BELL LABORATORIES RECORD

DEFORMATION OF MATTER

R. L. Peek

RADIO DISTRIBUTION FOR APARTMENTS

C. F. Boeck

POWER EQUIPMENT LABORATORY

J. R. P. Goller

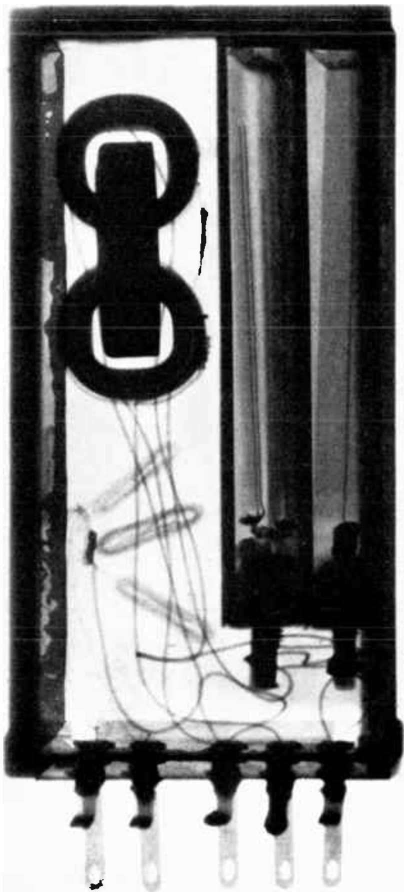
MARCH 1933 VOL. 11 NO. 7

s Record

Bell Telephone Laboratories, Incorporated
463 West Street, New York, N. Y.

In this Issue

BELL LABORATORIES
RECORD



VOLUME ELEVEN—NUMBER SEVEN

for

MARCH

1933

The Deformation of Matter

By R. L. PEEK
Materials Development

PHYSICAL testing is essentially the determination of the amount and character of deformation a material experiences when acted on by given forces. In general industrial practice physical tests are applied principally to metals, and for these there exist fairly simple relationships between the load applied and the deformation resulting, which are adequate for most engineering purposes. For telephone apparatus, however, the necessity for insulation requires the use of many materials—rubber and other organic substances—whose behavior is quite different from that of metals. As part of the studies of materials carried on in the Laboratories, therefore, it is necessary to develop physical tests adapted to such materials, and particularly to develop expressions for the fundamental relationships between force and deformation which will allow the behavior of such materials in actual service to be predicted.

Testing methods are of two general types. With one, the behavior of the material is studied under conditions simulating those that will exist in service. With the other, the test is employed to evaluate certain physical constants, which may then be used to predict the behavior of the material under any service conditions. An illustration of this latter type is the determination of Young's modulus from the relation between load and elongation of a metal. With this constant known, the load-deflection characteristics for any part made of the metal, such as a spring, may be computed.

When the laws governing the deformation of the material tested are unknown, tests of the first type are necessarily employed. In dealing with non-metallic materials such tests have been the usual practice, as in the determination of "cold flow" (the gradual yielding under load) of insulating compounds. When service conditions can be closely simulated such tests are entirely satisfactory, although the results are strictly limited to the given set of conditions. Frequently, however, service conditions cannot be duplicated, particularly with respect to the time element. In "cold flow" tests, for example, it is desired to know the deformation over a period of years, while it is generally impracticable to carry out tests requiring any considerable period of time for their completion. It is very desirable, therefore, to determine the laws of deformation of all such materials so that by the determination of certain constants, their behavior under all conditions of loading and time may be predicted.

Although only a limited use has previously been made of them in engineering practice, theories are available covering a number of types of deformation, which express the relationship between applied force and deformation in simple mathematical equations. The mathematical treatment considers the relationship between the group of forces acting on each elementary volume of the material, known as the stress, and the resulting deformation, which is called strain. By integrating the mathematical expression, the deformation for any particular body may be obtained. These basic relationships, of which there are four, may be referred to as fundamental types. No actual material, however, conforms exactly to any one of the fundamental types over a wide range of stress, but the deformation of practically all materials may be described in terms of a combination of two or more of the fundamental forms or some slight modification of them. The fundamental forms and the more important combined forms are listed in Figure 3.

Both stress and strain may be resolved into two components; one associated with uniform contraction or expansion in all directions, and one with shear, or change of shape. In most engineering problems, shearing strains and stresses alone are of interest, and only these will be considered here. A simple ideal example of shearing strain is the deformation of a body in which the motion is within parallel planes, and in this case the strain is given by the movement of points in one plane relative to the points in another, divided by the distance between the planes. The shearing stress is the force per unit area acting on the planes in the direction of the motion.

The most familiar relationship between stress (F) and strain (S) is that of direct proportionality: $F = \mu S$, where the constant μ is the shear modulus. A body reacting in this manner is said to be elastic. Most solid materials reveal this type of response, at least within certain limits of stress, and this relationship is basic to the design of most mechanical structures from locks to locomotives.

Another type of deformation, exhibited over at least certain ranges of stress by many insulating materials, is known as viscous deformation. Here the stress varies as the velocity with which the strain takes place, and in its fundamental form is given by the expression: $F = \eta dS/dt$, in which the constant η is the coefficient of viscosity. In a material responding in this manner the strain increases continuously with time and the greater the stress the greater is the rate of deformation.

In both of these relationships, the stress referred to is that required to overcome the resistance of the material to deformation. In all cases, however, strain involves motion, and if the motion varies, Newton's law—that the force acting on a freely moving body is proportional to the rate of change of velocity, or to the acceleration—must be considered. Newton's law therefore appears as one of the four relationships between stress and strain. It will be referred to as the inertia reaction, and the equation is $F = m\, d^2S/dt^2$, in which m is the density, or mass per unit volume.

The fourth fundamental form of deformation, exhibited by certain soft solids, is expressed by the relationship: $F = C$. A limiting value of stress exists ($= C$), called the yield value, below which no deformation takes place, and above which the deformation is controlled only by the inertia reaction. This type is called plastic deformation and is found in such materials as putty, modeling clays, and some waxes.

As already mentioned, it is only in rare cases that actual materials are deformed by stresses exactly in accordance with these fundamental forms except over very narrow ranges of stress. By taking certain combinations of them, however, a group of ideal types of stress-strain relationships may be developed which correspond to those existing in actual materials within the limits of accuracy required for most engineering purposes.

The ideal body to which most metals approximately conform is elastico-plastic. For lower values of stress the deformation is elastic, but at some critical value of stress it becomes plastic—the material will continue to deform without any increase in stress. Such a relationship is shown by the solid lines of Figure 1. Up to the critical stress, or yield value, C, stress and strain are strictly proportional, but above the yield value, the strain proceeds indefinitely without further increase in stress. On removal of the stress at any point of the elastic range, the body returns to its original shape. When the strain is carried beyond the elastic limit before the stress is removed, say to some point D, the

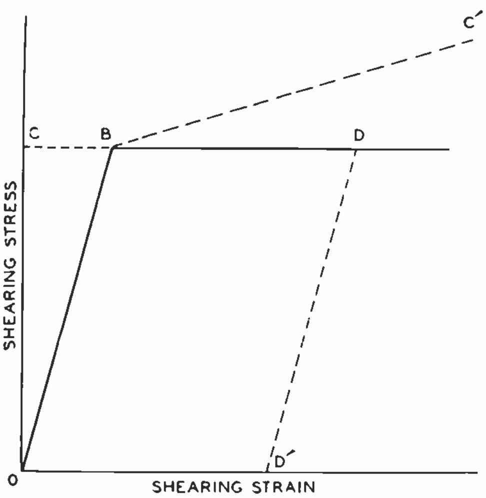


Fig. 1—Stress-strain relationship in elastico-plastic bodies

body will recover only the elastic portion of its deformation and a permanent set, represented by OD′, will remain.

Actual bodies differ from this ideal type in that most commonly the yield value C is not constant but increases with strain—the phenomenon of "strain hardening," indicated by the dotted curve BC′ of Figure 1—and in that there is some plastic deformation even over the elastic range. Also the demarcation between the elastic and plastic stage is not so sharply defined as indicated in the diagram. Actually the transition from one type of deformation to the other is gradual, and would be represented by a curved section joining the two straight lines. The limiting cases of such an elastico-plastic body are the pure plastic, in which the elastic stage is negligible, and the brittle body which fractures before the plastic stress is reached.

For steady motion at low velocities, pure liquids and ordinary solutions behave as viscous bodies, but for certain substances, although the stress varies with strain velocity, it is not strictly proportional to it. Such a body is called quasi-viscous and the stress-strain relationship may be written $F = b(dS/dt)^{\frac{1}{n}}$ in which b and n are constants. The pure viscous relationship is as shown by curve A of Figure 2, while that of a quasi-viscous substance is given by curve B. With the pure viscous substance, the ratio of stress to strain velocity has the constant value η for all values of strain velocity, while with quasi-viscous substances the ratio decreases as the velocity increases. If tests are applied to such quasi-viscous substances, therefore, the value of viscosity found will vary with the range of strain velocity obtaining in the test. Hence the use of such viscosity tests with quasi-viscous substances may be seriously misleading, since the range of strain velocity obtaining in the test may differ considerably from that imposed by the conditions under which the material is used in actual service. This is of considerable practical importance since the solutions used in applying cellulose acetate and other protective coatings are quasi-viscous in their nature, as are most liquids whose consistency varies only slightly with temperature and which are therefore preferred for use as damping fluids.

Both viscous and quasi-viscous materials will—in theory at least—continue to flow as long as any stress is applied. Many materials, however, require that the stress exceed some constant value before any flow occurs, while the stress in excess of this amount is proportional to the strain velocity. Such materials are called plastico-viscous and their reaction is indicated by curve D of Figure 2 where C represents the yield value, above which the deformation is viscous. The equation for this type has the form $F = C + \eta \frac{dS.}{dt.}$

For a considerable range of strain velocity, as is evident from Figure 2, the ratio of stress to strain velocity may be the same for a quasi-viscous substance as for a plastico-viscous. When the strain velocities are to be high, therefore, as in extrusion processes, there is little need to distinguish between quasi-viscous and plastico-viscous substances. In connection with cold flow, however, the distinction is very important, since here it is desired to know if a body will flow under a given stress applied for a long time. Under such circumstances a quasi-viscous material will always flow, while a plastico-viscous material will flow only if the yield point is exceeded.

Of the asphaltic materials employed as sealing compounds and as protective coatings for telephone apparatus, some are quasi-viscous and some

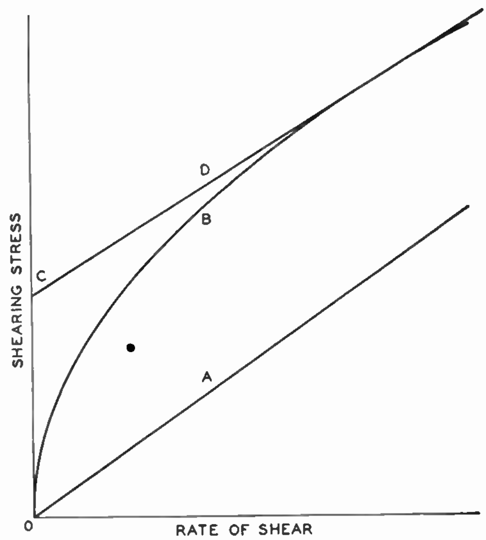


Fig. 2—For viscous deformation (A), quasi-viscous deformation (B), and plastico-viscous deformation (D), the stress varies as the rate of deformation or some fractional power of it

plastico-viscous, and their type must be distinguished before their behavior can be predicted. Most metals that can be extruded are plastico-viscous at extrusion temperatures, as are some of the rubber compounds.

Other varieties of complexity than those already listed are found in many materials. It has already been noted that most metals resist deformation in the plastic stage with a stress that increases as deformation proceeds, and the same effect is found in a number of plastic and plastico-viscous materials. On the other hand some plastico-viscous and quasi-viscous materials show an opposite effect: the resistance to deformation decreases as deformation proceeds—the phenomenon of thixotropy.

It has also been noted that in actual materials, the elastic and plastic stages are never as sharply distinguished as in the ideal elastico-plastic body. This is conspicuous with rubber compounds, which are predominantly elastic for very large deformations and yet show a permanent set on recovery from small strains. At higher temperatures some rubber compounds show a further complexity in possessing an elastic component while their behavior is predominantly quasi-viscous or plastico-viscous. This is evidenced by the expansion of the material on emerging from an extrusion orifice.

The determination of all the parameters of the complex expressions for many of the materials employed in the telephone plant is frequently difficult, and integration of the expressions to obtain the strain for any applied stress is often impossible. The character of the deformation, however, can usually be determined from simple tests, and this is frequently the most important information for engineering purposes. In studying cold flow, for example, it is really more important to know that a material is plastico-viscous, and therefore has a yield point, than to determine that yield value precisely.

FUNDAMENTAL FORMS:		IDEAL BODIES:	
ELASTIC	$F = \mu S$	ELASTICO-PLASTIC	$\begin{cases} F = \mu S \ (\text{FOR } 0 < S < S_c) \\ F = C \ (\text{FOR } S_c < S < \alpha) \end{cases}$
VISCOUS	$F = \eta \frac{dS}{dt}$		
INERTIAL	$F = m \frac{d^2S}{dt^2}$	QUASI-VISCOUS	$F = b\left(\frac{dS}{dt}\right)^{\frac{1}{n}}$
PLASTIC	$F = C$	PLASTICO-VISCOUS	$F = C + \eta \frac{dS}{dt}$

Fig. 3—Fundamental stress-strain relationships and some of the complex relationships belonging to ideal bodies

Tuned-Transformer Coupling Circuits

By A. J. CHRISTOPHER
Apparatus Development Department

SELECTIVE networks, employed to separate the various frequency bands, are fundamental to any carrier or radio system. They are in general preferably of the band-pass type, transmitting all frequencies between certain limits and greatly attenuating all those above or below these limits. Amplifiers are used, in addition, to raise the power level of the transmission band. Under some conditions, where the requirements are not severe, it has been possible to use single-tuned transformers, which, in conjunction with vacuum tubes, perform a satisfactory selection and amplification by themselves.

With this method, however, certain design characteristics make it impossible practically to obtain maximum amplification, sharp frequency discrimination, or the high quality required of high-grade carrier telephone and radio systems. There has been a demand, therefore, for something with the simplicity and economy of these single-tuned transformers that has a high degree of frequency discrimination, combined with high quality transmission. To meet this demand there has been developed a variety of low-loss air-core transformers, which have both primary and secondary windings tuned with capacities. Air-core transformers were used because of their suitability and inexpensive construction. Definite relations have been obtained between the constants of the transformer windings, the tuning capacities, and the impedances of the circuits between which the transformer operates. Furthermore, it can be shown that a structure satisfying these relations is essentially a band-pass filter and has all of its elements properly proportioned to provide the desired band selectivity, but it still retains the form and the functions of a transformer.

Where maximum amplification is of utmost importance, the capacity for tuning the secondary winding is

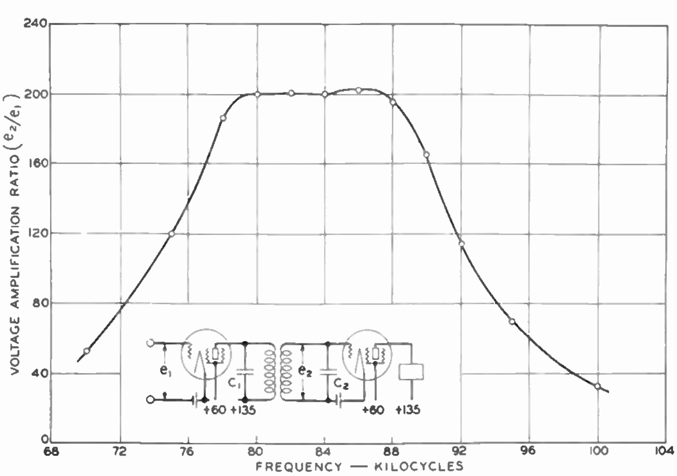


Fig. 1—Voltage amplification characteristic of a shielded-grid tube and a double-tuned transformer

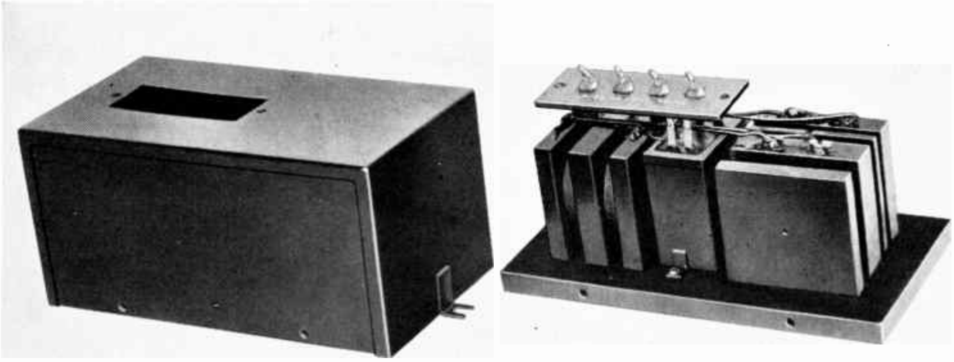


Fig. 2—Multiple-tuned transformer employed in field-strength measuring set

obtained by utilizing only the effective distributed capacity of this winding plus the effective input capacity of the vacuum tube to which it is connected. The capacity across the primary winding and the coupling between the windings is then proportioned to give the desired quality and band width. More than one transformer is sometimes used to obtain the necessary selectivity. Several may be connected together with either series or shunt condensers to obtain the equivalent of a multi-section band-pass filter. Networks of this type have been employed in place of the usual band-pass filter because of their simplicity, compactness, and relatively low cost. They may be used to connect either two equal or unequal impedances as well as to operate from an impedance directly into the grids of vacuum tubes.

The voltage amplification characteristic of a shielded-grid tube and a transformer having both its primary and secondary windings tuned by capacities, is shown in Figure 1. Such a transformer was used as the coupling circuit between shielded-grid vacuum tubes of a high frequency amplifier.

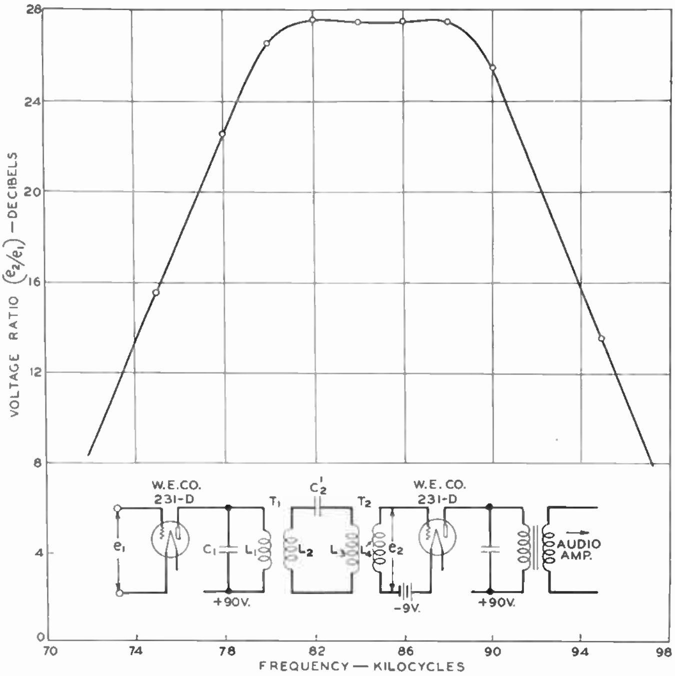


Fig. 3—Transmission characteristic of a triple-tuned transformer. Circuit schematic below

It should be noted that this type of transformer transmits with a high degree of uniformity all voltages between frequencies of 79 and 88 kilocycles while providing a discrimination against voltages ten kilocycles away from the edges of the band corresponding to approximately 14 decibels. This combination of a relatively wide and uniform transmission band and good selectivity is impossible of attainment with the single tuned transformer previously employed. Furthermore, by utilizing the effective electrode capacities and effective winding capacities for the tuning condensers illustrated in the circuit schematic as C_1 and C_2, the above characteristic is obtained with low cost and high efficiency; the voltage amplification shown over the band being practically equal to the amplification factor of the tube. A similar transformer is used in the last stage of the intermediate frequency amplifier of the 4-D radio receiver, used for monitoring broadcasting transmitters. To obtain maximum voltage amplification with this arrangement, the grid capacity of the detector and the distributed capacity

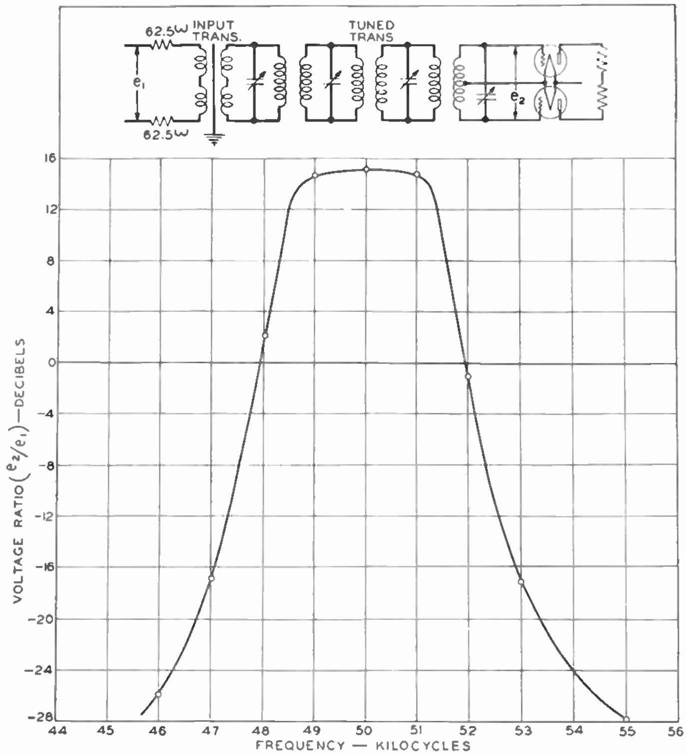


Fig. 5—Transmission characteristic of quadruple-tuned transformer. Circuit schematic above

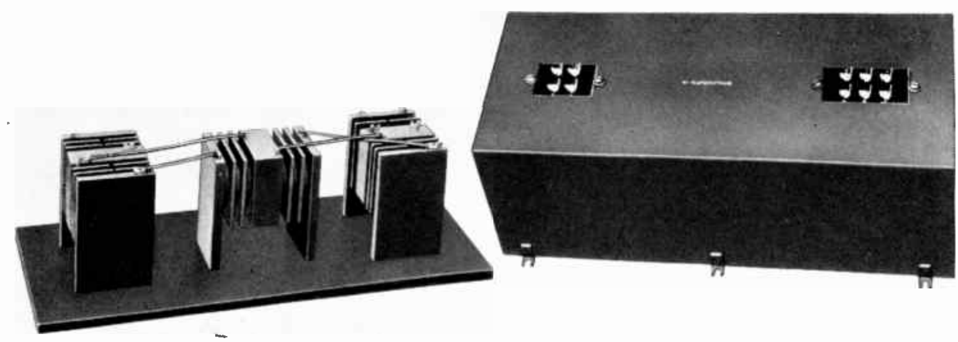


Fig. 4—A quadruple-tuned transformer for the carrier frequency range

of the secondary winding act as the tuning condenser for the secondary winding while an external condenser is placed in parallel with the primary winding.

The addition of transformer windings and condensers to the above type of structure is analogous to the addition of filter sections to the usual type of band-pass filter; the effect is principally greater frequency discrimination. Figure 2 shows the mechanical arrangement of the transformer and condenser elements of a coupling circuit in which more than two transformer windings and two condensers are used. Here two independent transformers are electrically connected through a series condenser. The transmission characteristic and circuit schematic are shown in Figure 3. This device is equivalent from a transmission standpoint to a confluent section of a band-pass filter. This design is used in the intermediate frequency amplifier of the 44A Test Set, used to measure field strengths of radio broadcasting stations. It can also be used successfully in the intermediate frequency amplifier of a superheterodyne radio receiving set. Better performance is obtained when operating a network of this type into a detector tube of the plate-rectification type than into a detector tube of the grid-leak type or into an ordinary amplifier tube. The lower input capacitance and conductance of the former type of detector tube will permit the cut-off frequencies to be located quite close to the extremities of the transmission band, which results in greater selectivity for an allowable variation in transmission over the band.

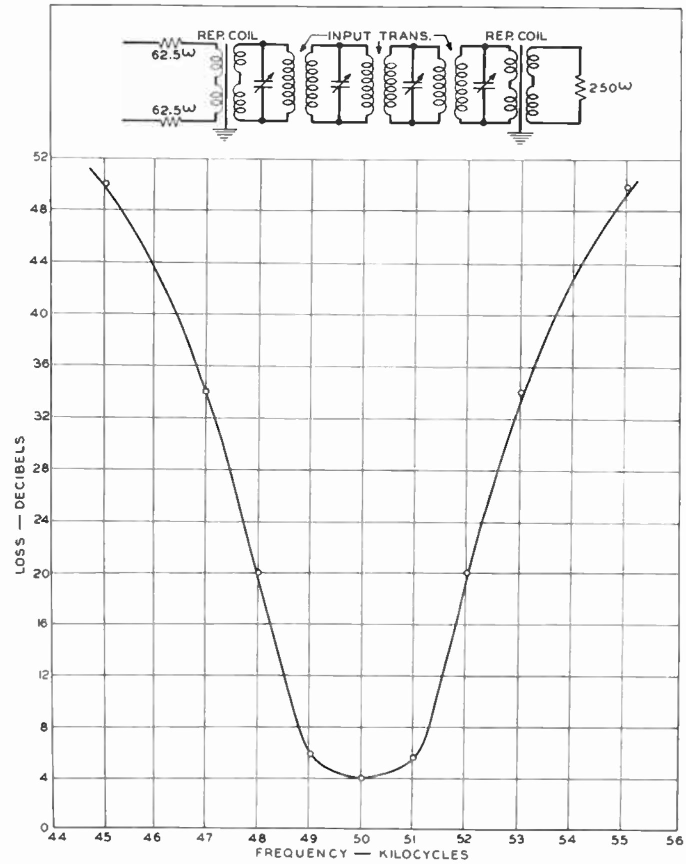
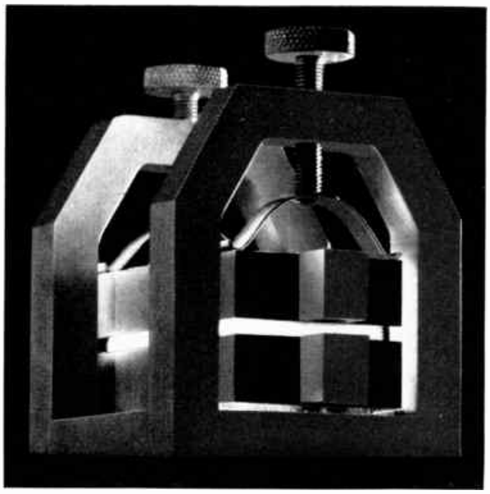


Fig. 6—Transmission loss characteristic of quadruple-tuned transformer. Circuit schematic above

The effect from a transmission standpoint of electrically connecting the three independent transformers shown in Figure 4 with condensers is shown in Figures 5 and 6. The condensers shown in the schematics are added externally and their capacities may be adjusted to locate the transmitted band anywhere between 50 and 150 kilocycles. This particular arrangement is used in power-line carrier-telephone systems to eliminate interference caused by other carrier systems on the same power circuit. As shown by the transmission characteristics, this type of structure will operate efficiently between finite impedances or between a finite impedance and the grid circuits of vacuum tubes.

Transformer coupling circuits of the general types described above are becoming of more importance in carrier and radio development where it is desirable to obtain uniformly high transmission efficiency over relatively narrow bands, and, at the same time, high attenuation outside the desired band. Their use is not necessarily limited to the frequency bands illustrated but may be extended to higher frequencies with satisfactory results.

The harbor-craft radio-telephone, described in the RECORD *last November, brought the ocean closer to shore when Captain Doucette of the trawler Gertrude M. Fauci rescued Captain Newton Wilkie and his crew from the schooner Dawn Wilkie on the high seas. That the Dawn Wilkie was foundering had become known several days earlier, and Mrs. Wilkie was waiting in suspense for further news at her home in St. John, New Brunswick. When the rescued Captain was told that he could telephone his wife from the trawler, he did so. From some 200 miles out of Boston, his voice flashed to the New England Telephone and Telegraph Company's station, and thence passed over land lines to his wife, telling her that he and his crew had been saved. Soon afterward a reporter, hearing of the rescue, stepped into one of the Boston Globe's telephone booths and put in a call in the usual way for Captain Doucette on the Gertrude M. Fauci. In a few minutes he had the captain on his line and conducted his interview. The accompanying photograph shows Western Electric radio equipment in the engine room of the trawler.*



Mounting Quartz Plates

By F. R. LACK
Radio Research

IN order to use vibrating quartz crystal plates as circuit elements, it is necessary to devise special methods of holding them. The holder must furnish means of transferring to the electric circuit the piezoelectric voltage developed on the surface of the crystal plate. It must have sufficient rigidity of form so that its mechanical relation to the vibrating plate will not change from any cause, and thus will not react on the frequency of vibration. At the same time, it must not restrict the desired vibration of a plate or introduce damping. These requirements are difficult to satisfy simultaneously.

In the original form of holder used for the frequency control of radio transmitters, the quartz element rests on a flat metal surface while the other electrode, a thin metal disc, rests lightly on the upper surface of the quartz. In this holder, when the quartz plate vibrates along its thickness, it lifts itself off the lower electrode a short distance and at the same time pushes up the upper electrode. Thus air-gaps form on both sides of the quartz plate (Figure 1), whose dimensions in part determine the capacitance between the electrodes.

The plate is free to move about laterally in the holder, and if a shift in position takes place, the interelectrode capacitance might change slightly. Moreover, a change in the relative position of the upper electrode and the plate may cause a

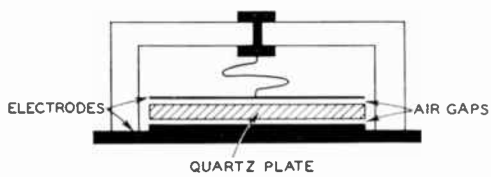


Fig. 1—The vibration of a quartz plate resting lightly between two electrodes will cause small air gaps to form between plate and electrodes

change in the distribution of pressure between them which will alter the effective mass of the vibrating system and thus the equivalent inductance of the quartz. Either of these effects will result in a shift of frequency.

In practice, it has been found that, when a plate is contained in a holder of this type, shaking the holder will sometimes produce frequency changes of the order of 500 parts in a million. Accordingly, the frequency calibration of the crystal and holder is accurate only if the crystal system is not disturbed after calibration, a condition prohibiting the use of this holder on ships or airplanes.

Various schemes have been suggested for keeping the quartz plate in

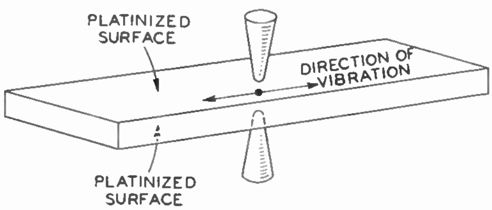


Fig. 2—A quartz bar vibrating longitudinally can be clamped at a nodal point. The upper and lower surfaces of the bar are platinized to form electrodes

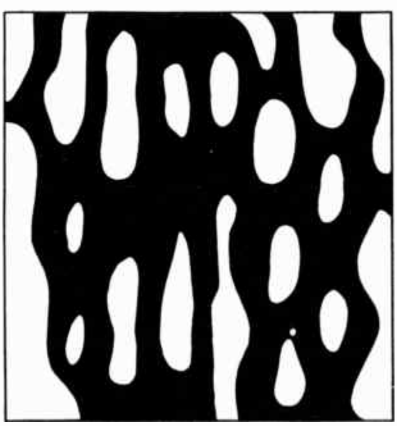


Fig. 3—A typical pattern of nodal areas on a vibrating quartz plate

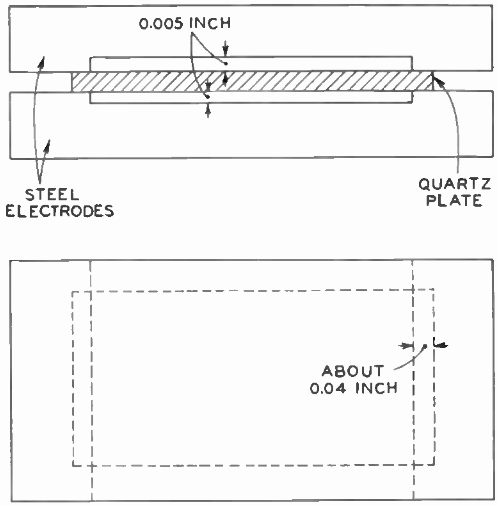


Fig. 4—Certain rectangular plates can satisfactorily be clamped at the edges perpendicular to the optic axis

a definite position relative to the coupling electrodes. Some form of clamping would be desirable providing the clamping mechanism had a negligible effect on the desired vibration of the crystal. The first thought is to clamp the quartz at the vibration node. This is readily possible when using long bars vibrating longitudinally. The nodal points on such bars can be accurately determined, and rigid clamping at these points is entirely successful (Figure 2). The electrodes in this case are obtained by coating the surface of the bar with platinum or gold.

In quartz plates whose principal vibration is in the direction of the thickness, complementary vibrations are also set up in the other two directions, and the crystal acts like a series of coupled resonant circuits. An extremely complex vibration pattern results, and the nodal areas on the surface of the plate are very irregular. A typical vibration pattern obtained with lycopodium powder is shown in Figure 3. This complex vibration has some advantages, for when the dimensions of the plate have certain ratios the "thickness" vibration, whose frequency increases with increasing temperature, is so coupled with a transverse vibration having a negative temperature coefficient that the frequency of the resultant vibration does not change over a wide range of temperature.

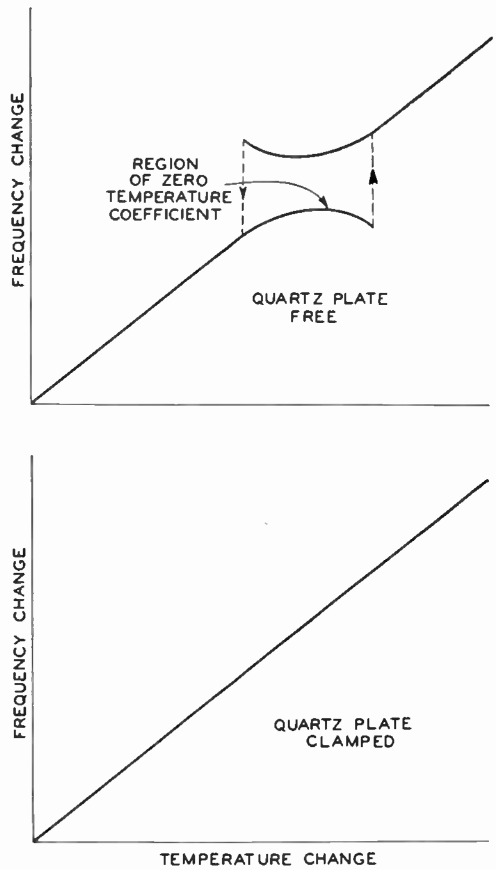


Fig. 5—Clamping has the effect of making the variation of frequency with temperature continuous (below), where this variation would be discontinuous (above) if the crystal was free

In some plates having this zero temperature coefficient, a nodal region appears in the center of the plate. It was found that a small hole could be drilled through the plate at this point and a fused quartz rod cemented in this hole to furnish a rigid support. To apply this method to other types of plate, it is only necessary to determine the vibration pattern and place the support at the nodes.

In general, however, the nodes of these complex vibrations shift so much with slight dimensional changes that it would be difficult to design a simple support that could be easily applied to all sizes of plate. In practice, it is found possible to disregard the vibration pattern and impress definite nodes on a plate by clamping in certain regions. These regions are so chosen that the vibration along the thickness is disturbed to an inappreciable extent. It is not possible, however, to retain all the characteristics of the free plate for the clamp prohibits some of the principal transverse vibrations. With the elimination of these transverse vibrations the possibility of obtaining a low temperature

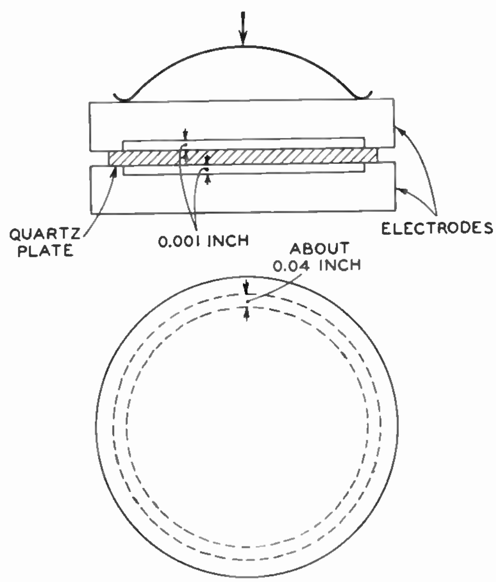


Fig. 6—Circular crystals can be clamped about the circumference

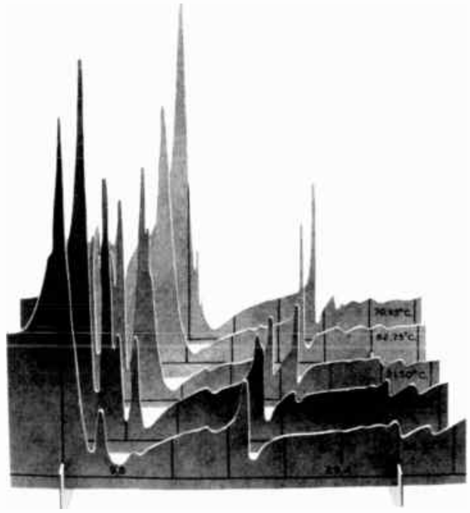


Fig. 7—The frequency spectrum of a quartz plate at different temperatures is highly irregular

coefficient is reduced but for the majority of commercial applications that is not a serious loss.

The frequency-temperature curve of the clamped crystal then becomes a simple straight line, instead of the discontinuous curve characteristic of the unclamped-zero temperature-coefficient plate (Figure 5). For use in a portable frequency substandard without temperature control, this linear temperature-frequency relation is more useful than a zero temperature coefficient over a limited temperature range, for the frequency of such a crystal can be determined directly by reading its temperature with a thermometer without recourse to a calibration chart. A 700 kilocycle plate in this type of holder clamped along the edge perpendicular to the optic axis (Figure 4 and the headpiece) was measured in the laboratory and then transported by car over 200 miles. On returning to the laboratory, the frequency was found to have been unchanged within the error of measurement (about five parts in a million.)

The success of this method of clamping the square low-frequency plates of large area led to a search for some similar method of clamping high-frequency crystals, above a million cycles, which are made circular for manufacturing reasons. It was found that these could successfully be clamped around the circumference, as shown in Figure 6. Circular plates so clamped are as satisfactory oscillators

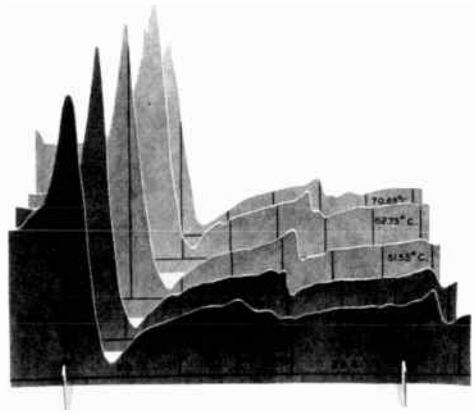


Fig. 8—Clamping a quartz plate greatly simplifies its frequency spectrum, as can be seen by comparison with Figure 7

as the unclamped plates, and there is no frequency change with handling. Moreover, this type of clamping eliminates a number of modes of vibration which make these high frequency plates difficult to adjust to a given frequency. The space models pictured in Figure 7 for an unclamped plate and for a clamped plate in Figure 8 show the current through the plate as a function of the frequency and the temperature. A comparison of the spectra of the plate when clamped and when free makes it evident that the clamping greatly simplifies the frequency spectrum of the plate.

Clamping quartz plates in their mountings in these ways has made it possible to calibrate quartz oscillators in the laboratory and ship them to distant points for installation in radio transmitters, with the assurance that the calibration will not be altered by shipment. It has also made possible the use of quartz oscillators in aircraft and shipboard installations, where vibration has hitherto affected their stability to a prohibitive degree.

A recently designed unit for the control of multifrequency radio transmitters to communicate with ships illustrates one of the many advantages of clamping. Nine quartz oscillators are grouped in a circle in a vertical plane, and a rotary switch arm, making contact with the binding posts on these oscillators, permits instant selection of the oscillator with the desired frequency (Figure 9). As the quartz plates are clamped it makes no difference in what position the crystal holder is mounted.

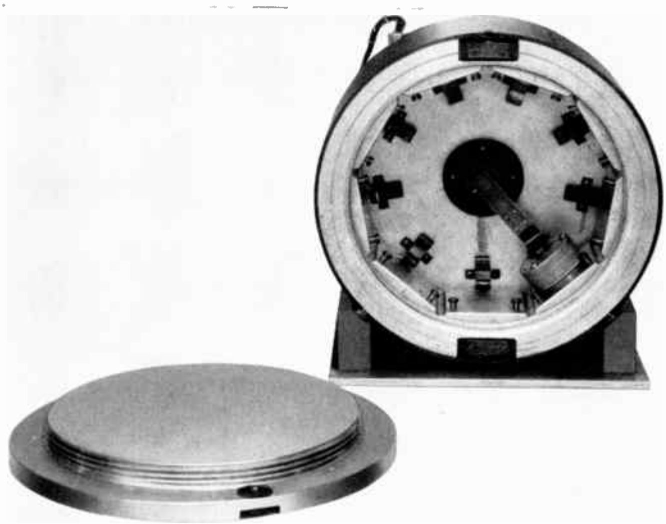


Fig. 9—Quartz oscillators could not be mounted in a temperature-controlled oven in this way if the plates were not clamped

A Radio Distribution System for Apartment Buildings

By C. F. BOECK
Radio Development

IN the early days of broadcasting, it was generally considered essential to provide a separate antenna for each broadcast receiver. This may easily be done in suburban areas, but is difficult in densely populated regions. Many apartment house roofs are cluttered with a maze of antennas which—constructed in accordance with the ingenuity of the various tenants—present a haphazard arrangement of unsightly appearance. To the users of the broadcast receivers in the building, however, such an arrangement presents many disadvantages more serious than those of appearance. To avoid the objectionable features of groups of individual antennas, the Laboratories have recently developed for the Western Electric Company a multiple channel radio distribution system which, although having a capacity of 3,000 receivers, employs only a single antenna.

The objection to employing a group of individual antennas close together, is that each is not an independent collector because it is actually coupled through its electric and magnetic fields to the others of the group. Receivers of the radiating type connected to any of these antennas will introduce interference into all the receivers. Also, the signal delivered to a receiver will be reduced whenever another receiver tunes in on the same station. Besides this interference entering through the antennas, local disturbances are picked up by the lead-in wires, which have not usually been properly designed or shielded.

Several attempts have been made to shield the lead-in wires from this local interference, but the results have not generally been satisfactory because sufficient consideration has not been given to the fundamental principles involved. Although the shielding has reduced the interference, it has reduced the strength of the broadcast signal at the same time. The reduction in strength of the signal makes it necessary to operate the receiver at high gain, and since most receivers are inherently noisy in the region of their maximum sensitivity, sufficient noise is generally introduced to offset the decrease in noise due to shielding. Thus while the ratio of noise to signal has been decreased at the input of the receiver, it has not been appreciably reduced at the output.

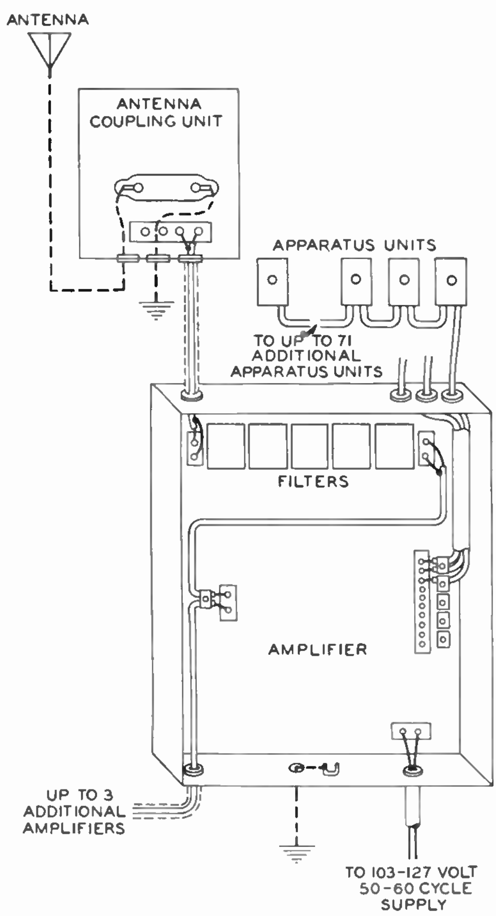


Fig. 1—Block schematic of Western Electric Company's 3A Radio Distribution System

Various arrangements have been devised from time to time to overcome these objections, and to provide all apartments with suitable antenna facilities. In some instances coils or loops of wire have been built into the ceilings of the various apartments. In others, loops have been installed in the partitions. Such collectors are inherently inefficient, however, and the coupling between neighboring collectors is usually too close to avoid objectionable interference between receivers.

In the new system developed by the Laboratories, known as the 3A Radio Distribution System, the various objectionable features of the earlier methods have been eliminated. This system employs but a single antenna properly designed to efficiently collect all signals in the broadcast band. Most of the problems of the design center around the distribution of the signals to the numerous apartments in the building, with a minimum of attenuation.

This is fundamentally a problem of transmitting high frequency currents, and may be solved by the principles employed in the design of long telephone circuits. Not only must the system transmit the signals faithfully and with a minimum of attenuation, however, but it must shield them from local disturbances. The system is thus based on an efficient and shielded distributing network fed from a single antenna, but includes in addition both antenna and receiver coupling equipment, and—particularly for the larger systems—amplifying equipment as well. A simplified schematic diagram for such a system is shown in Figure 1.

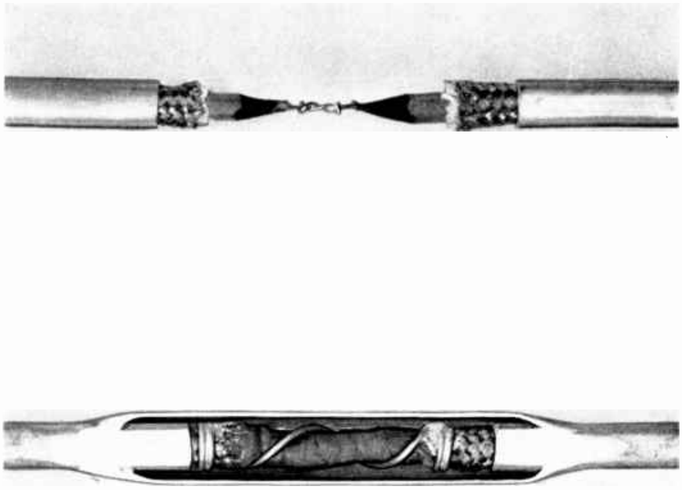


Fig. 2—In splicing the coaxial cable, the central conductors are first joined and then insulated with rubber tape. A heavy copper wire is then soldered to the sleeve of each section of the cable to complete the sleeve circuit, and a wiped joint is then formed as described in the Record for October 1932, *page* 43

The antenna coupling equipment provides a means for connecting the antenna to the distribution system. It includes a coupling transformer, and an arrestor to protect the system from lightning discharges. As shown in Figure 3, this unit is mounted in a weatherproof box which should be installed as close to the antenna as practicable.

Since a practical antenna obviously cannot collect sufficient energy to supply three thousand receivers, and also overcome the coupling loss, an amplifier is provided to furnish the additional energy required. Associated with the amplifier, and shown above it in the photograph at the head of this article, are attenuating networks. These are selective volume control circuits which are employed to reduce the level of any incoming signal which is sufficiently powerful to overload either the amplifier or the receivers.

The amplifier employed has four stages and employs unipotential cathode tubes designed for low hum. It is operated from the usual 110 volt lighting circuit and requires no attention except for occasional maintenance purposes. Each such amplifier will supply as many as 750 receivers, and as many as four amplifiers may be connected to the same antenna. Ten outgoing circuits may be connected to each amplifier and each circuit has a capacity of seventy-five receivers. The length of a circuit, both from the antenna coupling unit to the amplifier and from the amplifier to the most distant receiver, is usually limited to 750 feet, which allows 1,500 feet between the antenna and the most distant receiver. Although it is not expected that there will be many instances where more than 3,000 receivers are required, it is possible to supply any

Fig. 3—The antenna coupling equipment is housed in a weather-tight box and usually installed on the building roof near the antenna

number from a single antenna by employing additional amplifiers as repeaters.

The receiver coupling unit must provide a means of connecting the various receivers to the distribution circuit and at the same time of isolating them from each other. Since many receivers are connected to the same circuit, the coupling unit must introduce a low shunt loss and at the same time introduce sufficient attenuation between receivers so that no interference or tuning reaction may be expected. A passive network is employed which introduces a shunt loss of only .02 db but a loss between receivers of the order of 65 db. So effective is the arrangement employed that there is no detectable change in the volume or quality of the output of any receiver even when all the receivers connected to the system are tuned to the same station. One of the receiver coupling units and the method of connecting it to the shielded conductor is shown in Figure 4. The receivers themselves are terminated in plugs which are inserted into the jacks of a coupling unit.

A coaxial conductor is used exclusively for all wiring in this system. It provides an efficient transmission path for the radio frequency currents and also shields them from local disturbances. A central copper conductor is insulated with rubber, and over the rubber is placed a sleeve of tightly

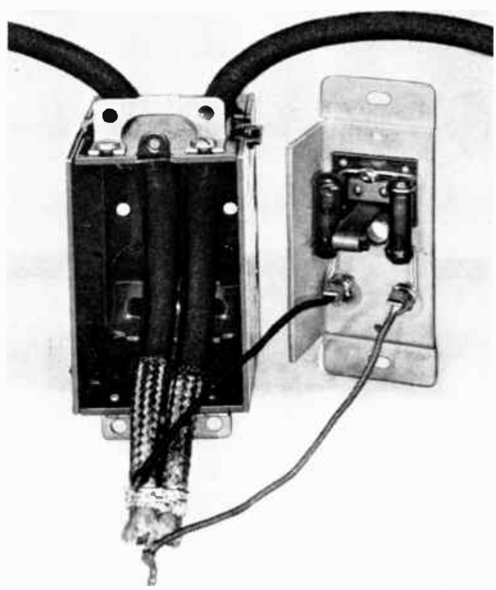
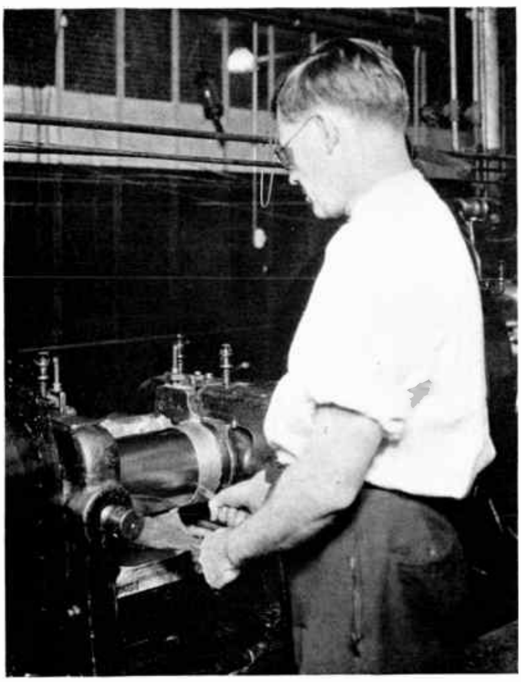


Fig. 4—Rear view of a receiver coupling unit showing the method of connection to the coaxial conductor

woven copper braid. The central conductor forms the high potential side of the circuit, and the sleeve—which is grounded—forms both the shield and the return path. Over the shield may be placed a cotton braid or a lead sleeve, depending on whether the cable will be located in a dry or wet place. Its construction makes the cable flexible so that, like armored cable, it may be "fished" between building walls and partitions. The construction and method of joining, when a lead sleeve is employed, is shown in Figure 2. At broadcast frequencies, the current, because of the skin effect, is confined to the outer surface of the central conductor and to the inner surface of the sleeve. The outer surface of the sleeve forms the shield and carries the disturbance currents which without such a conductor would affect the broadcast circuit.

With this system each receiver performs as though it were supplied from a separate and independent antenna, and any broadcast station is selected as desired. The increasing demand for radio facilities in large apartment buildings and hotels should provide a wide field of usefulness for this new distribution system.



In developing rubber compounds for various telephone uses, experimental batches are mixed in a "mill" consisting of two rollers running at different speeds to produce a frictioning effect. Subsequently the compounds are cured and tested. In mixing, the rubber on the front roller is periodically cut and put back into the mill, as E. L. Dias of the Chemical Laboratories is shown doing in the above photograph.

A New P.B.X. for Large Establishments

By G. V. KING
Local Systems Development

TO meet the need for private branch exchange facilities for very large establishments, a new dial P.B.X., known as the 702-A, has been made available. Although utilizing dial equipment for local interconnections, it employs a manual switchboard for handling all incoming central-office traffic. Incoming tie-line traffic may be handled either at the manual board or by dial apparatus as desired. It is intended for use in installations requiring between 3,200 and 9,600 lines, or where the particular features provided by this equipment are desired. These capacities are nominal, and will vary with the number of trunks, tie lines, and miscellaneous circuits, and with the arrangement of equipment on the face of the board. Where manual service only is desired the manual board of this P.B.X. may be used alone without any dial equipment and, known as the 606-A P.B.X., has a nominal capacity of 5,000 lines.

The large size of the switchboard of this new P.B.X. has made it both economical and desirable to provide certain features formerly employed principally in central offices. Among these are machine ringing and the audible-flashing recall. The former is a circuit arrangement that starts "ringing" automatically when a cord is plugged into a station jack, and the latter, one that—after a subscriber has operated his switchhook—causes a lamp associated with the cord circuit to flash at regular intervals and a single stroke buzzer to sound each time the lamp flashes. The lamp continues to flash and the buzzer to operate until the attendant goes in on the connection. The audible flashing recall may be employed either for both parties, or—with less expense—for one party only, at the customer's option.

The switchboard of the new P.B.X. is similar in structural arrangement and external appearance to those used in manual central offices. There are certain circuit differences, however, because of requirements peculiar to a P.B.X. Talking battery for all calls passing through a central office is supplied from the central office. The battery feed feature of a central office cord circuit is shown in Figure 1. When either the called or calling subscriber is a P.B.X. the same connection is employed: battery for both parties is supplied from a central office.

Because of this fact, however, the cords at a P.B.X. cannot be arranged to provide always the same battery connections. For calls to or from a central office, it is desirable to supply talking battery from the central office, and therefore the cord circuit must connect the station directly to the trunk. For local calls, on the other hand, where a connection is to be established between two stations of the P.B.X., battery must be supplied by the P.B.X. cord. Two types of connection are thus required of the same P.B.X. cord circuits: one for local calls, and one for central-office calls. The cord circuit is arranged to provide the required connection automatically. The two types of connection are shown in Figure 2.

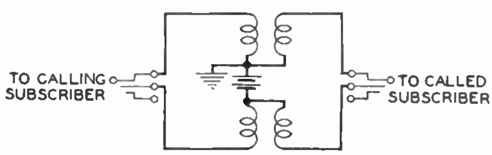


Fig. 1—Battery for talking is supplied by the cord circuit at a central office

In many of the earlier P.B.X. boards it has been possible to obtain these two types of connections with a simple cord circuit by employing a jack which, in addition to the usual tip, ring, and sleeve connections, made an auxiliary connection when a plug was inserted. This jack, known as the No. 295, is larger than those used at central offices but with the smaller number of lines terminating at the previous P.B.X. boards, the size of jack has not been of great importance.

With the new P.B.X. switchboard, because of the increased number of lines that must be provided for, it has not been possible to use the large No. 295 jack. Instead, the small No. 92 jack, used quite generally for central offices, is employed. It does not have the additional contact, however, so that a more complicated cord-circuit arrangement has been required to obtain both the busy indications and the two types of connection needed.

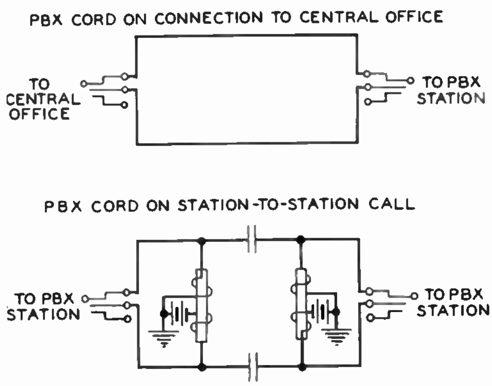


Fig. 2—At a P. B. X. the cord circuit is arranged to supply battery only for local calls. For central-office calls the cord circuit cuts directly through

The circuit provided is shown in Figure 3. With this arrangement the sleeve of the jacks must be connected to either ground or battery since some method must be provided for selecting the type of connection to be made by the cord circuit, and there is no auxiliary switch contact on the jack to make a connection when a plug is inserted. Ground is therefore connected to the sleeves of both trunk and line jacks but with the trunk jacks a high resistance is put in series with the ground. Connected to the sleeve lead of each end of the cord circuit are two relays in series. One of these is a marginal relay which does not operate through the high resistance in series with ground on the sleeve of the trunk jack. When a plug is inserted in a jack of a local line both of the relays operate, either FS and FM or RS and RM, depending on which end of the cord is inserted. Operation of the marginal relay prevents relay T from operating so that talking battery is connected in the talking circuit. When the plug is inserted in a trunk jack, on the other hand, only one of the relays in the sleeve of the cord circuit operates, FS or RS, and in turn operates relay T so that the circuit is cut through without battery.

Because ground is permanently connected to the jack sleeves, it is necessary to arrange the cord circuits so that battery alone gives the busy indication instead of either battery or ground as with the earlier boards. This has required the use of an additional relay, SL, to make the dial switches busy when a call has been completed manually. This relay operates whenever a plug is inserted in a station jack and connects ground to the dial switches to make them busy. When a call has been completed

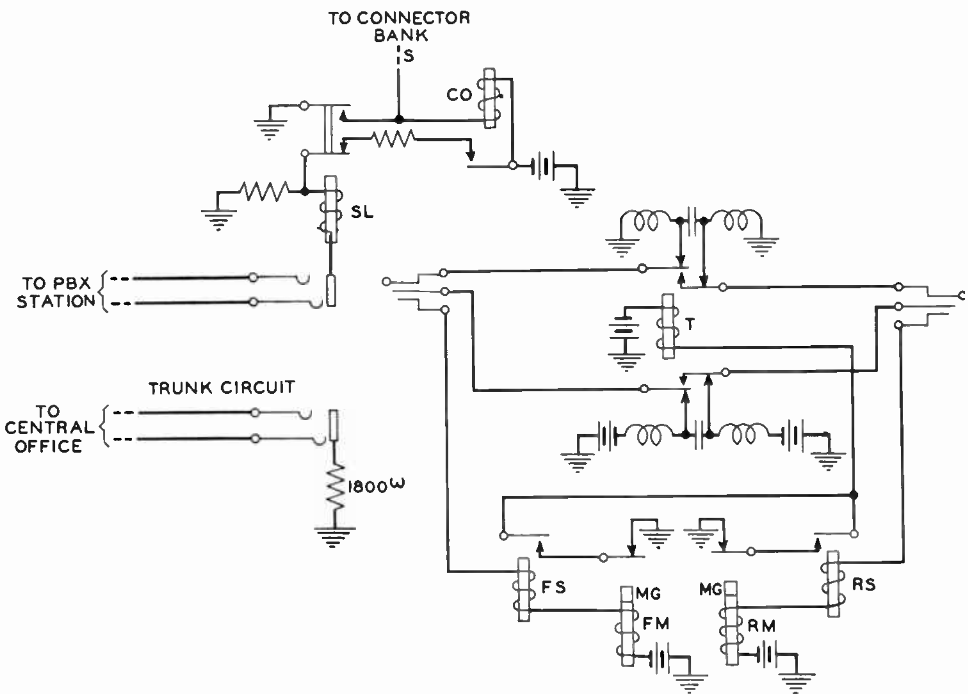


Fig. 3—By the use of additional relays a single cord circuit permits the two types of connection without the aid of large jacks

through the dial apparatus, the CO relay is operated, which makes the station jack busy through a back contact of relay SL. Insertion of a plug at the manual board also makes the other appearances of that jack busy by connecting battery to the sleeve through the FS and FM relays.

This arrangement, made necessary by the employment of the smaller jack, makes possible a somewhat simplified operation of the board. With the earlier boards, only one end of the cord was arranged for connection to central-office trunks. This made it necessary to answer central-office calls with one end of the cord and station calls with the other. With the new circuits all calls are answered with the rear cord and completed with the front, which is the usual central-office practice.

The dial equipment of the new 702 P.B.X. is similar to that used by step-by-step central offices although the line finder frames are somewhat longer to accommodate the additional relay in the line circuit. Line finders, selectors, and connectors are the same as the corresponding central-office switches except when it is necessary to restrict a group of stations from making central-office calls. At a P.B.X. where such restrictions are made, different line finders and first selectors, arranged for this feature, are provided. The line circuits differ from step-by-step central-office line circuits in that they are arranged for appearance at the manual board. With these new P.B.X.'s, large commercial and industrial establishments are given service and equipment essentially the same as a central office.

Power Equipment Laboratory

By J. R. P. GOLLER
Equipment Development

MANY types of power plants, varying in type and arrangement of apparatus and in size, are required for telephone systems to furnish power for the voice currents and for the various switching and signalling apparatus. Equivalent apparatus is also required for telegraph systems. The design and development of such power plants is undertaken by the power equipment group. Not only must the various component pieces be fitted together to form a satisfactory operating plant, but the many makes and types of apparatus performing any one function must be tested so that those selected will produce the most satisfactory assembly.

To provide facilities for the testing required, an adequate laboratory is necessary. Located on the first floor of section E, it consists of a number of test positions where the operation of various types of apparatus may be studied, and a very complete power plant capable of providing and distributing to the test positions all the many types of electrical power that may be needed. For these purposes a group of primary sources of power, both ac and dc, are provided in the laboratory, and in addition trunks are run from power rooms operated by the building staff, over which either power supplied from the outside or any of the types of power available in the building, such as batteries of various voltages, signalling tones, and ringing current, may be obtained.

Fig. 2—E. G. DeMott using the peak voltmeter

At the main powerboard, shown in Figure 1, are brought the leads from the batteries and the various charging equipments, and here also are jacks for distributing the various types of power to the test positions. Control equipment for the power and charging equipment is located on the two central panels, while on each end are the distributing panels where any available form of power may be connected to any of the test positions. These end positions are divided into upper and lower sections, each equipped with power jacks. At the jacks of the upper sections terminate the leads from the various power sources, while the jacks of the lower sections are connected to feeders running to the various test stations. Connections between upper and lower sections are made by patching cords.

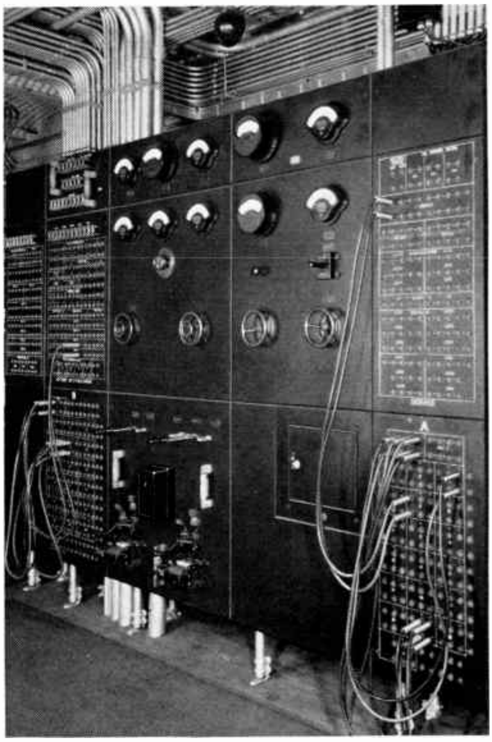


Fig. 1—Main power board in the equipment laboratory

The provision of two distributing panels secures as complete separation as possible between the comparatively small capacity supplies, such as batteries, rectifiers, and tone signals, from the higher capacity sources, which include the alternator and the various building services. The two distributing panels are marked A and B respectively, and this division into two classes of service is continued to the

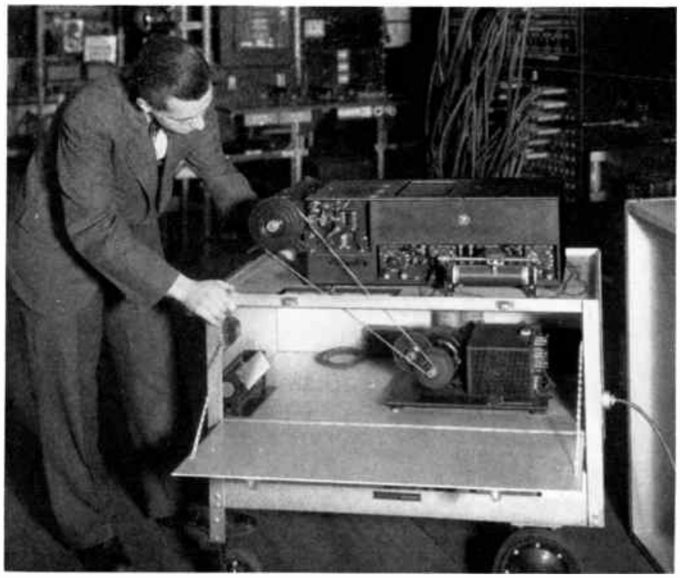


Fig. 3—W. J. Walton with the tea-wagon oscillograph

as the 24 and 48 volt battery, and currents up to 200 amperes may be obtained. The terminals of a six volt, 1,000 ampere generator, located in the basement, are also brought to this location for tests requiring heavy currents at low voltage.

With such facilities available practically any piece of equipment used in telephone power plants, except those of very large size, can be thoroughly tested with a minimum of effort.

various test positions at each of which are two jack boxes: one containing trunks to the lower section of the A panel and the other to the lower section of the B panel. Two types of test positions are provided to accommodate the wide diversity in size and shape of the equipment to be tested. One employs pipe mounting frameworks for supporting the equipment under test, as shown in the photograph at the head of this article, and the other, the usual high-back laboratory bench familiar throughout the West Street building. Standard writing shelves, such as are used in toll offices, provide space for instruments and the pad or book used by the engineer for recording his observations.

In addition to these test positions, which are limited in capacity to 30 amperes, a heavy current outlet is provided where current in excess of 30 amperes may be drawn. Here the alternating and direct current services of the building are available as well

Under a procedure commonly followed, commercial types of apparatus are brought into the laboratory for a test and an analysis of their operating characteristics. Later, a second sample of each type, modified to meet the recommendations of the development engineer, appears. This in turn is tested, and, if further changes are necessary, returned to the manufacturer for the required modification. Finally a production model is tested and, if accepted, that particular development is closed. For reasons pertaining to manufacturing costs, a manufacturer will often request authority to change an article already approved. In such cases a sample embodying the proposed changes is sent in and undergoes the same process.

Rectifiers, of both hot cathode and copper-oxide types, ringing machines, contactors of various forms, batteries, special signalling generators, small motor-generator charging sets, and all such apparatus are constantly being tested. The development of an automatic power plant calls for experimental work of considerable extent. Each such plant is a combination of well known equipment but usually requires in addition new equipment which has been previously studied but not generally used. Such power plants are set up in the power laboratory and put through prolonged tests calculated to prove the reliability of every part of them.

In addition to these provisions for all ordinary tests, much special apparatus and many unusual circuits are required to furnish the detailed and accurate data required, and to minimize the labor necessary to secure it. The peak voltmeter, shown in Figure 2, is a vacuum tube device that will measure peak voltages up to 1,000 volts. The tea-wagon oscillograph, of Figure 3, is in frequent service. Of considerable importance is the daily load circuit, which day after day applies a predetermined cycle of load to some piece of apparatus or completed charging plant which is being subjected to test.

Engineers and Progress

"We engineers may, I believe, congratulate ourselves on the contributions that we have made to civilization. The problems of this era are not the problems of the past. Economic history tells us that up to a period of, say, one hundred years ago, the problems of the world were problems of want as well as the problems of distribution. The methods of production did not permit of creating enough to enable more than a very small number of the inhabitants of the world to live on any basis above a bare level of sustenance. Our problem today is only a part of the former problem and should be a simpler one. It is not the problem that we haven't got and can't get the things necessary to give us a higher economic level. It is the problem of the distribution of plenty. The problem that must be solved now is not the problem of how to create enough to keep the bulk of the people of this country above the level of want. Our problem is, having the ability to produce it, how to distribute it to the population. This change in the social problem is the major contribution to the world of the scientist and those who have worked on the application of science, the engineers and others. . . .

"I firmly believe that the future holds in store for us engineers opportunities at least as great as, if not greater than, any that we have had in the past."

BANCROFT GHERARDI.

—From an address given at the annual dinner of the Society of Automotive Engineers, January 11, 1933.

Contributors to This Issue

R. L. Peek, Jr., is a graduate of Columbia University, having received the A. B. degree in 1921, and that of Met. E. in 1923. He joined the Laboratories in 1924, and was for several years in the Chemical Research Department, engaged in studies in physical chemistry, notably those concerned with the use of special methods of physical testing as guides to development work on new materials. In 1931 he transferred to the Materials Testing division of the Apparatus Development Department, where he is responsible for precision measurements, welding studies, and the development of new methods of physical testing.

A. J. Christopher received the degree of B.S. in E.E. from Carnegie Institute of Technology in 1921 and joined the Technical Staff of Bell Telephone Laboratories the same year. At first he was engaged in the design and development of voice-frequency transformers. Later he was placed in charge of a group developing high-frequency transformers for use in carrier systems. In more recent years he has been supervising the design of repeating, retardation, and induction coils for general telephone use.

F. R. Lack began a varied career when he entered the Western Electric Company in 1911. After shop and laboratory experience he was enrolled for a year in a student course given by Western Electric. In 1917 he went to France as a member of the research and inspection unit headed by Colonel Shreeve, where he attained the rank of First Lieutenant. Soon after his return he was sent to China to install a radio-telephone system between Peking and Tientsin, and to Japan where he installed printing-telegraphs. Back in the United States he attended Harvard University from which he was graduated in 1925 with the degree of B.S. Since then he has been with the radio-research group, specializing recently on crystal oscillators.

Carrier current development has been the chief activity of Christian F. Boeck since he entered the Laboratories in 1919. In particular he was active in the initial

R. L. Peek, Jr.

A. J. Christopher

F. R. Lack

C. F. Boeck

G. V. King

J. R. P. Goller

installation of the Type B system, and in the development of picture transmission. He has been connected with power-line carrier since its early days and had charge of laboratory work on the single side-band system which he describes in this issue of the RECORD. Subsequently he took part in the installation of this equipment. While continuing his interest in power-line carrier, Mr. Boeck and his group have recently been concerned with public-address engineering, and with the installation of sound-picture equipment on trucks.

Mr. Boeck is an alumnus of Carroll College, Wisconsin, and had three years of graduate engineering studies at Wisconsin and Columbia.

G. V. KING graduated from Carnegie Institute of Technology in 1920 with the degree of B.S. He spent one year in the engineering department of the Westinghouse Lamp Company and then joined the Western Electric Company, where for about two years he was with the installation department, chiefly engaged in tests of manual circuits. In 1923 he transferred to the Technical Staff of Bell Laboratories. His first work here was circuit analyzation but he shortly transferred to the P.B.X. group where he has engaged in the development of P.B.X. circuits. At the present time he is occupied with fundamental circuit development.

BOTH before and immediately after receiving the degree of B.E. from Union College in 1917, J. R. P. Goller spent a number of years in the power engineering field. This included work with the Long Island Railroad and with power companies in the New York area. He was also at the Army Radio School at College Park, Maryland for a time, and had additional service as a commissioned officer in the Signal Corps. In 1922 he joined the Technical Staff of the Laboratories where, with the Equipment Group, he has been engaged in various phases of power plant development. At present he is in charge of the Power Equipment laboratory.

The above photograph shows the stage which had been reached by January 10 in the installation of the new Western Electric 50-kilowatt transmitter for Station WHAM of Rochester. At the right, behind operators Alfred Balling and Wilfred O'Brien, are the low-power units of the new transmitter, and at the left is part of the high-power equipment. Scanning the plans are J. C. Herber (right) of our radio development group, and John J. Long, Jr., Chief Engineer of WHAM. The Western Electric 5-kilowatt set, with which this station used to transmit, will be held intact as a spare.

The fifty-kilowatt set incorporates many refinements; but its fundamental plan is simple. The carrier originates in a low-power oscillator (shown below) whose frequency is accurately controlled by a quartz plate. After three stages of amplification, the carrier is modulated by the voice currents, which have been amplified in two stages within the transmitter. Modulation takes place in the plate circuit of the third radio-frequency amplifier, which is designated the modulating amplifier. The modulated carrier then passes through three further stages of amplification and finally passes to the antenna over a balanced transmission line. The successive stages of amplification are coupled together by tuned circuits.

Across the miles *comes a* WELCOME VOICE

IT MAY be the voice of a son or daughter away at school. Of a mother or father in a distant city. Of a friend or neighbor who is wondering how you are. Of a business associate upon whose words some great decision rests.

Across the miles, the telephone brings those voices to you and carries your voice in answer. A bell rings and you reach out your hand, knowing that somewhere—near or far—another hand is reaching toward you.

The telephone enlarges the lives and opportunities of all who use it because it enlarges the power to communicate through speech. Contacts with people, ideas exchanged, words spoken —by these are our minds stimulated and the entire business of living made more pleasant and productive.

Because the telephone is so important to so many people, the Bell System strives to make its full usefulness available to every one, everywhere, at all times. Always it tries to emphasize the close contact between each telephone user and the unseen men and women who make good service possible. Always it aims to serve with courtesy, dispatch and sympathetic understanding.

Your telephone offers you the service of a friend. At any hour of the day or night, you have but to turn to it to command as many as you need of the Bell System's army of carefully trained workers.

AMERICAN TELEPHONE AND TELEGRAPH COMPANY

Printed in U. S. A.