BELL LABORATORIES RECORD

COAXIAL CONDUCTOR SYSTEMS
M. E. STRIEBY

SHORT-WAVE RADIO FOR THE WALDORF
H. T. BUDENBOM

MICROPHONIC RESEARCH
F. S. GOUCHER

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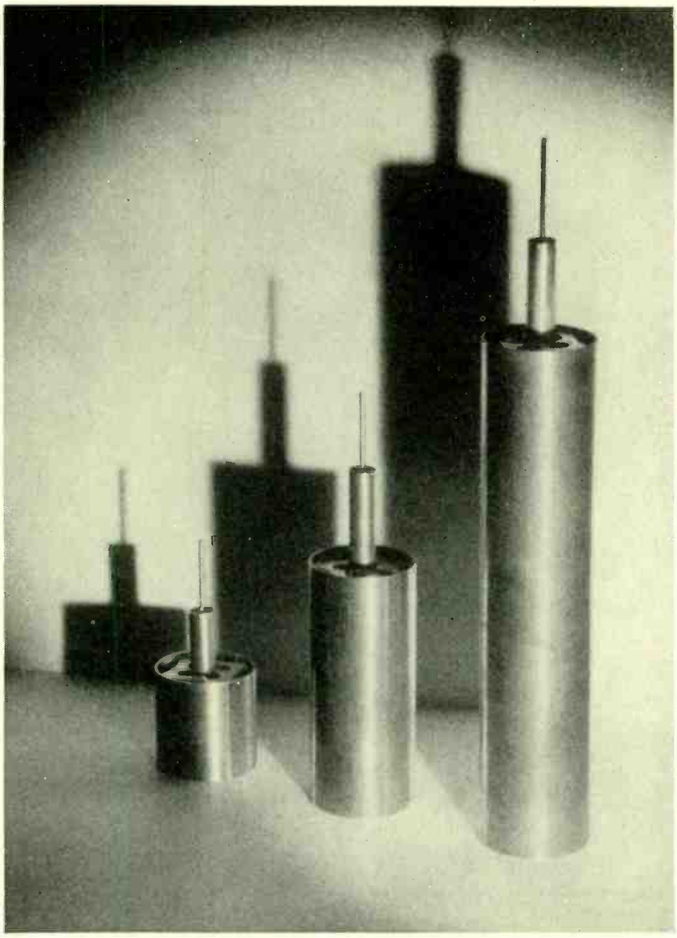

Coaxial Conductors

VOLUME THIRTEEN—NUMBER ELEVEN

for

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1935

Coaxial Conductor Systems

By M. E. STRIEBY
Carrier Transmission Research Engineer

Progress in the Laboratories in the development of a new type of cable circuit known as "coaxial" has reached the point where it is deemed advisable to carry out an actual installation in the field in order to obtain experience with such practical problems as cannot be explored in the laboratory. Accordingly the American Telephone and Telegraph Company proposes an experimental installation between New York and Philadelphia as announced in a recent petition to the Federal Communications Commission. A lead-sheathed cable of seven-eighths inch diameter can be placed in existing cable ducts. As shown below, this cable contains two coaxial circuits, one for each direction of transmission, and two "quads" of paper-insulated wires for control and signalling. It is hoped that the various parts of this experimental cable system can be in place by the first part of 1936. Tests of the new coaxial cable under actual operating conditions will be made as soon as the installation has been completed.

RESEARCH studies on carrier systems are aimed at making available more channels on each pair of wires. The present standard open-wire carrier systems transmit three telephone conversations in each direction on each pair of wires, a total of six channels occupying the frequency range up to about thirty kilocycles. If more channels are imposed on each pair of wires, and the upper frequency limit is raised correspondingly, interference and crosstalk become more and more serious problems. The interference may be greatly decreased by placing the conductors within the lead sheath of a cable, and carrier systems applicable to existing cables—although not now in use—have been set up which will yield about twelve channels on each pair of conductors, and require frequencies up to about 60 kc. Although interference from outside the sheath is greatly reduced in cable circuits, crosstalk between the circuits within the cable sheath becomes more and more difficult to control as the channel frequency is raised.

In view of this situation, it ap-

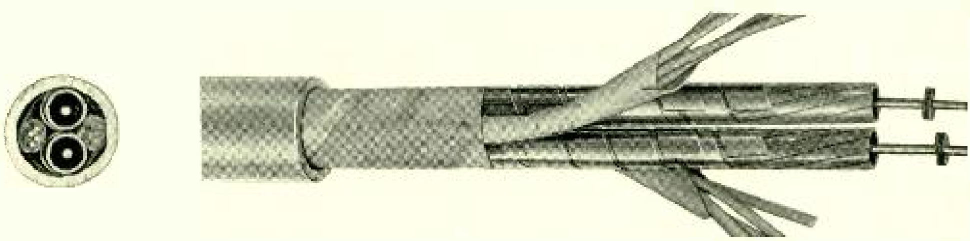


Fig. 1—Coaxial cable which is to be used in the experimental circuit between New York and Philadelphia

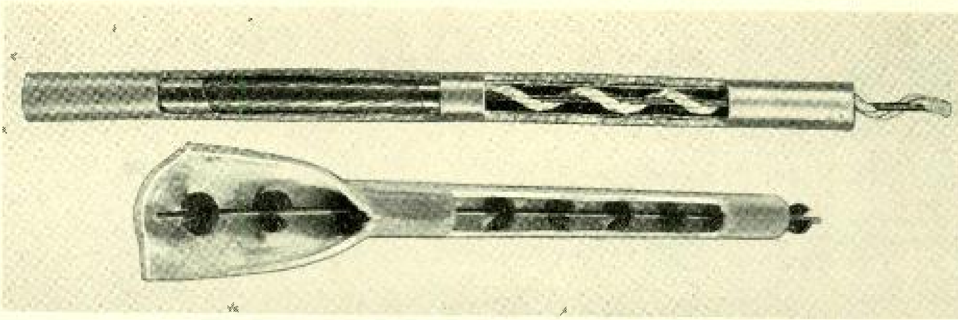


Fig. 2—Two types of Western Electric coaxial conductor which have proved very satisfactory under test

peared that a promising method of increasing the number of channels that could be carried by a single small physical structure might be to employ a single circuit well shielded from outside interference. A communication medium of this type would be suitable for frequencies as high as might be desired, because the protection provided against interference by a shield becomes better the higher the frequency. An additional advantage of such a circuit is that only a single repeater is required for the entire group of channels, while with a cable, a separate repeater is required for each pair of conductors. Such a system could be provided by using two wires within a shield, or the shield itself could be employed as one of the conductors. The latter form has been termed a "coaxial conductor" circuit because of the physical arrangement of the wire within the shield.

Starting as far back as 1920, preliminary consideration was given to the possibility of using a single line structure of the coaxial type for transmitting a frequency band extending up to something like a million cycles. It was recognized that to accomplish this result it would be necessary to provide, on an economical basis, not only a transmission medium capable of handling such a wide frequency band, but intermediate repeaters capable of amplifying the band, preferably without splitting it up, and terminal apparatus capable of subdividing the band into individual telephone channels without excessive wastage of frequency space. It was realized later, moreover, that a band of the order of a million cycles in width would be required for the rendering of television of satisfactory definition.

Study of these problems led Lloyd Espenschied and H. A. Affel to the conclusion that such broad-band wire transmission could be developed in practical form with a coaxial structure as the line transmission medium. To obviate the unduly high attenuation that would result at the high frequencies from losses due to the insulation, it was proposed that the inner conductor be so supported within the outer one that the intervening dielectric would consist mostly of air.

The coaxial circuit is by no means new; it is in fact a classical form of circuit. Since the time of Lord Rayleigh in the middle of the last century, the transmission properties of coaxial circuits have interested mathematicians and physicists, probably because the circular symmetry of such circuits led to exact mathematical solutions for ideal conductors.

Coaxial lines had, of course, been

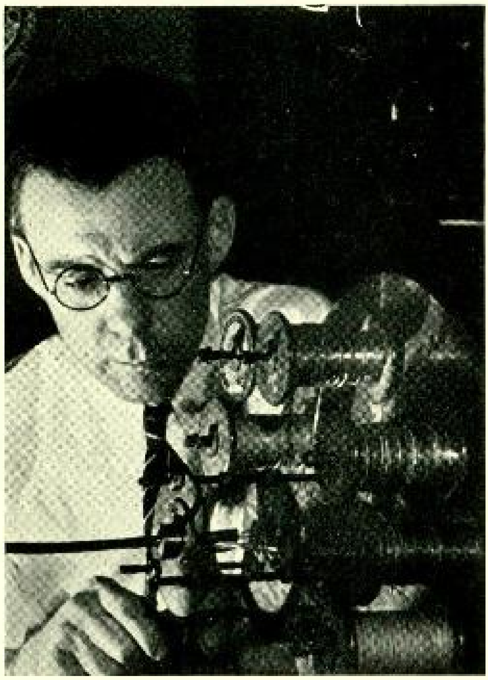


Fig. 3—J. F. Wentz making experimental coaxial conductors on an improvised stranding machine for preliminary tests

used at low frequencies particularly in the form of submarine cables, and the transmission theory of such cables had been investigated by John R. Carson. More recently a rigorous treatment of the problems met in the practical case of imperfect structures was obtained by S. A. Schelkunoff.

The coaxial structure had also been employed at radio frequencies as an antenna lead-in, and for this purpose had been designed to have largely air insulation to minimize high frequency losses. None of these earlier applications, however, contemplated the use of the coaxial circuit in a broad-band overland line system, adaptable to the needs of multiplex telephony and television. Accordingly, a more comprehensive study of a complete coaxial system, including line, repeaters, and terminal apparatus was undertaken by E. I. Green and engineers associated with him. Estimates were made of the comparative costs of telephone channels derived from such a wide-band system and obtained from other types of carrier systems, and of economical system design.

One of the first studies in connection with this development was to determine experimentally how nearly a physical coaxial circuit could be made to approach the theoretical performance. For this purpose a rather large coaxial line was selected, and about two miles of it installed under the direction of A. L. Richey at the test station near Phœnixville, Pennsylvania. This line consisted of a copper tube about two and one-half inches outside diameter, within which was mounted a smaller tube which in turn contained a small copper wire. Two coaxial circuits were thus made

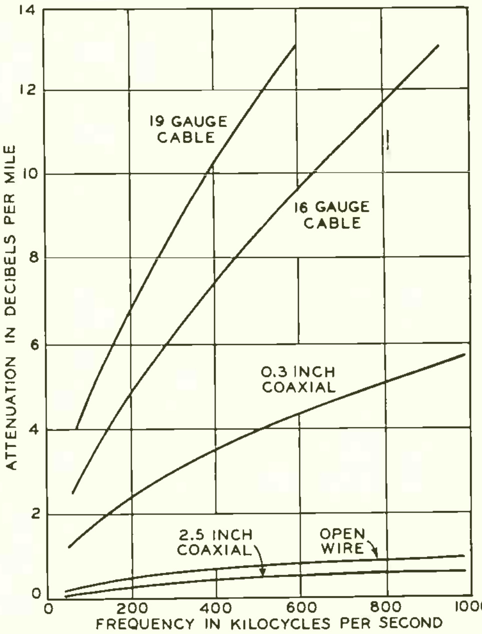


Fig. 4—Attenuation characteristic of the experimental, 2.5-inch, coaxial conductor and the 0.3-inch commercial types compared to that of open-wire and cable circuits

available. Transmission measurements of various kinds were made, which showed that the performance of the line could be predicted theoretically with remarkable accuracy.

After some progress had been made in the study of the combined line and amplifier system, it seemed most likely that an even smaller structure would prove to be most satisfactory for the objective in view. Because of the problems of installation, the most desirable form of conductor was something that could be rolled up on drums, hung on poles, and handled after the fashion of telephone cables. A wide variety of hand-made samples were experimented with in a search for a suitable structure. An experimental machine was set up by J. F. Wentz in the basement of the Laboratories and used by him to produce sufficient lengths of conductor for preliminary tests. Results obtained from these samples were so satisfactory that the development of structural designs was carried forward by G. A. Anderegg, W. E. Mougey, and others, and various cables were produced by the Western Electric Company, and used for tests in the factory and field. Two types are shown in Figure 2.

The attenuation characteristics of these coaxial conductors as compared to those of open-wire lines and cables are shown in Figure 4. At frequencies of the order of a million cycles, the attenuation of the 0.3-inch coaxial lines is such that repeaters are required at intervals of perhaps ten miles or even less. Such frequent use of repeaters would be impracticable were it not for the fact that the repeaters promise to be relatively inexpensive. As now contemplated, a repeater station might consist of a box hung on a pole or placed in a manhole

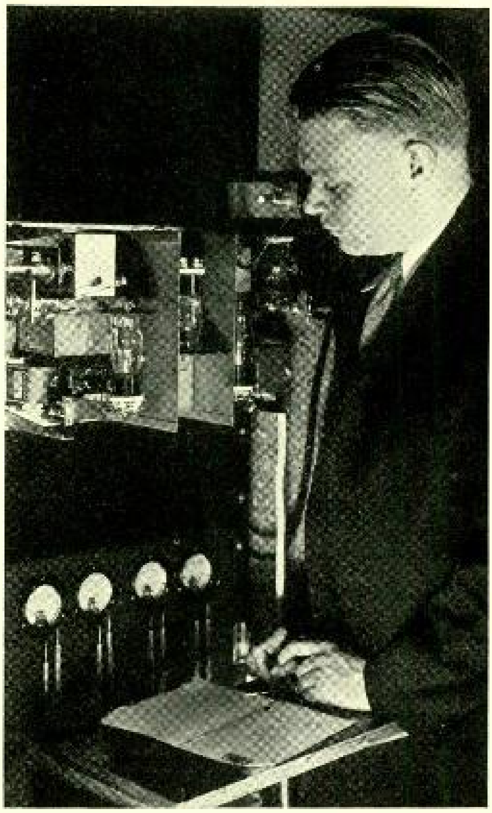


Fig. 5—K. C. Black with a high-frequency repeater developed for coaxial circuits

in much the same manner as loading pots are installed. This means, of course, that the repeater must be fully automatic—requiring attention only at infrequent intervals. Power required to operate it will be transmitted at sixty cycles over the coaxial line itself. A single repeater amplifies the entire frequency band.

The attenuation of copper-wire lines always varies with temperature—overhead lines being perhaps ten per cent higher than average on the hottest day in summer and ten per cent below average on the coldest day in winter. On a transcontinental coaxial circuit, this variation would reach tremendous proportions, and even on a circuit from New York to

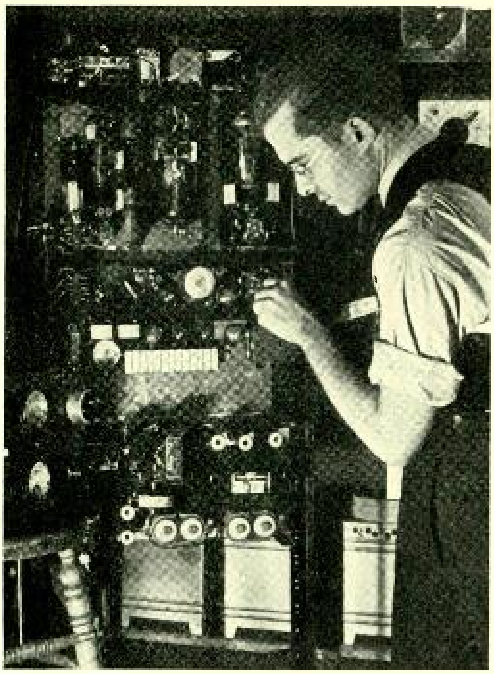


Fig. 6—R. R. Blair with experimental repeater and automatic control circuits

Philadelphia, the variation would be sufficient to make conversation impossible unless the transmission were regulated in some manner. Since most of these repeater stations would be unattended, their regulation must be automatic.

Various experimental repeaters have been built for frequencies as high as five million cycles. To obtain the necessary gain at these high frequencies, the tube development group was called upon for assistance, and has produced many new and useful tubes. Due to the large number of repeaters, each carrying a large number of channels, the principle of feedback developed by H. S. Black was employed to obtain high stability of gain and freedom from distortion. Various circuit arrangements have been tried out in the laboratory for frequency ranges up to as high as five thousand kilocycles. One such repeater, devised by K. C. Black for the frequency range of one hundred to one thousand kilocycles, is shown in Figure 5. It is expected to provide amplification and automatic regulation within a few tenths of a db over the entire frequency band for a temperature range of 120 degrees Fahrenheit. The regulation will be secured with the aid of a one-million-cycle signal transmitted over the line, and used at each regulator repeater to control the gain characteristic. An experimental repeater with power supply and automatic regulation is shown under test in Figure 6.

A million-cycle coaxial line would carry over two hundred voice channels. At the sending end of the line, conversations from two hundred telephone lines must be gathered together and placed on the single coaxial line, and at the receiving end these two hundred conversations must be separated and sent out over two hundred different circuits. The development of modulating and selecting apparatus to perform this function

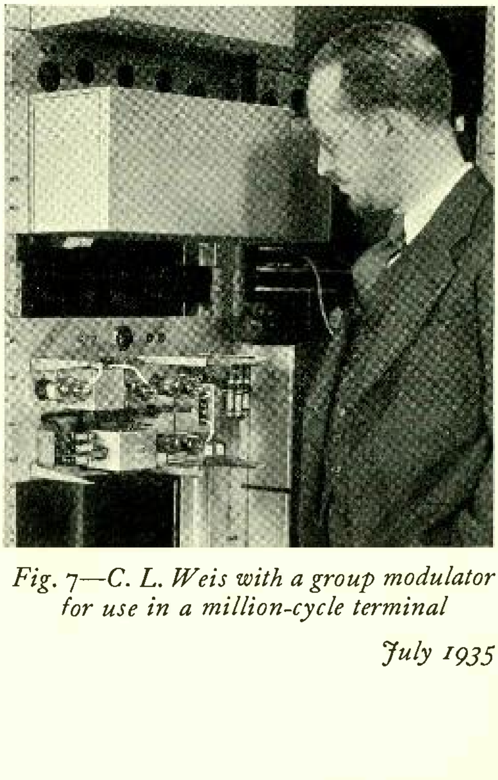


Fig. 7—C. L. Weis with a group modulator for use in a million-cycle terminal

at the two ends of the line was a considerable undertaking, but has resulted in satisfactory working models for thousand-kilocycle systems, and even for systems of considerably higher frequency.

As with other carrier systems, each voice-frequency channel at the sending end is modulated and so moved up in frequency for transmission along the line as a high-frequency side-band. For the coaxial system, however, more than one step of modulation is employed. In the first step, twelve voice-frequency channels are moved up to positions one above another so that they occupy the frequency range from 60 to 108 kilocycles—thus allowing four kilocycles for each channel. In a million-cycle system, twenty such groups would be used, nineteen of them modulated a second time and raised to successive positions one above another—giving a top frequency of 1020 kilocycles. A group modulator for this second step is shown in Figure 7.

Modulating and filtering circuits for such a complicated terminal have already been devised and tested in the laboratory. For selecting individual channels, quartz crystal filters* are employed. For selecting groups of channels, filters have been provided to pass a band 48 kilocycles in width, thus including twelve speech channels. Terminals designed to provide for a five-million cycle system and handling over a thousand channels have also been studied. Three steps of modulation would be employed. Experimental apparatus developed by A. G. Jensen for such a terminal is shown in Figure 8.

The coaxial line is also well adapted for transmitting over long distances

*Record, *June*, 1935.

Fig. 8—A. G. Jensen with high-frequency terminal apparatus and coaxial wiring

the extremely broad frequency bands required for television. Since the frequency range for high-grade television extends from the neighborhood of zero up to a million or more cycles, special modulating apparatus is required at terminals to lift the entire band to a range which can be transmitted over a coaxial system.

The introduction of carrier telephony some fifteen years ago was a tremendous step in the extension of the frequency range employed for transmission purposes. The development of fine-wire long-distance repeater cables decreased the cost of facilities but retained the transmission of voice frequencies. More recent developments of carrier on cable aim at the extension of frequency range to be transmitted over these long distance cables. The development of coaxial systems opens a further vista of still wider frequency ranges.

Projecting Circuit Performance on a Screen

By F. E. FAIRCHILD
Toll Transmission Development

BEHIND the high quality of telephone toll service available to every Bell System subscriber is an adequate maintenance program. Such a program can be successfully carried out by the plant maintenance forces only if they are provided with suitable tools for the measurement of toll circuit performance. These tools must be capable of indicating the results of the measurements quickly and accurately, and they must be simple to operate.

For transmission measurements, tools of satisfactory accuracy have been in use for many years. New developments, however, have made it possible to provide transmission measuring apparatus that is simpler to operate and that gives the results more rapidly than former apparatus, without any decrease in accuracy. One such arrangement has recently been developed for testing repeaters and circuit units. An interesting innovation is its use of a projection meter—the meter scale being projected onto a screen at the end of the aisle. The testing connections are set up at the various repeater bays, from any one of which the meter indication may easily be seen. The arrangement for a trial installation of the projection meter at a repeater station in Richmond, Virginia, is shown in Figure 1.

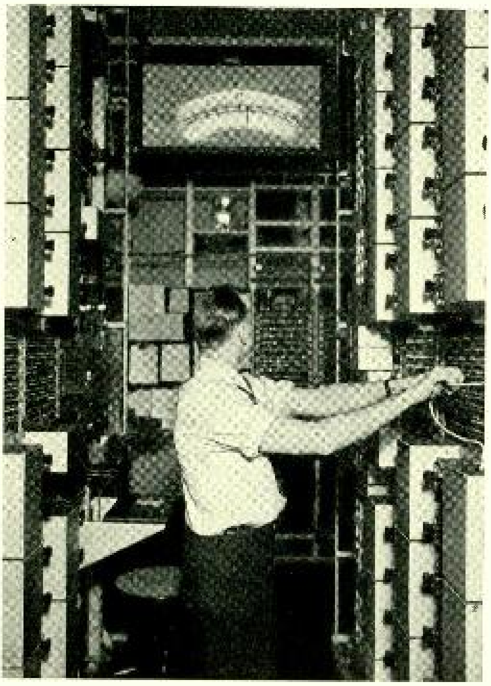


Fig. 1—A trial installation of the projection metering equipment

In repeater offices, the most important measurements required for the adequate maintenance of the various parts of a toll circuit are measurements, all made at 1000 cycles, of transmission level, of net loss of each circuit unit, and of repeater gain and change in gain with change in the filament currents of the vacuum tubes. The latter test is known as a filament activity test, and enables the maintenance force to know when a vacuum tube is nearing the end of its useful life so that it may be replaced before the gain falls off sufficiently to affect the operation of the circuit. Other tests are also required from time to time such as noise, singing point or return loss measurements, and measurements of net loss at frequencies other than one thousand cycles.

At the present time, these tests are made from a position at the end of each repeater aisle. An oscillator and a 6A Transmission Measuring Set are installed at these positions, and the sending and receiving circuits of the measuring circuit are terminated in jacks. The manner of making such measurements has already been described in the RECORD.* A number of testing trunks are run from jacks at the test position to jacks at every alternate repeater bay. Each repeater bay has a jack panel to which are run connections from the input and output terminals of the repeaters. By the use of patching cords at the repeater bays, connections may be easily made between the test trunks and the repeater.

To make a test such as a repeater gain measurement with this earlier arrangement, the attendant first connects the terminals of the repeater to two of the testing trunks, with a patching cord at the repeater bay. He then goes to the test position and patches these same test trunks to the terminals of the testing apparatus. Following this, a measurement is made. If adjustment of the repeater gain is necessary, the attendant returns to the repeater bay, makes the adjustment and then makes another measurement at the test position. This testing and adjusting is occasionally repeated several times for each measurement. During the routine check of repeater gains at the larger repeater offices, excess walking is avoided by employing two men for the work. One confines his attentions to making patches and operating the 6A Transmission Measuring Set at the test position, while the other makes patches and adjusts gains at the repeater bays.

The new method avoids this walking, or the use of a record man, by permitting all the work to be done at the repeater bays themselves. The work is further simplified by using a new form of transmission measuring apparatus instead of the 6A Set. This apparatus is similar in principle to that employed with the No. 8 Test and Control Board described in the RECORD already referred to, and does not require the manipulation of keys and dials that the 6A Set does. The input and output of the repeater are

*RECORD, *August*, 1934, *p.* 367.

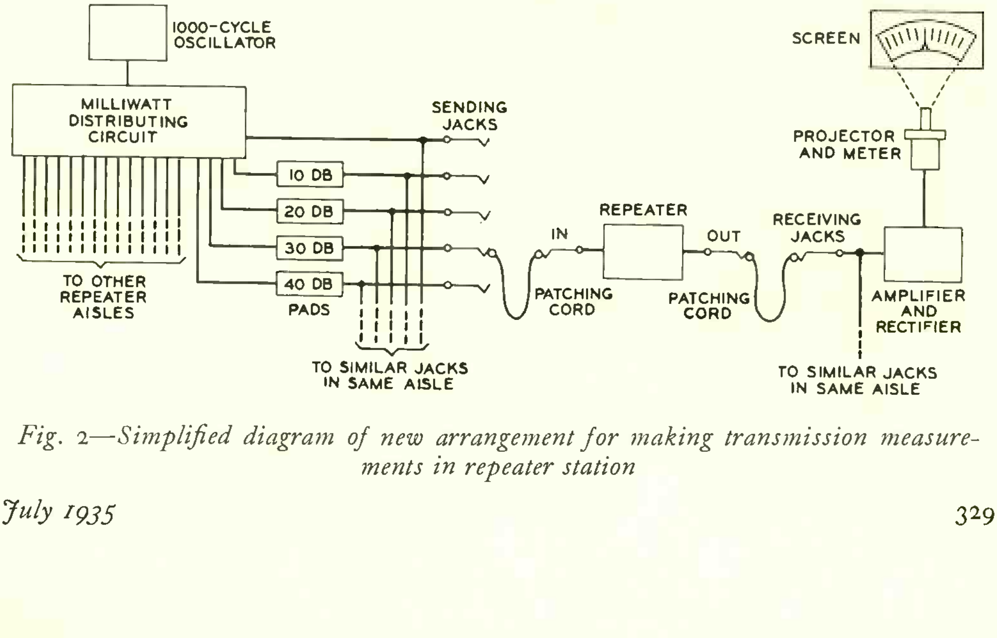


Fig. 2—Simplified diagram of new arrangement for making transmission measurements in repeater station

merely patched to jacks of the measuring set which are located near the repeater and the reading of gain or loss in decibels is displayed automatically on the screen at the end of the aisle.

The testing apparatus comprises an oscillator with a distributing circuit from which trunks are run to the sending jacks; and an amplifier, rectifier, and meter from which trunks are run to the receiving jacks. One oscillator and distributing circuit serves for 150 sending-jack appearances in the repeater aisles. It is mounted near the top of a bay in one of the repeater aisles, and requires only occasional attention. One receiving circuit is generally provided for each aisle. The projection meter for each receiving circuit is mounted a few feet behind the screen at the end of the aisle, and the amplifier and rectifier with a certain amount of auxiliary equipment are mounted at the position at the end of each aisle which formerly carried the 6A Measuring Set. About once a day the receiving circuit is adjusted, but it requires no attention while the tests are being made. A simplified diagram of the arrangement is shown in Figure 2.

Testing jacks generally appear at every fifth bay on each side of the aisle. Several sending jacks are provided at each such appearance, some connected through pads, so as to provide 1000-cycle sending powers of 1 milliwatt, and of 10, 20, 30, and 40 db below 1 milliwatt. A key is associated with each receiving jack to insert a 10 db pad in the receiving circuit and thereby double the range of the receiving meter. This makes it possible for the system to make transmission measurements over a range of from 15 db above to 5 db below 1 milliwatt.

The meter in its electrical characteristics is similar to that used with the No. 8 Test and Control Board but differs mechanically to permit its being placed in the slide holder of the projection lantern. Preliminary models of the meter and projector are shown in Figures 3 and 4. The scale and back of the case are of glass to permit light to pass through the meter. Because of the heat to which the meter is subjected, it is provided with an aluminum case with cooling fins on each end. In addition the projector mounts a small fan which provides a continuous circulation of air around the meter whenever the projector lamp is

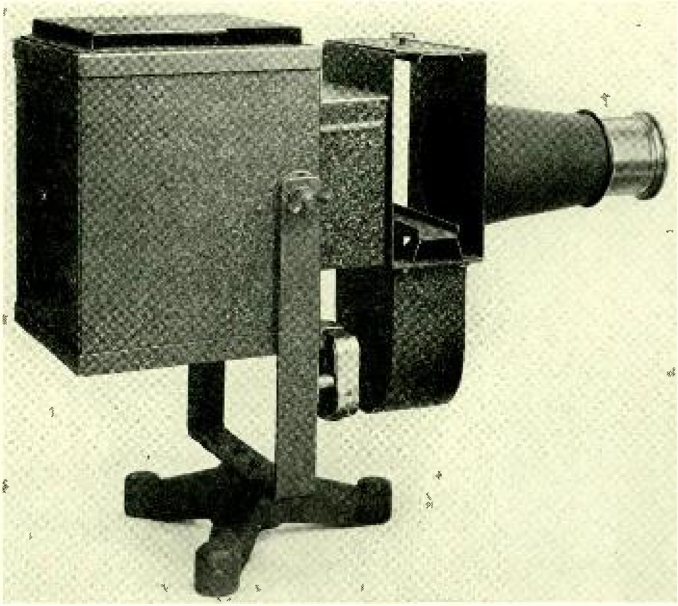


Fig. 3—A preliminary model of the projector

lighted. The regular lighting circuit of the office furnishes current for the lamp through a relay controlled by contacts in the receiving jacks, so that the meter is lighted only while a test is being made. In this way the life of the projector lamp is conserved, and the lighted screen acts as a busy signal to show that the test circuit of that aisle is in use.

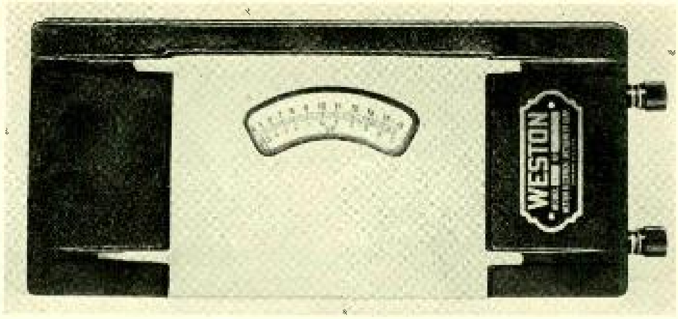


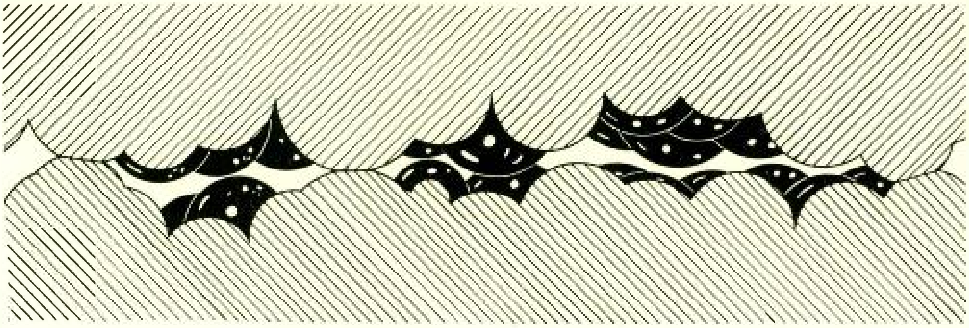
Fig. 4—A model of the meter

Where it is desired to make line-noise measurements with the projection-meter system, one noise amplifier is provided for the entire office. This is a device which amplifies and weights the individual frequency components of the noise currents so that a transmission measuring set connected to its output gives a suitable indication of the noise on the circuit. Noise jacks are provided along with the sending and receiving jacks in the repeater aisles. To make a noise measurement it is necessary only to patch the output of the repeater on the circuit to one of these noise jacks. This automatically connects the noise jacks in that aisle to the input of the noise amplifier and connects the output of the noise amplifier to the receiving circuit of that aisle. It also lights the projector, and the meter gives a measurement of the noise on the circuit.

In addition to the uses mentioned above, the system has proved to be an excellent tool for running down poor contacts and troubles in repeaters, since both hands of the attendant are free for locating the trouble, and the meter can be watched while the adjustments are being made. It may be possible eventually to provide suitable auxiliary equipment to permit return loss measurements to be made with the projection meter system. This possibility is being studied at the present time.

The Morris Liebmann Memorial Prize

has been awarded by the Institute of Radio Engineers to F. B. Llewellyn for his analysis and disclosures of the effects and the reactions which occur within vacuum tubes at ultra-high frequencies.



Recent Advances in Microphonic Research

By F. S. GOUCHER
Research Physicist

BECAUSE of its importance in the telephone art, as well as of man's irrepressible curiosity in regard to processes not thoroughly understood, the carbon microphone has been studied extensively ever since the discovery of the remarkable microphonic properties of low pressure contacts over fifty years ago. The action of the microphone depends primarily on minute movements between carbon particles which change the resistance in a current path. The current traverses an aggregate of particles loosely held between a diaphragm and the walls of a cell containing them. As yet no adequate theory of the relation between resistance change and contact movement has been established when the forces and movements are as small as those corresponding to the working range of a typical pair of particles in the present-day carbon microphone. Recent studies made in these Laboratories have, however, thrown a good deal of light on their mode of action.

Some years ago the foundations were laid for what we now believe will eventually evolve into a satisfactory theory. The underlying concept of this theory was that the electrical resistance depends on the contact area and that a change in area arises from the elastic deformation of the contact material under pressure. Based on the observation that carbon surfaces are microscopically rough, the theory in its earlier form postulated a spherical base, on the surface of which minute hemispherical hills, small in comparison with the contact area, participated in the elastic deformation as shown in Figure 1. Under compression both the underlying sphere and the hills are deformed, with the result that the number of hills in contact is increased

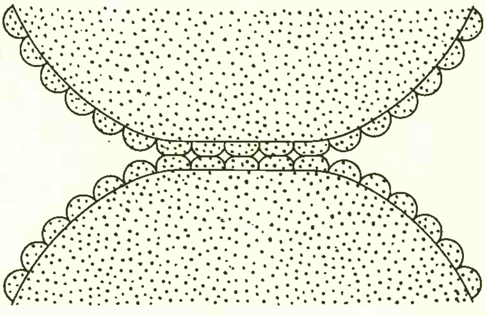


Fig. 1—Spherical bases, and the hemispherical hills on their surfaces, are all deformed when contact forces are large

and at the same time the areas of contact between the hills are enlarged. In this case the relation between contact force and the resultant movement between the particle centers is substantially the same as it would be if the spheres were smooth. When, on the basis of these assumptions, the electrical resistance is calculated as a function of contact force, the resultant relation agrees well with experiment for contacts over a wide range of force except in the small force range—the very range in which contacts operate in present-day microphones. In view of the many factors, such as gas adsorption and electric discharge across gaps, which might dominate contact behavior in this range, uncertainty in regard to the underlying cause of microphonic action in microphones still persisted.

Studies made in these Laboratories,* which have been partially recounted in the RECORD, eliminated many of these uncertainties and supported the view that area change arising from elastic deformation is the primary cause of microphonic action, even in the low force range. They indicated that the difficulty in arriving at a quantitative theory lay in a failure to make the proper assumption in regard to the nature of the surface involved in the elastic deformation.

*RECORD, *August*, 1930, *p.* 566.

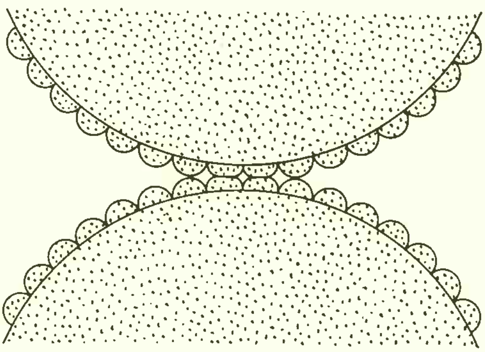


Fig. 2—In this case, under light contact force, the hemispherical hills alone are deformed

A new attack on the problem was initiated through a study of the relationship of force to displacement for pressures within the working range. By this direct method it was hoped to learn more about the nature of the surface participating in the elastic deformation. Such studies had never been undertaken before, largely because of the difficulty involved in measuring small displacements between contact centers, which, under working conditions, are probably less than a millionth of a centimeter. We have overcome this difficulty by the development of apparatus described elsewhere in this issue.†

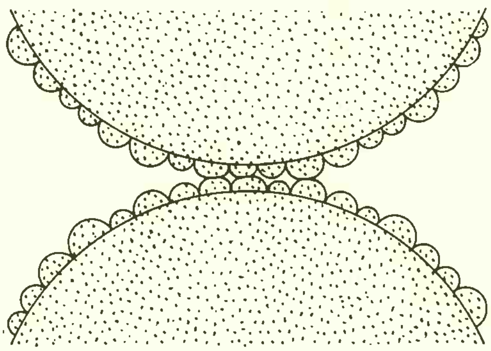


Fig. 3—When the hills are of various diameters, this is what happens when they are pressed lightly together. As in Figure 2, the bases are undeformed

In general, the experimental relationship between contact force and the movement between particle centers is given by the approximate equation $F = KD^x$ where F is the applied force, D is the displacement and both K and X are constants which depend on the geometry of the contact particles. Studies of a large number of microphonic contacts were made cov-

†By J. R. Haynes.

ering the upper limit of the working range of contact displacements and hence in the region contributing most to intelligible speech. The measurements give values of x that vary somewhat from contact to contact, but which on the average had a value about 3. With this fact determined, the next step was to discover, if possible, the form of contacting surface necessary to produce an exponent of this value.

When two smooth elastic spheres are pressed together, the exponent in the above equation is found to be 1.5, a result first calculated by Hertz. The exponent has a value greater than unity because of the increase in area with a consequent increase in stiffness as the spheres are pressed together. The higher value of our measured exponent suggests that we are dealing with a number of hills which are arranged in such a way that new hills are added rapidly under compression. Such would be the case if the idealized contacts shown in Figure 1 are held together with a force so small that only a few hills are brought in contact, as shown in Figure 2.

As an aid in the interpretation of the elastic behavior of such a contact, a large scale rubber model was constructed. Hemispheres of equal height cut from ¼-inch rubber balls were cemented on the surface of a segment of a 31-inch rubber sphere and suitable arrangements were made for measuring the forces applied and the displacements resulting when the segment was pressed against a flat plate. By using a flat plate instead of another similar contact, the value of the exponent is unaffected. As expected, the force varied exponentially with the displacement, the highest exponent 2.5 being obtained when the displacements were so small that there was no deformation of the large sphere. As the displacements increased so that the underlying base was also deformed, the condition holding for the case illustrated in

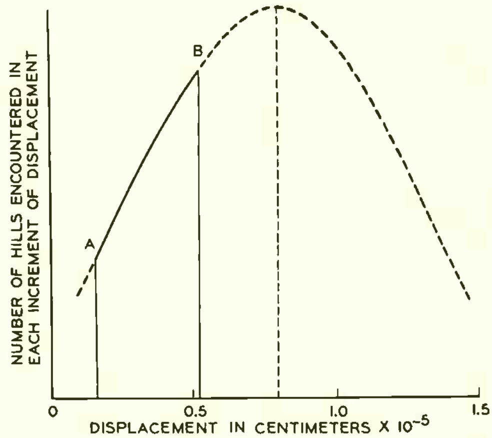


Fig. 4—The curve AB shows the number of new hills encountered as a plane moves into a group of hills. When a probability curve is fitted to AB, it follows the dashed line

Figure 1 was approached with a consequent decrease in the value of the exponent.

The value of exponent 2.5 is much nearer the experimental value 3 obtained with the actual carbon contacts than is that obtained with smooth spheres, but we know that hills of exactly equal height would not be found on the actual surface. Since it would appear that the value of the exponent depends only on the distribution of heights among the spheres and not on the shape or nature of the underlying base, an attempt was made to get a higher exponent by cementing hemispheres of only approximately equal height on a flat base and confining the displacements to that range which brought only those hills into contact which had larger than average height, as represented in Figure 3. The highest value of the exponent obtained in this way was 3.2, a surprisingly good agreement with our measured value. This, therefore, appeared to be the correct concept of the contact surface which we were seeking.

We were now in a position to analyze our measurements on carbon further. Assuming that hemispherical hills act independently, it was a simple matter to derive an expression showing how the relative number of hills encountered varies with compression for the range of movement covered by our measurements. The solid line A-B in Figure 4 gives the results of our analysis. If we imagine a physical plane moving from left to right toward the aggregate of hills, it will first make contact with the highest hill and then gradually touch more and more of them. The ordinates between A and B represent the relative number of hills brought into contact with each increment of displacement of the plane. We are probably justified in assuming that the heights of the hills are distributed at random about a mean value. So, as the plane approaches, the number of hills contacted for each increment of movement will increase up to a maximum and then decrease. A curve representing this relationship can be plotted from probability theory; such a curve, scaled to fit the experimentally-determined line A-B is shown by the dashed line in Figure 4. It is then permissible to assume that the average height of the hills is of the same order as the displacement of the plane between the point where it touches the highest hill and the point where the dashed curve turns downward. Thus the average height is about 1×10^{-5} cm.

Since this size of hill should be just visible under the most powerful microscope, we have made a microscopic analysis of high efficiency microphonic contacts which are spherical in shape and which, therefore, are more suitable to this type of study than the ordinary particle, which is irregular in shape. We find a striking confirmation of our prediction as to the size of

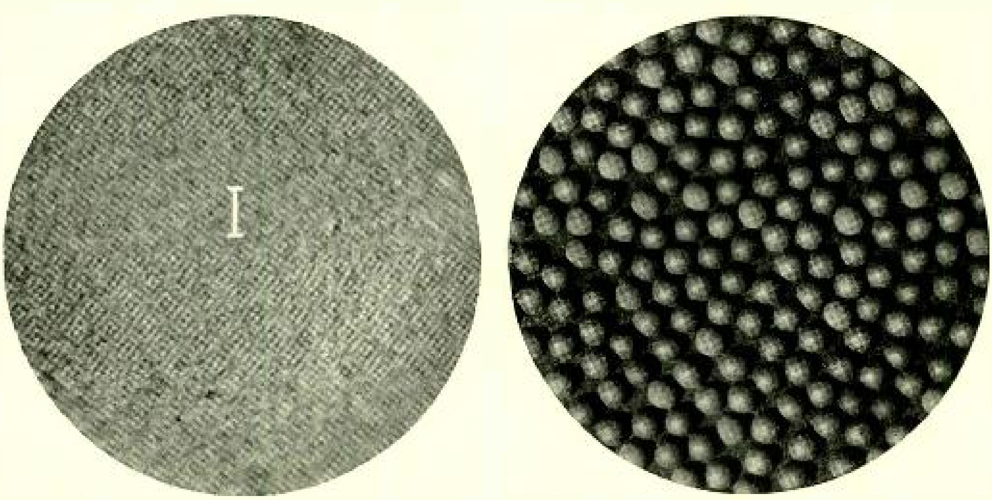
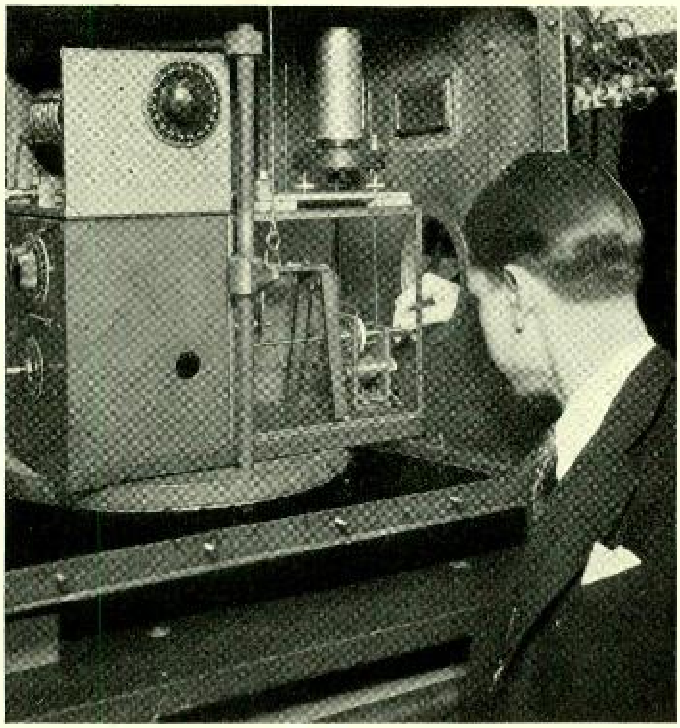


Fig. 5—A photomicrograph (left) of an actual carbon surface compared with (right) its elastic equivalent—a surface covered with rubber hemispheres of random height. The white line represents a dimension of about 2.5×10^{-4} *cm. on the unmagnified surface*

the hill. Figure 5 shows a photomicrograph of a typical carbon surface taken at a magnification of 2400. The white line represents a dimension of 2.5×10^{-4} cm. on the unmagnified surface. A careful examination will show that about 10 irregularities occur within this distance. This makes the average diameter of hill 2.5×10^{-5} cm., a result entirely consistent with our estimate of the average height, since the diameter of a hill, as viewed from above, would be twice that of the average height, assuming the hills to be hemispherical.

Although the resolving power of our microscope is the highest attainable it is insufficient to enable us to carry our observation as far as we would like, nevertheless we are justified, we believe, on the basis of our experiments in assuming that the region of contact between two particles would look very much as in the drawing at the head of this article. We have imagined a plane section through two particles cutting through the contact region at right angles to the contact area. The contour of the surface is shown in the sectional plane as well as a view of some of the hills within the contact region beyond this plane. The hills are, of course, not of equal radius but this assumption is compatible with the results of our analysis, in which the contact radius enters into the coefficient of our equation and does not affect the exponent.

Calculation based on the elastic behavior of these contact surfaces gives a relation between electrical resistance and contact force, when certain reasonable assumptions are made, which agrees reasonably well with measured values. This relationship indicates that the most rapid change in resistance with a given change in force takes place when the change in the number of hills with displacement is most rapid. It appears probable that we are now working in that range which takes full advantage of surface roughness in our high sensitivity microphones. This advantage is about two to one as compared with the result we would expect if the microphonic particles were smooth.



Measuring Displacements of Microphone Contacts

By J. R. HAYNES
Physical Research

RESEARCHES into the nature of microphonic action have required the development of apparatus for measuring extremely small displacements. In a microphone the greatest movement between contacts rarely exceeds a millionth of a centimeter, and it was felt necessary, therefore, to be able to measure displacements of about a hundredth of this amount, or a hundred-millionth of a centimeter—approximately the diameter of the hydrogen atom. In addition, provision had to be made for applying and measuring forces of the order of a dyne—less than two ten-millionths of an ounce. The apparatus provided, which has been successfully employed in the studies described in an accompanying article,* is shown in the illustration above.

The measurement of displacement involves, of course, the measurement of length. With the unaided eye and a suitable scale, length may be measured to a hundredth of a centimeter. By use of a modern high-power microscope, this limit of measurement may be extended to a hundred-thousandth of a centimeter, while with an interferometer, motions as small as a millionth of a centimeter can be detected. When still smaller

*By F. S. Goucher, p. 332.

displacements must be measured, an arrangement of electrical apparatus called an ultra-micrometer is usually employed to advantage.

The first instrument of this type was developed by Whiddington, and since then many ultra-micrometers have been built differing from the original only in certain details. While the instrument developed for microphone studies is like the others in principle, it differs in uniting a continuous reading of displacement with the highest sensitivity—two necessary requirements for microphone research, which have been more or less incompatible with the earlier apparatus that has been built.

An ultra-micrometer measures displacement indirectly by measuring the change in frequency of an oscillating circuit. The frequency of this circuit depends on the capacitance of a small air condenser that has one fixed plate and one plate that is attached to the object whose movement is to be studied. The arrangement is shown diagrammatically in Figure 1. As the object under test is moved, the spacing between the condenser plates is changed a like amount, and since the capacitance of a condenser is inversely proportional to the separation of its plates, the frequency of the circuit will also be changed.

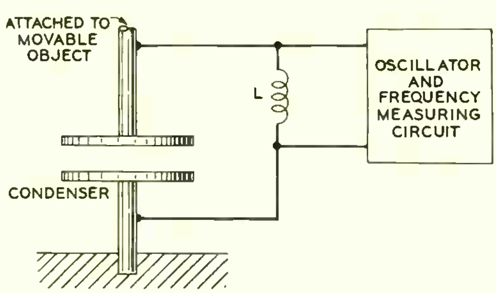


Fig. 1—In the ultra-micrometer one plate of an air condenser moves with the object under test

The actual percentage change in resonance frequency of an oscillating circuit for very small variations is one-half of the percentage change in the capacitance of the condenser, and thus of the percentage change in spacing of the condenser plates. To procure a comparatively large change

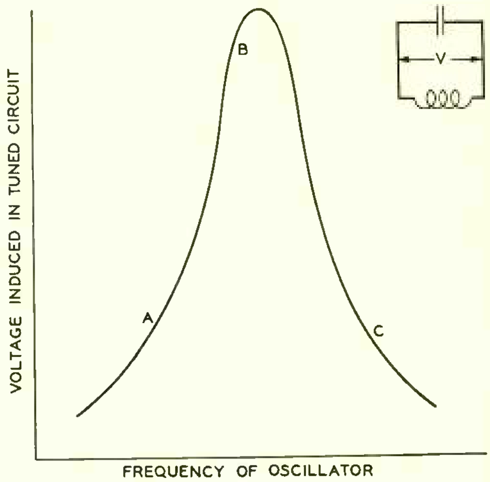


Fig. 2—When an oscillating circuit, upper right, is brought near a source of changing frequency, the voltage across the condenser changes according to the curve ABC

in frequency with a small displacement, therefore, it is necessary only to make the separation of the plates of the adjustable condenser very small. If, for example, the separation of the condenser plates were 10^{-3} cm., a displacement of 10^{-5} cm. would result in a one per cent change in capacitance and a 0.5 per cent change in frequency—a change that can readily be measured. The difficulty in measuring a displacement, or change in length, depends on its magnitude, while the difficulty in measuring a change in frequency depends not on the magnitude of the change but on that of the percentage change. The ultra-micrometer takes advantage of this fact, and by substituting a measurement of frequency change for one of displacement, gains greatly in sensitivity.

This principle is common to all ultra-micrometers—the various types differing only in their method of measuring the change of frequency produced by the displacement. The high sensitivity of the Laboratories' apparatus is obtained by employing a tuned circuit to detect the change in frequency. When a tuned circuit consisting of a capacitance and inductance in parallel—as shown at the upper right of Figure 2—is brought near an oscillator whose frequency is changing, the voltage across the condenser varies as indicated by the curve of this illustration. Such an arrangement is commonly called a wave meter. Over the section from A to B, a very small change in frequency will produce a relatively large change in voltage. The slope of the curve from A to B depends on the design of the oscillating circuit, and has been made very steep in the apparatus employed for the microphonic studies.

A galvanometer is provided for measuring the voltage of the auxiliary oscillating circuit. The deflection of the galvanometer beam, which measures the displacement of the contact, may be watched continuously, or a potentiometer in conjunction with the galvanometer may be used for reading comparatively large displacements. The potentiometer is adjusted until the galvanometer deflection is brought back to zero, and the reading of the potentiometer is then a measure of the displacement.

The complete measuring apparatus thus comprises three units: an oscillator, a wave meter, and a potentiometer. The circuit is shown in Figure 3. The oscillator has a nominal frequency of 2000 kc, and A is the parallel plate condenser that slightly changes this frequency in accordance with the displacement of the contact. B is a small adjustable condenser employed to change the frequency of the

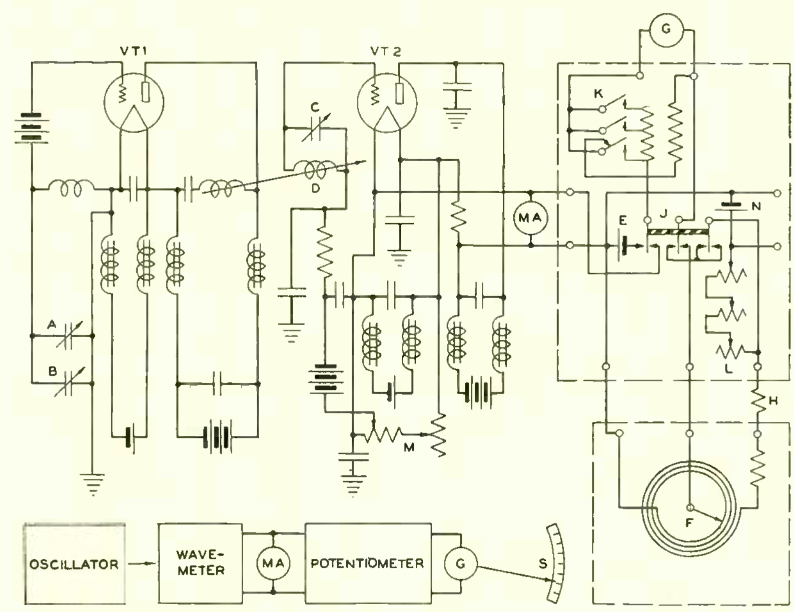


Fig. 3—Schematic circuit of Laboratories' ultra-micrometer

oscillator so that it falls on the steepest part of the wave meter curve of Figure 2. The voltage across the tuned circuit of the wave meter is rectified and amplified by a vacuum tube, and delivered to the terminals of a milliammeter. The potentiometer circuit is also connected across the terminals of this meter and by measuring the voltage across it gives a measure of the displacement of the contact.

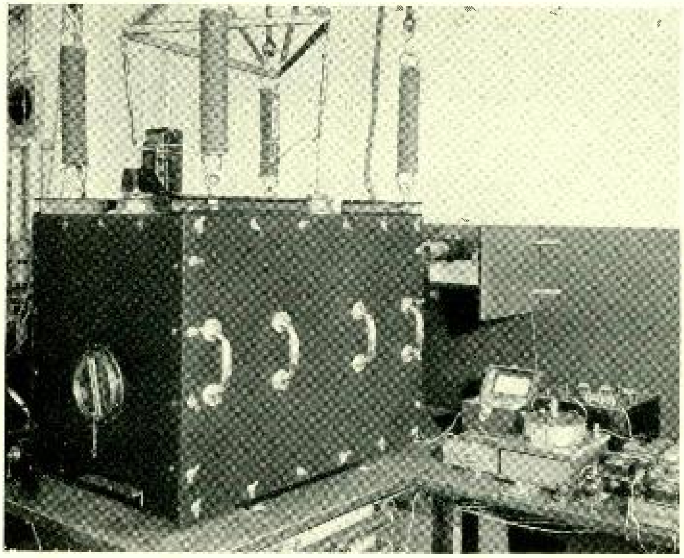


Fig. 5—Set-up of ultra-micrometer showing heavy suspended case carrying the major part of the apparatus at the left, the potentiometer and accessory meters on the bench at the right

The arrangement of the associated mechanical system used in the study of microphone contacts is shown in Figure 4. A rod, R, supported horizontally by springs S, carries on one end a carbon granule serving as the moving element of the contact under study, and on the other end, the movable plate of the condenser used to measure the displacement. A carbon plate, serving as the fixed element of the contact, is fastened to the shaft of a micrometer M_2, by means of which it is brought into contact with the granule. A similar micrometer opposite the other end of R carries the fixed plate of the condenser and allows the spacing of the plates to be adjusted.

Force is applied to the contact electrostatically through the condenser C_2. One plate of this condenser is mounted on the rod at the end carrying the contact, and the other plate is fastened to the micrometer shaft carrying the fixed carbon plate. The dimensions of the condenser are such that 200 volts applied to it produces

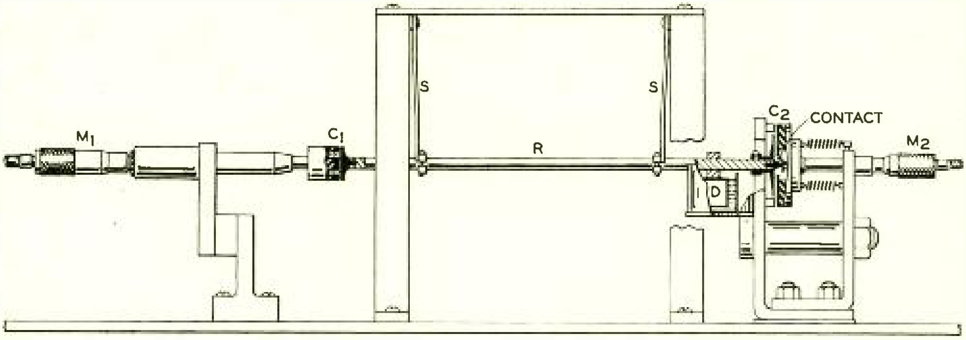


Fig. 4—Simplified diagram indicating major mechanical features of ultra-micrometer

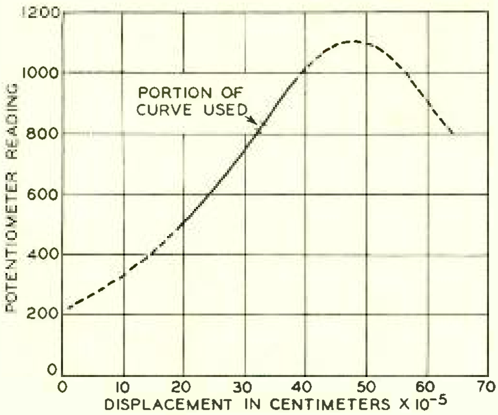


Fig. 6—Calibration curve of ultra-micrometer in terms of potentiometer reading. For microphone contact studies only a small section of the curve is employed

a force of 10 dynes on the contact. By this means exceedingly small forces may be applied to the contact without the production of heat or hysteresis effects which usually exist with other methods.

The cylinder D attached to the rod is immersed in castor oil to damp out mechanical vibration, and the entire mechanical system is carefully compensated for thermal expansions. The apparatus set up for measurement is shown in Figure 5. The mechanical system and its associated electrical apparatus including the galvanometer are mounted in a brass case supported by a delicate spring suspension. For protection from acoustical shock the entire apparatus is surrounded by a heavy lead case which has a heavy glass window at one end to allow the beam of light from the galvanometer to fall on a scale attached to the wall. Ports are also provided at each end of the container to permit adjustment of the apparatus without removal of the lead cover. The apparatus with one side of the casing removed is shown in the illustration at the head of this article.

Calibration of the ultra-micrometer is easily accomplished. The stiffness of the springs is known. When the fixed contact is moved back and a known force is applied to the rod through the condenser C_2, therefore, the rod is displaced a definite amount according to Hookes' law. For each applied force the displacement can be calculated, and the corresponding potentiometer reading recorded. A plot of these potentiometer readings against displacements gives a calibration. A typical curve is shown in Figure 6. With such a curve available, the displacement during a contact study is determined from the potentiometer, and the force, from the voltage applied to the condenser C_2.

Since the greatest displacements between microphone contacts is about 1×10^{-6} cm., a nearly linear relationship between voltage and displacement may be obtained by choosing a

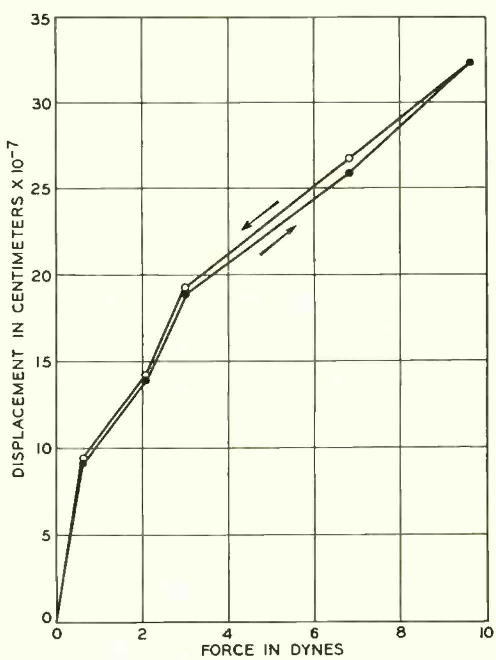


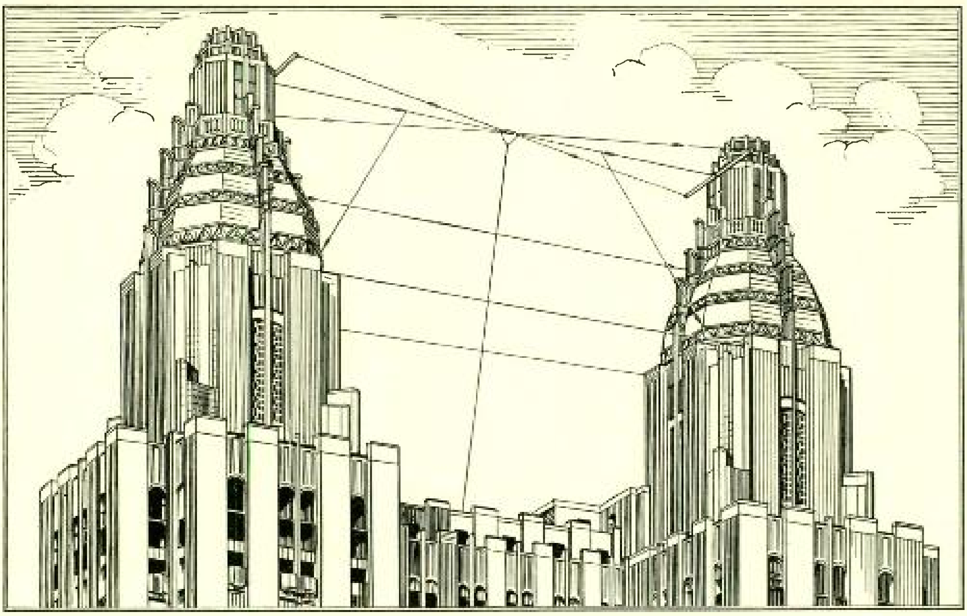
Fig. 7—Typical force—displacement characteristic of a carbon contact

suitable position on the calibration curve. It is thus possible to use the deflection of the galvanometer rather than the potentiometer reading as a measure of extremely small displacements. It was found that the sensitivity of the instrument could be made such that a displacement of 1×10^{-8} cm. moved the spot of light from the galvanometer one inch on the wall scale. This is a magnification of 250 million times.

The precision of the apparatus and its method of use are illustrated by the graph of Figure 7. This shows, for one particular contact, the relationship between displacement and force on the contact as the force is increased from zero to nearly ten dynes and then decreased to zero. The maximum displacement was a little over three one-millionths of a centimeter, but the apparatus was able to detect a difference in displacement at decreasing and increasing force as small as three one-hundred millionths of a centimeter—the displacement for the same force being slightly higher when the force is decreasing, than when it is increasing.

Vitamin B_1 Exhibit at Medical Convention

The preparation of vitamin B_1, its structural chemistry, physiological effects and medical uses were shown in a Scientific Group Exhibit at the recent convention of the American Medical Association in Atlantic City. The work portrayed represents the efforts of a group under the leadership of R. R. Williams of the Laboratories. Among others, R. E. Waterman of the Laboratories participated over a period of ten years in the isolation of the vitamin and the study of its physiological effects. The principal participants with Dr. Williams in the work in chemical structure were Drs. H. T. Clarke and E. R. Buchman of Columbia University. In this phase, A. E. Ruehle of the Laboratories also had a part. Dr. M. G. Vorhaus had charge of the experiments regarding clinical applications. The results of this work on vitamin B_1 indicate usefulness in the treatment of diabetes and particularly of neuritis.



Short-Wave Programs for Waldorf Guests

By H. T. BUDENBOM
Radio Development

SINCE its opening some four years ago, the new Waldorf-Astoria Hotel has provided radio broadcast programs for its guests in over two thousand rooms. A horizontal antenna, suspended between towers forty-seven stories above the street, is connected to high-quality Western Electric receivers on the sixth floor, from which point the programs are distributed over a building-wide network developed by the Laboratories. This system has already been described in the RECORD*. Since the Waldorf enjoys an international reputation, and attracts many foreign guests, the management felt it would be desirable to make available to them radio programs broadcast on short waves from their own countries, in addition to our local broadcasts. Moreover, the increasing general interest in short-wave reception would make the availability of short-wave programs an attractive feature for American patrons. To receive such programs the Waldorf has now installed a Western Electric short-wave receiver which can be connected to any of the circuits of the present distributing system.

Most of the short-wave programs are broadcast at frequencies from 6 to 25 megacycles, corresponding to wave lengths from fifty down to twelve meters, and it was decided that the Western Electric 13A Radio Receiver would provide the best quality of signal and most general satisfaction over this range. This receiver was designed for various applications in the short-wave field, including aviation, point-to-point, and ship-to-shore.

*RECORD, *February*, 1932, *p.* 187.

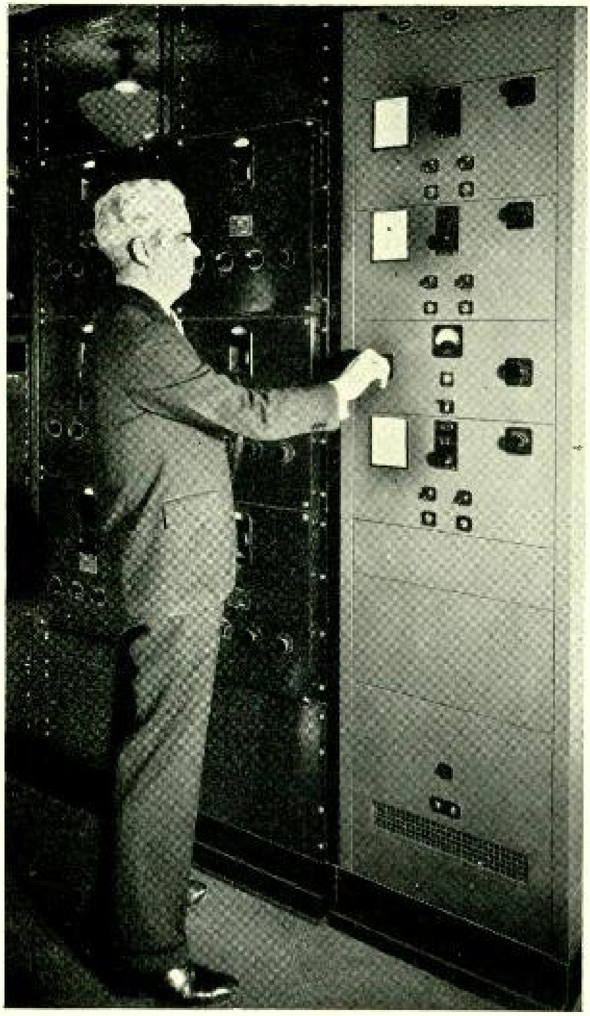


Fig. 1—H. R. Martin, Superintendent of Communication at the Waldorf, tunes the short-wave receiving unit

The scope of the receiver may be broadened, after purchase, by the addition of other units as desired.

Units available are three radio-frequency amplifiers, each with a different frequency range, an intermediate frequency amplifier, and an audio-frequency amplifier and power supply unit, as well as antenna tuning units, a patching panel, and an oscillator panel, which allows the set to be used for receiving telegraph signals. There is also available a panel, used chiefly for point-to-point communication, which may be employed to disable the receiver either when no carrier is being received or when the transmitter associated with the receiver is on the air. Of these various panels available, the installation at the Waldorf includes only the audio and intermediate-frequency amplifiers and the three radio-frequency amplifiers, which are sufficient for broadcast reception over the frequency range from 2.2 to 25 megacycles. Such an arrangement will permit them to receive not only all the short-wave broadcasts, but many police, aviation, and amateur radio-telephone channels as well.

It was first applied to the Caribbean radio telephone project, as already described in the RECORD*, but has since been widely used both at home and abroad. As shown in Figure 1, all the apparatus is housed in a seven-foot cabinet about twenty inches wide. The cabinet itself forms the back, sides, and top for a number of units, each of which has its own function and carries its own front panel.

The use of three separate radio-frequency amplifiers makes it much easier to tune in on a given station promptly. Depending on the time of day, a broadcast station may employ any of several frequencies. If it were desired to get a station which used either 6, 9, or 15 megacycles, for example, one amplifier could be tuned to 6 megacycles, one to 9, and one

*RECORD, *August*, 1933, *p.* 375.

to 15, and all three would be connected to the intermediate-frequency amplifier. If the station were on the air it would be immediately heard, and the two unnecessary amplifiers turned off. If it had not yet come on the air the operator would hear it the moment it did and would not lose the station announcement by having to tune successively to several frequencies.

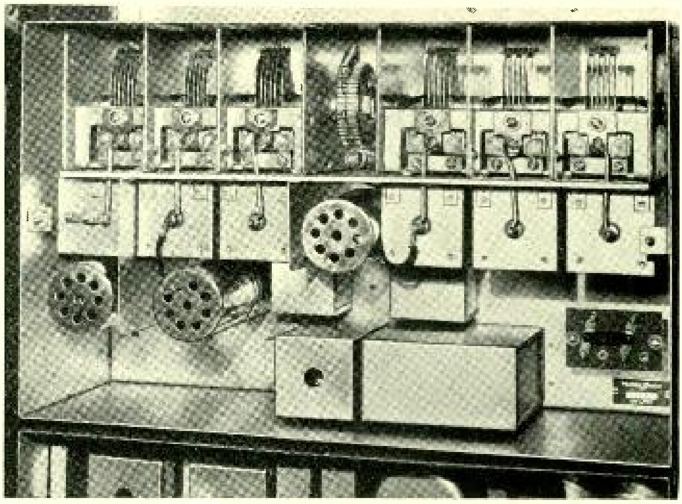


Fig. 2—The radio-frequency amplifiers incorporate accurate gang tuning through a worm drive with a double scale dial

The 13A Receiver is completely a-c. operated: the necessary transformers, rectifiers, and filters being incorporated in the voice-frequency amplifier unit. The signal gathered by the antenna first enters one of the radio-frequency amplifiers where it is amplified, passed through a series of selective circuits, and is then beat down to a frequency of 385 kc.—the frequency of the intermediate amplifier.* Here undesired frequencies are filtered out by sharply tuned circuits, further amplification is obtained, and the signal is detected. The resulting audio-frequency signal, which covers the band from 40 to 5000 cycles, is then further amplified in a suitable audio amplifier before distribution over the Waldorf system.

*Suppressor grid modulation is employed.

Outstanding features of this receiver are the high degree of selectivity, an electrical and mechanical design that insures dependable operation as well as high quality reception, and a sensitivity that permits good reception on signals as low as one microvolt. In the radio-frequency amplifiers there are five tuned circuits ahead of the modulator. These, together with the beating oscillator, are tuned by a six-gang condenser operated through a carefully constructed worm drive, shown in Figure 2, which gives very accurate selection. Frequencies separated less than one-tenth of one per cent may be readily

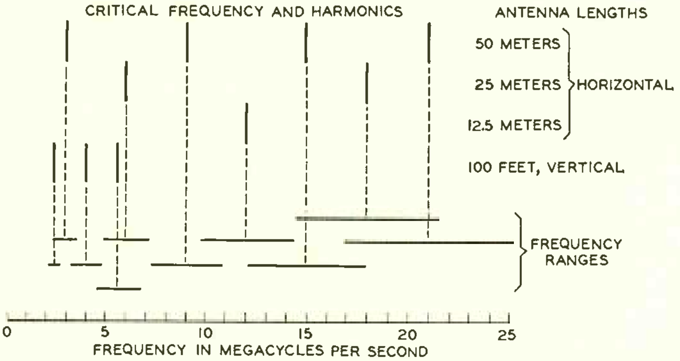


Fig. 3—Frequency coverage chart for the Waldorf antenna system

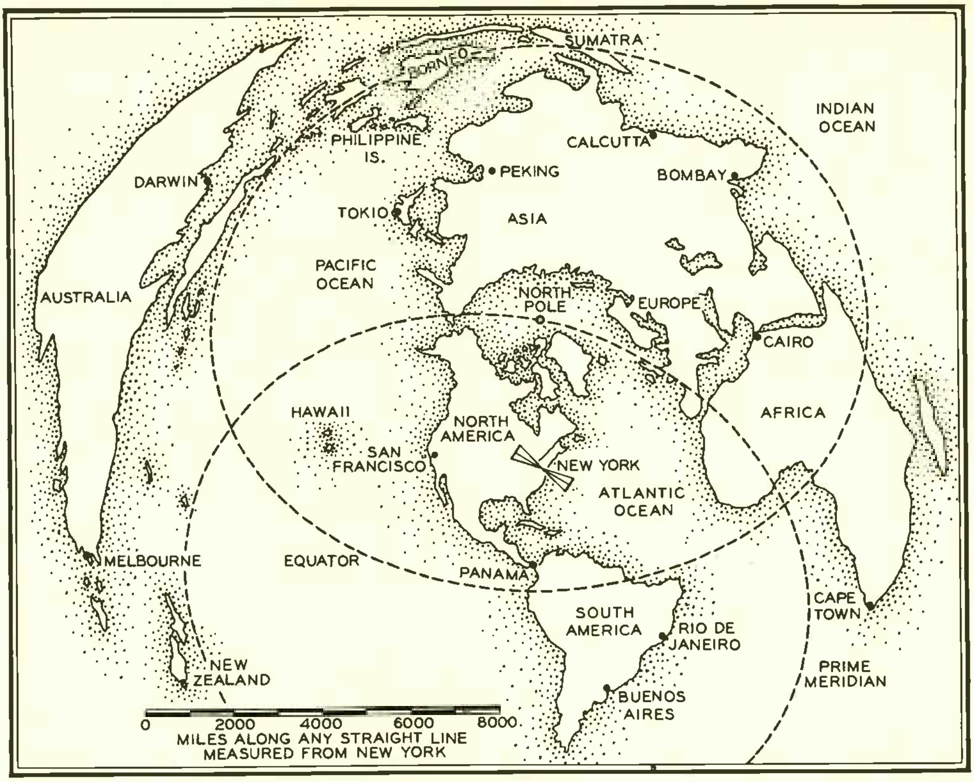


Fig. 4—A great-circle chart of the world centered at New York. The paths of radio waves coming to New York are straight lines on this chart

tuned in. In the intermediate-frequency amplifier, Figure 5, there are eight additional tuned circuits. In this amplifier there is also a band-changing switch which, in the event of bad noise conditions, can be used to decrease the width of the audible-frequency band and thus reduce the interference. Automatic gain control is provided, which is particularly important for short-wave reception, where the variation in signal strength with time may be considerable.

No matter how efficient a radio receiver may be, it must depend on the antenna to extract the maximum amount of energy from the arriving signal with the least amount of noise. Considerable attention was therefore given to the design of an antenna that would best secure these results, and at the same time would not mar the appearance of the building with tall ungainly structures. The multiple-doublet arrangement provided serves admirably to receive signals over a wide range of frequency and direction of arrival with a maximum of noise elimination.

When a horizontal wire is exposed to a high-frequency electro-magnetic field, it acts somewhat as a tuned circuit, and a current-measuring device placed at the mid-point would show maximum current when the length of the wire was approximately half the length of the radio wave. Such a wire differs in action from a tuned circuit, however, in responding not only to the fundamental frequency but to all odd multiples of this frequency. Thus a wire equal in extent to a half wave-length of a 3000 kilocycle signal, or 50 meters, would respond to frequencies of 3,000, 9,000, 15,000, 21,000 kilocycles, and so on. If such a wire is broken at its mid-point and a tuned circuit or a transmission line leading to a tuned circuit is inserted, the resulting arrangement is known as a doublet. After the introduction of this associated circuit the tuning of the wire is only moderately sharp, and as a result it responds fairly well over a frequency range extending perhaps 20 per cent above and below the various frequencies corresponding to the length of the wire. By using several of these doublets, therefore, it is possible to secure good reception over a wide range of frequencies.

In the Waldorf installation, three such doublets are employed, having approximate lengths of 12.5, 25, and 50 meters, arranged as shown in the illustration at the head of this article. This arrangement permits reception of all frequencies from 2200 to 25,000 kilocycles except for a slightly lower response over the narrow range from 3600 to 4800 kilocycles. This low frequency range is extended and reenforced, however, by using the vertical lead-in wire from the horizontal doublets as a vertical antenna. Such an arrangement, with the lower end of the vertical antenna connected to ground through the coupling transformer, acts as a vertical doublet with its lower half buried in the ground, and responds to odd multiples of wave-lengths of four times its length. By suitable "loading" the effective length of this vertical section may be considerably modified and, as arranged at the Waldorf, the vertical section of about 100 feet which is "loaded" by the doublets responds to

Fig. 5—In the intermediate-frequency amplifier, shown undergoing inspection by J. Stevens, Radio Technician of the Waldorf, the power of the signal is increased a hundred thousand million fold

frequencies of 800, 2400, 4000, 5600 kilocycles, etc. By design, however, the response of this vertical section to frequencies above 6000 kilocycles is progressively nullified in the special coupling transformer to the radio-receiver transmission line.

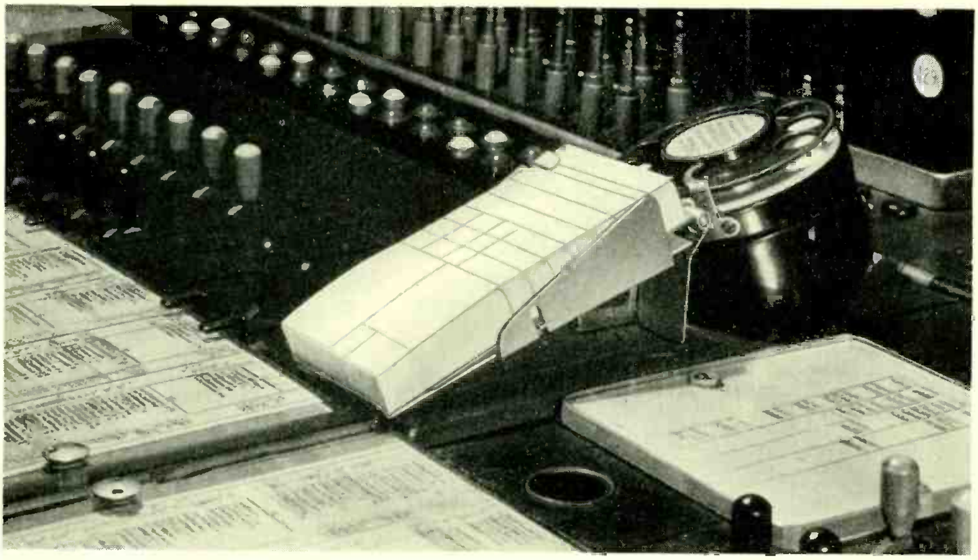
The manner of covering the wide frequency range by these horizontal doublets and the vertical half doublet is indicated in Figure 3. Here the odd-multiple response frequencies of the various antennas are indicated by the vertical lines, while the horizontal lines indicate the frequency range brought in, allowing a 20 per cent spread on each side of the multiple frequencies. The vertical lead-in consists of two wires twisted together—one wire being connected to each half of the horizontal doublets. The current from the horizontal antennas comes down one of these wires and up the other, thus traversing the vertical section in both directions. The current induced in the vertical section, however, travels in the same direction in both conductors. The special transformer at the foot of the vertical lead allows both of these currents to be fed to the radio apparatus, but shuts off the higher frequencies from the vertical part of the antenna.

Most transmitting antennas are effectively vertical rods, and the waves they emit are vertically polarized—providing the greatest effects on vertical receiving antennas. In traveling great distances, however, these waves undergo a series of reflections between the earth and the ionized regions of the upper atmosphere. By this multiple reflection their vertical polarization is changed to an elliptical polarization, with the result that they may produce even greater effects on a horizontal antenna than on a vertical one. For this reason the horizontal structure used at the Waldorf is very sensitive to waves coming from remote points, where because of the great distances involved the greatest sensitivity in reception is required. This form of antenna will also minimize interference by nearby stations, the waves of which are vertically polarized. It happens, moreover, that the waves from most man-made sources of interference affect a horizontal doublet much less than a vertical antenna. Most of this form of interference is at the higher frequencies and thus does not prove objectionable over the range from 2000 to 6000 kilocycles where the vertical section of the antenna becomes effective. Stations operating at these lower frequencies are for the most part local, representing mainly police, aviation, and amateur radio telephone channels. These waves retain sufficient of the vertically polarized component to be readily picked up by the vertical antenna.

This multiple-antenna system is thus highly suited to picking up high-frequency signals coming from great distances and lower frequency signals from nearby stations, both with a large signal-to-noise ratio compared to vertical receiving antennas. The effectiveness of the antenna is further enhanced, however, by taking advantage of the directional characteristics of a horizontal doublet. Greatest sensitivity is obtained for waves arriving in a direction at right angles to the doublet. In Figure 4 is a map of the world in gnomonic projection centered at New York. The distinguishing feature of such a scheme of projection is that a line joining New York and any part of the world lies in the true direction over which radio waves would travel. The horizontal antenna system of the Waldorf—considerably enlarged in scale—is superimposed on this map at New York, and it is at once evident that waves from most of the international broadcast stations would reach the antenna from a favorable direction. The end-on directions of the antenna are toward the South Atlantic and North Pacific oceans where there are practically no stations, but even end-on, the antennas have some response because the short-wave signals arrive at a slight angle above the horizontal.

With these facilities the Waldorf is now in a position to offer its patrons short-wave radio broadcast programs of a high order of merit. Short-wave stations in London and Daventry, England, in Paris, France, in Madrid, Spain, in Koenigswusterhausen, Berlin, Germany, at Rome, and in the Vatican, can be as readily heard as local broadcast stations under favorable conditions. Even the short-wave stations in remote locations such as Moscow, Tokyo, Rabat in Morocco, Melbourne in Australia, and the various South American stations will at times be available for instruction and amusement.

The Faraday Medal, Thirteenth Award, presented to Dr. Frank B. Jewett by the Institution of Electrical Engineers, London, England, on May 2, 1935



Holding the Ticket

By J. M. PEABODY
Telephone Apparatus Development

OPERATORS at the "A" switchboard of a central office complete toll calls to a number of nearby communities, without passing them through the regular toll office. Information pertaining to the call, such as names, numbers, and duration of the call are recorded on toll tickets, small slips of paper supplied to the operator in pads. For rapid and efficient operation, it is necessary to provide some device to hold this pad in place so that the operator can write on it or remove a filled ticket without having to hold the pad with her other hand.

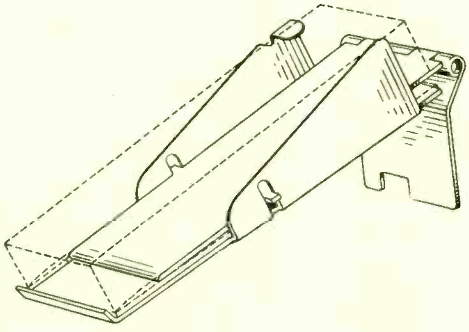


Fig. 1—The 11A ticket holder with a pad in position shown in phantom which makes clear the arrangement of the two major parts

Such pad holders have been in use for many years, but a new holder has recently been made available, which through a very simple and effective design holds the pad firmly without damaging it, and also prevents the tickets from being blown by drafts. Its construction, indicated in the illustrations, greatly facilitates the insertion and removal of the pads. The holder consists of a hinged and a floating section. The vertical part of the hinged section slips in a fitting fastened to the key-shelf, while the sloping section of the same part, which forms the main rest for the pad, slips between the pad and the cardboard back. A spring in the hinge holds the pad firmly in place. The floating section carries the side and foot supports for the pad, and also a small tab that holds the top of the pad down. The weight of this part hangs on this tab, but is restricted to vertical motion of a limited amount by slots in the two side flanges. This construction while simple to manufacture and easy to assemble performs its functions with remarkable effectiveness.

Contributors to This Issue

After receiving an A.B. degree from Acadia University in Nova Scotia in 1909, F. S. Goucher spent two years at Yale where he received the degrees of A.B. and M.A. The following year he went to Columbia as Research Assistant to Prof. Pupin and obtained his Ph.D. in 1917. He was overseas with the British Expeditionary Forces and at the close of the war remained in England carrying on research at University College, London, under a grant from the Scientific and Industrial Research Council. Later he was a research physicist with the General Electric Company, Ltd., at Wembly. In 1926 he joined the Laboratories and since then has been engaged in the study of carbon contacts with reference to their behavior in microphones. He received the honorary degree of Doctor of Science from Acadia University in 1934.

After receiving an A.B. degree from Colorado College in 1914, M. E. Strieby studied electrical engineering at Columbia for a year, and then continued his studies at the Massachusetts Institute of Technology. In 1916 he received the B.S. degree in Electrical Engineering from M. I. T. and Harvard, and at once joined the Engineering Department of the New York Telephone Company. The following year he left them to join the Signal Corps of the United States Army. He served as Captain with the Signal Corps overseas until demobilization in 1919, when he joined the D. and R. Department of the American Telephone and Telegraph Company. Here he engaged in various phases of toll transmission work. In 1929 he transferred to the Laboratories where he has been occupied with studies of new high-frequency carrier apparatus and

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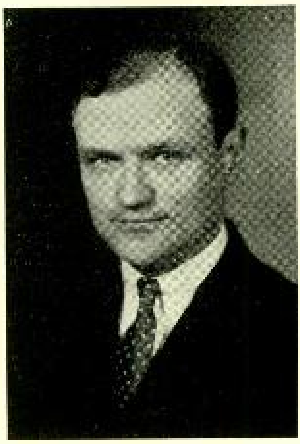

H. T. Budenbom

J. R. Haynes

J. M. Peabody

F. E. Fairchild

technique, and their application in cable carrier and coaxial systems.

H. T. Budenbom received a B.S. degree in electrical engineering from Purdue University in 1922, and immediately joined the technical staff of the Laboratories. Here, with the Transmission Engineering Department, he acted as a consultant to the local systems group on transmission practices. While here he received an E.E. degree from Purdue and also took post-graduate work in electro-physics at Columbia University. In 1928 he transferred to the radio development group where his work, except for some radio interference studies, has been on radio receiver development.

J. R. Haynes received the degree of B.S. in Physics from the University of Kentucky in 1930, and at once joined the Technical Staff of the Laboratories. Here, as a member of the Physical Research Department, he has been engaged in the study of microphonic action. The forces and displacements occurring in a microphone are of extremely small magnitude, and their measurement has required the design and construction of exceedingly refined apparatus. Mr. Haynes has been primarily responsible for the provision of measuring apparatus that has greatly facilitated the gathering of satisfactory data on microphone action.

After attending the University of Pennsylvania, John M. Peabody served in the United States Army for two years during the war. In 1919 he joined the Engineering Department of the Western Electric Company, and after a short time spent with the Drafting and Specification Departments, he transferred to the Apparatus Design Department. Here he has since been actively engaged in the development of keys and miscellaneous apparatus used on manual switchboards.

F. E. Fairchild received the E.E. degree from Cornell University in 1921, and at once joined the D. and R. Department of the American Telephone and Telegraph Company. He was first located at Phœnixville, Pennsylvania, where he spent several years in open wire transposition and cross-talk studies. He then returned to New York and engaged in the design of transmission measuring apparatus. He continued this work until he left the Bell System about the first of this year to enter business for himself.