage yard of the Gulfport Creosoting Company. This test was run in cooperation with Dr. Lindgren and his associates who had conducted the pulpwood experiments only a few miles away.

Some of the southern pine poles were sprayed with sodium fluoride while others were not. After a sixty-day seasoning period, *Trichoderma* growth was light to medium on the sprayed poles while the unsprayed controls had little if any mold growth. As had been true in the pulpwood experiments, there was less incipient decay in the molded poles. After seasoning, and just prior to treatment, there was a continuous heavy rain for four days, during which the sprayed poles showed a heavy absorption of water. This demonstrated that the mold had increased the permeability of the wood and that there was a need for covering molded poles to prevent excessive water pick-up prior to treatment.

After this preliminary work on southern pine, the obvious next step was to try to apply *Trichoderma* to the treatment of Douglas fir, a species of pole timber far more difficult to treat than southern pine. Douglas fir is very refractory; that is, it is oftentimes difficult to obtain adequate penetration of preservatives by conventional pressure processes. Many variations in the standard treatment procedures have been tried in attempts to improve the results. The operation of expensive treating apparatus for thirty to seventy hours now is required for adequate conditioning and treatment of the thin Douglas fir sapwood, as compared with only seven or eight hours for treatment of the thick southern pine sapwood. It was hoped that the mold would shorten the conditioning and treating times.

Studies were begun at the Murray Hill Laboratories in 1951 to determine whether the permeability of Douglas fir could be increased by the growth of *Trichoderma.* Three-quarter inch Douglas fir sapwood cubes were used in the tests. Interest centered on the sapwood because the heartwood of most types of wood used for poles cannot be penetrated by any practical means and, since heartwood is naturally durable, treatment is considered unnecessary. The blocks were handled in groups of five to reduce the percentage error inherent in weighing. In all, over 2,000 blocks were used in the various experiments.

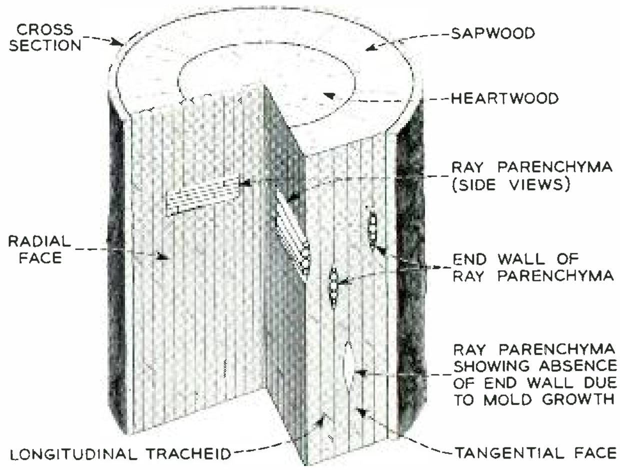

Fig. 1 — Three-plane drawing of a section of Douglas fir, showing ray parenchyma in which Trichoderma viride *mold grows.*

A study was conducted to determine the effect of dipping the blocks in four per cent sodium

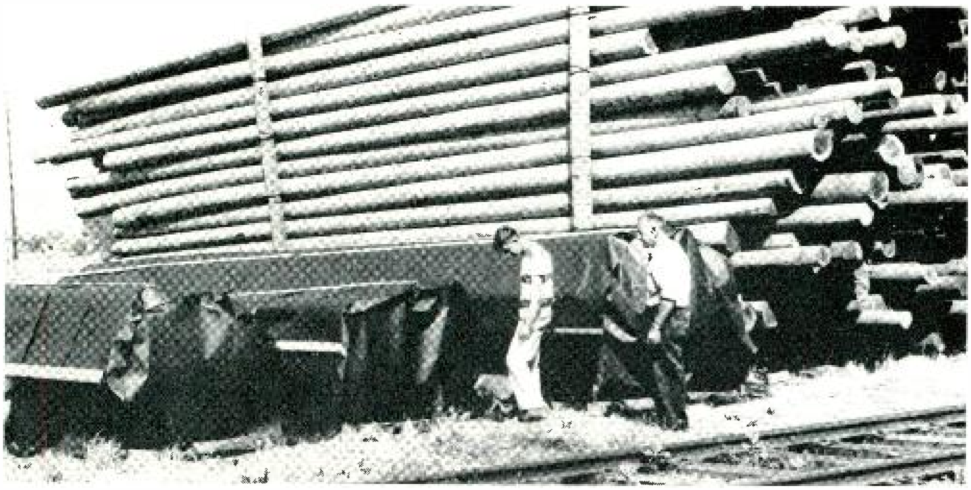

Fig. 2 — Douglas fir field experiment, Oregon, in 1952. L. R. Snoke, left, inspects tar paper covers on group of poles.

fluoride alone and in fluoride solutions containing various nutrients. It was thought that these nutrients might act to stimulate the growth of *Trichoderma*. As can be seen in Table I, the blocks that had been dipped in four per cent sodium fluoride and inoculated with *Trichoderma* showed an increase in weight after treatment of 60.7 per cent, almost three times that of the control blocks, and about one and one-half to two times that of the blocks that received a nutrient dip.

Another question, that of effecting more uniform mold growth, had been raised during the field test on southern pine poles. During this field test, the incidence of infection and germination of the mold spores had varied under natural conditions. In the laboratory, each group of blocks had been inoculated by placing, on one block in each group, a small piece of culture medium on which *Trichoderma* was growing. After treatment, there were dark areas representing good penetration on a few blocks in each group. It seemed logical to assume that these dark areas also represented maximum growth of the mold, probably on the inoculated block and on one or two blocks adjacent to it. It was believed that if every block in the group could be inoculated uniformly, more even penetration would result.

Table I – Effect of 4 Per Cent Sodium Fluoride (NaF) Containing Various Nutrients

	Handling of Blocks	Percent Increase in Block Weight due to Treatment
Group I	(Control Group): NaF – None Inoculation – None	21.8%
Group II:	NaF – 4% Inoculation – *Trichoderma*	60.7%
Group III:	NaF – 4% Inoculation – *Trichoderma* Nutrient – 1% Sucrose	31.7%
Group IV:	NaF – 4% Inoculation – *Trichoderma* Nutrient – Urea (saturated solution)	45.4%
Group V:	NaF – 4% Inoculation – *Trichoderma* Nutrients – 1% Sucrose – Urea (saturated solution)	22.9%

From these observations, it was decided that a laboratory experiment should be conducted incorporating the inoculum in the fluoride solution. In this test the mold was grown on a solid culture medium; the growth was then scraped off under aseptic conditions and mixed with the desired solutions. The sterilized blocks were then inoculated by means of dipping them into the mixture of the inoculum and liquid.

It was found that *Trichoderma*, when blended in four per cent sodium fluoride solution, would not grow on wood, but that when the mold was blended in a two per cent fluoride solution, growth appeared uniformly on all sides of all blocks. The absorption of preservative in the molded blocks was two to three times that of control blocks, and the penetration was more uniform.

Although these laboratory tests were not the only ones conducted in connection with this study, they illustrate the kind of problems that were encountered and how they were solved. They also illustrate the occurrence of the unanticipated in experimental work done with living organisms.

The next question was, what effect would *Trichoderma* have on Douglas fir poles under field conditions? A field test was begun in Oregon in the summer of 1952. The period from July to October was chosen, since this is the most favorable time of year for the seasoning of poles in the Pacific Northwest. There is usually very little rain during these months, and the poles dry out in a reasonable length of time.

L. R. Snoke of the timber group at Bell Laboratories supervised the handling of the poles. One hundred and eighty trees were felled and debarked. Immediately thereafter the poles were divided into three major groups and several subgroups, as listed in Table II. Records were kept of the daily weather conditions and of the moisture contents and mold growth of each group. The mold growth and moisture contents varied considerably among the three groups and also between the subgroups. Very little growth occurred on the uncovered groups or on the covered but open-piled groups because the poles dried too rapidly and the mold did not have a chance to establish itself. Therefore only the three covered, close-piled subgroups (see Figure 2) will be discussed. There was mixed infection, including *Trichoderma*, on the second group, which had been sprayed with two per cent sodium fluoride, and also on the first or control group. The third group, however, which had been sprayed with two per cent sodium fluoride containing the inoculum of *Trichoderma*, was infected predominantly with this mold.

TABLE II — DOUGLAS FIR FIELD EXPERIMENT
GROUPING OF POLES

		Covering	*Method of Piling*
GROUP I	(Control Group):		
NaF	— None	A Tar Paper	1. Close-piled
Inoculation	— None		2. Open-piled
		B Not Covered	1. Close-piled
			2. Open-piled
GROUP II:			
NaF	— 2%	A Tar Paper	1. Close-piled
Inoculation	— None		2. Open-piled
		B Not Covered	1. Close-piled
			2. Open-piled
GROUP III:			
NaF	— 2%	A Tar Paper	1. Close-piled
Inoculation	— *Trichoderma*		2. Open-piled
		B Not Covered	1. Close-piled
			2. Open-piled

The trial was terminated in October after the poles had dried down to a moisture content of 15 to 20 per cent and so were ready for treatment. Although Douglas fir poles are normally treated for long hours under pressure, the non-pressure (hot and cold bath) treatment chosen for the test was one that had been employed successfully for this species to meet the standard requirement of 0.30 pounds per cubic foot of dry pentachlorophenol in the second half inch in from the surface of the pole.

After treatment, borings and discs were taken from several poles in each of the three groups to determine the pentachlorophenol content. The average retention of covered and close-piled poles in the second group (sprayed with sodium fluoride but not inoculated) was 0.37 pounds of dry pentachlorophenol per cubic foot (see Figure 3, Section 18), and of covered and close-piled poles in the third group (sodium fluoride and *Trichoderma*) was 0.41 pounds per cubic foot (Figure 3, Section 66). These retentions are in excess of specification requirements, but are certainly of the same order of magnitude. The conclusions that can be drawn from the treatment records for covered and close-piled poles in both groups II and III given in Table II could only be that *Trichoderma* was

Fig. 3 — J. A. Taylor exhibits Douglas fir discs, left to right: No. 140, showing deep penetration (full sapwood depth) of preservative in control group as compared to No. 66 from sprayed and inoculated groups and No. 18 from sprayed group.

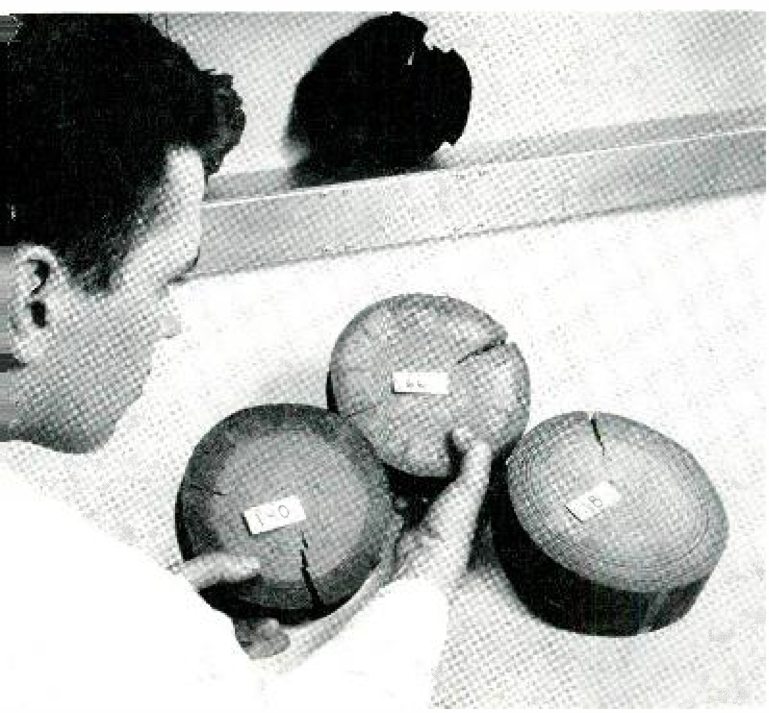

Fig. 4 — Wood blocks being dipped in pentachlorophenol-petroleum solution to determine effect of mold on penetration of preservative.

relatively ineffective in improving the treatability of Douglas fir poles.

The really surprising results of the experiment were obtained with the covered and close-piled poles of the control group I. These had received no supplementary treatments with sodium fluoride or *Trichoderma*. Here the average retention was 0.82 pounds per cubic foot, double that obtained in groups II and III. Penetration of the sapwood was almost complete in every case (see Figure 3, Pole Section 140). In the light of earlier experiences with *Trichoderma* in southern pine poles, the inferences to be drawn from this striking reversal could point to the action of some organism native to the Pacific Northwest that grew abundantly under the test conditions. Samples of mold growth on the poles of Group I were obtained and the various organisms were isolated. It was possible from these isolates to select the mold that had been found growing throughout the sapwood. This mold, the identification of which is now being undertaken, may well have been responsible for the greatly improved permeability of Douglas fir poles. Continuing studies are being carried out to determine more fully the conditions under which suitable mold growths can be encouraged to give regulated improvements in permeability.

Before the commercial use of molds can become a reality, there are practical aspects that must be considered. The effect of the mold on the cleanliness and bleeding tendencies * of the pole will have to be established. Strength tests on full-sized poles may be necessary to be certain that the wood is not affected adversely by the mold. Finally, treatment with molds will have to be competitive with current production methods.

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* RECORD, *September*, 1953, *page* 321.

THE AUTHOR

JEAN E. PERRY received the B.S. degree in chemistry and bacteriology from New Jersey College for Women in 1951. Following her graduation she joined the Outside Plant Department's timber group at the Laboratories. With the exception of a few months spent in the bioassay laboratory testing the action of preservatives, Miss Perry has concentrated in research using molds in the preservative treatment of poles. Among the molds used, she has been especially concerned with *Trichoderma*. She has also worked on the preparation and action of enzymes obtained from molds. Miss Perry, now Mrs. Albert Granger Ives, left the Laboratories in April, 1954, and is living in Nancy, France, where her husband is stationed with the United States Army.

In high-frequency transmission systems, such as L3 coaxial carrier, component values must be held within narrow limits. Measurement of components with commercially available admittance bridges is usually not satisfactory, since the bridges do not have the high order of precision required. For this reason, special bridges are developed. A bridge using capacitance standards, recently constructed at the Laboratories, maintains excellent accuracy at frequencies as high as 30 mc.

A Precision 30-Mc Admittance Bridge

L. E. HERBORN *Transmission Development*

Multi-channel transmission systems such as L3 carrier* require many transmission networks. These networks include filters, equalizers, and regulators, all of which must meet exacting transmission requirements at critical frequencies and over specific frequency bands. The design and manufacture of the networks require knowing at the operating frequencies, either the resistance and inductance, or the conductance and capacitance of the components.

Whenever very accurate values of these quantities are to be determined, experience has shown that a bridge is best suited for the measurements. Capacitance standards are more nearly constant over a wide frequency range than other types such as resistance or inductance; consequently, a bridge was developed that uses capacitance standards for measuring both capacitance and conductance. The bridge measures conductances up to 5,800 micromhos and capacitances up to 190 micro-microfarads, either positive or negative, at frequencies from one to thirty megacycles. The concept of negative capacitance is conveniently used for inductive components; if required, the value of inductance may be readily calculated. All values are read from the scales without referring to calibration charts. Any suitable ac source and detector may be used.

This particular bridge operates as a Schering type – one of the many generic offspring of the more familiar Wheatstone bridge. Figure 1 is a schematic diagram of a typical dc Wheatstone bridge, made up of four resistance arms. At balance, the indicator reads zero because there is no voltage across it. Under such a condition, the value of the unknown element R_x is:

$$R_x = \frac{R_B \cdot R_D}{R_A},$$

and changing R_x to its corresponding conductance G_x – the reciprocal of the resistance – the balance equation becomes:

$$G_x = \frac{R_A}{R_B \cdot R_D}.$$

When an ac source is used and the resistors in the A and D arms are replaced by capacitors, the balance equation changes to:

$$G_x = \frac{C_D}{R_B} \cdot \frac{1}{C_A}.$$

* RECORD, *January*, 1954, *page* 1.

Similarly, when the resistors in the C and D arms of the original Wheatstone bridge are replaced by capacitors, the balance equation becomes:

$$C_x = \frac{C_D}{R_B} \cdot R_A \, .$$

The combination of these two circuits into one becomes a Schering-type bridge.

The basic circuit of a Schering-type bridge is shown in Figure 4. With the ratio C_D/R_B and the resistance R_A fixed, the series capacitance C_A balances out the conductance G_x of the unknown, while the parallel capacitance C_C substitutes for the capacitance C_x of the unknown and the G_C acts as ballast. The procedure for making measurements is to first balance the bridge with the unknown disconnected, and then again with the unknown connected. Using "primes" to indicate the capacitance values for the second balance, the conductance and capacitance of the unknown are, respectively:

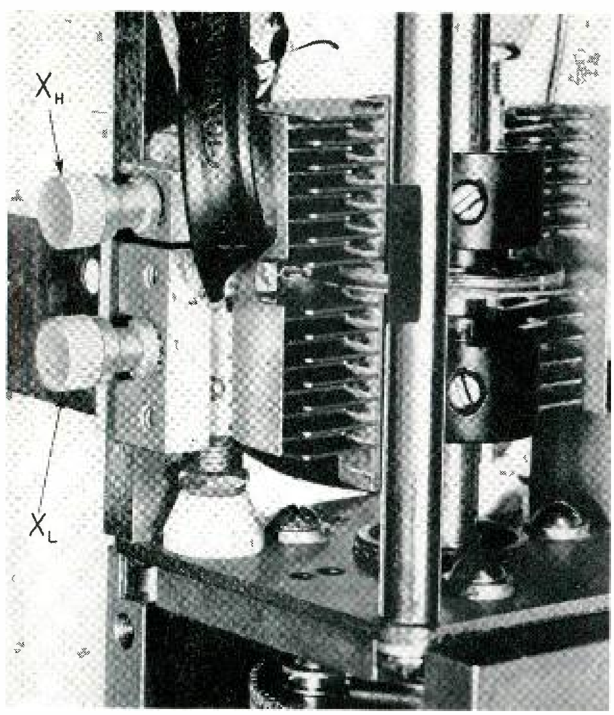


Fig. 2 — The test terminals are mounted directly on the parallel capacitance standard.

$$G_x = \frac{C_D}{R_B} \cdot \left(\frac{1}{C'_A} - \frac{1}{C_A}\right)$$

and

$$C_x = C_C - C'_C .$$

The advantage of this type of bridge is that the values of the unknown are determined directly from differences measured on calibrated capacitance standards.

In these equations, the symbols represent the specific values of the bridge components at the frequency of measurement. If the components were all pure elements, then the corresponding values would hold over a wide frequency range. Unfortunately, such purity of elements cannot be easily maintained because the components and wiring have small amounts of inductance and capacitance between themselves and to ground. These inductances and capacitances are called "residuals." The main ones are indicated in the schematic diagram, Figure 5, as dashed-line elements. Of course, at low frequencies, their effects on the bridge circuit are comparatively small. As the frequency of measurement is raised, their effects become increasingly more important and could cause increasingly greater errors. Fortunately, these residuals can be neutralized or minimized by proper compensation.

For example, the symbols in the ratio C_D/R_B in the balance equations for Figure 4 represent the specific component values at the frequency of measurement. In terms of assumed pure component elements C_D and R_B and the associated residuals shown

Fig. 1 — A simple dc Wheatstone bridge.

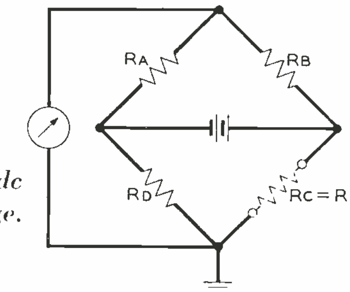
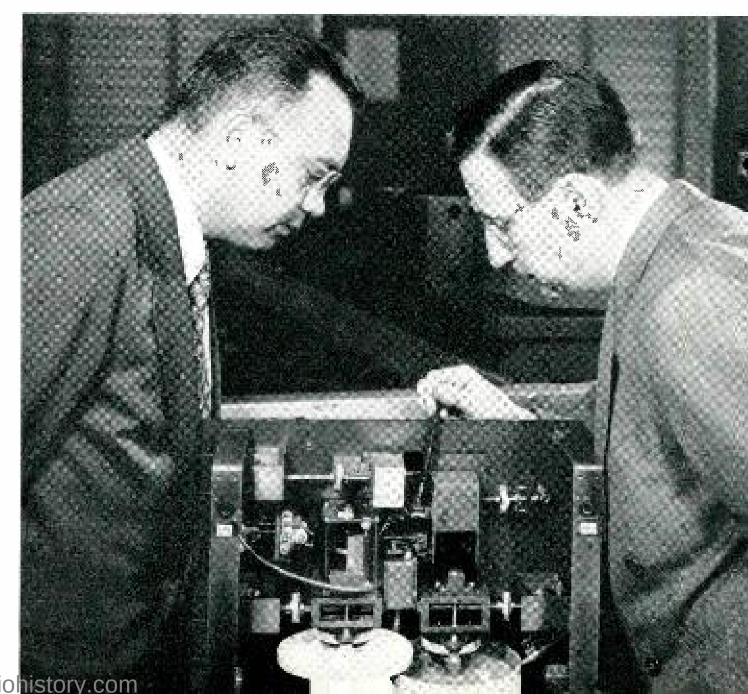


Fig. 3 — The author, right, points out the "clip-in" RC unit in the a arm of the bridge to R. W. Coons.



in Figure 5, the expression for the effective value of this ratio is

$$\frac{C_d\,(1+\omega^2 L_d C_d)}{R_b\,[1+\omega^2 C_b(2L_b - C_b R_b^2)]}.$$

From this expression it is evident that both the numerator and the denominator change with frequency (the ω terms). However, the required constant ratio is obtained by adjusting one or more of the residuals, such as L_b, until both numerator and denominator have the same frequency characteristic. Similarly, in the *a* arm, the effect of the residual inductance L_a with an increase in frequency is equivalent to increasing the series capacitance. For this arm, the inductance is neutralized by a capacitor connected across R_a, of a value determined from the expression $C_R = L_a/R_a^2$. Thus the effective series capacitance of the *a* arm is equal to C_s at all frequencies. Likewise, the residual inductances L_c and L_e in the *c* arm cause measurement errors

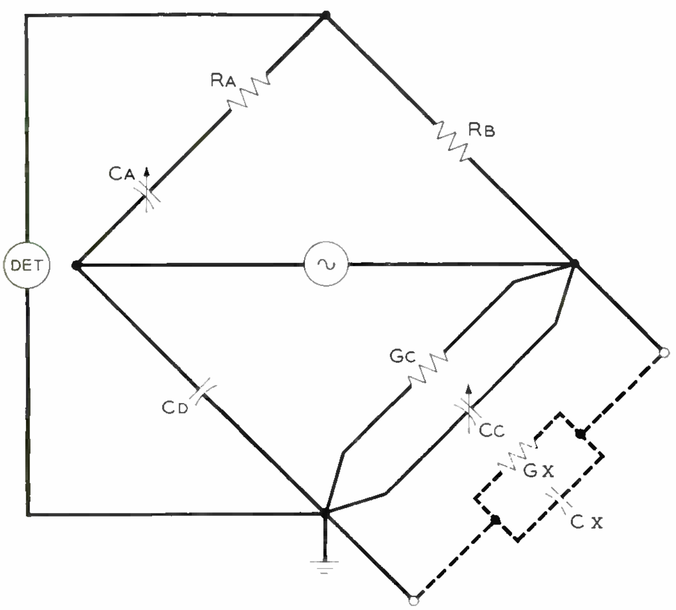


Fig. 4 — The basic circuit of a Schering-type bridge.

at the higher frequencies. By making L_e equal to L_c however, the expression for the unknown is

$$C_X = (C_p - C'_p)\,(1 + 2\omega^2 L_c C'_p)$$

in which the error term $2\omega^2 L_c C'_p$ is minimized to that due only to the second balance — the smaller of the two capacitance-standard balance values. Because the method of measurement is one of partial substitution, equivalent to introducing only the conductance component of the unknown into the bridge circuit, no severe phase-angle adjustments are necessary for the *b* or *d* fixed arms of the bridge.

A complete schematic is shown in Figure 6. The circuit residuals are stabilized by shielding components that are above ground, and by isolating the power source from the bridge with a double-

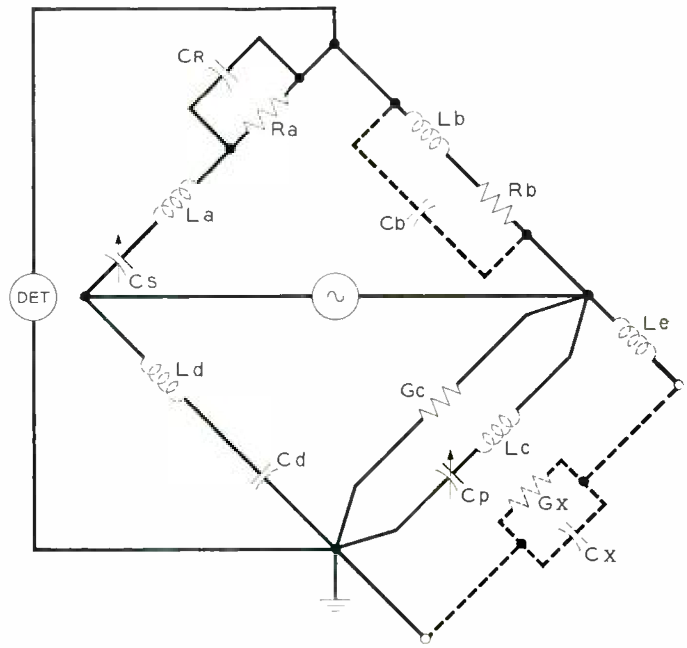


Fig. 5 — An actual Schering-type bridge showing the "residual" elements (dashed lines).

shielded transformer. The intershield capacitance of transformer T is the main capacitance across the *d* arm. The residuals of resistor R_b are so compensated that the resistance of the *b* arm has the same frequency characteristic as the capacitance of the *d* arm of the bridge.

Both the series capacitance standard C_s and the parallel capacitance standard C_p are compact units constructed to have the smallest residual inductance and loss possible. The series capacitance standard C_s consists of a split stator and a single rotor. One section provides a conductance measurement range equivalent to 350 micromhos and the other section is equivalent to 5,800 micromhos. The $G_{LO} - G_{HI}$ switch connects into the circuit the section being used. The parallel capacitance standard C_p is so constructed that the bridge corners across which the unknown is connected are two closely-spaced copper bars mounted on the capacitor frame and insulated from it, Figure 2. Three capacitance-compensated resistors mounted on clip-in units, for connecting in the *a* arm, permit changing the initial balance setting for a range of 0 to 190, 100 to 90, or 190 to 0 micro-microfarads.

All components of the bridge are mounted on the rear of the panel, Figure 3. The conductance and capacitance measuring standards are operated by the knobs designated G and C, respectively (headpiece), through gear drives. Spinner-type knobs permit rapid changes of setting while hypoid bevel gears and spring-loaded worm gears eliminate backlash and permit an exact setting. Each has a six-inch calibrated dial and a three-inch counter-type dial. The six-inch dial is equivalent to an eighteen-inch direct-reading scale. The smallest division on the capacitance scale is 1 micro-microfarad; that on the direct-reading conductance scale for the G_{HI} range is ten micromhos, and that on the G_{LO} range is one micromho. The three-inch counter-type dial, in combination with a vernier dial on the spinner knob, is for interpolation between the small divisions on the direct-reading scales. This interpolation improves the readability by a factor of approximately one hundred.

Dials G_0 and C_0 control small adjustable compensators in the *c* arm and are used to balance the bridge initially for settings of exactly "zero" on the conductance scale and 0, 100, or 190 micro-microfarads on the capacitance scale. With this arrangement, the value of the unknown is easily obtained from the final measurement read.

Two additional binding posts R_H and R_L are normally connected by a short jumper wire. For measuring low-Q impedances or resistors, with values beyond the range of the bridge all the way to zero ohms, the jumper is removed and the unknown is connected in its place. This connects the unknown in series with the G_0 compensator and measurements obtained from the bridge balances are corrected to apply across these terminals.

Since the bridge uses capacitance standards only, provides a constant ratio of the fixed arms, and uses special construction to minimize or neutralize the circuit residuals, its over-all performance over the entire frequency range compares favorably with that of lower-frequency precision-type bridges with accuracies of about 0.25 per cent. The eighteen-inch continuous-reading scales give direct readings, thus providing a rapid method of measuring the admittance components of an unknown. The bridge is being used in connection with the development of transmission apparatus where a wide range of measurements, both high-Q and low-Q are required at frequencies up to thirty megacycles.

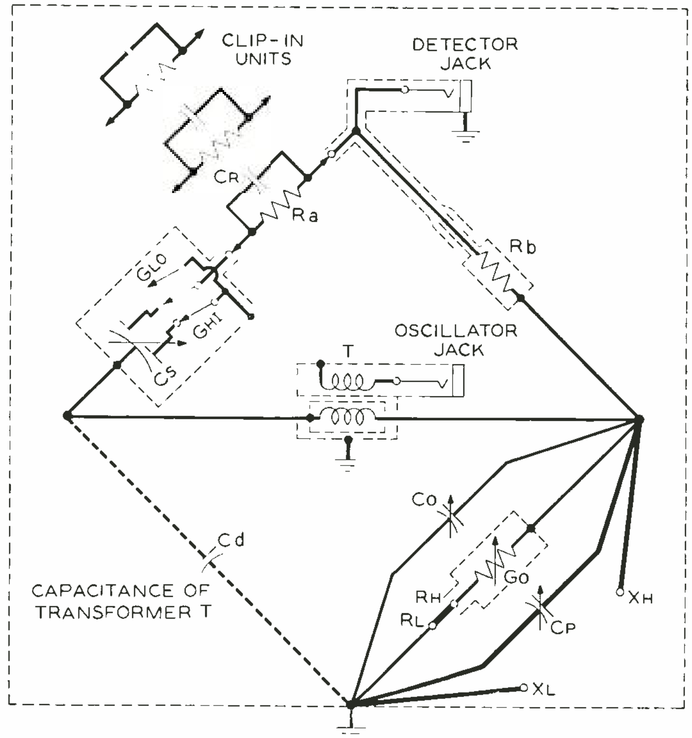
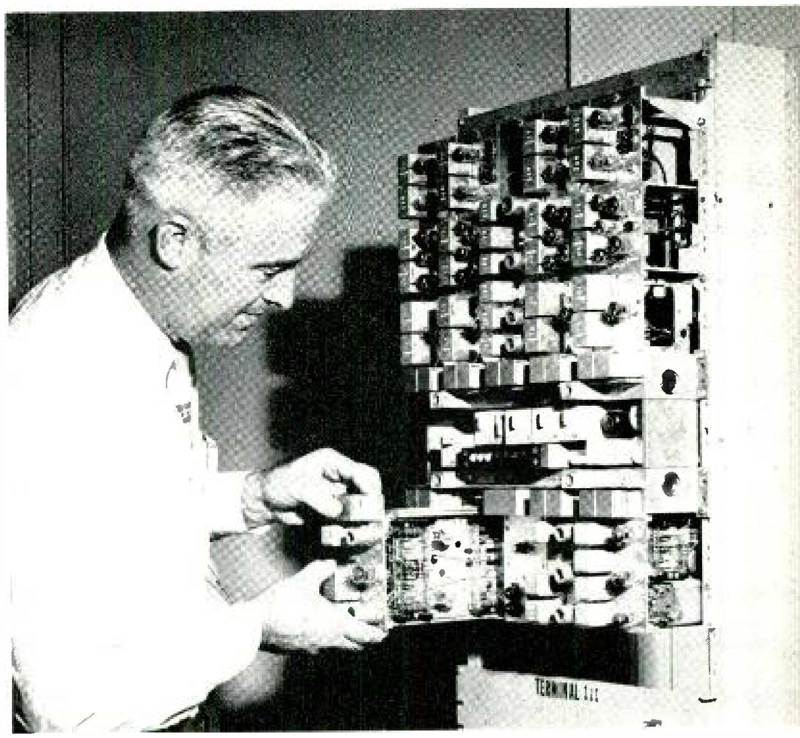


Fig. 6 — The circuit of the precision admittance bridge.

THE AUTHOR:

LUDWIG EDWARD HERBORN received his B.S. degree from Cooper Union. Mr. Herborn has been with the Bell System since 1923, when he joined the Western Electric Company, transferring to the Laboratories in 1925. From 1923 to 1928 he participated in the design, construction and testing of the high-speed permalloy cable terminal equipment operating between New York and Emden, Germany. Since 1928 Mr. Herborn has been engaged in the development, design and construction of precise measuring equipment for testing telephone apparatus. This work has included theoretical studies and laboratory tests aimed at providing more precise and rapid methods of measuring impedances in the range from audio to radio frequencies. During World War II, Mr. Herborn collaborated in the circuit development of military equipment. Since 1949 he has been at the Murray Hill laboratory.

Repeaters and Group Circuits in Type-O Carrier



H. T. KING
Transmission Systems Development I

One of the methods in Type-O carrier of keeping the cost of manufacture and maintenance low is the use of basic equipment designs for more than one purpose. Especially good examples of this multipurpose use are the repeaters and group units, where one basic amplifier design serves for either direction in repeaters and for receiving at a terminal. In addition, a group transmitting unit is essentially one-half of the same basic design.

One of the prime factors in the design of Type-O carrier was economy of both manufacture and operation. Another was that it be possible to add carrier channels to existing open-wire lines in groups of a few channels at a time. Type-O carrier,* then, is not a single system. Rather, it is composed of four independent systems operating in different frequency ranges. Each system uses 36 kc (OA uses only 34 kc) of the frequency spectrum from 2 to 156 kc, with guard bands between systems. In ascending order of frequency they are OA, OB, OC, and OD; Figure 1 shows the frequency allocations.

Aside from power supplies, Type-O comprises three general classes of equipment: channel and twin-channel units used only at terminals, group units used at terminals, and repeaters. Group units are so named because they handle telephone conversations only in groups of four two-way channels. They might equally well be called "system" units, since four channels is the maximum for each system. Repeater units are also "system" units for they handle whatever line frequencies are utilized by the system being repeatered.

In a Type-O system (except OA), frequency-

Above — The author shows how units plug into a terminal frame. The group oscillator and group transmitting units are just to left and right of center in the bottom row. The group receiving unit at top center is the same as a repeater unit.

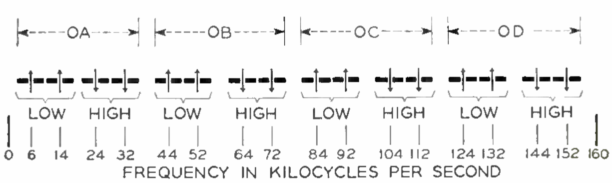


Fig. 1 — Four channels are allotted to each Type-O carrier system.

* RECORD, *June*, 1954, *page* 209.

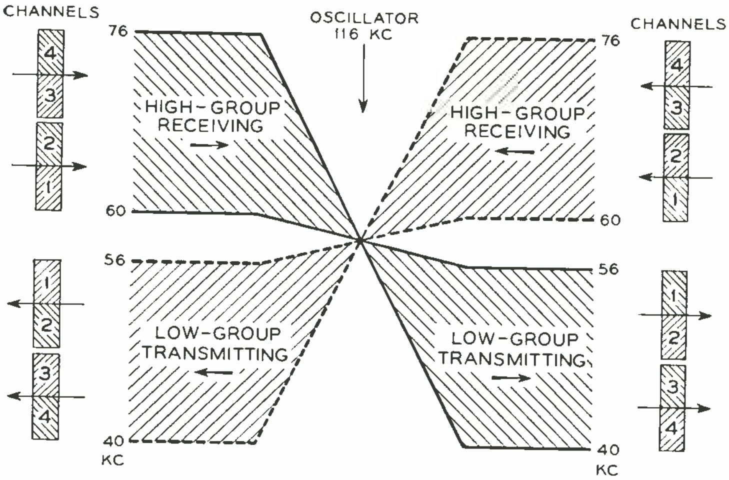


Fig. 2 — Frequency-frogging in an OB high-low repeater.

frogging is used at repeaters to reduce interaction crosstalk and minimize the effects of line slope. All four channels are received at a repeater in a single 16-kc band and transmitted to the next repeater or terminal in a second 16-kc band. Frequency-frogging is the process of interchanging these bands, Figure 2. For example, an OB repeater may receive the low group — 40 to 56 kc — from the repeaters or terminals on either side of it. An oscillator in the OB repeater supplies a 116-kc carrier to the modulators of the amplifier-modulator units, and the received low group is translated to the high group for transmission. In addition, the groups are inverted, 40-56 kc becoming 76-60 kc; this is known as a low-high repeater. If the repeater receives the high group — 60 to 76 kc — and transmits it as low group — 56 to 40 kc — the repeater is known as high-low. Directional filters plug into the repeater units, making one type of repeater unit usable for either low-high or high-low operation by a simple physical reversal of the filter units.

When frequency-frogging is used, a modulator is required for each direction of the repeater. In Type-O, this is a simple "lattice" modulator using copper-oxide varistors, similar to those used in re-

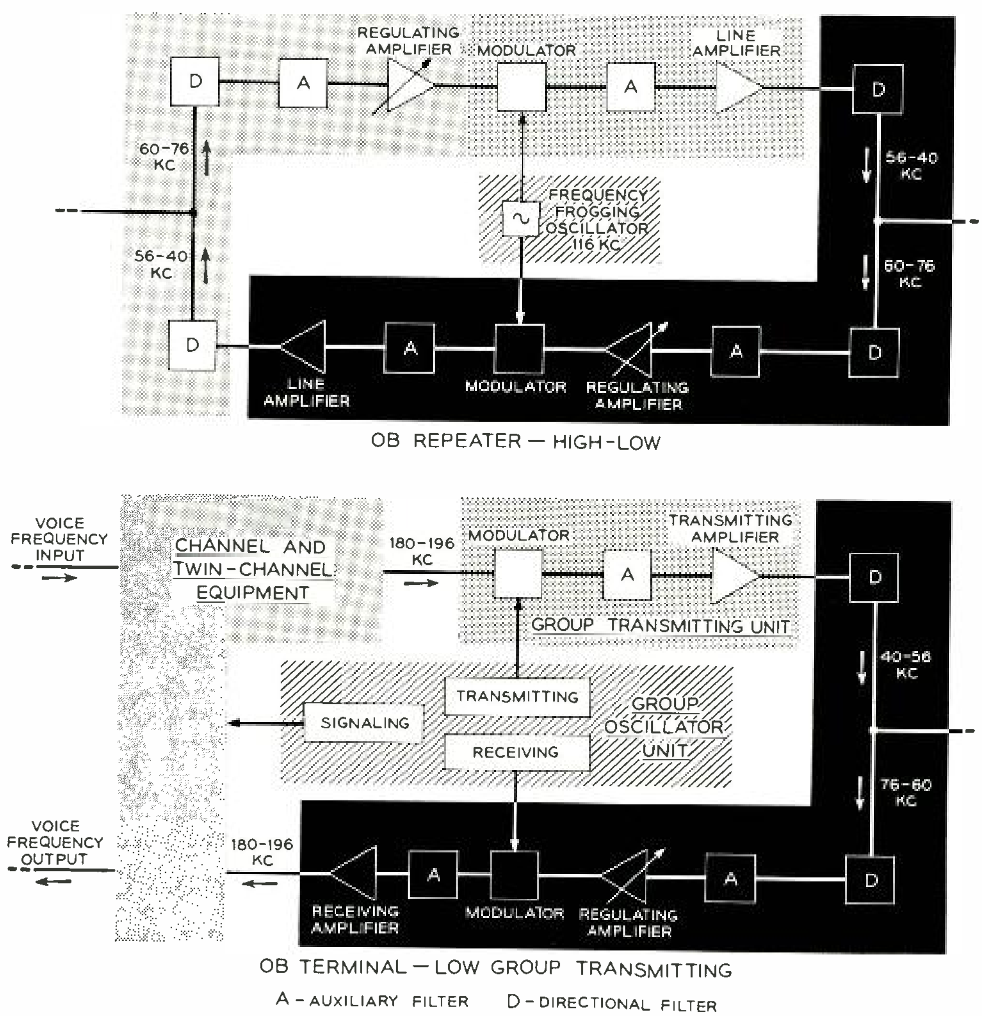


Fig. 3 — An OB repeater contains two repeater units and an oscillator. At a terminal, a group receiving unit, group transmitting unit, and group oscillator perform the same functions.

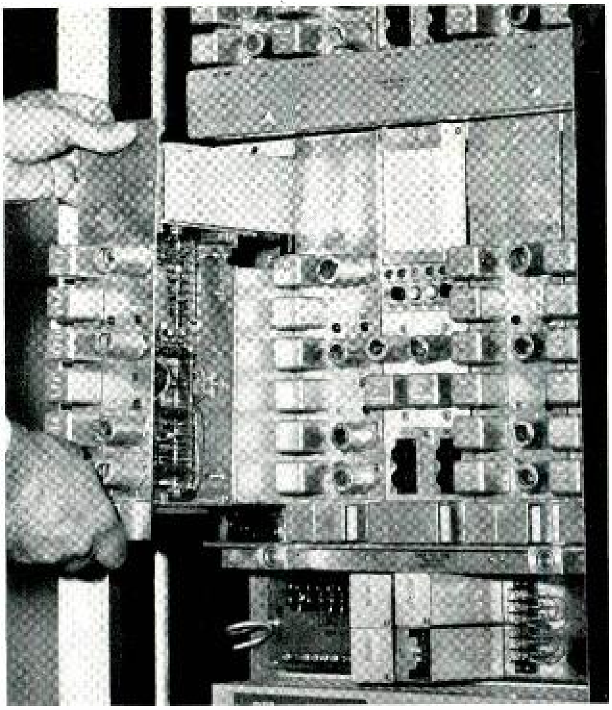


Fig. 4 — Two complete repeaters and a frequency-frogging oscillator mount on one frame.

peaters of Type-N carrier.* Ahead of each modulator is a two-stage regulating amplifier, which maintains a practically constant input to the modulator for line losses from 0 to 40 db. In extremely bad weather, ice sometimes forms on the line wires, and the line loss may be as much as 50 db when a radial thickness of 1/4 inch of ice accumulates. Under such conditions the modulator input is reduced about 2.5 db. This is usually corrected for by subsequent repeaters or, at a terminal, by the twin-channel regulators. Some impairment in transmission is likely to occur however, due largely to increased interchannel modulation crosstalk under such extreme conditions.

The functions of a repeater include selecting the proper frequency band, compensating for line losses, providing frequency-frogging, and amplifying the frequency band for transmission. These functions, except for the frequencies involved, are the same for both high-low and low-high repeaters. In Type-O, auxiliary filters are used in addition to the directional filters to remove unwanted modulation products and to reduce crosstalk. A repeater unit, then, consists of a directional filter with input and output sections, an input auxiliary filter, a regulating amplifier, a modulator, another auxiliary filter to "clean up" the output of the modulator, and the line amplifier that is illustrated in detail in Figure 3.

Two repeater units plus an oscillator unit make up a two-way repeater for a single four-channel system. A repeater frame, or shelf, has mounting and power facilities for two complete repeaters as shown in Figure 4. These repeaters may be for different systems on the same open-wire pair, or for the same type of system operating on two different pairs. Special cabinets are used for pole-mounted repeaters, with each cabinet containing two repeater frames and associated equipment sufficient for four repeaters.

Considerable thought was given to the matter of economy, and the designers realized that some units of a system might well serve more than one purpose. Comparison of the block diagrams of an OB terminal and an OB repeater in Figure 3 shows that the receiving portion of a terminal performs the same functions as either half of a repeater. Because of this, one basic amplifier-modulator unit was designed to do both jobs. In a terminal, a basic repeater unit is used for receiving but is called a group receiving unit. In the group receiving unit, however, that portion of the auxiliary filter unit immediately following the modulator does not pass line frequencies. Instead, it passes only the "base-band" frequencies – 180 to 196 kc – used in channel units, since the incoming line frequencies have been translated to this band in the modulator. The group receiving unit output feeds into the twin-channel and channel equipment instead of into a directional filter as in repeaters.

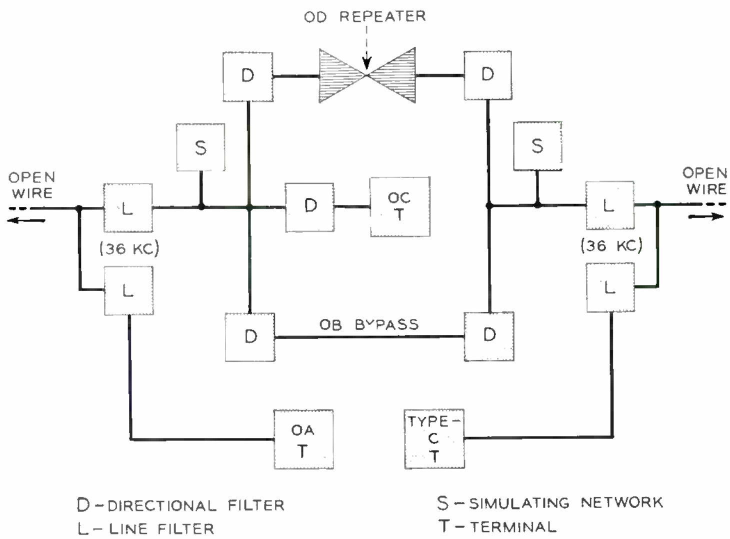


Fig. 5 — One of the many possible arrangements of the Type-O carrier system.

Two additional group units are used at terminals:

* RECORD, *September*, 1953, *page* 347.

group transmitting and group oscillator. The group transmitting unit, containing a modulator, a modulator filter, and a transmitting amplifier, performs some of the functions of a repeater unit. The modulator input is the "base-band" of frequencies from the channel and twin-channel equipment of the terminal. The output of the modulator is at the desired line frequency and, depending upon the group oscillator frequency supplied to the modulator, it may be either high group or low group.

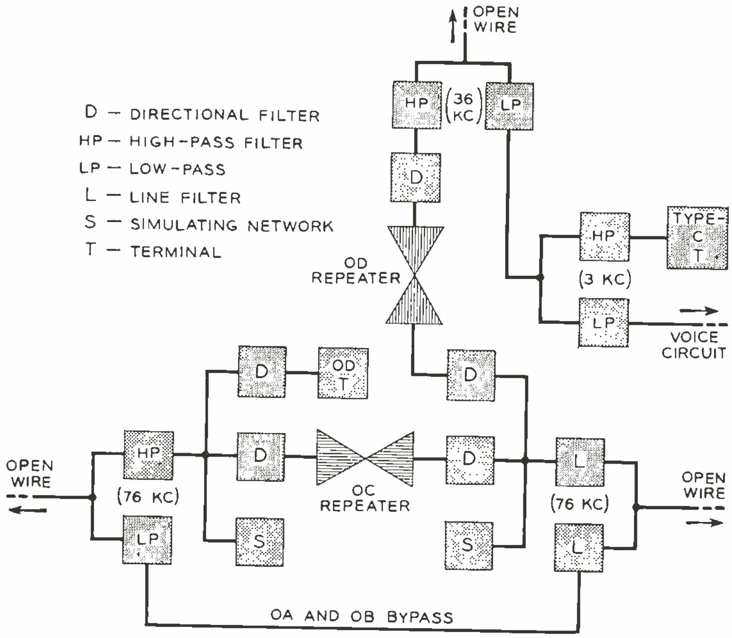


Fig. 6 — A possible arrangement of Type-O carrier systems at a branch point.

The group oscillator unit contains three oscillators. Two of these, which are crystal-controlled high-frequency oscillators, supply to the group transmitting and receiving units respectively the proper frequencies for translating "base-band" frequencies from the channel units to line frequencies and vice-versa. Strapping arrangements permit interchanging the connections to these two oscillators when it is desired to change a terminal from high-group transmitting to low-group transmitting or the reverse. Also in the group oscillator unit is the 3,700-cycle oscillator that supplies tone to the channel units for signaling purposes. This oscillator is a Wien-bridge RC-type oscillator such as is used in Type-N carrier for this purpose. Since it is common to four channels, it is included in this unit for convenience.

Type-O carrier was specifically designed to be applicable to existing open-wire lines with a minimum of line retransposition. OB systems are generally used on lines already equipped with Type-C carrier, and OC and OD systems may be added if the lines are retransposed. OA, however, occupies the same frequency space as non-frequency-frogged type-C. To coordinate with Type-C carrier that might be on other pairs of a line, OA repeaters are not frequency-frogged and the high and low groups proceed unchanged from one terminal to the other. For this reason, OA repeaters do not include modulators or oscillators. OA group receiving units contain adjustable slope-equalizing networks to compensate for the slope of the line (only in frequency-frogged systems do successive line sections compensate for each other). Since, as in the other systems, the OA group receiving unit must contain a modulator, special repeater units are provided for OA. Offsetting the cost of an additional type of unit, the lower frequencies of OA require less regulation and permit the use of much simpler filters. In the OA group transmitting unit, for example, the modulator filter is eliminated and the transformer windings are used as filter elements.

THE AUTHOR:

Harold Taylor King was graduated cum laude from Harvard College in 1930 with a Bachelor of Arts degree and was employed by the Laboratories the same year. Since then Mr. King has been engaged exclusively on development work in connection with carrier telephone and telegraph systems of single and multichannel and short and long haul types. Mr. King saw active service in the field artillery during World War II. He served in Italy, France, Germany and Austria as an executive officer and then as a commanding officer of a heavy artillery battalion. He received a Bronze Star Medal. For a short period, recently, he was engaged in development of a carrier system for rural subscribers. However, he returned to short-haul carrier development and is presently the project engineer on the development of a new short-haul cable carrier system.

In some instances a repeater installation will contain repeaters of all four systems, while in others only one or two will be used. Since the higher frequencies of the OC and OD systems require repeaters spaced roughly half as far apart as the two lower frequency systems, some repeaters will contain only OC and OD repeater units. Also, one system may have a terminal or a branch point where the other systems do not. For one or more of these reasons, it is sometimes necessary to bypass one system, or even a group of systems, yet repeater the others. In other installations, some systems must be repeatered while others must be terminated. Figures 5 and 6 illustrate typical situations that may be encountered. In some instances, bypassing is accomplished by connecting directional filters back to back. In other situations, high- and low-pass line filter combinations are used to separate OC and OD systems from OA and OB or to separate OD from the other systems. Since the OB, OC and OD directional filters are designed to work in parallel, the absence of one or more of these causes undesirable transmission effects on those that remain. For this reason, compensating networks are supplied to simulate the presence of filters that are not used. Several different types of compensating networks are available to take care of the different arrangements that may be encountered.

Group units are operated from the usual central office 48-volt and 130-volt power supplies; repeaters may operate on 130 volts alone if no 48-volt supply is available. In pole mounted repeaters, each repeater cabinet supplies 130 volts dc from rectifiers on 115-volt commercial ac power. In emergencies, the repeaters may be arranged to automatically switch to standby power supplied by batteries and a 130-volt dynamotor in a separate pole-mounted cabinet.

New Highways for Long Distance Traffic

A major step in placing long distance telephone traffic on a dial basis – a step involving substantial changes in Long Lines' routing structure – took place on November 21 when 4A switching systems were placed in operation at White Plains, N. Y., Charlotte, N. C. and Denver, Colo. These systems bring to 32 the total of No. 4 type crossbar systems in the Bell System, of which 16 will be of the 4A type. They are part of a program to convert to the nationwide dial switching plan designed to improve the speed of long distance service and keep the cost as low as possible.

In the 4A system, an outstanding feature is automatic alternate routing whereby the system can automatically offer a call to one or more other routes if all the circuits in the first route are busy. To make efficient use of this feature, which is made possible by equipment called "card translators," it is necessary to carry out major rearrangements in trunking facilities. Under these, a majority of the circuit groups are engineered on a "high usage" basis which contemplates overflowing a part of the traffic automatically to other groups in such a way that all the circuits are used at high efficiency. At the same time, relatively few calls will ever encounter a delay in completion. The rearrangements will provide both good service and more economical use of facilities.

To enable automatic alternate routing to follow the most efficient paths, rerouting of many circuits is necessary. Planning for the rerouting job began four years ago when Long Lines made studies of all traffic which should be routed through the No. 4 systems by using automatic alternate routes. The plans were later reviewed in the light of 4A capacity.

The routing changes involved in the White Plains, Charlotte and Denver systems call for discontinuing 90 existing circuit groups and establishing 100 new ones between various offices. As part of this job, traffic people throughout Long Lines and other units of the Bell System have been working for several months to furnish 2,600 operating centers across the country with revised routing instructions. This has required 22,000 changes in routes at 330 larger offices, and even more changes in routes to 1,800 other offices. In addition, in practically all the larger telephone centers, changes are required in first preference route lists and in bulletins at switchboard positions so that operators may start using the new routes as soon as the systems are cut over.

Intertoll Features of No. 5 Crossbar

K. M. FETZER *Switching Systems Development*

The No. 5 crossbar system for the automatic switching of telephone calls was designed primarily for local central offices. However, it also has such tandem and intertoll features as automatic alternate routing and code conversion. These features are designed to aid the expanding nationwide program for direct distance dialing.

Broadly speaking, there are three types of telephone switching: local, tandem, and intertoll. In local switching, the desired telephone connection is set up within a single office or is switched to a second local office for completion. A tandem office, however, acts as a central distributing point for local offices surrounding it, and thus saves the extra equipment and outside plant that would be necessary if all the offices were independently connected to each other. In tandem switching, a call is switched from the local to the tandem office, and thence to a second office for completion. The third or intertoll type of switching involves longer distance calls, and a chain of several intertoll offices may be required for a particular long-distance connection.

To understand the role of the No. 5 crossbar system in such switching patterns, it is necessary to visualize the orders of complexity involved. In terms of the number of possible switching combinations and in terms of transmission requirements, long-distance switching is more complex than is local switching, and tandem switching occupies an intermediate position. No. 5 crossbar, although designed primarily as a local switching system, includes tandem and intertoll features that are useful in many locations. Particularly, by incorporating some of the more complex long-distance switching features, it is contributing to the program that has as its objective customer-dialing of all calls throughout the United States and Canada. No. 5 crossbar is helping to establish larger and larger areas of customer dialing and is aiding the gradual growth toward the ultimate objective.

With this broad pattern in mind, let us explore the types of installations for which No. 5 crossbar is particularly suited. In the nationwide plan,* cities and towns are assigned differing ranks according to their strategic importance as long-distance switching centers. A single city, St. Louis, is designed as the National Center. Eight other cities rank as Regional Centers. Next in order come Sectional Centers, then Primary Centers, Toll Centers,

Above — The author observing operation of intertoll trunk circuit, Bell Laboratories No. 5 crossbar switching equipment.

* Record, *November*, 1953, *page* 369.

and Toll Points. In line with this terminology, the lowest ranking switching point is the End Office or Local Office.

No. 5 crossbar is suitable for the local and tandem portions of the switching in any of the cities. The intertoll features of the No. 5 system, however, are most suitable for the Primary Centers, Toll Centers, and Toll Points. The higher ranking Regional and Sectional Centers, and the National Center, have more severe trunking and transmission requirements for which the No. 5 was not designed. The No. 4A or 4M switching systems are instead used in the National Center and in the Regional Centers. Sectional Centers require 4A, 4M, or crossbar tandem equipment; No. 5 can be used in such a center, but will probably be restricted to a few of the smaller installations.

For the purpose of distinguishing between the functions of No. 5 crossbar and those of the other switching systems, it is necessary to appreciate the significance of automatic alternate routing and code conversion in the nationwide plan. For the most efficient and economical use of switching equipment and trunking paths, routes must be planned so that trunks are in use a high percentage of time.* This is accomplished by letting the more direct routes carry a substantial part of the ordinary loads, and by sending "overflow" traffic over alternate routes. To handle the more complex switching, larger numbers of alternate routes are required. Code conversion is also important in the nationwide plan, since numbering-area digits or office-code digits must sometimes be converted to another group of digits for switching to step-by-step offices.

* Record, *February*, 1954, *page* 51.

The No. 5 crossbar system provides as many as three alternate routes. The No. 4-type offices, for comparison, provide as many as five alternate routes in the higher ranking centers. No. 5 crossbar also has maximum ability to code convert. It can delete up to six digits from a ten-digit number, and can add one, two, or three arbitrary digits, as required.

The automatic alternate routing feature is illustrated by Figure 1. This drawing represents a possible layout of eight Toll Centers, three Primary Centers, and one Sectional Center, with intertoll trunk routes interconnecting them. Actual routing arrangements may be much more complex than those described in the following paragraphs, but this example will illustrate a situation involving two of the possible three alternate routes.

Consider first a call from Toll Center (1) to Toll Center (4). This call could be switched over the direct route to Toll Center (4). If these trunks are busy, however, the call can be switched over a first alternate route via Primary Center (2); and if the first alternate trunks are busy, the second alternate route is via Primary Center (1). A No. 5 crossbar office at Toll Center (1) would be able to test these separate groups of trunks in sequence to find an idle path for the connection.

It will be noticed that in Figure 1, some of the trunks are designated "high usage" and others are designated "final." As these labels imply, the high usage routes will always be tried first, whereas the final routes are used only when the high usage routes have not been provided or cannot handle the traffic. The final routes are generously supplied with trunks; in telephone language they are termed "liberally engineered," so that the probability of find-

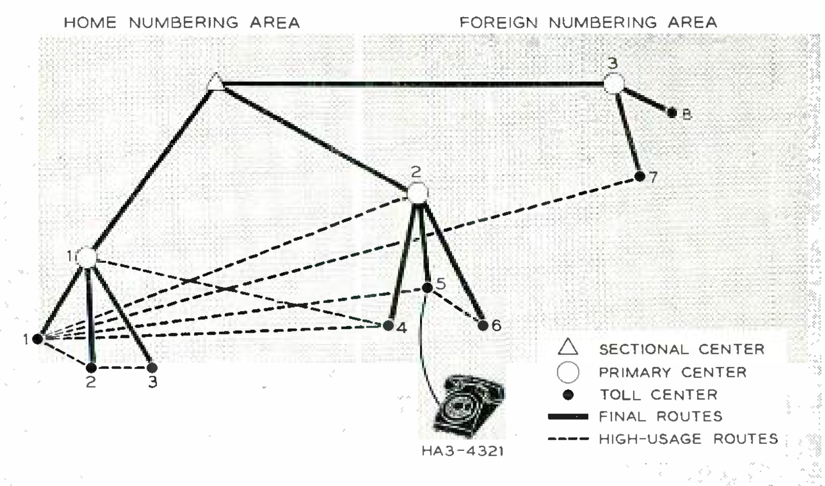


Fig. 1 — Possible layout of Toll Centers, Primary Centers, and a Sectional Center, illustrating No. 5 alternate-routing and code-conversion features.

ing all trunks busy in a normal busy hour should be no more than three in one hundred. In a high usage route this probability is greater.

Figure 1 also serves to illustrate code conversion, a second feature of No. 5 crossbar that is necessary to the national switching plan. Assume that the local and intertoll switching systems at Toll Center (1) and Primary Center (1) are No. 5 Crossbar, but that Primary Center (2), which is in a different numbering area, is a step-by-step office with step-by-step intertoll switching. A customer served by Toll Center (1) might want to dial another customer served by Toll Center (5), whose directory number is HA3-4321. The calling customer in this case would dial a ten-digit number, perhaps 301-HA3-4321. In completing the call over a direct trunk to Toll Center (5), the No. 5 crossbar equipment at Toll Center (1) would delete the 301, since in this situation only the seven-digit number is required for completing the call from Toll Center (5) to the called customer.

If the call is switched over an alternate route via Primary Center (2), however, an arbitrary code may be necessary to get through the step-by-step switches. The No. 5 crossbar equipment at Toll Center (1) would therefore delete the 301 and would substitute the arbitrary code, perhaps 083. Over a second alternate route, this code conversion would have to be accomplished at the Sectional Center. Here, Toll Center (1) would send out the complete 301-HA3-4321, which would be passed on to the Sectional Center. The Sectional Center would then code convert to 083-HA3-4321 for switching through Primary Center (2).

These are some of the broad aspects of the nation-wide dialing plan as related to No. 5 crossbar

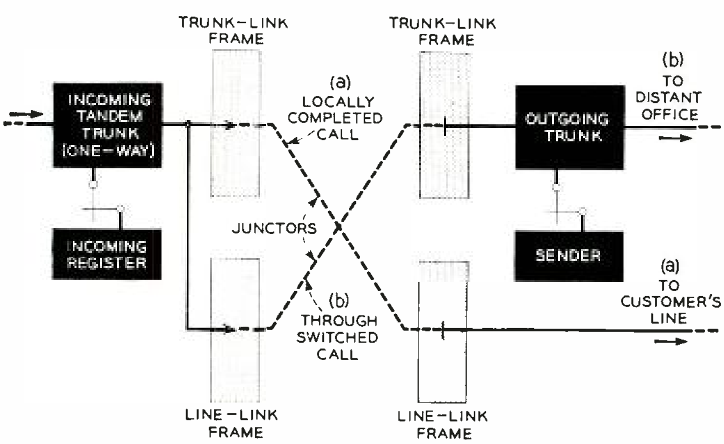


Fig. 2 — Switching paths through No. 5 crossbar for calls incoming over tandem trunks.

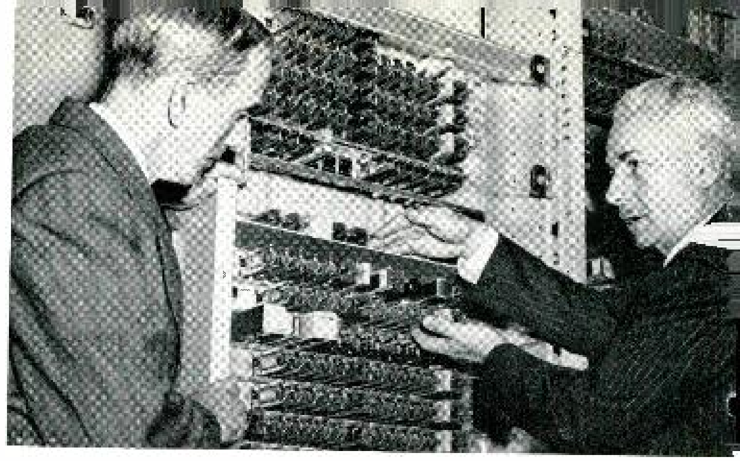


Fig. 3 — W. J. Scully (left) and R. E. Hersey discussing digit registers in the No. 5 crossbar equipment at Bell Telephone Laboratories.

switching. We can now look more closely inside the No. 5 system and see how the tandem and intertoll switching is accomplished with minimum departure from the pattern of local switching. The registers, markers, senders, and other equipment that set up the tandem and intertoll calls through the office are the same common-control elements that set up local calls. Likewise, the line-link frames and trunk-link frames through which the tandem and intertoll calls are switched are the same as those used for local calls.

Figure 2 illustrates the paths through a No. 5 crossbar office on a call that comes in over a tandem trunk and that is either completed locally or switched through to a distant office. If the call is completed locally, the switching is the same as if the call came in over an incoming non-tandem trunk. If the call switches through the office, the incoming tandem trunk assumes to a large degree the aspects of a customer line originating a call, and the switching is very similar to that of a customer call to a distant office.

Incoming intertoll calls are terminated locally or switched through in much the same way as the calls over tandem trunks. There are important differences, however, which are partially illustrated in Figure 4. It should be noted that intertoll trunks are often two-way, whereas tandem trunks are one-way. Also, arrangements must be provided so that a long-distance operator can connect to outgoing intertoll trunks. More complex signaling methods are employed on intertoll trunks, and in addition to the usual selecting and supervisory signals, re-ring (recall) signals are passed over these trunks in cases where operators are involved in the connection. Among the other differences between the two types of trunking, automatic transmission adjustment is often employed on intertoll trunks, and such trunks must be so arranged that they can be switched to specific operators who may be assisting in the establishment of the long-distance connection. Finally, as illustrated in Figure 4, an incoming intertoll call destined for switching through the office has less chance of being blocked out by traffic congestion than does an incoming tandem call. This is because the intertoll trunk appears in two line-link frames, whereas only one is used for a tandem trunk. These differences indicate the more complex requirements

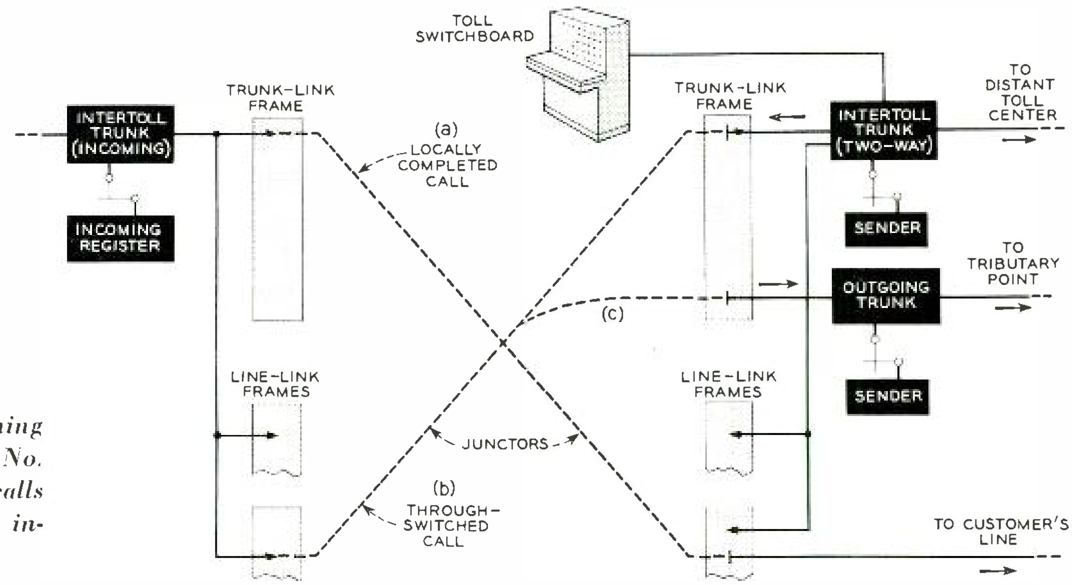


Fig. 4 — Switching paths through No. 5 crossbar for calls incoming over intertoll trunks.

for the switching of long-distance calls, and they illustrate the added duties assumed by a No. 5 Crossbar office when handling intertoll switching.

Figure 4 does not illustrate local customers being switched directly to outgoing intertoll trunks. The longer-distance calls are at the moment set up and ticketed by long-distance operators, except in a few offices like Englewood, New Jersey, which have been arranged for foreign-area customer dialing.* The intertoll features of the No. 5 crossbar system, however, will permit the extension of the range of customer-dialing, since the intertoll trunks are readily adaptable to customer-dialing access.

The main job in life for a No. 5 crossbar switching system is to provide local switching. If the No. 5 office is located in or contiguous to a large city, a long-distance call will ordinarily be directed to another switching system which will complete the call. However, if the intertoll features can be readily superimposed on the local switching, No. 5 equipment can direct the completion of a long-distance call and can handle all types of through-switched traffic more flexibly than any other presently used local switching system.

* RECORD, *January*, 1954, *page* 11.

THE AUTHOR:

KARL MCATEE FETZER received a B.E. degree from North Carolina State College in 1914. He has worked for the Bell System since 1920, when he joined the Western Electric Company in New York City after six years' experience in railway signaling. He transferred to the Laboratories in 1925 and has been working at West Street since that time. He was engaged in the development of toll switching and associated circuits from 1920 to 1942. In 1923 he was given charge of the toll circuit laboratory and in 1929 he became supervisor of a group concerned with terminal and signaling circuits. For three years during World War II, Mr. Fetzer worked on naval ordnance developments and he received a citation fom the Navy Bureau of Ordnance. Since 1945 Mr. Fetzer has been engaged in the development of the No. 5 crossbar local and intertoll switching system. He holds patents on toll switching circuits and one on an ordnance testing device.

Papers Published by Members of the Laboratories

Following is a list of the authors, titles, and place of publication of recent papers published by members of the Laboratories:

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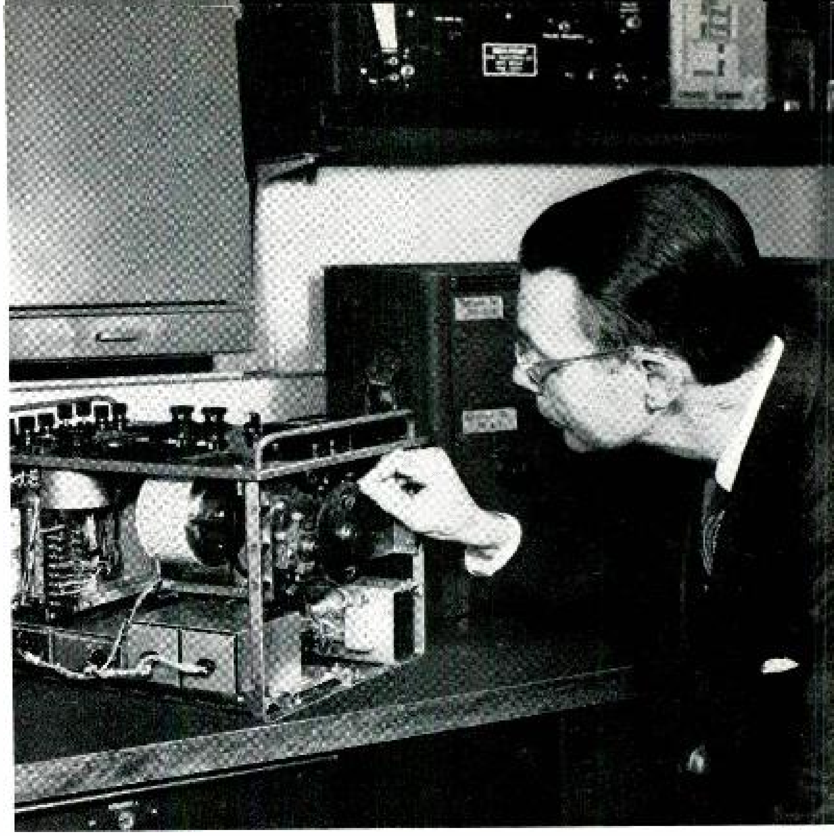
A New Frequency Analyzer



T. A. SPENCER *Transmission Development*

For many years, an important communication problem has been the "noise" and other interfering voltages induced onto telephone lines from nearby power lines. This noise is complex, being composed of many individual frequencies of different magnitudes. A first step in eliminating these induced voltages is to determine their characteristics. The new 4A frequency analyzer provides direct-reading scales for both frequency and magnitude measurements of interfering voltages and, in addition, is fully portable.

"Inductive co-ordination" is a term with little significance for many people, but to others it is of vital importance. Generally, it concerns the cooperation of various power companies and electrified railroads with the Bell System, in reducing the amount of noise induced onto telephone lines. In this instance, "noise" includes more than just unwanted sounds in telephone conversations or broadcast services supplied by the Bell System; induced voltages, although not necessarily troublesome as "noise," may often become high enough to damage telephone equipment or otherwise interfere with operation.

If power lines and telephone lines run parallel for a substantial distance, these voltages will be induced on the telephone lines. Distance between lines, types of line construction and circuits employed, harmonic content of the power voltages and currents, electrical balance of telephone lines, and other factors influence the severity of the inductive interference that will be produced. Cooperation can reduce this problem, but when it exists, some means of classifying and measuring the harmonic composition of the induced voltage is an aid in specifying a remedy. A frequency analyzer is used for this purpose.

Currently, a 10A analyzer attachment is used in combination with a 2B noise measuring set for these measurements. The new battery-operated portable 4A frequency analyzer, developed specifically for such measurements, has greater sensitivity and a wider frequency range, is calibrated to indicate frequency directly, is faster in operation, and is less subject to errors.

Since most "noise" is complex in nature, several frequencies may be involved; the new analyzer will indicate each specific frequency separately, and will also indicate the magnitude. It operates on the heter-

Above — The author checks the gears for minimum backlash. The helical scale moves longitudinally below the panel window as the drum rotates.

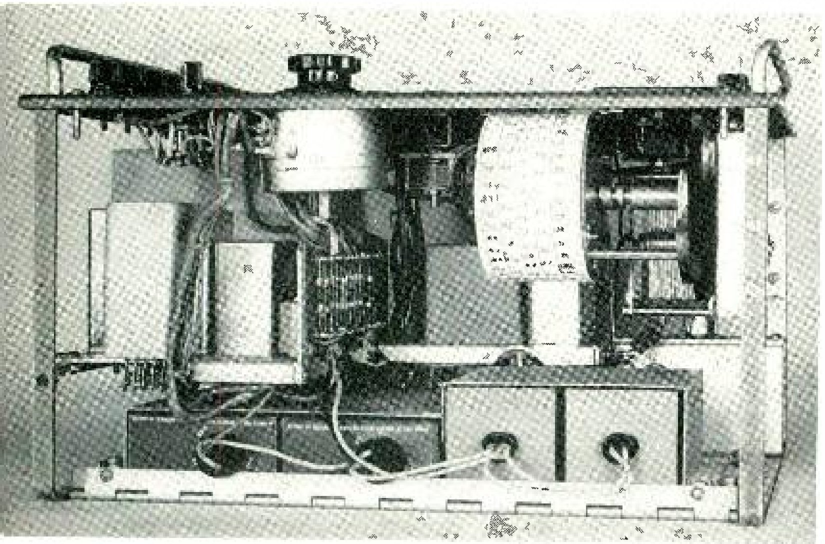


Fig. 1 — Front view of analyzer after removal from case.

odyne principle, that is, the beating of one frequency against another. In this instrument, a known variable frequency beats with the unknown interference to produce a difference frequency that will be passed by a narrow-band 80-kc band pass filter. For this condition,

$$80 \text{ kc} = f_v - f_x,$$

or

$$f_x = f_v - 80 \text{ kc}$$

where f_x represents the unknown interfering frequency and f_v represents a known frequency produced by a local variable oscillator.

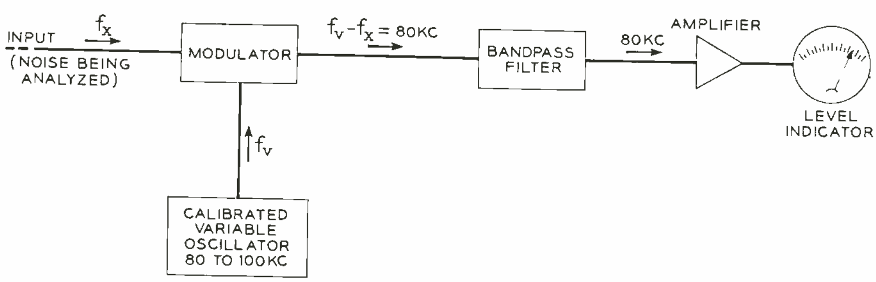


Fig. 2 — A simplified block diagram showing the operating principle of the 4A frequency analyzer.

As shown in the simplified block diagram of Figure 2, the output of the calibrated variable oscillator has a range of 80 to 100 kc and is always 80 kc higher than the unknown frequency. After modulation, the band-pass filter passes only the 80-kc difference component and rejects all other components. The magnitude of the passed component is proportional to that of the unknown frequency and is indicated accordingly on the level indicator. The actual level is obtained by adding the meter reading to that of the attenuator designated DECIBELS. Circuit-wise, the attenuator is located between the input and the modulator. The frequency is read directly from the calibrated scale where the 0 and 20 kc points correspond respectively to outputs of 80 and 100 kc from the variable oscillator.

An engineering model being used to make a test is shown in Figure 3. The input is connected at the left to one of four pairs of binding posts, depending on the type of circuit under test, and the input selector switch is positioned accordingly. A telephone receiver provided with the instrument may be connected to the MON binding posts beneath the meter to monitor the signal and to determine aurally the character of the component being measured. The set includes a local 900-cycle oscillator used for calibration of both level and frequency, and a battery protection feature to insure that there is no battery drain after the cover has been replaced.

The frequency is calibrated in kilocycles and covers a range from 25 cycles to 20 kc; in 60-cycle steps from 60 cycles to 3 kc, and in 100-cycle steps from 3 to 20 kc. As shown in Figure 1, the scale consists of a helix around a 4-inch diameter drum, and the total scale length is 60 inches (about twelve times as long as that commonly encountered in home radio sets). The scale mechanism is operated by the thumb wheel at the right of the scale window. The scale drum rotates in step with the thumb wheel and makes five revolutions while the associated variable capacitor rotates 180 degrees, giving a ratio of 10 to 1. As the drum rotates it follows a helical groove having the same pitch as the scale and moves axially past the narrow window to display the appropriate part of the scale.

Various other means for providing an expanded scale were considered, including a spiral scale on a disc, a non-consecutive scale requiring the use of a switch to select the wanted part of the scale, and a continuous film scale. The helical scale on a sliding drum is considered a good solution for

Fig. 3 — R. A. Patterson makes a test of an interfering frequency. The receiver gives aural recognition of the interference.

the intermediate-length scale involved and minimizes the amount of panel space used. Calibration of the drum is simplified by using a fixture temporarily mounted in the scale window.

It is estimated that with normal use the A battery will last 250 hours, and the B battery will last 400 hours. The batteries are arranged for ease of battery replacement, individually or collectively, and the whole battery compartment can be readily removed to give greater access to the wiring. The instrument is fully portable, and the over-all weight is only 42 pounds. It has a frequency range of 20 kc, a band width of 10 to 15 cycles, a level-measuring range of 85 db, a discrimination of 60 db at 60 or more cycles from the midband frequency, and an over-all accuracy of ± 0.5 db.

This 6-tube set is a valuable tool for use in any frequency analysis problem within its range. The design has placed special emphasis on the application of the analyzer to Bell System inductive coordination problems, and in field use it has proved convenient and effective for this purpose.

THE AUTHOR

THOMAS A. SPENCER joined the Bell System in 1921 and became a member of the Laboratories in 1924. From 1925 to 1932 he acted as liaison between factory engineers and research and development organizations. He became supervisor of this group, which was primarily concerned with manual and toll telephone systems, in 1928. Mr. Spencer was later concerned with automatic telephone switching systems and twelve-channel carrier telephone equipment. In 1937 he became supervisor of liaison between factory engineers and research and development organizations on carrier telephony, radio transmission and manual telephone systems. Between 1940 and 1949 Mr. Spencer worked with carrier telegraph switching facilities, radio telegraph facilities for the armed forces, telephone interoffice trunk signaling and oscilloscopes, and automatic message accounting equipment for automatic telephone switching systems. Since 1949 he has been associated with primary frequency standard facilities and electronic devices, including test sets. Mr. Spencer attended North Carolina State College and Georgia Technical Institute. He is a New York State Professional Engineer and a former member of the A.I.E.E.

R. Bown Named to Government-Industry Research Committee

Ralph Bown, vice president of the Laboratories, has been named to a Government-Industry Research Committee recently organized by the National Academy of Sciences – National Research Council.

The committee will be concerned with the common interests and relationships of industrial and governmental research, particularly in the area of applied research. This will include exploring the need for better acquaintance and understanding between government and industry research leaders.

When its services are requested, the committee proposes to consider first the extent to which the need can be satisfied by existing mechanisms. If appropriate, the committee may then designate a group which would work to improve understanding and relationships between government and industry people in the field concerned.

W. G. Pfann to Receive the Mathewson Gold Medal

William G. Pfann of the Laboratories' Metallurgical Research Department, who invented the zone-melting process, was recently named to receive the Mathewson Gold Medal, annual award of the American Institute of Mining and Metallurgical Engineers. The zone-melting process is an extremely simple method for refining germanium and other materials to practically perfect purity.

Mr. Pfann was named as the recipient of the award for 1955 in recognition of his contributions to the science of metallurgy, as described in three papers in the Institute's monthly publication, *Journal of Metals*. The Mathewson Gold Medal is named for C. H. Mathewson, who headed the School of Metallurgy at Yale University. Past recipients have included some of the most famous names in American metallurgy. The medal will be presented to Mr. Pfann on February 16 at the Conrad Hilton Hotel in Chicago.

Mr. Pfann has been employed by the Laboratories since 1935. He received a B. Ch. E. degree from Cooper Union in 1940. He worked on silicon rectifier development from 1942 to 1945, on electrical contact studies from 1946 to 1947 and on transistor materials and processes beginning in 1948.

Seven Laboratories Men Named As I.R.E. Fellows

Seven Laboratories men are included in the group of seventy-six leading radio engineers and scientists recently named as Fellows of the Institute of Radio Engineers. Presentation of the awards, with citations, will be made by the President of the Institute at the annual banquet on March 23, 1955, at the Waldorf-Astoria Hotel during the 1955 national convention. The Laboratories recipients of the Fellow awards, effective January 1, are:

KENNETH BULLINGTON – For his contributions to the field of radio propagation.

C. C. CUTLER – For his research on microwave antennas and tubes.

R. L. DIETZOLD – For his application of mathematics to network design and military problems.

J. B. FISK – For his contributions to the development of the magnetron and his leadership in basic electronic research.

E. I. GREEN – For his contributions in the development of communication systems and apparatus components.

R. S. OHL – For his contributions to the development of solid state point contact rectifiers.

WILLIAM SHOCKLEY – For his contributions to development of the transistor.

The grade of Fellow is the highest membership grade offered by the Institute and is bestowed only by invitation on those who have made outstanding contributions to radio engineering or allied fields.

H. T. Friis Receives Poulsen Medal

Harald T. Friis, Director of Research in High Frequency and Electronics, was honored recently with the presentation, by the Danish Academy of Technical Sciences, of the Valdemar Poulsen Gold Medal.

The medal, named in honor of the late Valdemar Poulsen, Danish inventor and pioneer in electrical engineering and communications, was awarded to Dr. Friis in recognition of his notable contributions in the field of radio technology and especially his "important works on the application of short and ultra-short radio waves and, simultaneously, on atmospherics."

Dr. N. E. Holmblad, a member of the Danish Academy of Technical Sciences, presented the medal to Dr. Friis in the presence of Thorkild Wegener-Clausen, Acting Danish Consul General, and a number of Dr. Friis's Bell System colleagues, at a dinner in New York City.

Talks by Members of the Laboratories

During November, a number of Laboratories people gave talks before professional and educational groups. Following is a list of the speakers, titles, and places of presentation:

Anderson, O. L., Visco-Elastic Density Changes in Glass, Annual Meeting of the Society of Rheology, Washington, D. C.

Archer, R. J., Rate of Evaporation of Water Through Monolayers of Fatty Acids, Meeting of National Academy of Sciences, Columbia University, New York City.

Arnold, W. O., The Problem of Displaying Air Traffic Control Information – Including Description of New Type Three Dimensional A.T.C. Information Display, East Coast Conference on Airborne and Navigational Electronics, Baltimore, Md.

Baird, J. A., Transistor Principles and Applications, Texas A & M College, College Station, Texas.

Beck, A. C., Measurement Techniques for Multi-Mode Waveguides, Joint Symposium on Modern Advances in Microwave Techniques, New York City.

Boysen, A. P., and Walker, C. L., Surface Temperature Correlation with Deep Water Sound Transmission, Tenth Navy Symposium on Underwater Acoustics, Austin, Texas.

Bozorth, R. M., The Physics of Magnetic Materials, Ithaca Section of the A.I.E.E., Binghamton, N. Y.

Brattain, W. H., see Garrett, C. G. B.

Burns, R. M., Chemistry in Telephony, Analytical Chemistry Seminar, Massachusetts Institute of Technology, Cambridge, Mass.

Ciccolella, D. F., The Bell Solar Battery, Hydraulic Old Timers Section, A.I.M.E., New York City.

Collins, R. J., Reynolds, F. W., and Stilwell, G. R., Electrical and Optical Properties of GaSb Films, American Physical Society, Chicago.

Cutler, C. C., Characteristics of the Spent Beam of a Traveling Wave Tube, Conference on Traveling Wave Tubes with Non-Linear Characteristics, Cornell University, Ithaca, N. Y.

Danielson, W. E., Space Charge Waves on an Accelerating Stream of Uniformly Charged Laminae, Symposium on Fluctuation Phenomena in Microwave Sources, New York City.

Darlington, S., Network Synthesis Using Tchebycheff Polynominal Series, Philadelphia Chapter of I.R.E., Professional Group on Circuit Theory, Philadelphia.

Dickieson, A. C., A 4,000-Mc Radio Relay System, Student Section of A.I.E.E. at Lehigh University, Bethlehem, Pa.

Dodge, H. F., Chain Sampling and Skip-Lot Sampling, Metropolitan Section of the American Society for Quality Control, New York City.

Early, J. M., Junction Transistors at Very High Frequencies, New York Chapter of the I.R.E. Professional Group on Electron Devices, New York City.

Eder, Miss M., Warner, R. M., and Keene, F. R., Statistically Designed Experiment of the Factor Type Applied to Point-Contact Transistors, I.R.E. National Symposium on Quality Control, New York City.

Fletcher, R. C., Hyperfine Splitting in Electron Spin Resonances of Donors in Silicon, American Physical Society, Chicago.

Fuller, C. S., Applications of Physical Chemical Methods to the Semiconductor Field, Northwestern University, Chicago.

Garrett, C. G. B., and Brattain, W. H., Photo-Effects in Germanium at Room Temperature, Photo-Conductivity Conference, Office of Naval Research, Atlantic City, N. J.

Garrett, C. G. B., Physical Properties of Germanium Surfaces, Physics Colloquium, Brown University, Providence.

Geller, S., and Schawlow, A. L., The Crystal Structure and Quadrupole Coupling of BrCN, Joint Meeting of Pittsburgh Diffraction Conference and American Crystallographic Association, Mellon Institute, Pittsburgh.

Germer, L. H., The Role of Field Emission in Electrical Breakdown, Symposium on Field Emission, Pittsburgh.

Gohn, G. R., Fatigue – The Problem and Some Solutions, S.S.M.E. Annual Meeting, New York City.

Graham, R. E., Modulated Control Systems, Joint Study Group of New York A.I.E.E. and I.R.E. Communications Divisions, New York City.

Hanna, O. A., Laminated Cross-Arms, Forest Products Research Society, New York City.

Hannay, N. B., The Mass Spectroscopy of Solids, Chemistry Colloquium at Indiana University, Princeton Section of American Chemical Society, Bloomington, Ind.

Haynes, J. R., and Hornbeck, J. A., The Trapping of Minority Carriers in Silicon, Photo-Conductivity Conference, Office of Naval Research, Atlantic City.

Herring, C., Theoretical Ideas Pertaining to Traps or Centers, Conference on Photo-Conductivity, Office of Naval Research, Atlantic City.

Hornbeck, J. A., see Haynes, J. R.

Keene, F. R., see Eder, M., Miss

Keywell, F., Measurements and Collision Theory of High Vacuum Sputtering, Seventh Annual Gaseous Electronics Conference, New York University.

Kohn, W., Theory of Hyperfine Splitting of Donor States in Silicon, American Physical Society, Chicago.

Kompfner, R., Recent Developments in Traveling Wave Tubes, Seminar, Faculty of Applied Physics, Harvard University, Cambridge, Mass.

Luttinger, J. M., Recent Developments in the Effective Mass Theory for Semiconductors, American Physical Society, Chicago.

Mason, W. P., Low Temperature Attenuation Measurements in Lead Single Crystals and their Bearing on Acoustic Losses due to Dislocation Motions, Acoustical Society Meeting, Austin, Texas.

McFee, R., Research in Electrocardiography, A.I.E.E.-I.R.E. Medical Electronics Conference, Chicago.

Moshman, J., A Two-Sample Procedure for Linear Discrimination and Normal Samples, Graduate Seminar in Mathematics, Princeton University, Princeton, N. J.

Pearson, G. L., The Bell Solar Battery – A Silicon p-n Junction Photovoltaic Device, North Carolina Section A.I.-E.E., Raleigh, N. C.

Talks by Members of the Laboratories, Continued

Peterson, J. W., Contact Charging Between Insulators and Metals, Seminar on Solid State Physics, Cornell University, Ithaca, N. Y.

Pierce, J. R., General Sources of Noise in Microwave Tubes, Symposium on Fluctuation Phenomena in Microwave Sources, New York City.

Pierce, J. R., Recent Developments in Microwave Tubes, Microwave Symposium, New York City.

Raisbeck, G., The Bell Solar Battery, Joint A.I.E.E.-I.R.E.-E.S.W.P. Meeting, Pittsburgh.

Raisbeck, G., The Bell Solar Battery, 25th Anniversary Meeting of Mahoning-Shenango Valley Engineering Society, Newcastle, Pa.

Reiss, H., Mathematical Methods for Zone Melting Processes, Institute of Metals Division, American Institute of Mining and Metallurgical Engineers, Chicago.

Reiss, H., Ionization and Solubility of Impurities in Semiconductors, Brookhaven National Laboratory, Patchogue, Long Island.

Reynolds, F. W., see Collins, R. J.

Ross, D., Turbulent Flow in the Entrance Region of a Pipe, American Society of Mechanical Engineers, New York City.

St. John, G. E., Noise Figure of Traveling-Wave Tube, Symposium on Fluctuation Phenomena in Microwave Sources, New York City.

Schawlow, A. L., see Geller, S.

Sharp, W. O., Transatlantic Submarine Cable, Mens Club of First Methodist Church, Floral Park, Long Island.

Slepian, D., Communication Systems and the Geometry of N Dimensions, I.R.E. Section, Columbus, Ohio.

Slepian, D., Information Theory, Western Society of Engineers, Chicago.

Stilwell, G. R., see Collins, R. J.

Terry, M. E., The Analysis of Variance, Meeting of the Power and Industrial Section of A.I.E.E., New York City.

Tien, P. K., and Walker, L. R., Calculation on Overload Characteristics of Traveling Wave Amplifiers, Cornell University, Ithaca, N. Y.

Tyne, G. F. J., Miniaturized Apparatus Components, Erie County Technical Institute, Buffalo.

Von Ohlsen, L. H., The Small Signal Performance of the 416B Planar Triode Between 60 and 4,000 Megacycles, I.R.E. Symposium on Fluctuation Phenomena in Microwave Sources, New York City.

Walker, C. L., see Boysen, A. P.

Walker, L. R., see Tien, P. K.

Warner, R. M., see Eder, Miss M.

Washburn, S. H., Information Processing of Digital Control Circuitry, Student Group at Tufts College, Medford, Mass.

Patents Issued to Members of Bell Telephone Laboratories During the Month of October

Andrus, J. – *Cutting Tool* – 2,691,858.

Balch, H. T. – *Modulator Circuit* – 2,692,371.

Beck, A. C., and Ring, D. H. – *Frequency Stabilized Oscillator* – 2,691,734.

Briggs, H. B. – *Semiconductive Light Valve* – 2,692,952.

Cesareo, O., and Strickler, W. B. – *Automatic Calculator* – 2,692,082.

Christensen, H., and Teal, G. K. – *Method of Fabricating Germanium Bodies* – 2,692,839.

Cornell, W. A. – *Electrical Circuits* – 2,691,729.

Dickieson, A. C., Edwards, P. G., Robertson, D. D., and Wurmser, A. V. – *Speech Interpolated Communication System* – 2,692,303.

Edwards, P. G., see Dickieson, A. C.

Fondiller, W. – *Isothermal Electromagnetic Apparatus* – 2,692,961.

Galt, J. K. – *Ferrite Inductors* – 2,692,978.

Hanson, R. L. – *Oscillation Generator* – 2,692,337.

Haynes, J. R. – *Electrical Translation Device Including Semiconductor* – 2,691,736.

Hoyt, F. A. – *Coin Collector* – 2,691,484.

Ketchledge, R. W. – *Transmission Regulation* – 2,692,307.

Kock, W. E. – *Aperture Antennas* – 2,692,336.

Kreisel, R. R., and Polk, R. E. – *Apparatus for Testing Leaky Receptacles* – 2,691,297.

Kuch, F. C. – *Flaw Tester for Tape* – 2,692,499.

Lander, J. J. – *Carbonyl Process* – 2,692,499.

Lang, W. Y. – *Printing Telegraph Apparatus* – 2,692,911.

Mathes, R. C. – *Composite Magnetic Recording Tape* – 2,691,072.

Matthias, B. T. – *Electrical Device Embodying Ferroelectric Lanthanum – Containing Substances* – 2,691,738.

McLean, D. A. – *Insulated Conductor* – 2,691,057.

Morton, J. A. – *Electron Beam Amplifier* – 2,692,351.

Nordahl, J. G. – *Radiotelephone Communication System* – 2,691,723.

Polk, R. E., see Kreisel, R. R.

Ring, D. G., see Beck, A. C.

Robertson, D. D., see Dickieson, A. C.

Robertson, G. H. – *Electron Discharge Devices* – 2,691,765.

Shive, J. N. – *Semiconductor Amplifier* – 2,691,750.

Strickler, W. B., see Cesareo, O.

Strickler, W. B. – *Testing System* – 2,692,728.

Teal, G. K., see Christensen, H.

Thurber, E. A. – *Process for Producing a Silica Coating* – 2,692,838.

Wager, H. N. – *Method of and Apparatus for Producing Improved Lead-Out Conductor for Electrical Coil* – 2,691,811.

Wallace, R. L. – *Valve for Infra-Red Energy* – 2,692,950.

Wurmser, A. V., see Dickieson, A. C.