BELL LABORATORIES RECORD

ULTRA-SHORT-WAVE TRANSMISSION
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ARTIFICIAL MOUTH AND EAR
E. W. Holman
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ARC RESISTANT MATERIALS
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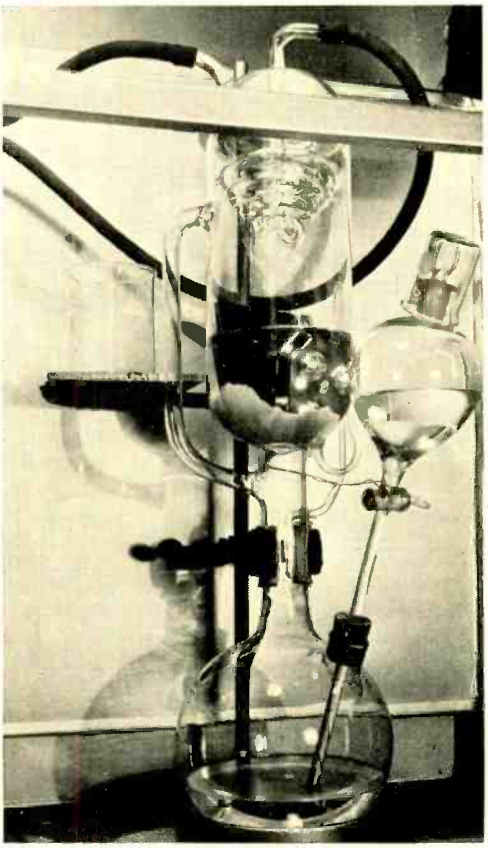

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Ultra-Short-Wave Transmission

By C. R. ENGLUND
Radio Research

IN 1865 Clerk Maxwell, British mathematical physicist, obtained a general mathematical formulation of electromagnetic theory in terms of the electric and magnetic fields and their space and time variations. By separating the variables in the formulation, he discovered that both the electric and magnetic fields were subject to the partial differential equation known as the "wave" equation. This meant that electromagnetic phenomena were essentially wave phenomena, and strongly bolstered the hypothesis that light itself was nothing but an electromagnetic entity.

Since that time confirmation of Maxwell's deductions has become indisputable and we now think of radiated electromagnetic waves as ranging in length from 25 kilometers to 10^{-12} centimeters*. Starting from the long wave end of this sixty-octave range, we label its parts in sequence as radio, heat waves, light, X-rays, gamma rays. Probably cosmic rays, in part at least, should be added to the list.

Heinrich Hertz in 1888 first demonstrated the existence of waves which were undeniably "electromagnetic", as the term was then understood. He first employed wire-bound waves and later struck out with ether-borne ones. The wavelength being short, he required only short transmission line lengths and reflection spacing distances to demonstrate the typical wave properties of his phenomena. Hertz excited his resonators by spark discharges, analogous to the hammers used in percussion musical instruments, and the lengths of the resulting waves were those characteristic of the dimensions of these resonators: 0.66 and 9.8 meters respectively in two sets of experiments.

The study of electromagnetic radiation had made some further progress when Marconi came into the picture in 1896. Marconi, primarily interested in communication, took the experimentation out of the laboratory to the out-of-doors and eventually discovered the secret of coupling the spark generator to the ether so as to get a fair impedance match. Oliver Lodge in England contributed the tuning principle, Braun in Germany made many fundamental studies, and in a very short time "radio" became an adolescent art. The Atlantic Ocean was first spanned by Marconi in 1901 and 1902, using a wavelength of about 1100 meters.

The early experimenters all used spark excitation and soon discovered that the longer the distance to be covered the longer the necessary wavelength. Static appeared as soon as receivers were made sensitive enough to expose it, and the Kennelly-Heaviside reflecting layer in the upper reaches of our atmosphere was also discovered. Shortly before the Bell System began its radio studies, the crystal radio receiver with high-impedance telephone receivers was

**One million-millionth of a centimeter or one tenth micron.*

nearly universally used. Transatlantic circuits employing frequency multipliers, high-frequency alternators and enormous antenna structures were in process of development, and the ship traffic was equipped with relatively efficient quenched-gap transmitters. The De Forest audion and the Poulsen arc were displacing the crystal detector and spark generator. Transatlantic traffic was carried on waves about 12000 meters long, and ship traffic was chiefly handled at 300 meters with a 600-meter optional wave. These were "wild and woolly" days for radio, with the ether free to all and with some spark generators operating on band widths as great as 200 kilocycles. The amateur had all to himself the unwanted and apparently useless range below 200 meters.

The Bell System became active in the radio field in 1914-15. Its interest was primarily in radio telephony, and it employed for both transmitting and receiving purposes the high vacuum tube which it had already used successfully in wire telephony. This introduction of the vacuum tube into the radio field proved of the utmost significance.

With the further development of vacuum tube systems in the ensuing twenty years, the radio panorama has greatly changed. Some ten years ago, the Kennelly-Heaviside reflecting layer was discovered to be able to return short-wave transmissions* to the earth at distances even up to antipodal values, completely passing them over a good deal of the intervening earth surface. The shorter the wavelength the longer the range and the "skip distance". As might be expected this reflecting power is not constant but varies markedly with wavelength and time of day. Indeed the short-wave engineer, while

*120 *to* 10 *meters.*

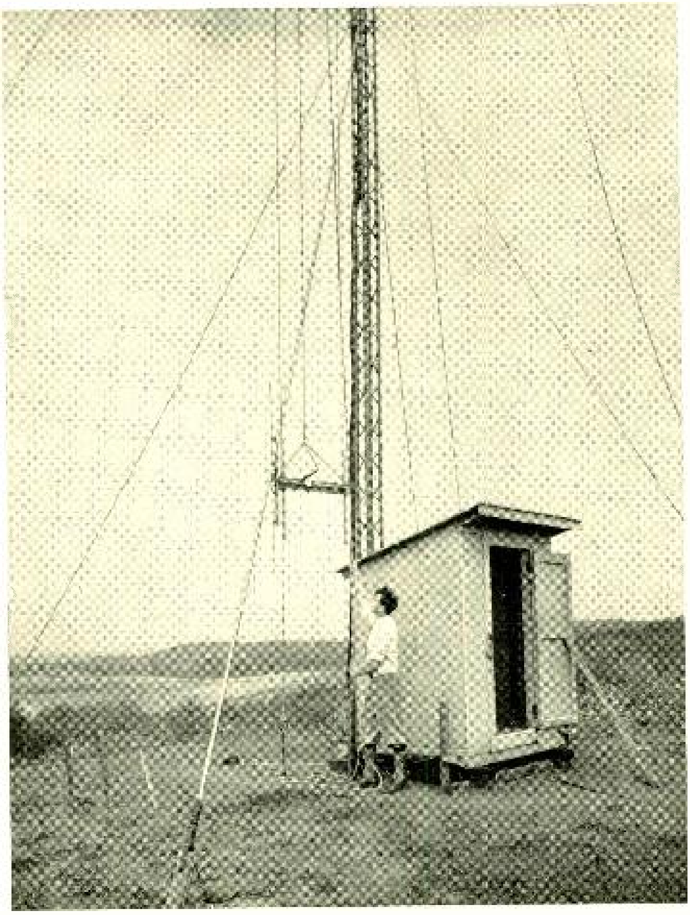


Fig. 1—*For transmission of ultra-short-waves to an airplane for field strength observations, a transmitting antenna was located on Beer's Hill near the Holmdel laboratory*

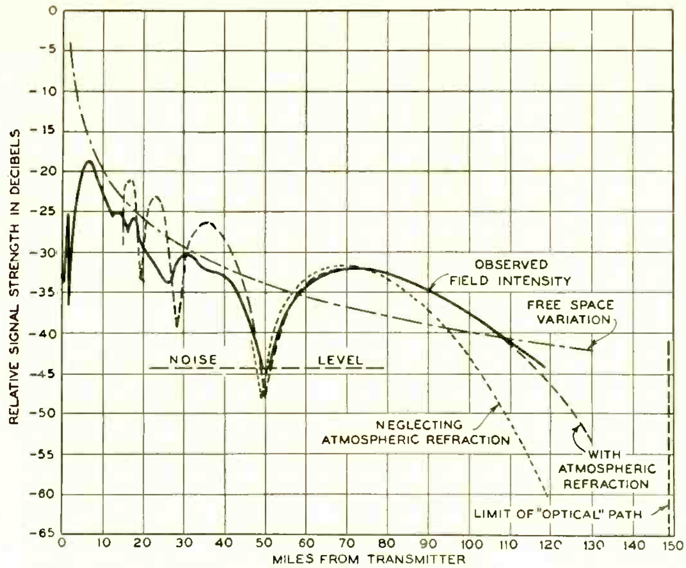


Fig. 2—A close approximation to the observed (solid) curve of airplane reception of short waves can be obtained by simple calculations (dotted and dashed curves)

must take things as they find them; and since ordinary power tubes are not readily operable as generators below three meters, and the ether is carefully allocated and delimited above five meters, the range mentioned is self selective so long as the precise wavelength used is not especially important.

The main features of ultra-short-wave transmission can be relatively simply described in terms of a set-up in which a transmitter is located on a smooth-surfaced, treeless hill and the strength

privileged to bid good-bye in great measure to the terror of the long-wave engineer, natural static, has had to accustom himself to a degree of signal fluctuation or "fading" entirely undreamed of before. On digging down for more signal in deep fades, he meets tube and circuit noise in his receiver, and during magnetic storms he finds his "circuit" open and inoperative. Nevertheless most of the present long-distance circuits use short waves, and the very moderate antenna dimensions for even highly directive systems make it economical to provide several antennas for each circuit, so that the wavelength can be shifted.

Below ten meters the Kennelly-Heaviside reflection is apparently unable to return the radiation to the earth, and accordingly transmission conditions become more stable again. It is in this range, particularly from three to five meters, that the most recent exploring work has been done by these Laboratories. Explorers

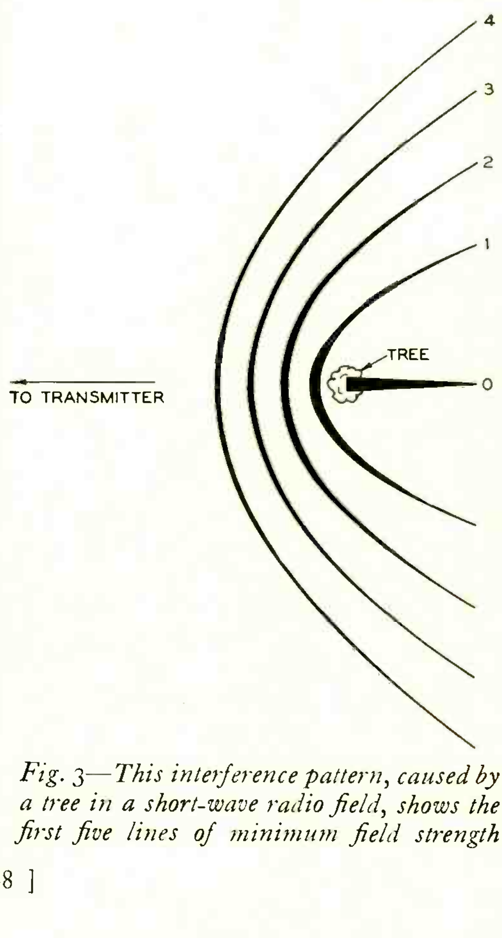


Fig. 3—This interference pattern, caused by a tree in a short-wave radio field, shows the first five lines of minimum field strength

of signals received from it is observed at various points. If the receiving set is carried in an airplane, the reception, so long as the hill is visible, is what would be expected from the vector sum of the direct radiation plus additional components due to reflection from the transmitting hill and the earth's surface in the middle distance. These two reflectors are very good mirror surfaces at 4.5 meters and, though the hill surface is not plane, its its proximity to the transmitter makes it quantitatively a good reflector. The curves shown in Figure 1 have a cyclic character because of the progressive shift, with increasing distance, in the phase relations of the direct and reflected radiations.

Air refraction, the same which prolongs the sunset and forces a surveyor to take a back sight on leveling, bends the radiation around the earth and effectively increases the range attained. As the distance increases and the hill drops toward the horizon, the transmission does not fall to zero at grazing incidence or indeed for some distance below it, for the radiation is diffracted around the earth's surface. The intensity falls rapidly with additional distance after grazing incidence has been passed, and the extreme range is soon reached.

If the receiver is brought down from the airplane reaches and planted on a hill similar to the transmitting one, the transmission is still calculable if the receiver hill is taken into consideration as a third mirror surface. No static is to be heard and the transmission is actually steadier than transatlantic long-wave transmission at a similar distance. Apparently only ultra-short waves are free from any trace of Kennelly-Heaviside reflection. So far no day-to-night effect, characteristic of all longer wavelengths, has been observed, nor has any extra long distance transmission been received.

Descending once again with the receiver, this time to the tree-bordered undulating roads criss-crossing the landscape, we find that the regular reflections from broad features of the terrain are almost completely masked by a standing wave pattern which is due to trees, ground irregularities and the like. The pattern is so pronounced at some locations that the reception can vary 50 decibels in moving less than 20 feet. The shadow lines which surround an idealized tree, and by the same token any linear conductor such as a guy wire,

Fig. 4—W. W. Mumford is operating the equipment mounted in an automobile for measuring the strength of ultra-short-wave fields near the ground

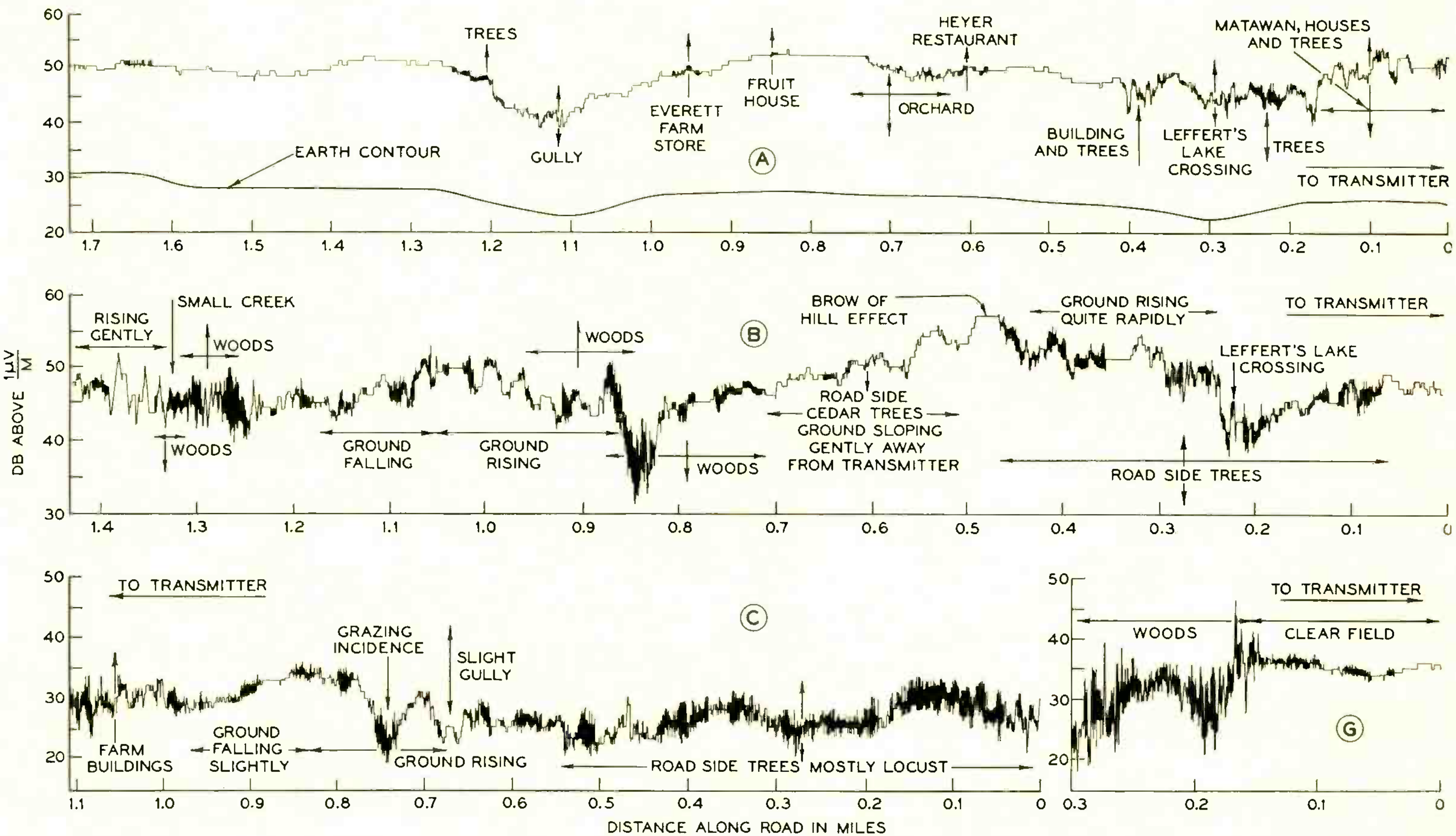
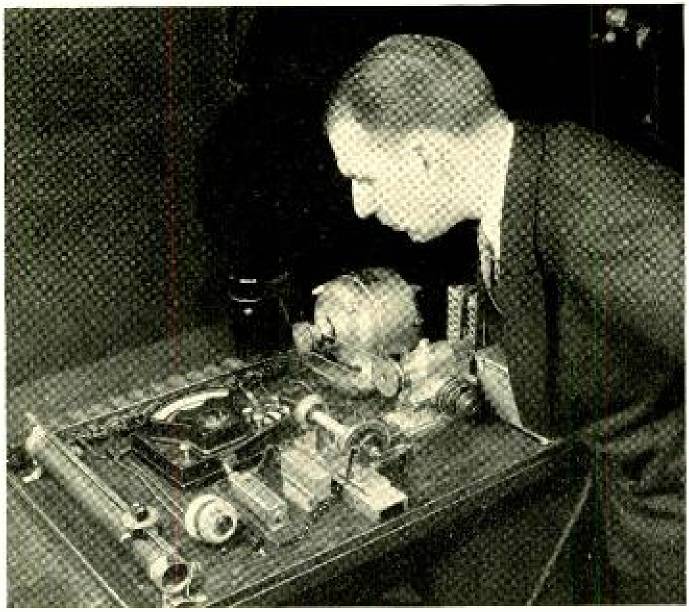


Fig. 5—These four records show the highly irregular fields observed by a receiver in a car moving along roads approximately radial to the short-wave transmitter at Holmdel, N. J.

are illustrated in Figure 2; and samples of the records obtained driving along roads in the neighborhood of the transmitter are shown on Figure 3. The reradiation from extended conducting bodes is quite noticeable and airplanes passing overhead have been found to indicate their presence by means of the beats between the radiation reflected by them and that received directly. Similarly a prowler approaching an ultra-short-wave receiver might betray himself by his motion yards away.

It is relatively easy to construct directive or "beam" antenna systems to operate at these wavelengths. Mobile "pack sets", for ranges up to several miles might be made nearly as convenient to transport as lunch baskets, and one need but stand on rubber heels grasping the output lead to serve as a very good antenna. Due to the high frequency a great number of channels are available, and as the range is limited these may be duplicated in various parts of the country. Very wide bands are also feasible, if care be taken to avoid areas of standing wave patterns; and this width of band, and the steadiness of ultra-short-wave signals, fill two of the requisites for a television channel. Altogether, there is promise of a considerable future for these ultra-short-waves.



The importance of insulating materials in the Bell System plant makes it necessary to test carefully all materials prepared for use to insure that they will be satisfactory when built into apparatus. The equipment shown here, and described on page 92 of this issue, evaluates the arc resisting properties of insulating materials

X-Ray Examination for Metal Defects

By LESTER E. ABBOTT
Telephone Apparatus Development

X-RAYS, which for years have aided physicians in diagnosing the hidden ills of their patients, have become a valued tool of the engineer in discovering the hidden flaws and defects in metals. X-ray examination often yields vital information as to the cause and nature of the defect revealed which could not otherwise be obtained without making a complete destructive test of the sample, and thus permits the early introduction of corrective changes in a design or a manufacturing process. These Laboratories have accordingly conducted studies in the development of X-ray technique and its application to the solution of metallic materials problems constantly encountered in telephone engineering.

Examining an object by X-rays is similar in certain respects to photographing the object by ordinary light. Both X-rays and ordinary light affect the sensitive emulsion of photographic film. In ordinary photography the light reaching the film is that reflected from the object photographed, and the density of the developed film depends upon the variations in the quantity of light reflected from different portions of the object. In making an X-ray examination the film is placed underneath the object, and the X-rays reach the film by passing through the object. It is their relatively shorter wave-length that enables them to penetrate objects which are opaque to visible light. The density of the developed negative depends upon the quantity of X-rays able to penetrate entirely through the object and strike the film.

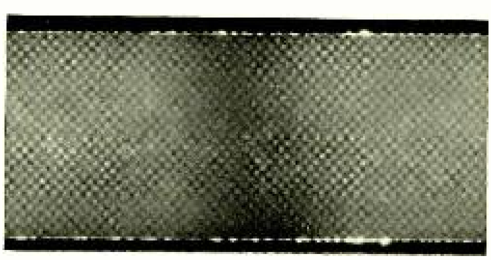


Fig. 1—The mottled appearance of this X-ray photograph of a cast metal bar indicates shrinkage cracks in the bar

This quantity varies with the total mass of material which the X-rays must traverse. Where the object is thin or constructed of metal of low density a large concentration of rays will pass, and the developed film will be dark over this area. Where there are thick sections or dense metals such as lead or gold, very little radiation will pass and the developed film will be light.

X-ray photographs of metallic parts, such as castings, welds or forgings, are thus well adapted to reveal the numerous types of defects which consist of variations in thickness or density. In castings failure of the gases in the molten metal to escape before the metal solidifies may cause gas pockets. Non-metallic materials such as moulding sand may have accidentally been present in the melt when cast, and thus have become included in the casting. The shrinking of the metal as it cools and solidifies may have cracked the casting (Figure 1).

For similar reasons welds may contain gas pockets such as those shown in Figure 2, undesirable oxides or cracks; or the fusion with the welded parts may be incomplete. In forged parts defects usually take the form of fine cracks, developed during manufacture or caused later by fatigue, shock or season-cracking.

In the preparation of an X-ray negative of a metallic part, a sheet of X-ray film is placed in a light-tight film holder (B of Figure 3), made up of thin aluminum sheet, and laid upon the table, A, at a point directly underneath the Coolidge X-ray tube, C. The metallic part to be examined is then laid on top of the casette containing the film in a position such as that occupied by the die-cast parts in Figure 3, so that the X-rays from the tube must pass through the part before reaching the film. As the X-rays pass through the metallic part, some are absorbed, others are deflected from their path and scattered about in the metal and surroundings, and some pass on through the part to the film in the casette.

If the metallic part is homogeneous the film receives an even dosage of X-rays over the entire image, and develops to an even blackness. Defects or inhomogenieties of any sort having a different absorption coefficient from the remaining material absorb more or less of the X-rays passing through them, and this effect is recorded by the film. For example, fewer X-rays are absorbed by a pocket of entrapped gas than by the homogeneous material adjacent to it, the film receives a greater dosage of X-rays at the point directly underneath such a defect, and the developed negative shows a darker spot at this point. A material of greater density, such as an inclusion of lead, absorbs a greater amount of X-rays than the adjacent material, and a lighter spot is found on the developed negative.

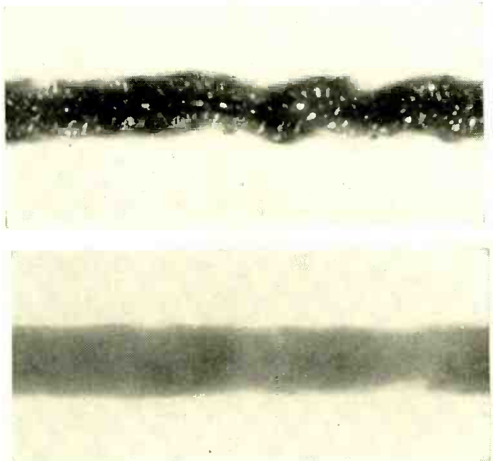


Fig. 2—Of two welded butt joints, X-rays revealed inclusions of gas in one (above) and no such defects in the other (below)

As these variations in the density of the developed negative are often very slight, the analysis of an X-ray negative is usually carried out by placing the negative in front of an illuminated opal glass panel and viewing it by transmitted light. The interpretation of the various differences in density in terms of the size, location and probable seriousness of the defects is the most important step in the examination, and requires a knowledge of the methods of fabricating metal parts, and broad experience in X-ray technique.

To make these interpretations as reliable as possible, careful studies were made of the sensitivity of X-ray examination in discerning the various types and sizes of defects. It was tus permits thicker sections of metal to be X-rayed. Since even the larger commercial X-ray machines do not allow much more than three inches of steel to be X-rayed satisfactorily, the use of radon, a gas which emits gamma rays, is receiving considerable attention. These gamma rays are of even shorter wave length than X-rays, and thus are able to penetrate as much as ten inches of steel to produce a satisfactory negative.

Harold DeForest Arnold

THE Members of the Executive Council of the Acoustical Society of America desire to express, for the entire membership, their appreciation of the contributions of Harold DeForest Arnold to the science of acoustics, and their admiration of the kindly modesty and inspiring genius with which he guided the efforts of the large group associated under his leadership in attacking the numerous problems in this field. We have lost an honored and esteemed friend.

DR. ARNOLD was possessed of great genius for the quick and sure perception of essentials. His startling originality stimulated and inspired all with whom he came in contact. Impatient of superficial judgment and external appearance, his mind went instantly and clearly to the heart of any problem. Always forgetful of himself, choosing to remain quietly in the background, he developed and pushed forward those working under his direction. Kind and generous, he was always most effectively sympathetic with anyone overtaken by adversity.

HE assisted in the founding, and has served this Society as a member of its Executive Council, but his influence has far transcended any formal position which he has held.

IN recognition of his contributions to the science of acoustics, to our Society, and to honesty and truth as expressed in science, we wish to place this record oh the minutes of the Society, and with deep realization of the loss which has been sustained, we extend our sincere sympathy to the wife and family from whose association he has been taken.

For the Council

Vern O. Knudsen — E. E. Free
Halsey A. Frederick — Wallace Waterfall
Edward C. Wente — Floyd Rowe Watson
G. Oscar Russell — Edward W. Kellogg

August First
Nineteen Hundred Thirty Three

Measuring Inductance with a Resistor

By T. SLONCZEWSKI
Telephone Apparatus Development

In a large class of measurements, the value of an unknown quantity is determined by adjusting a standard until a zero indication is obtained. This is known as the null method of measurement. A common example is the chemical balance, where an unknown weight is placed in one pan, and then known weights are added to the other until the pointer comes to the zero position. In this example the measurement is of the direct type since the standard is of the same kind as the unknown, and an exact equality is indicated by the zero reading.

Frequently, however, a direct type of measurement results in cumbersome adjustments, and so it is often more convenient to use an indirect method: one in which the adjustable standard differs in kind from the quantity measured. By providing a beam on which a known weight may slide, such an indirect method may also be obtained with the balance. In this case the weight is fixed in value, and the length of the lever arm is adjusted; the adjustable standard is thus one of length rather than of weight. The operation of weighing is much improved by this method since it is more convenient to slide a constant weight along a beam than to assemble a group of standard weights up to the required total value.

In electrical measurements the indirect method is frequently to be preferred. In an indirect method developed by the Laboratories for measurements of inductance and effective resistance, a bridge circuit is employed in which a resistor is used to determine the value of an unknown inductance. By the use of this method measurements may not only be made more easily, but the apparatus is smaller and simpler to maintain.

Before this indirect method was developed, measurements of inductance and effective resistance of coils during manufacture and inspection were made almost exclusively by a simple comparison method employing a bridge circuit as shown in Figure 1. Standards of both inductance and resistance are connected in series in one arm of the bridge, and are adjusted by decade switches until

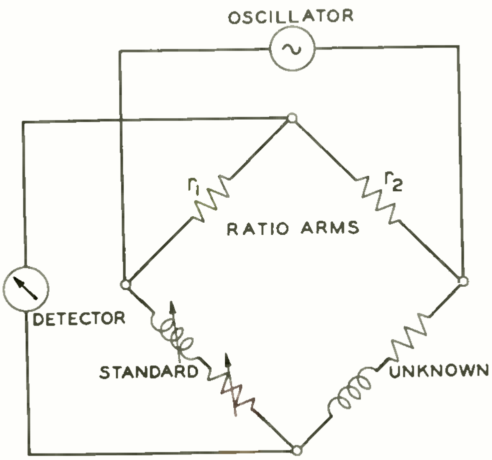


Fig. 1—The comparison bridge for the measurement of inductance has a resistance in each ratio arm, and employs a variable inductance as a standard

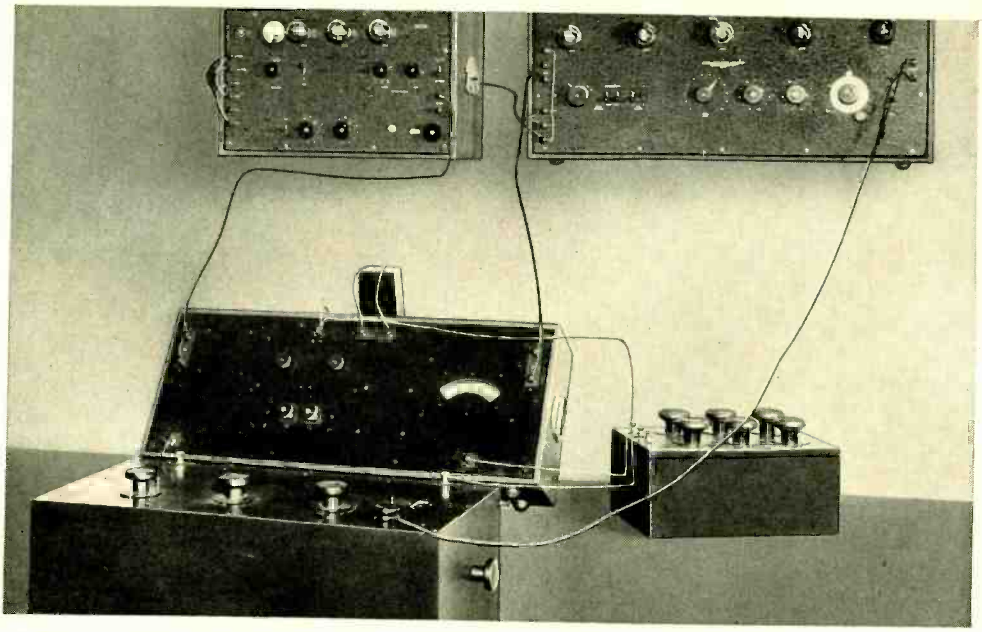


Fig. 2—The comparison bridge requires separate standards of inductance and resistance

a zero indication is obtained. At balance, since the resistances of the ratio arms r_1 and r_2 are equal, the impedances of the unknown and of the standard are equal, and as a result the inductance of the unknown is equal to that of the standard, and the effective resistance of the unknown is equal to the resistance of the standard plus the effective resistance of the inductance standard.

When only low accuracy is required, the nominal values of the inductance and resistance standards may be used with satisfactory results, but for the usual grade of measurements corrections have to be applied to the values read off the dials. Even with the best possible commercial designs, stray capacitances between the turns of the coils and between the coil and the surrounding conductors are sufficiently large to cause appreciable variations of inductance with frequency. It is necessary, therefore, to calibrate the effective inductance for each setting of the standard at a number of frequencies, and to record the results on a calibration chart to be used with the standard. Besides requiring this calibration, the inductance standard is bulky because of the "nested"* shielding required. Because of this, the inductance standard is built as a separate unit as is the resistance standard so that three units are required for the bridge as shown in Figure 2.

The resistance of the inductance standard also varies with frequency because of eddy current losses and distributed capacitance, and so a calibration must likewise be made for resistance. In standards employing magnetic materials a resistance increment due to hysteresis loss is present, and the current intensity has either to be allowed for or to be restricted in range.

It was found upon investigation that by employing a bridge network

*Record, *Nov.*, 1931, *p.* 88

due to Owen*, which contains no inductance standard, indirect measurements of inductance could be made that were particularly well adapted to commercial uses.

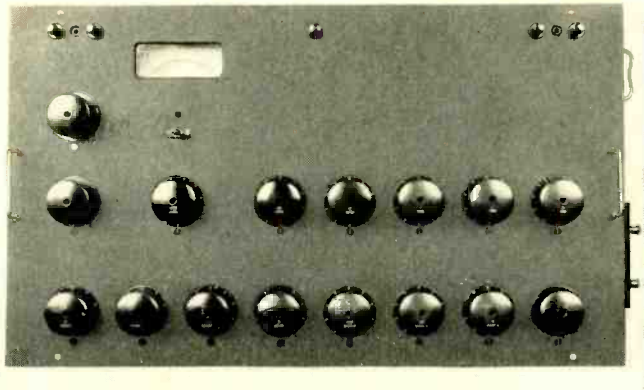


Fig. 4—The new bridge incorporates its standards and ratio arms in a single compact unit

Instead of having a resistance in each of its ratio arms, the Owen bridge, shown schematically in Figure 3, has a resistance in one and a capacitance in the other. The unknown is connected in the branch opposite the capacitance ratio arm, while a variable resistance and a variable capacitance are employed as standards in the arm opposite the resistance ratio arm. The advantage of this type of circuit is that to balance the inductance of the unknown, the operator need only adjust the resistance standard, and to balance the resistance component of the unknown, only the capacitance standard is adjusted. This is possible because when the bridge is in balance, the unknown inductance is equal to the product of the capacitance and resistance of the ratio arms and the resistance of the standard, while the unknown resistance is equal to the product of the capacitance and resistance of the ratio arms divided by the capacitance of the standard.

*Proc. Phys. Soc. London, *Oct.* 1, 1914

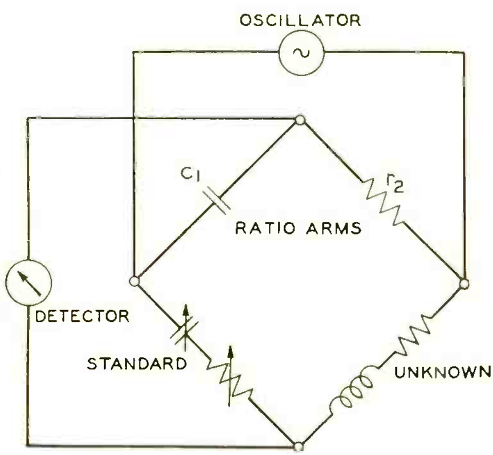


Fig. 3—In the Owen bridge one of the ratio arms is a resistance and the other a capacitance, while the standard consists of a variable capacitance and a variable resistance

Since the values of the resistance and capacitance of the ratio arms are fixed, the only variable in the measurement of an inductance is the standard resistance. Instead of engraving the value of this resistance in ohms on the dials, therefore, the product of this resistance by that of the two ratio arms is engraved so that the inductance of the unknown may be read directly from the dials in henrys. In a similar manner the dials of the standard capacitances are engraved to give the resistance of the unknown directly.

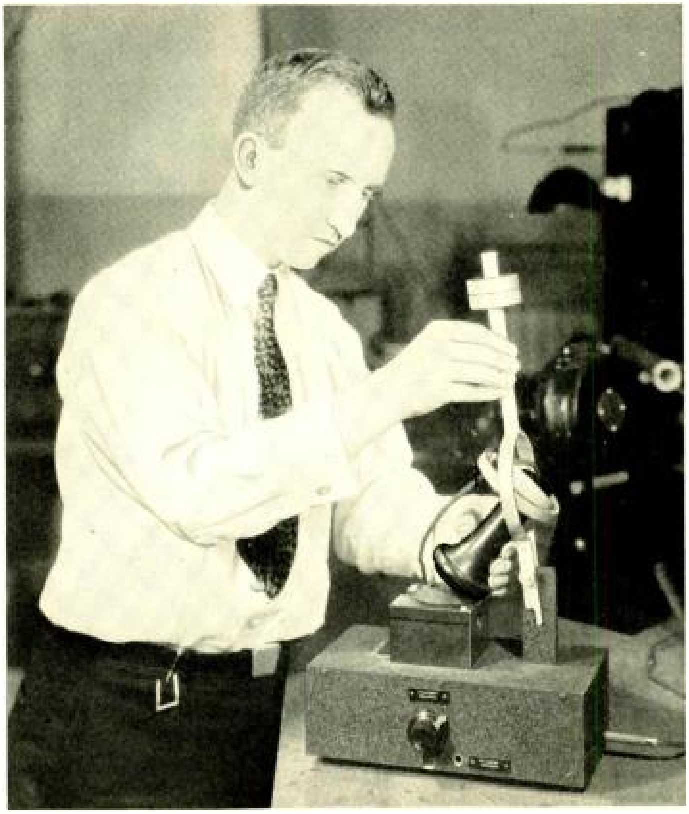
The advantage of the Owen type bridge is that a resistance takes the place of an inductance as the variable standard. A resistance is less bulky than an inductance standard, and small size, in general, means small stray capacitances. The effective resistance of a resistance coil, moreover, is much less affected by stray capacitances than is the inductance of an inductance coil, and as a result it has been found possible to construct a six dial standard with its resistance practically independent of frequency.

In the purity of the standard the Owen bridge also has an advantage. In the comparison bridge the standard is an inductance and the value found for the effective resistance of the unknown must be corrected for that of the standard. In the Owen bridge, also, an impurity of the standard, which in this case would be a reactance, would cause an error in the measurement of the unknown. The reactance of resistance coils, however, can be made either positive or negative by proper design so that by suitable adjustment the error in effective resistance is reduced to a negligible value. Resistance coils, in addition, may be adjusted to very nearly their nominal values, are independent of current value, and are stable with time and temperature. As a result, costly calibrations are dispensed with entirely, and the bridge maintenance is inexpensive.

These advantages of the Owen bridge have been known for a long time, of course, but because of the asymmetry of the bridge, it has been impossible heretofore to maintain the proper phase relation between the two ratio arms over a wide range of frequency. In the comparison bridge both of the ratio arms are resistances, and the major requirement is that they be equal in magnitude and phase angle. Any inequality in phase angle may be adjusted by placing a condenser across the arm of lower capacitance. With this adjustment the phase angle will be the same in both arms for all frequencies, and the requirements will be met.

In the Owen bridge, on the other hand, one ratio arm is a resistor and the other a condenser, and for a proper balance the impedance vectors of the two arms should be at right angles to each other. The phase angle of a condenser suitable for use in the bridge arm remains practically constant with frequency. The phase angle of the resistance, however, increases with frequency due to the effect of the distributed capacitance, and as a result the difference in phase between the two arms does not remain 90° for all frequencies. To make it do so would require that a compensating coil with a positive reactance which would remain constant with frequency be connected in the resistance arm. It is only the development of a coil with a reactance that does remain constant with frequency, and of a proper shielding scheme, that has made the Owen bridge of practical importance for this work.

The new bridge, exclusive of oscillator and detector, has only two rows of dials and a meter for measuring the current through the unknown, as shown in Figure 4. As already noted, one of the sets of dials measures the resistance component of the unknown and the other the inductance component. Although the new bridge has a larger inductance range than the one it replaces, it is much smaller and easier to manipulate and to maintain. It is well suited to work involving precision measurement of inductance and effective resistance. By the Western Electric Company it is employed for measuring the inductance of coils manufactured for use in audio frequency filters.



An Artificial Ear for Receiver Testing

By F. L. CRUTCHFIELD
Transmission Instruments Engineering

IN living up to its ideal of universal telephone service, the Bell System must be prepared to give satisfactory transmission between any two telephones connected to its system. This random pairing of instruments imposes on the instruments themselves a requirement of uniformity of operating characteristics. Performance specifications have therefore been set up for receivers and transmitters which stipulate the efficiency of conversion from electrical to acoustical energy, and vice versa, and define the tolerances to be allowed. To be certain that the output of the manufacturing and repair shops meets the specification, inspection procedure has been developed in which use is made of testing equipment designed to make rapid, accurate measurements of the operating characteristics of telephone instruments under conditions of use similar to those imposed by the subscriber.

As a result of a study of the conditions under which telephone receivers are used, equipment suitable for testing receivers of different types has been developed. This apparatus, designated as an artificial ear, was designed to apply to a receiver an acoustic load equivalent to the load applied by a typical human ear and to measure the output of the receiver as perceived by an average human observer. It comprises an artificial ear coupler, a small condenser transmitter and associated amplifier, and a volume indicator. Provision is also made for inserting weighting networks.

The appearance of the unit, including the artificial ear coupler, transmitter and amplifier, with a desk stand type of receiver being placed in position for testing, is shown in the headpiece. In the base of the unit, upon which the artificial ear coupler is mounted, is a two-stage amplifier. An upright member fixed to this base provides an axis of suspension for a gimbal and lever which serve to control the position of the receiver and the pressure with which it is applied to the coupler while ensuring that this pressure is uniformly distributed over the seating surface. The receiver rests on a molded soft rubber insert having an internal contour corresponding to that of a typical human ear. An acoustic leak, consisting of a short tube terminated by a sheet of acoustic resistance metal invented by H. C. Harrison, is provided for connecting this irregularly shaped chamber with the external air to simulate the leak between a receiver cap and a representative human ear. This soft rubber insert is cemented to a block of hard rubber in which is located the continuation of the auditory canal and a small condenser transmitter used for measuring the acoustic pressure in this canal. Adjacent to this transmitter is an acoustic network which terminates the auditory canal. This

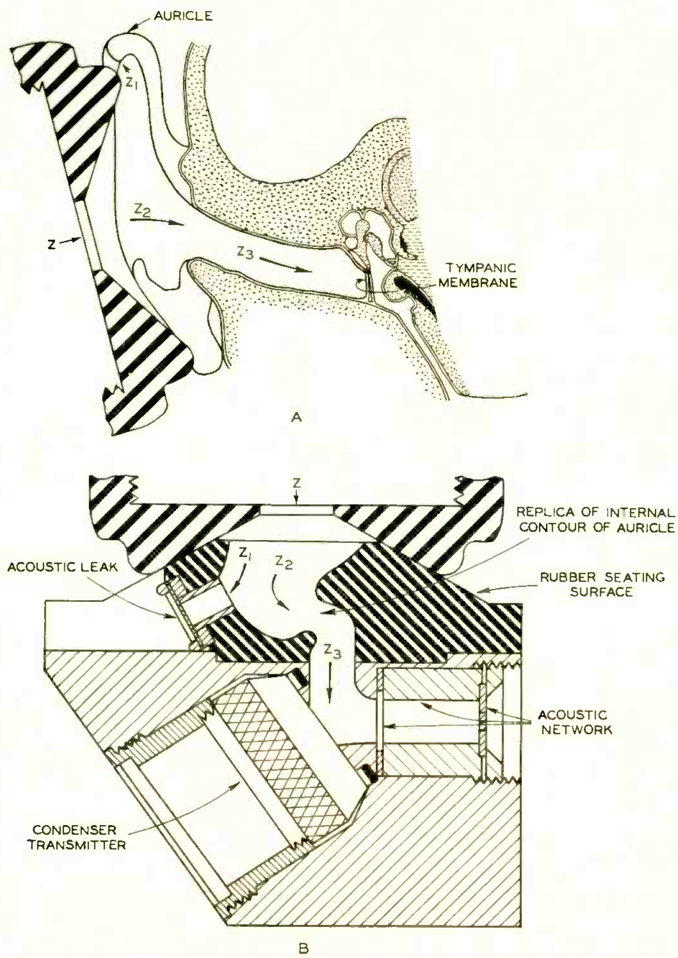


Fig. 1—A comparison of the human ear with its prototype shows their close similarity. Z, Z_1, etc. are acoustic impedances

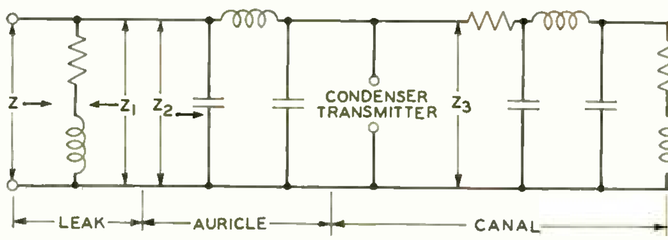


Fig. 2—Equivalent electrical network of the artificial ear. Letters refer to impedances of Fig. 1

network consists of the series resistance of a section of acoustic resistance metal; the mass and elasticity of the air in a short tube, and the resistance of a perforated metal plate. A schematic section of the artificial ear coupler with the small condenser transmitter is shown in the lower part of Figure 1 compared with the corresponding section of a human ear above it.

In normal use the measuring circuit of the artificial ear is terminated in a volume indicator of the type developed by T. G. Castner and used in the Western Electric Sound Meter.* The meter scale is graduated in decibels, and an attenuator allows the input to be adjusted for a satisfactory deflection. The output of the receiver under test is then the algebraic sum of the attenuator and the meter readings, in decibels above a reference level. An electrical network may be inserted which will compensate for the varying sensitivity of the human ear at different frequencies The indicating instrument associated with the volume indicator reacts to impulses of short duration as well as to sustained sounds in a manner similar to the human ear.

Human ears, in general, are so shaped that there are small passages from the space enclosed between the receiver cap and the ear, to the outer air. The resulting leak, consisting of acoustic mass and resistance, shunts the stiffness of the enclosed air and introduces a loss at low frequencies. The mass element of the leak, in the typical case resonates with this stiffness near 400 c.p.s. producing a peak in the acoustic impedance characteristic looking from the receiver cap into the ear. Acoustic impedance measurements* made on the artificial ear give quite satisfactory agreement with those obtained on a typical male human ear.

Further confirmation of the reliability of the new device is found by electrical measurements on receivers. The frequency of mechanical res-

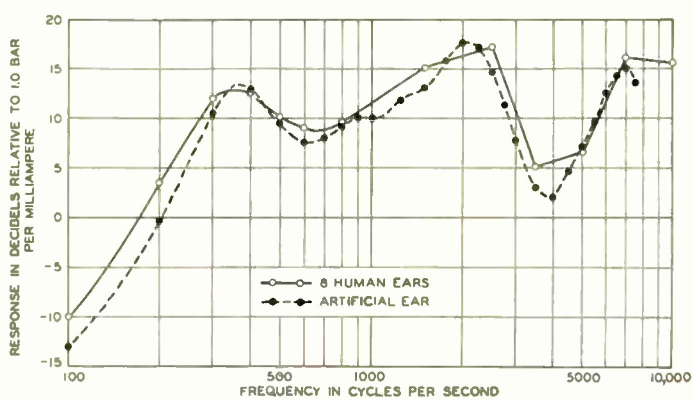


Fig. 3—Comparative calibration curves of a moving-coil receiver on human and artificial ears

*"*A Portable Sound Meter*," Record, *May*, 1932.

**Inglis, Gray and Jenkins*, Bell System Technical Journal, *April*, 1932.

onance of the vibrating system of a receiver applied to the artificial ear is well within the range of similar observations made on human ears. The damping constant, as calculated from the electrical impedance data for a receiver on an artificial ear is also well within the range of similar calculations for receivers on human ears. Both of the above statements are equally true for handset and desk stand receivers.

A final check is the comparison between calibration curves of the same receiver on the human and the artificial ear. By a technique developed in these Laboratories,* it was possible to measure the pressure in dynes per square centimeter in the human ear canal relative to the voltage applied to the receiver terminals. When the ratio between these quantities is plotted against frequency, the curves for the same receiver applied to the artificial ear and to the human ear are found to agree quite closely.

The above data obtained with the new artificial ear and all available pertinent data obtained with human ears show that the new instrument is a good approximation, both in its effect on the receivers and in its own frequency characteristic, to a typical male human ear. It is proposed for use in connection with the new artificial voice to provide a system capable of quickly and accurately measuring the characteristics of separate telephone instruments and complete telephone circuits under conditions approximating those of use by subscribers. Such a system has the advantages of exact specification, control of test conditions, and rapidity in collecting data; and so makes possible measurements with single frequencies, band frequencies, or with speech by means of the same instrumentalities. Engineering and maintenance of the telephone plant will be facilitated by the use of equipment of this nature which, placed in the several manufacturing and repair shops, provides a single testing means for testing the various types of receivers and transmitters. The use of the artificial ear is not limited to testing desk stand or handset receivers. It is applicable to tests of the audiphone receiver with its earpiece which enters into the ear canal.

A further application of the artificial ear is as an adjunct to a reference telephone system, increasing the usefulness of the latter equipment by standardizing the testing technique.

* *Inglis, Gray and Jenkins, loc. cit.*

An Artificial Voice for Transmission Studies

By F. W. HOLMAN
Transmission Instruments Engineering

THE maintenance of uniform telephone service requires the careful inspection of new and repaired equipment before use in the telephone plant. This inspection should be of such a nature as to give results consistent with actual service conditions. As most telephone transmitters are designed to be used at a comparatively short distance from the mouth of the speaker the transmission characteristics of any particular transmitter will depend not only on the physical factors involved, but to a certain extent on the reaction of the person using the transmitter. The use of actual speakers for testing transmitters would give results under conditions similar to actual use, but this method has certain limitations for laboratory and shop tests. Some of these limitations involve the time required to make the test, uncontrollable variation in the speakers, and certain tests, such as single frequency measurements, which are either difficult or impossible to make.

Some of these difficulties are over-

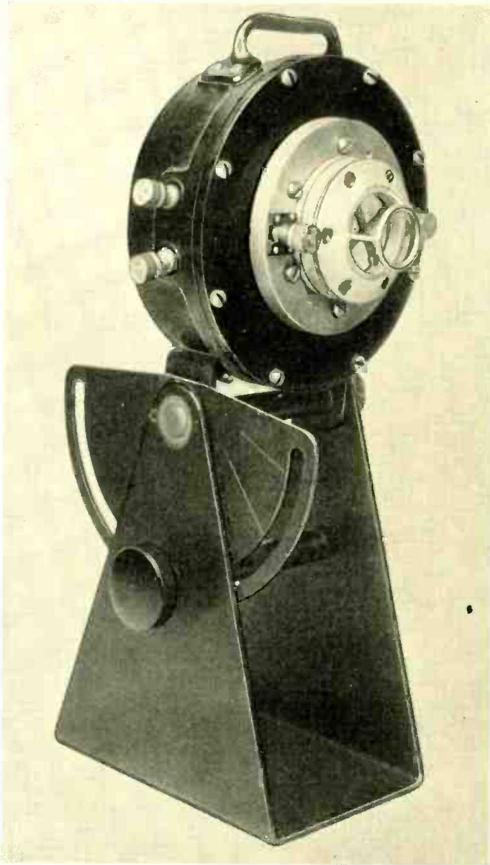


Fig. 1—The artificial mouth, a modified receiver of the dynamic type is mounted on an adjustable support

come through use of voice substitutes which are satisfactory for use in maintaining the uniformity of instruments of the same type, but which are limited for use in engineering design problems because they fail to meet certain fundamental requirements. In the design of the voice substitute described in this article, the fundamental requirements considered were that it should be capable of reproducing without amplitude or non-linear distortion the important range of frequencies found in human speech at acoustic outputs normally encountered in speech, that the sound field distribution around the mouth and the distortion of the sound field caused by the introduction of the transmitter near the mouth should be the same as for the actual speaker, and that it should be specifiable, reproducible, and constant in operation.

In order to obtain the correct sound field distribution around the artificial mouth it was found necessary to have the sound radiate from a small opening about the size of the human mouth. Measurements were made on several types of sound sources which indicated that the distortion of the sound field due to the introduction of a transmitter was about the same for any source having an opening of this kind provided that the opening is located in a baffle equivalent to the size of the head. With this information as a basis a loud speaker unit* of the #555 type, which is used in the reproduction of sound pictures, was selected for the artificial mouth unit, the normal horn coupler being replaced with a special ring having an opening of 1½″ diameter. The opening of this ring is covered with a sheet of acoustic resistance metal which serves to reduce the resonances in the unit and any coupling effects between the unit and transmitters placed in front of it. The equivalent lip position of the artificial mouth was determined experimentally and is marked by a wire ring mounted in front of the opening. This ring serves as the plane from which measurements are made. The artificial mouth is mounted on a suitable stand to enable it to be rotated to the proper position for testing.

The use of the small opening to obtain the correct sound field dis-

*"*A New Loud Speaking Receiver*" *by A. L. Thuras*, Record, *March*, 1928.

tribution makes it difficult to obtain high output at low frequencies. At low frequencies the radiation resistance of the opening is small while the acoustic impedance looking into the mouth is large and a large reflection loss occurs. As the frequency increases the radiation resistance of the opening increases, approaching a relatively constant value at frequencies in the neighborhood of 5000-6000 c.p.s. or higher. The effect of this, particularly at the lower frequencies, is shown in Figure 2, which is the response-frequency characteristic of the artificial mouth as measured at the equivalent lip position with no obstruction in the sound field other than the small measuring device. At the higher frequencies the response is modified by the resonances in the unit.

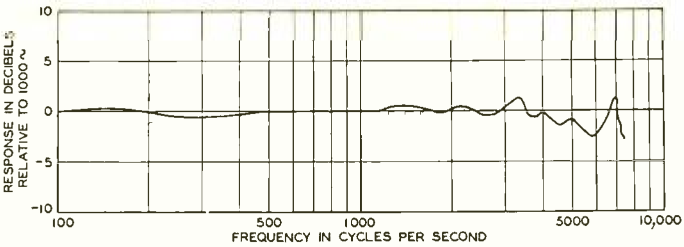


Fig. 3—Response-frequency characteristic of artificial mouth as equalized

Since one of the requirements of the artificial voice is that it should reproduce the important speech frequencies without amplitude distortion some form of compensation must be provided to correct for the variation in response of the unit. This is accomplished by means of an electrical equalizer, with the resulting response-frequency characteristic of the complete system as shown in Figure 3. Thus an essentially uniform response is obtained from about 100 c.p.s. to about 7000 c.p.s.

As the equalizer acts to reduce the overall efficiency at higher frequencies to that at 100 cycles, the combination of equalizer and artificial mouth becomes rather inefficient, and an amplifier capable of delivering a large power output is required. The No. 59A amplifier, which is designed for use in the reproduction of sound pictures, is used with any suitable source of power such as an electrical oscillator. Other sources such as the vertical phonograph reproducer, which have low outputs, sometimes require more gain than is provided by the No. 59A amplifier, in which case a No. 63A amplifier, designed to be associ-

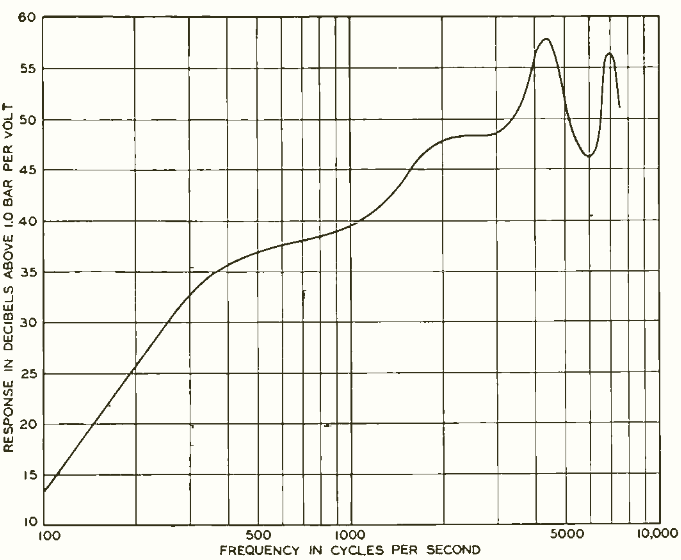


Fig. 2—Response-frequency characteristic of artificial mouth without equalizer

ated with the No. 59A, is also included.

Several sources of electrical energy are available for the various types of tests to be made. An electric oscillator of the heterodyne type is normally used for measurements requiring single-frequency currents. An electrical phonograph is suitable for reproducing speech and bands of frequencies in addition to single frequency tones. Where measurements on actual voices under controlled conditions are to be made the energy may be that supplied from a high quality transmitter.

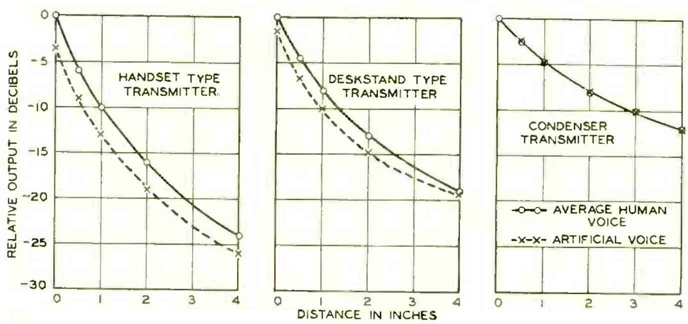


Fig. 4—How the output of transmitters falls off as they are moved away from the sound source

Measurements of the sound power available from the artificial voice have been made for both single frequencies and for reproduced speech. The maximum output obtainable at single frequencies without appreciable distortion was found to be approximately proportional to the response of the mouth and therefore to vary with frequency approximately as indicated by Figure 2. Such distortion as was found was due principally to the presence of odd harmonics, the third harmonic being the highest in magnitude. Speech about 15 db louder than that of the average telephone user can be obtained without noticeable distortion.

As a check of the sound field distribution around the artificial mouth, tests have been made on the distance-vs.-loss characteristics of several different types of transmitters with actual voices and with the same voices reproduced from phonograph records through the artificial voice. The results of these measurements are given in Figure 4 for a high quality condenser transmitter, desk stand type transmitter, and a handset type transmitter.

In conclusion, the results indicate that a satisfactory approximation to the human voice has been realized. Acoustic outputs can be obtained to cover most testing requirements without appreciable amplitude or non-linear distortion. The sound field about the artificial mouth is about the same as for the human mouth. Speech reproduced by the artificial voice sounds natural and comparative articulation measurements of speech from an individual and its reproduction by the artificial mouth differ by only a few per cent. The design can be specified and reproduced with accuracy and it is rugged and constant in operation.

Experience in the use of the artificial voice covering about a year's time shows it can be used to replace the human voice in most types of laboratory measurements and that it is adaptable to routine shop and manufacturing tests.

Amplifying Watch Sounds

By A. F. BENNETT
Transmission Instruments Engineering

THE ticking of a time piece is of peculiar human interest—it attracts the attention of the youngster, and at quiet hours is often a source of comfort to older folks. But to the skilled watchmaker the sound of a watch means far more—it tells him the condition of delicate bearings and moving parts. By the aid of the sound emitted from the watch he is often able to detect damaged parts which need replacement.

When the watch is very small, however, the sound given off is usually very faint, and in many cases it is so difficult to hear that it is almost impossible to make use of the sound in repairing a watch. Apparatus has recently been devised in the Laboratories which makes it possible to amplify the faint sound given off by a very small watch and so facilitate repair. While there are a number of ways in which this amplification might be brought about, in selecting the method it was desirable to choose one which introduces a minimum of distortion. Otherwise, the sound will not be faithfully reproduced and a false diagnosis might result.

Since the sound is radiated from the case of the watch, its vibrations, if suitably amplified and converted to sound, will be a good measure of the sound emitted by the watch. This amplification is accomplished in a novel and interesting manner. The metal case of the watch is made to act as one plate of an electric condenser, and is separated by a very thin sheet of paper from the other plate or electrode which is of about the same size. The plates are charged by a battery connected across them through

Fig. 1—M. K. Gordon, Jr. is shown operating the apparatus for amplifying watch sounds. For purposes of comparison and regulation the equipment is provided with two first stage amplifiers, one for the watch under observation and one for the master watch. The intensity of the sounds of the two watches may be adjusted by the volume controls on the lower panel. The two amplifiers are mounted on the upper portion of the relay rack

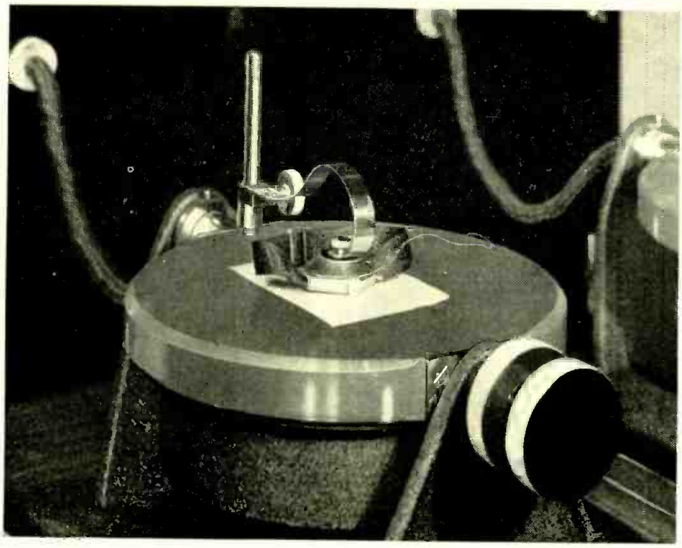


Fig. 2—A small plate or electrode is embedded in the insulating disc directly beneath the watch. The watch case is grounded and acts as the other plate of the condenser. The fluctuations in potential caused by the vibrations of the watch case are amplified by a vacuum tube amplifier located in the case beneath the circular table. The table may be rotated and locked in position by the knobs at the right

a high resistance. The stationary electrode is connected to the grid of a vacuum tube amplifier. Thus, the minute movements of the watch case cause corresponding variations in the capacitance of the condenser formed by the watch and electrode. The resulting fluctuations in potential are amplified by an amplifier of high gain and reproduced in a receiver. By means of this apparatus sounds inaudible to the unaided ear may be raised to almost any desired intensity.

An equipment such as that described has been prepared by the Laboratories for use by Tiffany and Company in the repair of fine watches (Figure 1). The watch is held in place directly over the small electrode by a spring member terminating in a rubber cup. The electrode is a small nickel-silver disc embedded in a circular plate of special insulating material. The first stage vacuum tube is located directly beneath the electrode in order to reduce the stray capacitance, and hence the extraneous noise, to a minimum.

A watch may operate perfectly when held at a certain angle, but because of a defect in some member or misalignment of some bearing, the movement of the mechanism may be seriously restricted in other

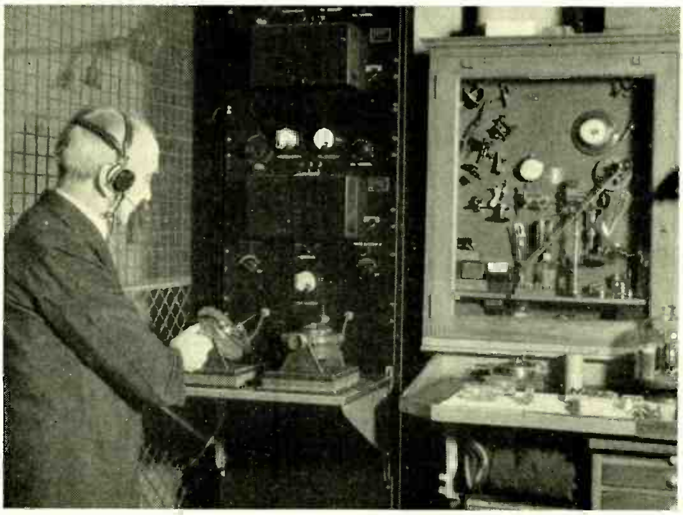


Fig. 3—Ferdinand T. Haschka, master horologist who heads Tiffany & Company's watch shop, compares a watch under adjustment with a master watch

positions. All this is evidenced by changes in the sound when the position of the watch is shifted. Accordingly, the table on which the watch is held is arranged to be rotated to any angle and locked.

The watch-holding mechanism and first stage of amplification are mounted on a sponge rubber suspension to reduce the extraneous noise caused by building vibrations. Two special amplifiers of three stages each, equipped with suitable volume controls, are included in the equipment.

By the use of a master watch and the amplifying equipment, it is possible to reduce greatly the time needed for regulating a watch. The master watch is placed on a duplicate amplifying equipment, which is connected in circuit so that both the master watch and the watch under adjustment may be heard simultaneously. Volume controls are provided so that the sounds may be made of approximately equal loudness. Very slight differences in the speed of the two watches may then be detected. Hence, the speed of the watch may be quickly checked against that of the master. In this way much time may be saved in the adjustment of the watch, particularly in timing it in various positions.

As in all electrostatic apparatus, insulation resistance is here of outstanding importance. Fluctuations in the insulation resistance between the electrode and the watch give rise to undesirable noise, and a low value of insulation resistance may cause serious loss in sensitivity. In choosing the insulating material it was also necessary to select one whose insulating properties remain substantially constant even under conditions of high humidity. Victron, a coal tar derivative, has been found satisfactory for the insulating disc on which the vacuum tube, grid leak resistances and other circuit elements are mounted, and on which the watch rests. Very thin condenser paper impregnated with a Victron solution has also been found to give satisfactory service as the dielectric material.

This apparatus has been in use for about a year in the watch repair shop of Tiffany and Company, who have found it of great value in connection with their work.

Evaluating Arc Resistance of Insulating Materials

By K. G. COUTLEE
Telephone Apparatus Development

ARC resistance is a peculiar characteristic of insulating materials that so far has not been correlated to any other property. Two pieces of a certain type of material, made under exactly the same specifications, may prove quite different in their ability to withstand arcing. This has been found to be true of the phenol fibre used until recently for the cams of sequence switches*. Because of the importance of the satisfactory operation of these switches to the panel system, testing apparatus has been developed to determine the arc resistance of insulating materials. By studies carried on with this apparatus, a new material has been developed that not only has a high resistance to the deteriorating effects of arcing, but that does not vary in its arc resisting characteristics from sample to sample as the earlier material did.

The effect of an arc is to carbonize the insulating material on the surface of which the arc takes place. As a result of this carbonization the material becomes conducting, and its effectiveness as an insulator is lost. Sequence switch cams consist of metal segments fastened to the two faces of phenol fibre disks, on which brushes ride and make or break contacts with the metal segments as the disks rotate. Every time the circuit is broken, a small arc forms. Many thousand, and in some cases hundreds of thousands, of revolutions are made by the sequence switches each year, and since there may be 5000 switches in a single office and each switch may have as many as 25 cams, maintenance would be very high if a material of high arc resistance were not employed.

The arc formed may cause failure in either of two ways. It may carbonize, and thus make conducting, a path on the phenol fibre along the track of the brush after it leaves the metal segment. When this happens the circuit is not broken as the brush leaves the segment, but is maintained through the carbonized insulation for some distance beyond. As a result, the proper sequence of the operations controlled by the switch is destroyed.

In other cases the effect of the arc is to burn a hole through the phenol fibre where the brush leaves the edge of the segment. This allows current to flow through the hole to segments on the other side of the cam, and thus also results in improper action of the switch.

The apparatus developed to study the arc resistance of insulating materials is shown in use in the photograph at the head of this article, and in more detail in Figure 1. In many features it simulates the sequence switch. Metal segments are mounted on both faces of the insulating material to be tested, and standard

*Record, *December*, 1931, *p.* 119.

sequence switch brushes ride on them. The test specimen is of the same diameter and thickness as the phenol fibre disk employed in sequence switch cams. Two stationary brushes ride on the front of the cam: one near the center where it is in continuous contact with the metal, and one near the periphery where it is alternately in and out of contact as the cam rotates. In the circuit with these brushes is an inductive load consisting of a network of relays, and the arcing is formed by the opening of this circuit as the outer brush leaves each segment of the rotating cam.

To accelerate the deterioration, and thus to secure information regarding different materials in the shortest possible time, the current is made twice as great as the maximum usually carried by sequence switches, and the speed of the cam is made one third of the normal value. At the lower speed the arc tends to hold over much longer. The result of these changes in current and speed is to produce failure in far fewer revolutions than would be required in actual service.

It was desired, of course, to have the apparatus stopped automatically when failure of either of the two types mentioned occurred. This was accomplished by mounting a third brush to ride on the outer edge of the rear face of the cam. This brush is connected to a relay which, when operated, trips the circuit breaker supplying power to the motor that rotates the cam. The circuit arrangement is shown schematically in Figure 2. Here the segments on the rear face of the cam, which are narrower than those on the front, are indicated by dotted lines. The third brush is mounted from an arm projecting from a protractor scale so that it can be rotated around the disk in reference to the fixed brushes. This brush is generally set so that it is just coming into contact with a segment on the rear face when the outer fixed brush has moved 15° away from contact with a front segment. This 15° was taken as the maximum allowable distance for an arc to hold over along the surface.

If the arc has so charred the surface that it holds over for 15°, as indicated by the broken line at "X" in the illustration, current will flow from brush "A" to the metal segment and to brush "C", which has just made contact with the segment on the rear, since the segments on the front and rear faces are connected electrically. From the brush "C" this current flows through the relay, and stops the motor. The reading of the revolu-

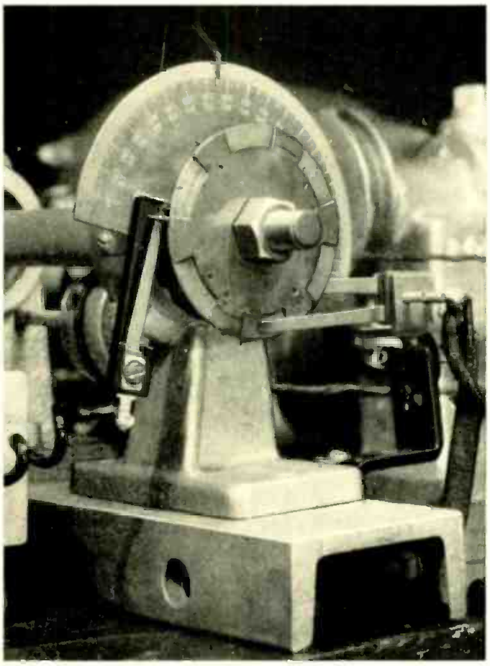


Fig. 1—Samples of insulation of the same dimensions employed in sequence switches and standard sequence brushes as used for the tests

tion counter, which is connected to the drive shaft of the apparatus, will then indicate the number of revolutions that have been made before the failure occurred, and is a measure of the arc resistance of the insulating material.

If instead of charring the insulation along the surface, a hole had been burned through the insulation at the edge of a segment on the front of the cam, the situation, when the test stopped, would be as shown in Figure 3. Under these conditions current would flow through brush "C" and the relay, when "C" was directly over the hole burned through the insulation. At this instant the brush "A" would be resting on a metal segment and the circuit would be completed through it. In both of these cases, the load current passes through brush "B"; the current through brush "C" and the relay being in shunt with the load.

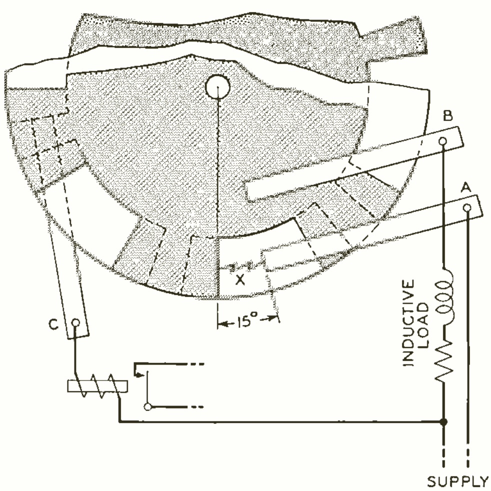


Fig. 2—Schematic diagram showing the path of current when an arc holds over across the surface of the insulation

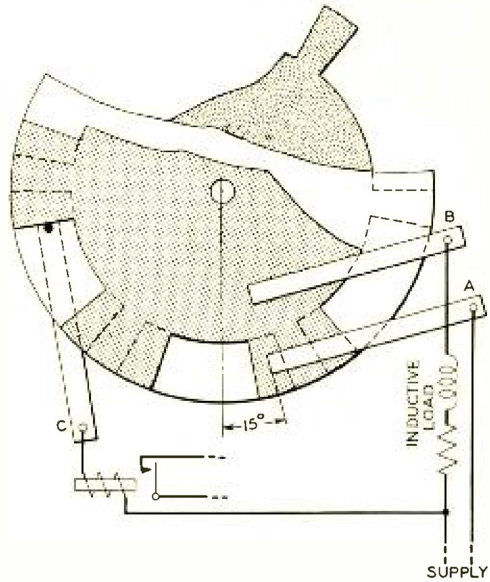


Fig. 3—Schematic diagram showing how the apparatus is stopped when a hole has been burned through the insulation

Aided by the quick test results which can be obtained with this apparatus, it has been possible through cooperation with the Western Electric Company, and with outside suppliers of insulation, to develop a new type of phenol fibre which has markedly improved arc resistance. Furthermore, the results obtained from different lots of the new material are very constant, while different lots of the old varied over an extremely wide range. Apparatus designed on the same principles but more compactly arranged is now being employed by the Western Electric Company to perform their routine inspection tests of the arc resistant phenol fibre used in sequence switches.

Contributors to This Issue

After receiving the degree of B. S. in Chemical Engineering from the University of South Dakota in 1909, C. R. Englund went to the University of Chicago for two years of graduate study. He then went to Western Maryland College as Professor of Physics and Geology, and a year later to the University of Michigan as Laboratory Assistant. In 1914 Mr. Englund left academic work to join the Engineering Department of the Western Electric Company, now these Laboratories. Here he has been engaged in radio research, taking part in many of the Laboratories' numerous developments in that field in the last twenty years. He is now in charge of a group devoted to short-wave radio investigations.

Although graduate study leading to the M. S. degree immediately preceded E. W. Holman's entrance into these Laboratories in 1929, he had had more than a year's practical experience with the Mountain States Telephone and Telegraph Company following his graduation by the University of Colorado in 1926. In the Transmission Instruments Engineering group Mr. Holman has been engaged in the development of testing methods for telephone transmitters and receivers, and particularly in the development of the artificial mouth.

With the background of undergraduate studies at Guilford College and a Master's degree from North Carolina State College, F. L. Crutchfield entered these Laboratories in 1926. In the Transmission Instruments Engineering group he was first concerned with fundamental calibration of condenser transmitters by the thermophone. He then participated in studies of room noise leading up to the phonographic reproduction of noise in test rooms. Recently he has assisted in the development of tests for several receivers and transmitters. An outgrowth of this work was the artificial ear described in this issue. He is now in charge of the Master Transmission Reference System, and recently has undertaken the calibration of instrument standards.

T. Slonczewski received a B.S. in E.E. degree from the Cooper Union Institute of Technology in 1926 and immediately joined the Technical Staff of the Laboratories. With the Electrical Measure-

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F. L. Crutchfield

T. Slonczewski

L. E. Abbott

K. G. Coutlee

ments Group he was first associated with the development of alternating current bridges, but more recently has been concerned with the development of vacuum tube circuits. Since joining the Laboratories he has continued his studies at Columbia University, where he has taken graduate work in physics.

L. E. Abbott was graduated from Brooklyn Polytechnic Institute in 1928 with the degree of M. E. As a member of the Materials Group he has worked on fatigue studies of sheet non-ferrous alloys and lead cable sheath, and lately has been engaged in welding and x-ray development. In 1931 Brooklyn Polytechnic Institute awarded him the degree of M. S. in M. E.

A. F. Bennett

K. G. Coutlee joined the Laboratories in 1916 and since that time his work has been concerned mostly with the electrical characteristics of insulating materials particularly their dielectric losses under low potential telephone frequencies and low and high potential radio frequencies. He was instrumental in developing special laboratory testing apparatus for dielectric studies at radio frequencies. Since 1928 he has been with the Insulating Materials Group of the General Apparatus Development Department dealing with insulating material problems and developing methods of test for the control of raw materials used in telephone apparatus.

A. F. Bennett joined the instrument standards group of the Laboratories in 1914, and during the war took part in the development of submarine detection apparatus. After the armistice he turned to studies of the granular carbon transmitter, and took a leading part in the development of the handset transmitter, the barrier-type operator's transmitter, and the instruments for the portable audiphone. At the present time he has charge of the development of transmitters for use in the telephone plant and elsewhere.