BELL LABORATORIES RECORD

ELECTRIC SHOCK ON THE HEART
L. P. FERRIS

ADHESIVES
J. B. DeCOSTE

HIGH-EFFICIENCY RADIO AMPLIFIER
W. H. DOHERTY

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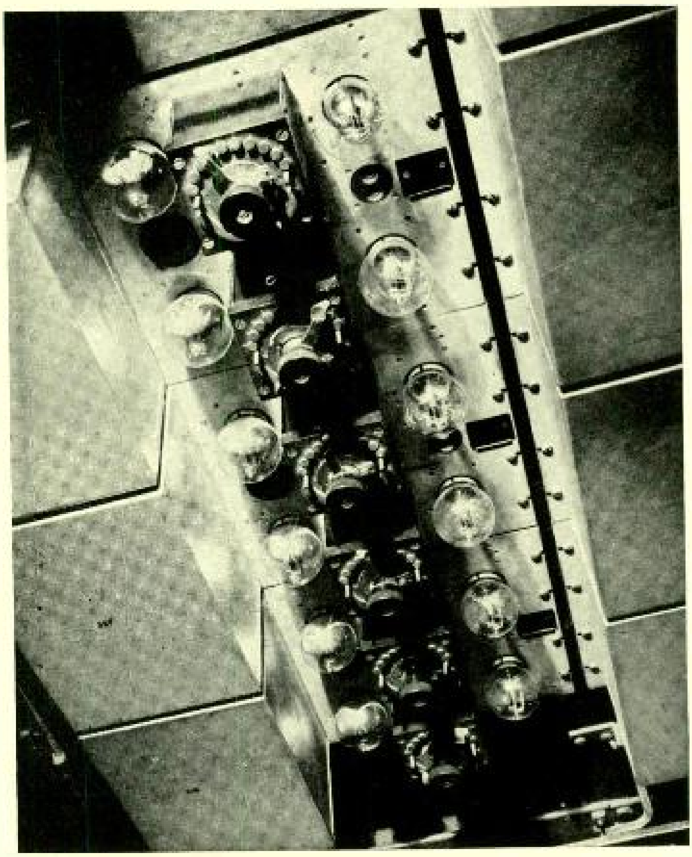


A bay of telephone repeaters

VOLUME FOURTEEN—NUMBER TEN

for

JUNE

1936

Effect of Electric Shock on the Heart

By L. P. FERRIS
Protection Development

EXPERIMENTAL investigations of the effects of electric shock on living things long antedate all commercial uses of electricity, but this work of the early experimenters left much to be desired, particularly in defining the limits of shock which are dangerous to man. As a basis for the development of protective measures and practices, such knowledge is obviously important. To obtain some of the needed data a joint investigation by the Department of Physiology of Columbia University and the American Telephone and Telegraph Company was initiated in 1927 and has since been continued with the help of Bell Telephone Laboratories.*

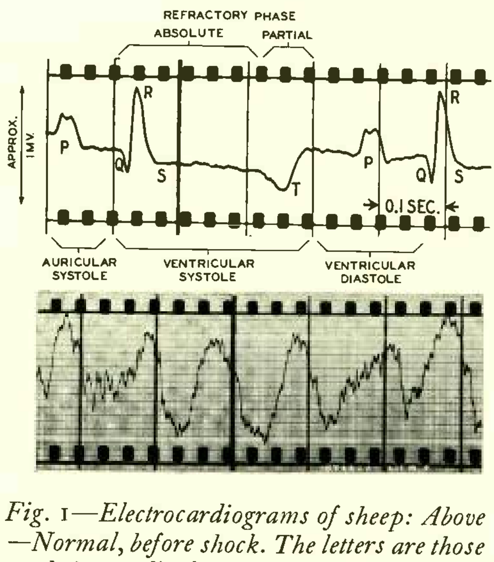


Fig. 1—Electrocardiograms of sheep: Above—Normal, before shock. The letters are those used in medical practice to indicate the waves of the electrocardiac cycle. Below—Ventricular fibrillation after a severe electric shock has been received between the right foreleg and the left hind leg

In seeking a value of current which if exceeded would be dangerous to man, it is important to consider for different practical conditions the effects which are brought about as the current is increased. The threshold of sensation is reached at about one milliampere for a frequency of 60 cycles. Other investigators have found that with 15 milliamperes from hand to hand a subject is unable to release himself. Any currents which prevent voluntary control of the muscles are dangerous because their pathway might include the respiratory muscles and stop breathing. No serious or permanent after-effects are likely merely from the cessation of respiration, provided it is not continued beyond the point where the victim can be resuscitated by artificial respiration. Currents somewhat greater than those just necessary to stop breathing may derange heart action and cause fatalities even though the duration of such shocks is but a few seconds or less, far too short to be important from the standpoint of interruption

*Drs. H. B. Williams and B. G. King of Columbia University have coöperated throughout this investigation with P. W. Spence of the Bell Laboratories and the author. The experimental work has been for the most part conducted in the Physiology Laboratories at the Medical Center by Mr. Spence, Dr. King and assistants. Mr. M. E. Strieby of Bell Laboratories participated in the early part of the investigation. A more detailed report of these studies entitled "The Effect of Electric Shock on the Heart" can be found in the May, 1936, issue of *Electrical Engineering*.

of respiration, and obviously too short to give any opportunity for rescue before the end of the shock. Death in these cases is brought about by ventricular fibrillation, in which condition the ventricular muscle fibers of the heart contract in an uncoördinated manner, twitching and quivering, in contrast to their normal coördinated rhythmic movement. As a consequence the pumping action of the heart ceases and the failure of circulation results in an asphyxial death within a few minutes. The medical profession has long recognized that when this condition is set up in man it is very unlikely to cease naturally before death. The value of current just under the threshold for fibrillation may, therefore, be taken as the maximum current to which man may safely be subjected, since, regardless of rescue or after-treatment, death is liable to result from greater currents. The experimental investigation described here was, for this reason, directed towards a determination of the variation of this threshold current with a number of factors which enter into the practical application of the results. A number of species of animals were included in the tests to establish the trend of the effects with variation in physiological and morphological factors, but most of the experiments were upon animals comparable in body weight and in heart rate and weight to man, so that the results which were obtained would be indicative of what might be expected in man.

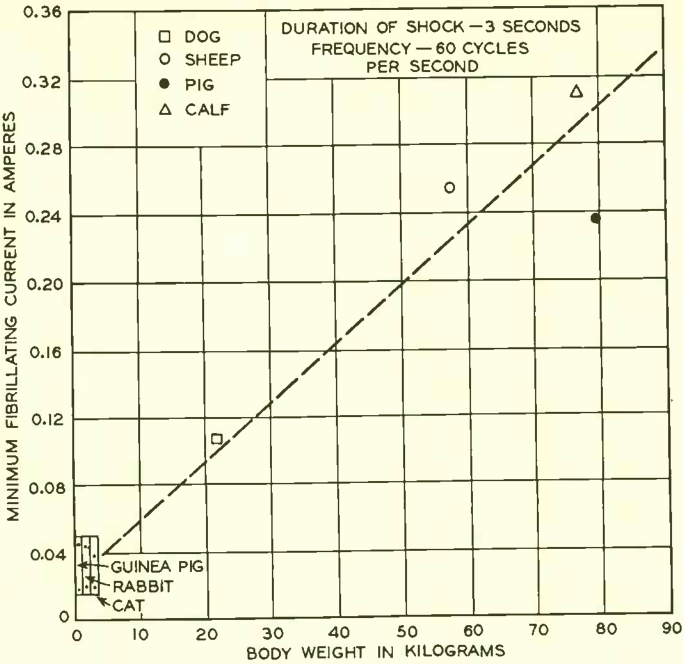


Fig. 2—The minimum current which will cause ventricular fibrillation is roughly proportional to the weight of the animal

The animals were kept under surgical anaesthesia during the tests and the behavior of their hearts was studied by making electrocardiograms of each animal before and after shock. These were recorded together with the shock current and voltage, by a three-string oscillograph. An electrocardiogram is a graphical record of the time variation of the voltage which is always associated with the action of the heart. A normal sheep electrocardiogram is shown by the upper part of Figure 1, while the lower part is an electrocardiogram of a sheep whose heart is in ventricular fibrillation.

The threshold currents required to cause fibrillation in seven different species of animals were determined under standard reference conditions which included the use of 60-cycle alternating current for a duration of 3 seconds, with electrodes on the right fore and left hind legs—conditions typifying those of many accidental shocks to man. The general results are shown in Figure 2 in which the minimum fibrillating current is plotted as a function of the body

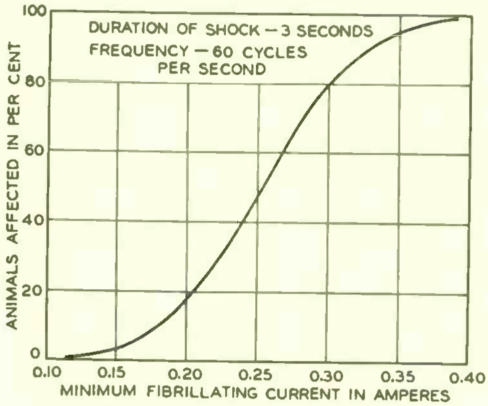


Fig. 3—The current required to produce fibrillation in sheep varies appreciably from one animal to another

weight of the different species. Individuals depart widely from the general trend of these results as is shown by Figure 3. The average weight of an adult man is approximately 70 kilograms and these results on the whole indicate that currents in excess of 0.1 ampere at 60 cycles, from hand to foot, will be dangerous for shock durations of 3 seconds or more.

Inasmuch as the path of the current through the body affects the proportion of current which reaches the heart, the current path as determined by the points of contact with an external circuit influences the amount of current necessary to cause fibrillation. Based upon the animal tests, it is concluded that for man, pathways from arm to leg, across the chest, chest to arm and head to leg, may be expected to give about the same threshold. The pathway between the arms should give a somewhat higher threshold and from leg to leg the proportion of current reaching the heart is so small that fibrillation is not liable to result, even at currents of 15 amperes or more. Such currents would, however, probably burn or otherwise injure the victim, unless the contacts were good and the shock of short duration.

For shocks which last a second or more, the threshold fibrillating current at 25 cycles is about 25 per cent higher than the 60-cycle value and the direct current threshold about 5 times that at 60 cycles. This relation probably does not hold for shock durations of a small fraction of a second, in which case thresholds for these frequencies would be expected to approach one another.

For shocks whose duration might be limited by quick-acting circuit breakers or other protective devices to a small fraction of a second, it was expected that the effect would depend upon the phase of the cardiac cycle during the occurrence of the shock. In Figure 1 (top) the so-called "waves" of the electrocardiogram are lettered in accordance with common medical practice, and the different phases of the cycle are indicated. Special circuits were developed to take advantage of the conspicuous differences among the electrocardiac impulses of a single heart beat to initiate operations which controlled the application of the shock and the recording of the current, the voltage and the electrocardiogram. Figure 4 is a schematic diagram of the apparatus employed for this purpose. By proper timing and biasing, the marginal tripping circuit operated only on the QRS wave. The timing of the shock in relation to this reference point was regulated by an adjustable electrical delay circuit and the duration of the shock was controlled by another similar circuit. The feeble impulses of the heart itself were thus made to control the power switches which applied the shock. The oscillograph was started a few seconds before shock and operated continuously, recording the pre-shock electrocardiogram, oscillograms of shock current and voltage, and a post-shock electrocardiogram of sufficient duration to show the effect of the shock on the heart. The exact time relation of the shock to the immediately preceding electrocardiac cycle can thus be determined, assuming only that the heart continued its normal beat for the fraction of a second between the disconnection of the cardiograph and the application of shock. Typical records obtained in these tests are shown in Figure 5. Time lines appear ten times a second. The upper record of Figure 5 A shows a shock followed by a coördinate heart beat, while the lower record, B, is of a shock which resulted in ventricular fibrillation. The action currents from the body muscles which persist after the powerful muscular contractions during the shock obscure to some extent all post-shock electrocardiac records, making them appear to have high-frequency irregularities, but the post-shock portion of Figure 5 A reveals the same typical sequence of prominent deflections which appear before shock, proving coördinate heart action. As a result of giving over 1,000 such controlled shocks to sheep, it was discovered that in order to produce fibrillation, shocks of 0.1 second or less must occur during the partially relaxed period of the cardiac cycle, corresponding to the T-wave of the electrocardiogram. This sensitive phase of the cardiac cycle is about twenty per cent of the whole. Outside of it fibrillation cannot be produced, with extremely rare exceptions, by currents up to at least 15 amperes, which was about the limit

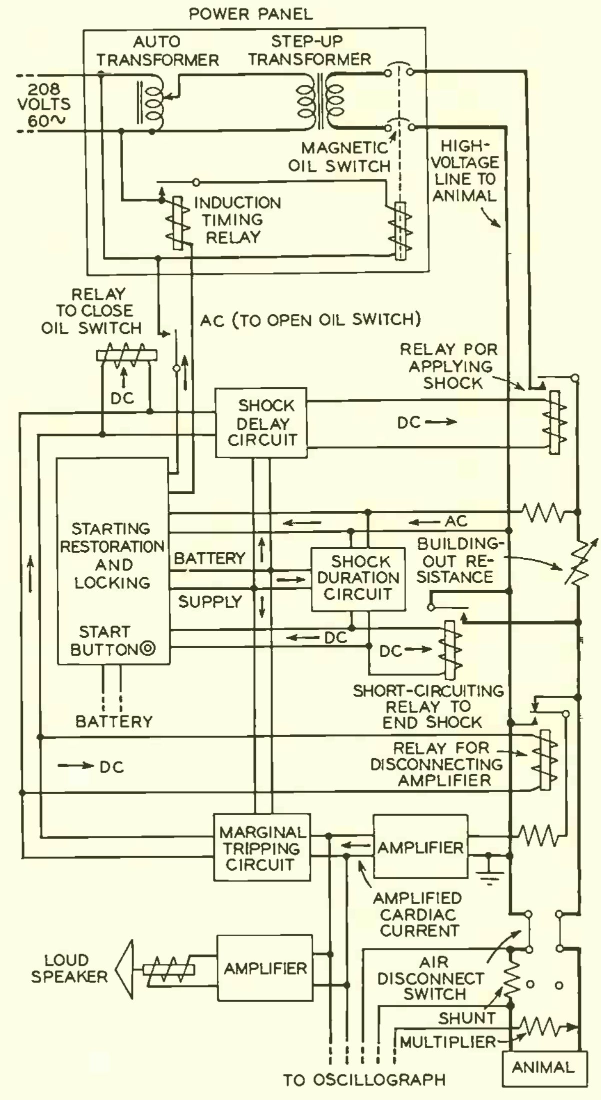
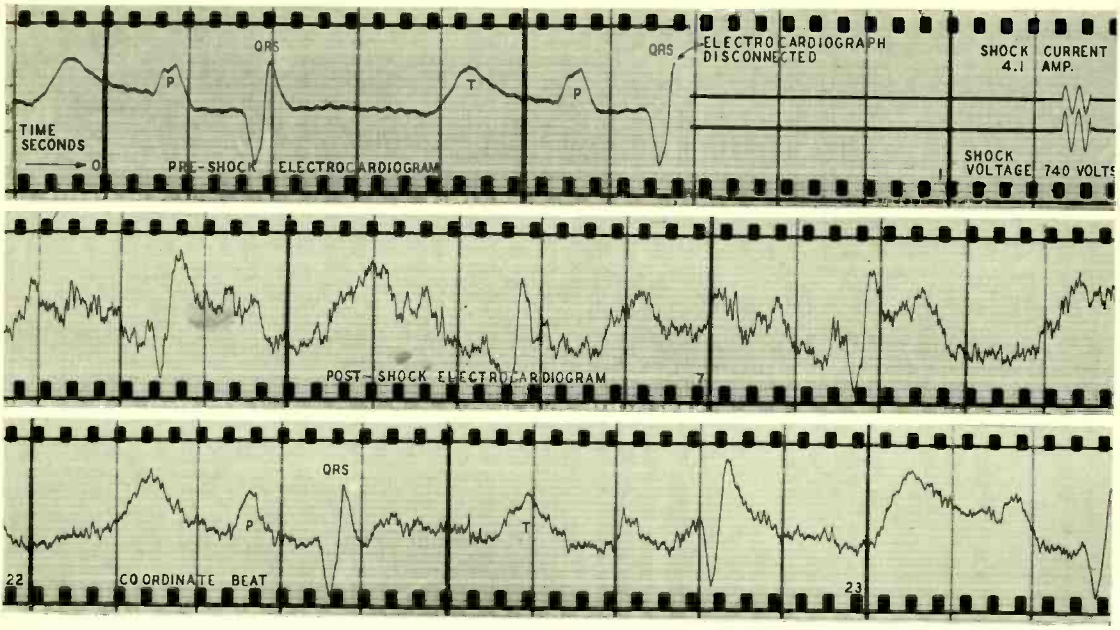
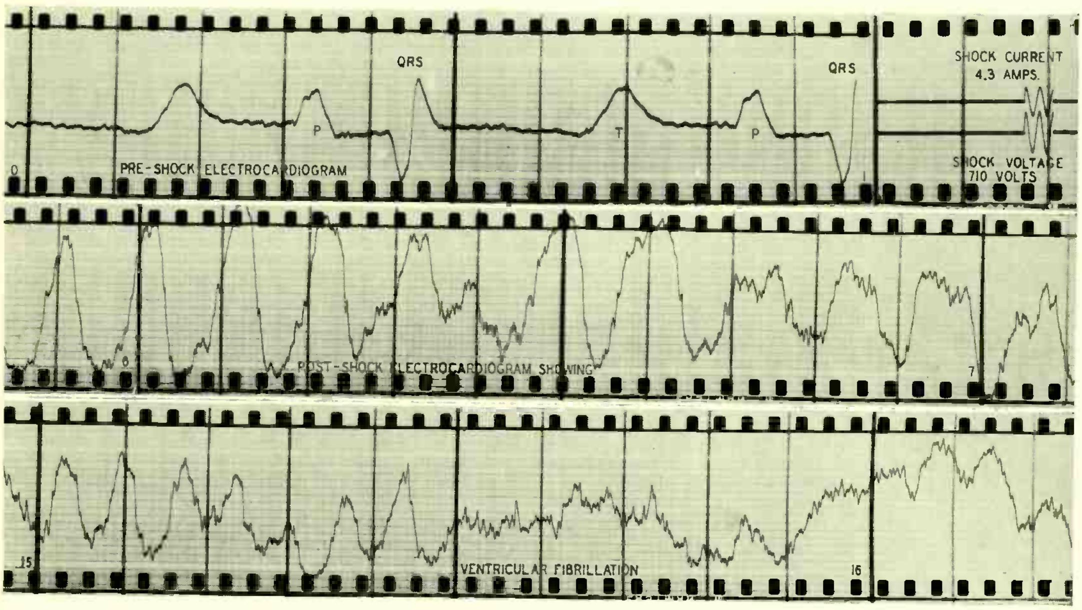


Fig. 4—Diagram of the apparatus used for applying shocks at predetermined points of the heart cycle



A



B

Fig. 5—Typical records of 0.03-second shocks to sheep: Top Group—during insensitive phase of cardiac cycle. Bottom Group—during sensitive phase of cardiac cycle. The electrodes were fastened to the right foreleg and left hind leg

of the tests which were carried out.

With the discovery of the sensitive phase of the heart cycle the threshold current required to produce fibrillation for short duration shocks was then determined. It is seen in Figure 6 that the threshold current varies inversely with shock duration, but not uniformly—being most sensitive to change as the duration approaches the time of one heart beat. For shocks of 0.1 second or less it is ten or more

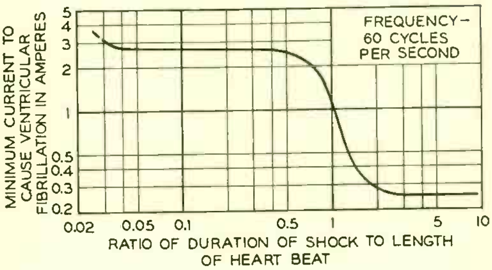


Fig. 6—Considerably greater current is required to cause fibrillation if the shock is of very short duration

times the threshold for durations of one second or more—a fact of great importance in the development and application of protective devices and methods.

Shocks a third or more of the heart cycle in duration may cause fibrillation, even though they would not extend into the sensitive phase of the cycle if the heart continued its normal beat. The reason is probably the initiation of a premature heart beat which brings about a premature sensitive phase prior to the end of the shock.

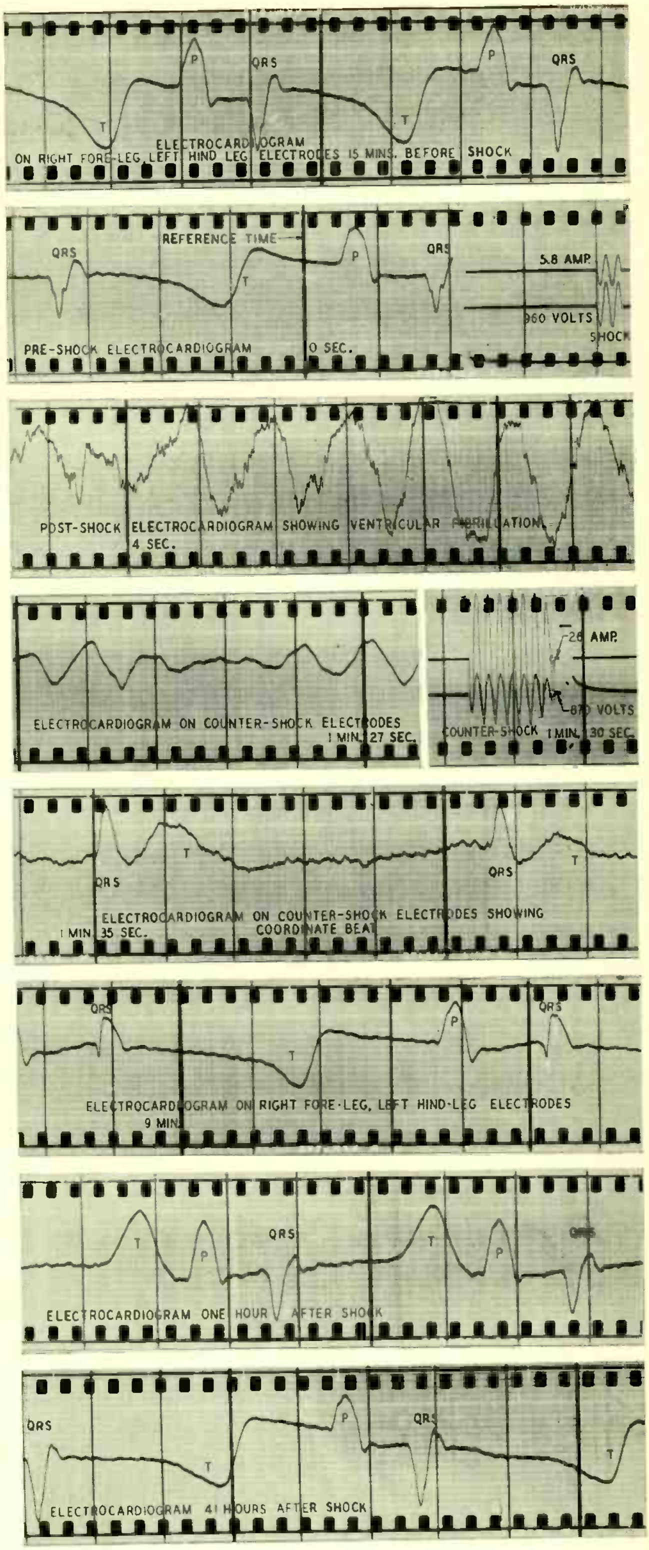


Fig. 7—Right: Record of restoration of sheep heart from ventricular fibrillation by a countershock. Electrocardiograms taken immediately preceding shock, immediately after shock showing ventricular fibrillation, and at intervals following countershock. The latter records show the progressive development of normal heart beat

The susceptibility of the heart to fibrillation by short shocks increases with current up to several times the threshold as might be expected, but then the liability of fibrillation, strange as it may seem at first sight, diminishes and becomes very small for currents of the order of 25 amperes through the body in the vicinity of the heart. However, other serious injury may be expected from such currents when brought about by accidental contacts.

More surprising even than the fact that high currents are less prone to produce fibrillation than low currents, is the fact that fibrillation once caused by a relatively low-current shock can be arrested and the heart action brought back to normal by a subsequent electric shock of high intensity and short duration through the heart. This seems to be a rather striking and true example of the old adage that "The hair of the dog is good for the bite." In the experimental study of the threshold conditions which bring about fibrillation, this normally fatal effect was necessarily the end result of most of the tests and an opportunity was thus afforded to investigate the effect of this so-called countershock method of restoring heart action. The method was first reported by the physiologists Prevost and Battelli, who worked at the University of Geneva in 1899 on dogs and smaller animals. In the investigation reported here, the method was successfully applied not only to dogs, but to sheep, hogs and calves. A record of the restoration of a sheep's heart from ventricular fibrillation by countershock is shown in Figure 7.

To be successful, a countershock must be administered promptly after the fibrillating shock, probably within a few minutes. The need for maintaining respiration by artificial means is in no way lessened. In fact, the administration of artificial respiration even in the interval before the application of a countershock is highly advisable, not only for respiration itself, but because of the accompanying slight circulation which will assist in the nutrition of the heart and delay the degeneration of the brain. Because our experiments using an arbitrarily chosen countershock on animals comparable in size to man showed a successful restoration in about sixty per cent of the cases, we can conclude that the method of countershock has distinct possibilities of successful application to man. The optimum conditions of countershock and practical apparatus and techniques for its application are matters which can only be determined by further work.

High-Fidelity Radio Broadcasting

By E. L. OWENS
Radio Development Department

IF a broadcasting system performed its function perfectly, it would serve only as a medium for converting sound into electrical energy so that it could be transmitted through the ether with no form of distortion. Nothing would be omitted from the sounds picked up, nor would anything be added to them. More specifically this means that all the component frequencies of the program would be transmitted at their true relative volumes, and that no additional energy in the form of noise or other disturbances would be added. For a listener to obtain the maximum benefit from high fidelity broadcasting, his receiving equipment, of course, would have to be capable of a precisely equivalent performance.

Since the quality of the transmitter's output depends chiefly on the frequency range, the volume range, and the amount of harmonic distortion, these three characteristics may be used to gauge the fidelity of a transmitter. A high-fidelity transmitter is one that approaches near enough to perfection to make the programs reproduced by a suitable receiver enough like the original to be satisfactory to a critical listener. The requirements for a high-fidelity transmitter would vary with the type of program to be transmitted. For perfect reproduction of music, all frequencies from about 40 to perhaps 15,000 cycles would have to be transmitted equally. The very high frequencies, however, are required for only a few of the musical instruments, and since they are present only in small volume, and are not detected at all by some people, an upper frequency limit of 8000 cycles is taken as meeting the high-fidelity requirements under present conditions.

Volume range also varies with the type of program. The range of sound power of a large symphony orchestra may be of the order of ten million to one, or 70 db. For smaller orchestras or single instruments this range would be much less. The limiting factors of volume range in the transmitter are the load carrying capacity of the equipment at the upper end, and the noise level at the lower, since the noise must be lower in level than the weakest sound to be transmitted. Noise, which includes all unwanted frequency components that would be reproduced with the program, is objectionable chiefly to the extent that it interferes with the received program. The amount of this interference depends not only on the magnitude of the noise currents but on their frequency. Research work carried on in these Laboratories has determined the relative disturbing effects of noise at all frequencies.* In general it is of much less importance at low frequencies and at the very high frequencies. For this reason the only satisfactory way of measuring noise in a broadcasting circuit is by use of a weighting network which automatically corrects the noise at various frequencies to conform to its actual effect on reception.

From the standpoint of reception, the usable volume range depends upon a number of external factors, such as room noise and static disturbances. Because of this situation, a weighted noise level 40 db below the signal at 100 per cent modulation would result in as high a fidelity as would generally be usable by the listener. To merit a high-fidelity rating, however, the transmitter should be capable of better performance than this, so as not to contribute to the noise level when receiving conditions are good.

Harmonic distortion in broadcasting equipment is caused by the non-linearity of certain elements in the

*RECORD, *March*, 1936, *p.* 233.

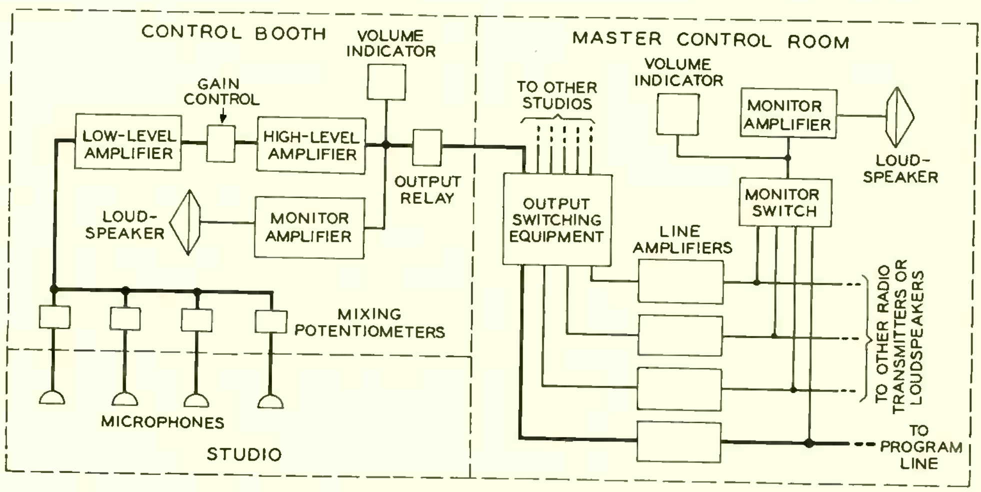
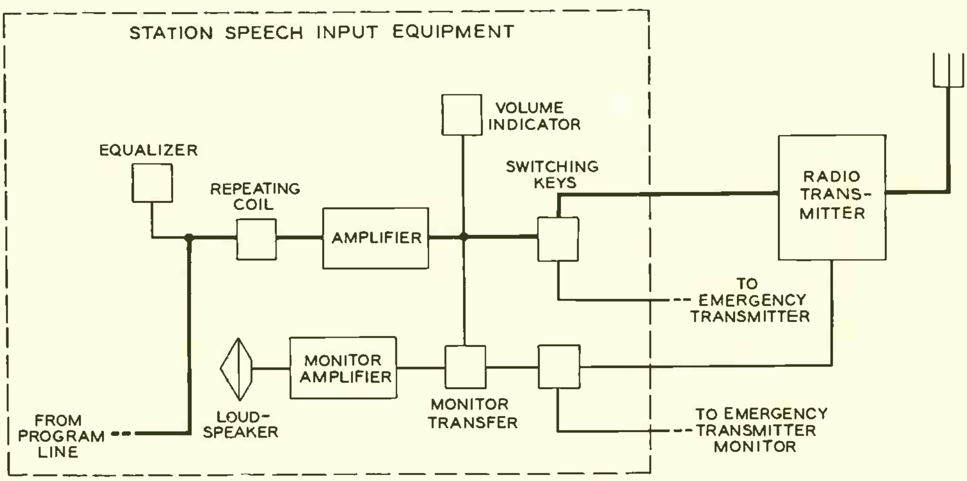


Fig. 1—Schematic layout of a

system, which results in the introduction of frequency components not present in the original. Since these components are harmonics of lower ones, their effect becomes more pronounced as the frequency band is widened. For high-fidelity programs these harmonics should not exceed 5 per cent for peaks of modulation approaching 100 per cent since amounts in excess of 5 per cent cause distortion that can be readily detected. This value should decrease for lower levels and should not exceed 2 per cent at 30 per cent modulation. To keep the harmonic distortion below these values requires a careful design and adjustment of all component parts of the system.

These various suggested requirements for high-fidelity broadcasting have, of course, no official standing, and to some extent are arbitrary, but any station meeting them could be said to have high-fidelity characteristics according to present-day standards.

A broadcasting system, to meet the above requirements for high-fidelity transmission, requires careful design and engineering of the entire system considered as one coördinated unit from microphone through studio speech input equipment, master control room, program wire circuits, station speech-input equipment, and radio transmitter. In the past it has sometimes been assumed that when units that were individually satisfactory from a transmission standpoint were installed and connected together in a high fidelity system, their operation would be satisfactory from an audio-frequency standpoint without the necessity of making overall measurements on the system. While this might be considered a logical assumption when high quality units make up the system, it does not take into consideration the fact that due to the complexity of a modern broadcasting system and the number of units involved, the cumulative effect of small variations in the characteristics of amplifiers and repeating coils, small capacitances in inter-unit wiring, or slight impedance mismatches in mixing circuits, amplifier coupling circuits, and line-terminating equipment may cause the overall frequency characteristic to



modern broadcasting system

fall far short of the desired performance. Such effects can be detected and isolated only by complete overall measurements as well as by measurements of all of the individual sections of the system.

Station WOR, owned and operated by the Bamberger Broadcasting Service, is the first high-power radio station to meet all the requirements for high-fidelity broadcasting as outlined above. This new 50 KW transmitter, located at Carteret, N. J., was developed by the Laboratories and manufactured by the Western Electric Company. The transmitting station has already been described in the RECORD.* All programs for Carteret pass through a master control room in New York which is supplied from ten studios located in New York and Newark.

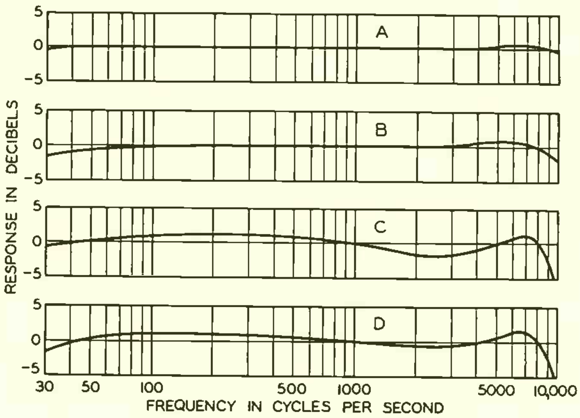


Fig. 2—Frequency characteristics of various sections of the WOR system: A—studio alone, B—studio and master control room, C—transmission line and speech input equipment at transmitter station, and D—overall characteristic of the complete system

Most of the programs originate in the New York studios, which are of various sizes so as to accommodate any program from a single speaker to a large symphony orchestra. All are equipped with Western Electric moving-coil microphones, and each has an associated control booth from which the operator has a view of the studio through a plate glass window. Each of these booths is equipped with a control unit on which is mounted the microphone mixing potentiometers, the master gain-control switching keys, and a volume indicator, and each has an amplifier bay. This latter bay includes both low-level and high-level amplifiers and associated power equipment, a meter for measuring amplifier plate currents, a jack panel, and a line equalizer for incoming program lines from remote pick-up points. A high-quality loud speaker is included in each booth for aural monitoring. All of these studios are in use most of the time; one actually broadcasting and the others being used for rehearsals.

Low-level mixing circuits have been used throughout the system. The output of the mixing circuit in each control booth is connected to the input of the low-level amplifier, and the master gain control is located in the circuit between the low-level and high-level amplifiers. All studio amplifiers are completely a-c operated. The vacuum tube filaments are heated directly with alternating current, and the plate voltage for the tubes is obtained from a rectifier through a filter of suitable design.

The high-level amplifiers in the control booths terminate in an output switching circuit in the master control room, so that the outputs of one or more studios may be connected to the line amplifier that supplies the program to the radio transmitter. An equalized 16-gauge non-loaded

*RECORD, *April*, 1935, *pp.* 226 *and* 232.

cable circuit connects the master control room with the speech-input equipment at the Carteret station.

In the final adjustment of this system tests were made of the various sections as well as overall from microphone to radio-transmitter output. Some of the frequency characteristics are shown in Figure 2. Curve A is from the microphone input circuit of Studio No. 1 to the output of the booth amplifying equipment, while Curve B shows the overall characteristic from the microphone input circuit to the output of the master control room. It will be noticed that for the studio itself the characteristic is flat to within ½ db from 30 to 10,000 cycles. The overall characteristic to the output of the master control room is about as flat over most of the range although it drops off slightly at the upper and lower ends, but even at 30 and 10,000 cycles it is down less than 2 db. This section includes all switching circuits, gain control attenuators, and both low-level, high-level, and line amplifiers, with a gross operating gain of 116 db, or nearly a million millionfold increase in power. Harmonic distortion in this section is well under one per cent.

Curve C shows the characteristics of the transmission line from New York to Carteret combined with the speech-input equipment at the radio-transmitter station. It is flat to within 2 db from 30 to 9000 cycles. The overall characteristic, from the microphone input terminals in New York to the output of the radio transmitter at Carteret, is shown by Curve D. This also is flat to within 2 db over the same range of frequency.

The total harmonic distortion at the output of the radio transmitter is shown in Figure 3 for levels from 30 per cent to 100 per cent modulation and with a pure 400-cycle signal. The weighted noise level of the entire system, including the radio trans-

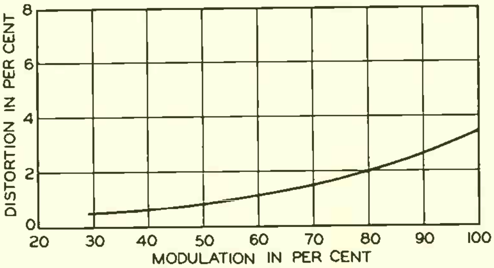
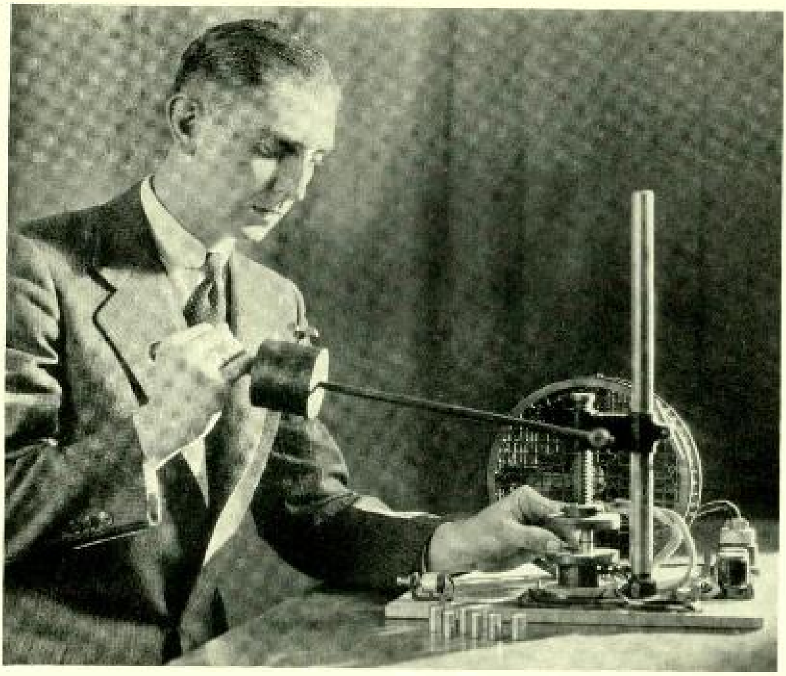


Fig. 3—Harmonic distortion characteristics for broadcasting station WOR

mitter, the station speech-input equipment, the program line to New York, and the studio speech-input equipment is 62.5 db below the signal at 100 per cent modulation. With such a noise level, it is obvious that the volume range of the system will well meet the 40 db mentioned as a requirement. This is a somewhat greater volume range than is broadcast by most stations at the present time.

High-fidelity operation imposes considerable responsibility on the station personnel, since to secure continuously satisfactory performance frequent checks must be made of all operating characteristics. More careful monitoring on programs is also required, since over-modulation of the radio transmitter will ruin the quality of any radio program no matter how high grade the equipment may be. By proper attention to these operating procedures, WOR's new system is capable of the best that modern broadcast service permits, since the characteristics of the system well meet the high-fidelity requirements listed above and are superior to them in most respects.



Adhesives

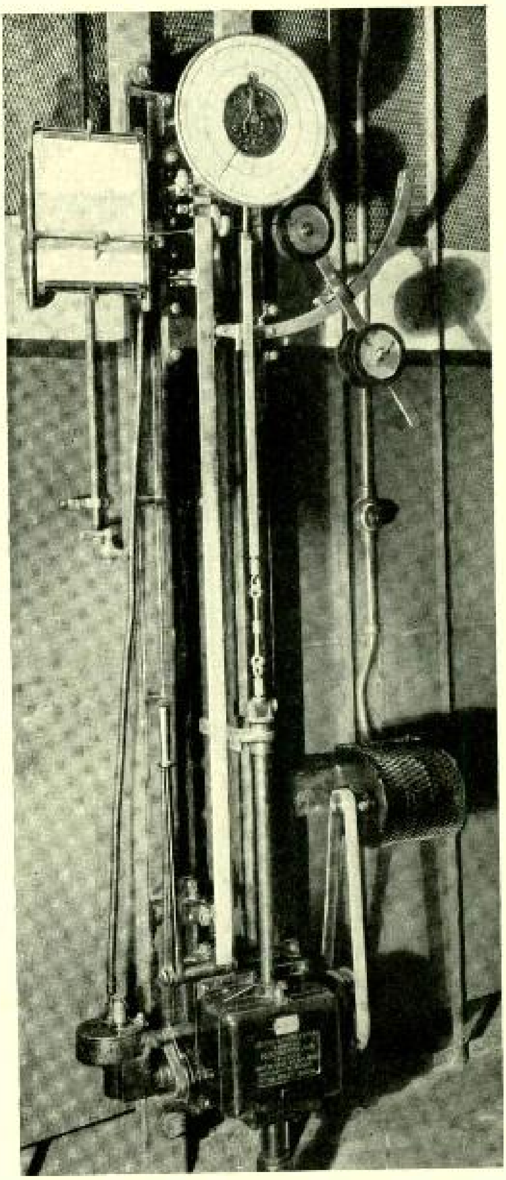
By JOHN B. DeCOSTE
Chemical Laboratories

ADHESIVES are used in many different types of telephone equipment because cementing parts together is a simple method of construction which is often preferable to any other process. Adhesive joints are not only light in weight and occupy a negligible amount of space but many times their use permits an assembly which otherwise could not be made. Moreover, recent improvements in adhesives have so greatly increased their strength that it is now possible to realize tensions of one-half ton per square inch in air-dried joints, and of almost a whole ton where the adhesive is applied dry and then melted by heat. When properly selected they will produce joints which will withstand temperatures and humidities safely above those at maximum summer conditions.

Adhesives are for the most part organic in nature and may be divided into two classes: the agglutinous, which includes animal glue, casein, dextrin, and gum arabic; and the resinous, such as the vinyl and alkyd resins, the natural resins such as rosin and shellac, the varnishes, and pyroxylin cements. The agglutinous adhesives are water soluble and are characterized by poor electrical insulation and moisture resistance. Their use is chiefly confined to parts of the telephone plant which are remote from electrical circuits. The resinous adhesives on the other hand generally have good insulation and moisture resistance, which render them particularly valuable in the assembly of telephone equipment.

There are two methods of using adhesives to make a joint. The one most commonly employed is to disperse the adhesive in a suitable solvent and apply it to one or both surfaces, which are then pressed together while the adhesive is still wet. The joint is then allowed to dry in the air at room temperature, although mild heat may be applied if desired to accelerate the drying process. The other method is a process in which sufficient heat is used to melt a dry thermoplastic adhesive previously placed between the surfaces to be joined. Various processes are possible which differ mainly in the way the thermoplastic adhesive is carried to the surfaces. For this purpose powdered resins, adhesive tissues, stick adhesives, or thermosoftening resin solutions are used. The thermoplastic method has the advantage that parts to be joined may be coated with adhesive in advance and assembled at a subsequent time. It is also possible to make joints quickly and easily with excellent uniformity of strength. A limitation of the thermoplastic method is that the parts joined must not be exposed in service to temperatures high enough to resoften the joint.

The mechanism of adhesion depends upon the nature of the surfaces joined. It involves two principles of which the most common is represented by joints of porous materials such as wood, paper, or fabrics. The adhesive penetrates these surfaces and, on hardening, anchors itself to their irregularities. This is called "mechanical adhesion." The other mechanism is represented by joints of impervious and smooth materials such as glass or metal. This may be termed "molecular adhesion" and is only partly understood. Actually the two types of adhesive action operate in all joints with one or the other exerting the predominating influence. Pure cases illustrating either one of these mechanisms of



Adhesive strength is determined by measuring the force which is required to pull apart the adhesive joint of a test specimen adhesion probably do not exist.

Molecular adhesion is a very interesting phenomenon. A suitably chosen adhesive will adhere to a highly polished surface without any visible means of support. The accepted explanation is that a preferred orientation takes place among the adhesive molecules due to surface forces which are probably of an electrostatic nature. This orientation of the molecules of an adhesive at a joint interface is essential in producing molecular adhesion, but it is also important that every adhesive material have powerful cohesional forces operating inside the substance, otherwise the adhesive will rupture within itself, and the joint thereby fail. For this reason it is generally advisable to use adhesives in as thin a layer as is practical in order to minimize the setting up of internal strains in the adhesive layer when it solidifies. In selecting base materials for use in adhesive compounds the more brittle substances are usually avoided. Sometimes plasticizing agents are incorporated to increase the flexibility of the adhesive.

Resinous substances are extremely complex in their structure and their adhesion is therefore difficult to study in a fundamental way. However, some insight into molecular adhesion has been gained by using pure simple organic compounds as adhesives. These are melted between flat surfaces of various materials and allowed to solidify by cooling, after which the adhesion is measured by determining the load required to rupture the joints in tension. Although the relationship between adhesion and chemical structure is not completely understood, no adhesives which adhere strongly to metals have been found among the non-polar (chemically symmetrical) substances, whereas strong joints have been obtained with several polar (chemically unsymmetrical) compounds. For example, the joint strength of naphthalene which is non-polar, is only 25 pounds per square inch on copper, whereas that of alpha naphthol and alpha naphthoic acid, two polar derivatives of naphthalene, are above 300 pounds. The relative importance of polar groups has not yet been determined but in many cases it has been shown that the presence of hydroxyl (-OH) and carboxyl (-COOH) groups is a great aid in obtaining strong joints, particularly with the cyclic organic compounds. These results are in accord with the orientation theory of adhesion. Polar compounds because of their unsymmetrical structure would have the possibility of orienting themselves preferentially while the symmetrical non-polar compounds would be limited in this regard.

An idea is often advanced that adhesives adhere to metal surfaces by first visibly etching them in order to secure a mechanical bond. This idea was investigated by comparing the adhesion obtained on gold with that obtained on the more chemically active surfaces of copper, steel, and aluminum. The joint strengths were of the same order in each case, which indicates that on these metals at least there is no necessity for an adhesive to etch the surface in order to obtain a good hold.

Further knowledge of the physical and chemical properties of adhesives and an understanding of the mechanics of adhesion are needed because of the importance of these materials and the wide variations in their characteristics. No adhesive has as yet been compounded which is suitable in all types of joints.

A New Power Amplifier of High Efficiency

By W. H. DOHERTY
Radio Development

THOSE who are accustomed to operating vacuum tubes at the low power levels employed in wire transmission or in radio receiving systems are frequently startled to learn of the extremes to which one must resort in the operation of power amplifier tubes in radio transmitters. The transmitting tube, far from being operated over a small and linear part of its characteristic, is subjected to large alternating grid voltages which cause the plate current to be zero over approximately one-half of the radio-frequency cycle, and frequently to reach the saturation value determined by filament emission on the other half-cycle, with accompanying large grid currents. This extreme mode of operation makes possible much larger power outputs than could be obtained if operation were confined to the linear part of the tube characteristic.

Figure 1 shows the circuit of a simple form of the conventional radio-frequency power amplifier, in which two tubes are connected in parallel and coupled to the transmitting antenna. The coupling circuit is so tuned as to be equivalent to a pure resistance load of the desired value over the relatively narrow transmission band occupied by the carrier and the side-frequencies due to modulation, while for frequencies much lower or much higher than the carrier, the impedance of the circuit is very low. Hence, although the radio-frequency plate current wave contains large harmonic components due to the extremely non-linear operation of the tubes, only the fundamental component encounters any appreciable impedance, so that the plate voltage wave is very nearly sinusoidal. The power delivered by the tubes to the circuit is therefore almost entirely at the fundamental frequency. High-quality amplification of a modulated wave then requires merely that the fundamental component of the plate current be proportional to the radio-frequency grid voltage. It turns out that if the tubes are biased nearly to the cut-off point, so that plate current flows only during the positive half-cycle of the alternating grid

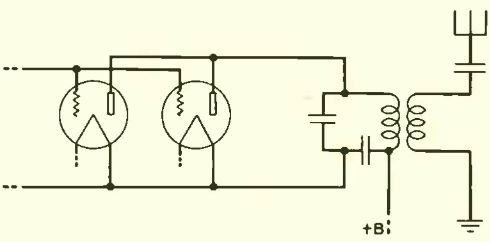


Fig. 1—Radio-frequency power amplifiers are coupled to the load by tuned circuits which present a very low impedance to the tubes at harmonics of the carrier frequency

voltage, a close approximation to this requirement of proportionality is readily obtained.

Under these conditions, which are represented in Figure 2, most of the plate current flows while the plate potential is near its minimum value, and if this minimum value is sufficiently low—i. e., if the amplitude of the plate voltage wave is sufficiently great—the power lost in the tubes, which is proportional to the product of instantaneous plate voltage and current, will be small, and the efficiency correspondingly high. The efficiency is, in fact, very closely proportional to the amplitude of the plate voltage swing. By permitting the plate voltage to swing down to a value as low as 10 or 15 per cent of the applied d-c plate potential, large power outputs may be obtained at an efficiency of 60 to 70 per cent; but unfortunately such large amplitudes correspond only to the peaks of modulation, and since these peaks at 100 per cent modulation have amplitudes of twice the carrier amplitude, the plate voltage swing for unmodulated carrier must not be more than half of its peak value.

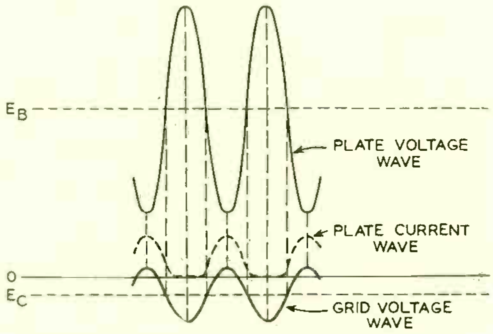


Fig. 2—Most of the plate current of a power amplifier flows while the plate potential is in the vicinity of its minimum value, so that the tube loss can be made small by a plate voltage swing of large amplitude

The efficiency of the conventional power amplifier, then, is but 30 to 35 per cent when the carrier is unmodulated, and only slightly more for the average percentage modulation of the usual broadcast program. An efficiency of 33 per cent means that the d-c power supplied to the plate circuit of the amplifier must be about three times the carrier output, and two-thirds of this input power has to be dissipated at the anodes.

With power levels of 50 kilowatts and higher becoming almost commonplace in radio broadcasting, it has become very important to find means for increasing efficiency to reduce the cost of power. Since early in 1934 a succession of tests have been conducted at the Whippany Laboratory on a new power amplifier circuit in which the usual practice of dividing the load equally between the tubes at all times was discarded. The idea was conceived that by obtaining the power from a reduced number of tubes up to a certain point—in particular the carrier output—these tubes could be operated at this point at their maximum plate voltage swing, and consequently at high efficiency; then if the remaining tubes were brought into action in a certain manner they would not only contribute to the output, but would so change the operating conditions for the original tubes as to permit the latter also to increase their output power without having to increase their output voltage.

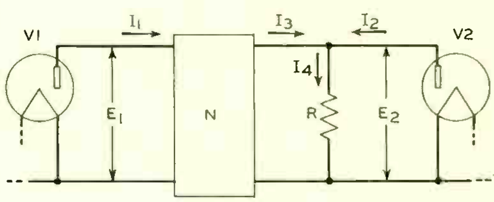


Fig. 3—In the high-efficiency circuit, an impedance-inverting network, N, *is inserted between one of the tubes and the load*

Figure 3 shows schematically the method of connecting the tubes to the load in the new high-efficiency circuit. V1 and V2 are two tubes that in the conventional amplifier might have been connected in parallel with a circuit whose impedance, for the fundamental frequency, may be represented by the resistance R. In the new circuit a network N is interposed between R and V1, the tube which is to deliver the carrier power. This network is the equivalent of a quarter-wave transmission line, and like such a line has the interesting property that its impedance as measured at one end is inversely proportional to the impedance connected at the other end.

For all values of grid excitation from zero up to the carrier level, V2 is prevented by a high grid bias from having any plate current, and the power is obtained entirely from V1. The network N is so designed as to present to V1 an impedance so high as to require this tube to operate at nearly its maximum possible radio-frequency plate voltage swing in order to deliver the carrier power. The efficiency of the amplifier at the carrier output is accordingly high, and may be from 60 to 70 per cent.

If we were to plot the current in the load impedance R against the radio-frequency voltage applied to the grids of the tubes, as in Figure 4, the curve would be essentially linear up to the carrier point A and then, if V2 were not allowed to come into action, would flatten off along a path AB because the plate voltage swing on V1 had attained its maximum value.

By permitting V2 to begin coming into play at point A we obtain a two-fold action: V2 not only contributes power to the load, but in coming into play in parallel with R it effectively

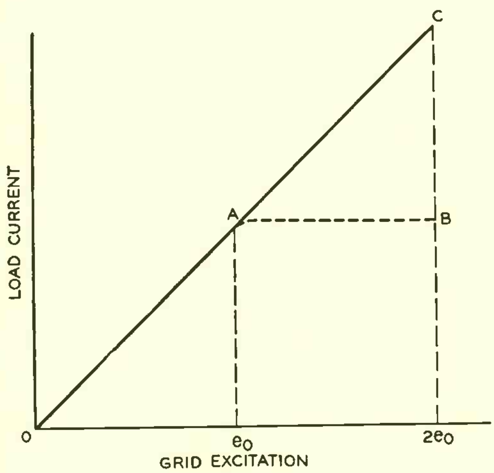


Fig. 4—If the second tube were not permitted to come into action at the carrier excitation e_0, the load current could not increase, and so would follow the path OAB

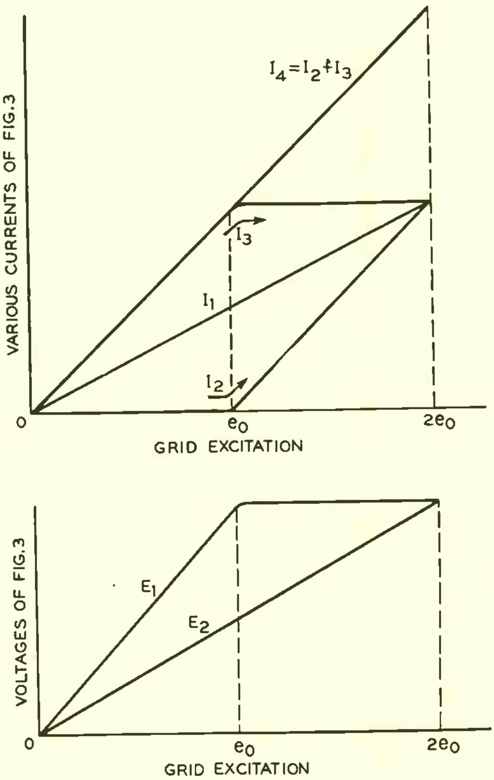


Fig. 5—(Above)—The current I_2, *furnished to the load by tube* V2, *supplements* I_3 *to make the total load current linear with respect to the grid input voltage. (Below)—As the grid excitation is modulated about its carrier value* e_0, *the plate potential of tube* V1 *does not respond to the positive half-cycles of modulation, since it has reached its maximum value at the carrier output*

increases the impedance in which the network N is terminated. This increase in terminating impedance, by virtue of the inverse characteristic of this type of network, results in a decrease in the impedance presented to V1, so that the radio-frequency plate current, and hence the power output, of V1 may increase without any increase in its alternating plate voltage, which was already a maximum at point A. As the grid excitation on the tubes increases beyond its carrier value e_0, V2 contributes more and more power to the circuit and thereby permits V1 also to supply more power, until, at point C, which corresponds to the instantaneous peak of a completely modulated wave, half of the power in R is being contributed by V2. The network N is at that instant effectively terminated in 2R ohms instead of the original R ohms, and the impedance presented to V1 is half of its original value, permitting V1 to deliver twice its original output power with no increase in its output voltage. The total power in the load, then, at the peak of modulation is the required value of four times the carrier power, corresponding to an increase in load current to twice its carrier value.

It is a characteristic of networks having the impedance-inverting property of network N that a definite current at either pair of terminals is associated with a definite voltage at the other pair of terminals, entirely without regard to the terminating impedances. From this rather remarkable property we may deduce that if the output voltage E_1 of tube V1 is linear with respect to the grid excitation up to the carrier excitation e_0 of Figure 4, and then remains constant up to the peak excitation $2e_0$, then the current I_3 fed into the load from network N behaves similarly, as shown in Figure 5(a); whence,

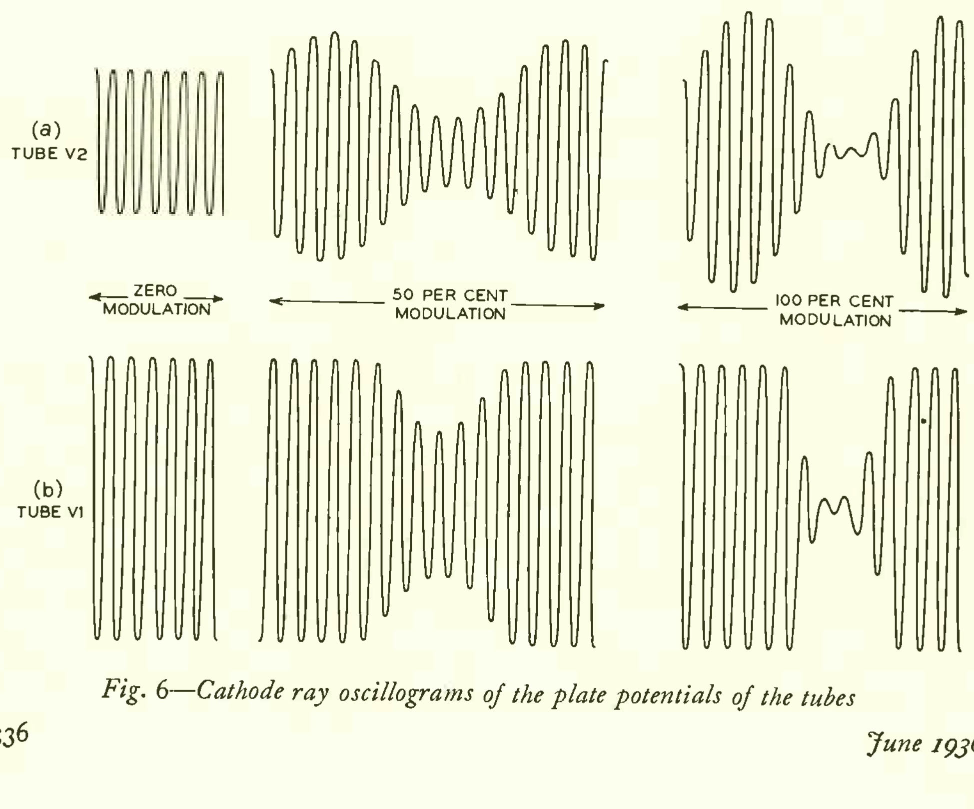


Fig. 6—Cathode ray oscillograms of the plate potentials of the tubes

in order to have the total load current I_4 linear with respect to grid excitation, the current I_2 fed into the load from tube V2, which is zero at the carrier point, must rise linearly beyond this point and be equal to I_3 at the peak of modulation.

From this same property of network N we also deduce that if the voltage E_2, across the load and the second tube, is linear with respect to grid excitation, then the current I_1 fed into network N by tube V1 must also be linear. Figures 5(a) and 5(b) therefore give the complete picture of the conditions existing at the plates of the two tubes for all values of radio-frequency grid input voltage to the amplifier, and the behavior of each tube during the modulation cycle may be studied by considering the grid excitation to vary at audio frequency about its average value e_0, to the extent corresponding to the percentage modulation.

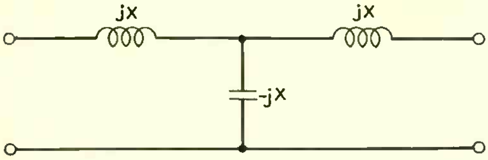


Fig. 7—A section of simple low-pass filter at 0.7 times the cut-off frequency consists of three equal reactances, and has a 90-degree phase shift together with the desired impedance-inverting characteristic

When samples of the radio-frequency plate potentials on the two tubes during modulation are viewed on the screen of a cathode ray oscilloscope, the patterns are of the shape shown in Figure 6. Patterns (a) represent the envelope of the plate potential of V2, which, being directly associated with the load, is required to be sinusoidal when the modulating signal is a pure tone. Patterns (b) show the envelope of the plate potential of V1, which, though sinusoidal over the negative half of the modulating cycle, is twice as high as that of V2 over this range, and being unable to increase appreciably beyond its carrier value, remains flat during the upper half of the cycle of modulation.

The network N employed to obtain the impedance inversion may be one of a number of networks of which an example is given in Figure 7. They always have a 90-degree phase shift, which means that the plate potentials on the two tubes are always in quadrature. This requires the insertion, in the grid circuit of one or the other of the tubes, of another 90-degree network in order that both tubes may be excited from the same source. The complete amplifier then assumes one of the forms indicated in Figure 8.

The numerous tests conducted on the high-efficiency amplifier at var-

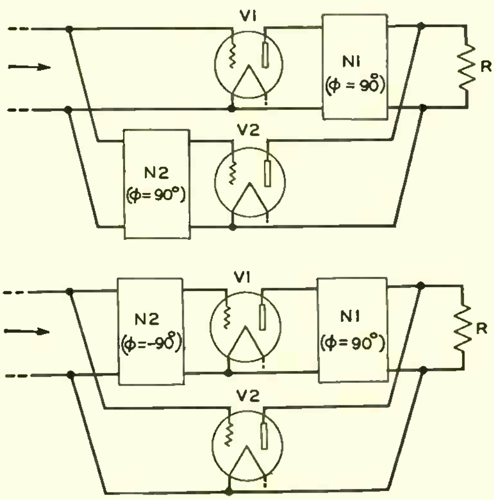


Fig. 8—With a 90-degree phase shift in the plate circuit of one tube, a compensating phase shift must be inserted in the grid circuit of one of the tubes so that both tubes may be excited from the same source

ious power levels have been uniformly successful, and the new circuit is being incorporated in the new high-power broadcasting equipment of the Western Electric Company. The overall efficiency obtained in the tubes and output circuits is 60 per cent for unmodulated carrier and a few per cent higher with complete modulation. This represents a reduction in the plate power consumption of the final stage of a radio transmitter by nearly a factor of two, as compared with the power required by an amplifier of the conventional type. A 50-kilowatt amplifier, for example, with 33 per cent efficiency would require a d-c plate input of 150 kilowatts, of which 100 kilowatts would be dissipated at the anodes of the water-cooled tubes. With the new circuit the power input for unmodulated carrier is 83 kilowatts, and the dissipation accordingly only 33 kilowatts, permitting a considerable saving in the water cooling system as well as in power requirements. These items are of great importance in modern broadcasting where the cost of apparatus and power constitutes a large part of the operating expense.

By the application to radio transmission of another Laboratories development, the feedback principle* of H. S. Black, to reduce the effects of non-linearity in the amplifier characteristics, the new high-efficiency equipment has been made to perform with a quality of transmission which satisfies the most rigorous requirements of high-fidelity broadcasting.

Finally, the new circuit, being purely an amplifying scheme, can be applied to special types of transmission, such as the single-sideband transmission employed in the transoceanic service of the Bell System.

*RECORD, *June*, 1934, *p*. 290.

Vail Medal Awards for 1935

For the second time since the establishment, in 1920, of the Theodore N. Vail Memorial Fund, special recognition was given to the entire personnel in an area of a telephone company by the National Committee of Award. A special plaque has been awarded to the employees of the Mountain States Telephone and Telegraph Company at Helena, Montana, "for outstanding performance, when, during the month of October, 1935, a succession of earthquakes of varying intensity and extending over a period of about three weeks caused damage to telephone plant and other property and placed an especially heavy demand upon the entire telephone organization. Through the courageous action and splendid cooperation of employees of all departments, telephone service was maintained, crippled plant was restored to service and telephone service was available continuously to rescue and relief agencies, greatly accelerating their activities."

In the report of the Committee for 1935 announcement was also made of the award of two silver medals, each accompanied by $250, to the following:

To Ruby C. Bahr, a Telephone Operator of the Community Telephone Company, Fairfield, Wisconsin, "for alertness, initiative and prompt and intelligent action which led to the apprehension of a dangerous criminal."

To Mamie Inez Pitts, a Telephone Operator of the Southern Bell Telephone and Telegraph Company, Pontotoc, Mississippi, "for courage, resourcefulness and loyalty to public service, despite grave personal danger, during a tornado."

X-Ray Diagnosis for Telephone Apparatus

By LESTER E. ABBOTT
Telephone Apparatus Development

X-RAY technique has been found extremely helpful in a number of engineering fields. One of the most obvious advantages is that destruction of the object examined is not required to discover its internal condition. This has made x-ray examination a valuable engineering tool for detecting hidden flaws and defects in metallic objects.* Another useful field for x-rays, particularly in telephone work, is for the examination of assembled apparatus suspected of containing defective wiring or misaligned parts. Such apparatus is often housed in a sheet steel case of appreciable thickness, and may consist of condensers, inductances, resistances or a combination of these depending upon the particular type of telephone apparatus considered. To complicate the problem further, these assemblies are frequently sealed in position by completely filling the space around the parts with a potting compound. Thus the x-ray procedure must result in recognizable differences on a photographic film between assembled parts which may be composed of combinations of metals and non-metallic materials, all of different dimensions, and completely embedded in a potting compound.

This objective is attained by taking advantage of the differences in absorbing power for x-rays of the several parts of the apparatus photographed. The image produced on the x-ray film is therefore a shadow picture, the gradations in the shading of which depend upon the variations in the x-ray absorption of the different materials and the thickness of the parts. It is possible to draw an analogy between the taking of a photograph and the making of an x-

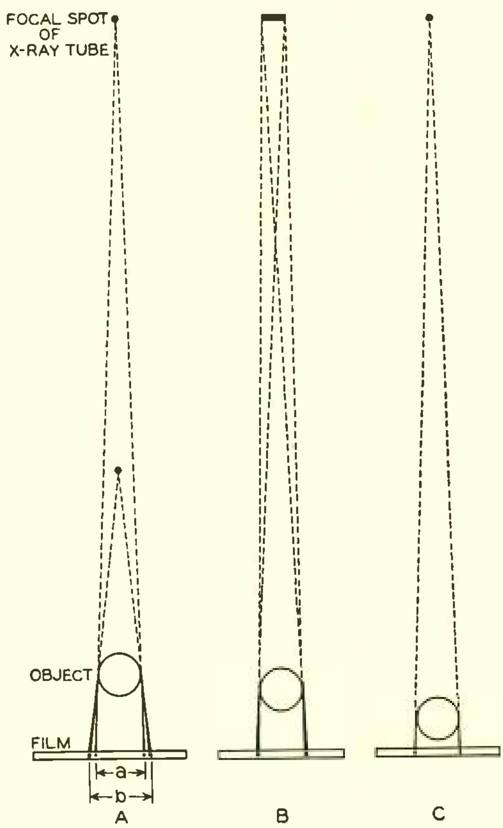


Fig. 1—The sharpness of an x-ray photograph improves as the distance of the x-ray tube from the object increases and the size of the focal spot of the tube decreases; also as the distance from the object to the photographic film decreases

*Record, *November*, 1933, *page* 72.

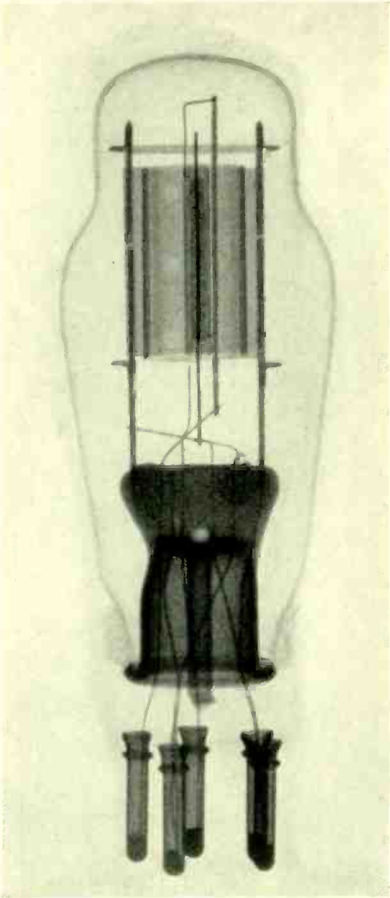


Fig. 2—The filament and grid assembly of a completed vacuum tube can be inspected with x-rays

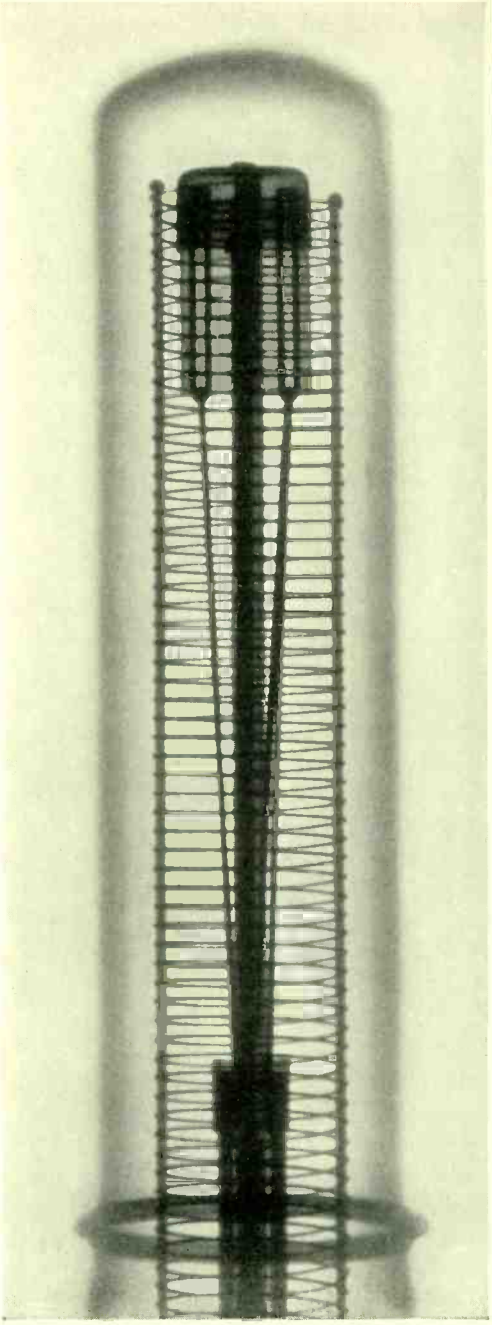


Fig. 3—X-ray photographs through the metal jacket of transmitter tubes disclose the parts within

ray picture, but there is a fundamental difference because no method of focusing x-rays is known, so that sharp definition can be obtained with them only if their source approximates a point.

Since the focal spot of an x-ray tube is usually an oval of definite size with the long dimension not exceeding one-quarter of an inch, the only means of controlling the sharpness or definition of an x-ray negative is by increasing the distance which separates the tube from the object under examination. This results in the focal spot acting more nearly as a point source. The projected image of an assembled object is more nearly correct in dimensions when a long x-ray source-to-film distance is used, as may be seen by comparing *a* and *b*, in Figure 1, A. In B of Figure 1 is shown the spreading of the projected image due to the use of an x-ray tube having a large focal spot. The position of the objects in the apparatus under examination in relation to the position of the x-ray film also affects the definition of the x-ray negative. The sharpness of the image decreases as the distance of the film from the object increases because of x-ray scattering. This is suggested in Figure 1, by comparing A, case *a*, with C. In practice a source-to-film distance of from twenty-four to thirty-six inches is generally used to obtain satisfactorily sharp images. Additional sharpness might be had—especially if the assembly under examination has considerable depth—by using even greater source-to-film distances, but the exposure time required would be greatly increased, since the inverse-square law applies to x-ray radiation, and an exposure at forty-eight inches takes four times that required for a twenty-four-inch source-to-film distance.

The x-ray method of non-destructive examination has been applied successfully to a number of telephone problems of widely different types. In vacuum tube development work, for example, it is desirable to check the filament and grid assembly before test, and to check any changes which occur during test or after failure. Since the filament and grid assembly is usually completely blocked from visual examination by the plate, x-ray examination is employed to obtain the desired information. A small tube of the glass-enclosed type, in which the position of the various elements may be clearly seen, is shown in Figure 2.

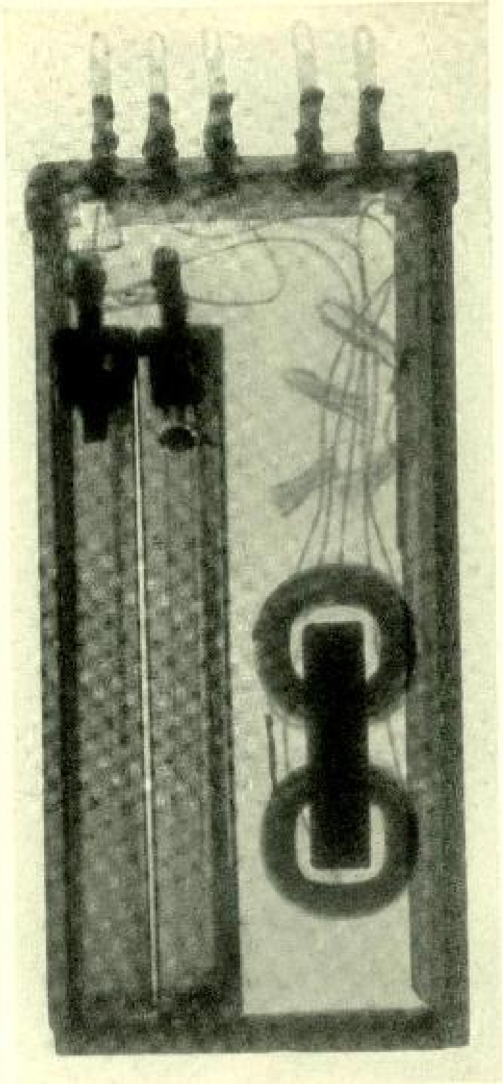


Fig. 4—An apparatus assembly embedded in pitch can be inspected with x-rays

Larger types of tubes, transmitters for instance, have the grid and filaments completely encased in a metal jacket which acts as the plate. Such tubes are inspected easily by x-rays, and a uniform technique for examination makes it possible to check fairly small changes in the position of the elements by comparison of radiographs taken several months apart.

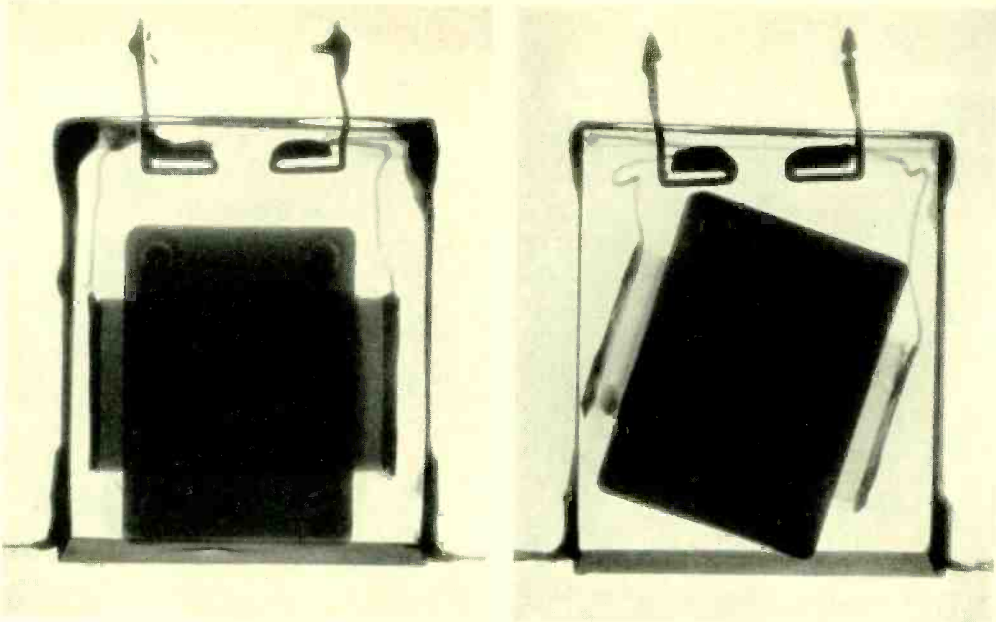


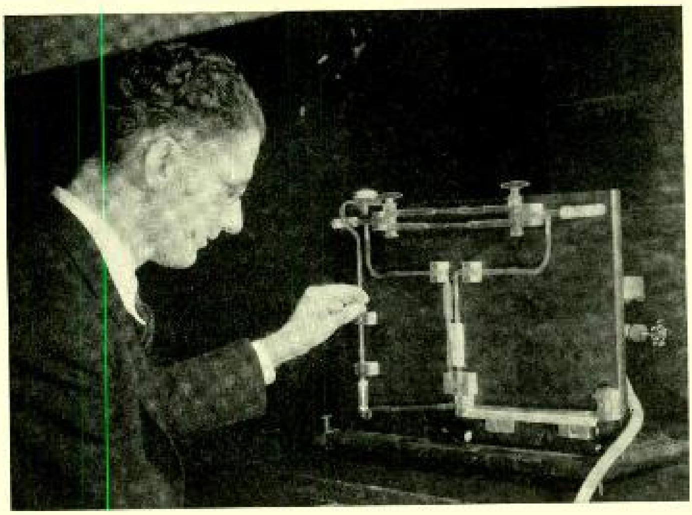
Fig. 5—The cause of apparatus failure can often be determined quickly from an x-ray photograph

Usually in these inspections two radiographs are taken at right angles to each other so that the information obtained may be complete. Figure 3 is a typical radiograph of this type.

When an assembly consists of condensers, coils and resistances, embedded in a potting compound, there is always a possibility of misalignment of the parts, or of short circuits caused by the resistances or lead wires being sealed against the sides of the container. In Figure 4 is shown one of two views of an assembly of this type, which was x-rayed to determine the position of the small resistances. It should be noted that the detail obtained is such that even the voids present in the potting compound are visible.

When apparatus is received for test in connection with an engineering complaint, x-ray examination may often furnish definite proof of the cause of failure, and in addition provide a permanent record of the faulty condition on the x-ray negative, prints of which may be included in the engineer's report. Figure 5 shows views of two condenser units which were x-rayed in connection with an engineering complaint investigation. The condenser on the left has a broken wire, and the other was considerably misaligned when assembled, which greatly increased the possibility of trouble developing in service.

To sum up the advantages of the x-ray method of examining assembled apparatus—it is a non-destructive test; it may be repeated at regular intervals on apparatus under life or service test and thus reveal any internal changes of a physical nature which occur; it is an excellent means for checking the alignment of parts in a complicated assembly; and it furnishes a permanent record of the condition of the apparatus examined, at a known date.



An Acoustic Resistance Meter

By T. J. POPE
Transmission Instruments Development

DURING the early youth of electrical science, the behavior of electricity in a circuit was likened to the flow of water through a system of piping, and in fact such analogies are still used in pre-college instruction. Not only was the analogy drawn, but many of the terms now used to describe electric circuit phenomena such as "flow," "current," "pressure," and "resistance" are taken directly from fluid dynamics. With the extensive study of acoustics in more recent years, the borrowing of terms has taken a reverse direction, and many of the more complex conceptions of electric circuit theory such as impedance, resonance, and capacitance have been taken over by the science of acoustics, which is one branch of fluid dynamics. In many ways the analogy between acoustic and electric systems is very close, as is brought out in one respect by the acoustic resistance meter employed for many purposes in studies of sound.

A common way of determining the value of an electrical resistance is to measure the voltage drop across it while it is carrying a known current. From Ohm's Law the resistance is then equal to the quotient of the voltage by the current. The circuit would be as in A of Figure 1. A rheostat permits the current to be set at some convenient value, which is read on an ammeter, and the drop across the resistance is read on a voltmeter. In the fluid analog, shown at B, a pump replaces the battery, and a valve, the rheostat; and suitable flow and pressure meters give the current flowing and the pressure drop across the resistance, indicated by an enlarged section of pipe filled with obstructing material, such as steel wool. If the current flow is measured in cubic centimeters per second and the pressure drop in dynes per square centimeter, the resistance will then be in what is usually called acoustic ohms.

The ammeter in 1A consists of a small known resistance with a voltmeter connected across it with its scale marked in the values of voltage divided by the fixed resistance, or current flowing, since V÷R=I. A more complete representation of the circuit would thus be that shown in 2A, which is similar to 1A, but with the ammeter replaced by a known resistance shunted by a voltmeter. The corresponding fluid circuit is shown in 2B, where a manometer and a resistance replace the flow meter of 1B. The arrangement of 2B, when air is the fluid, is an acoustic resistance meter to measure the acoustic or mechanical resistance of the piece of apparatus inserted at X. But why call this acoustic resistance? The term acoustic applies to sound, while no sound is involved in this apparatus at all, at least none that is desired or measured. A flow of air, and an air resistance are what is measured. The reason for and justification of the term, however, is not hard to find.

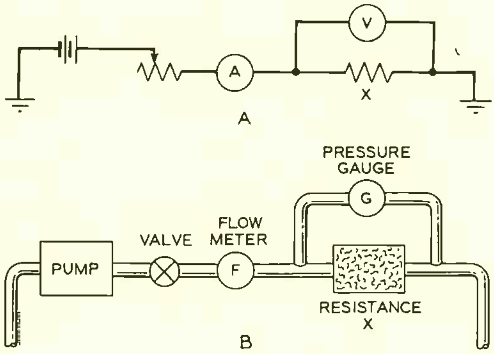


Fig. 1—A—a simple arrangement for measuring electrical resistance; B—an equivalent method for measuring the resistance to fluid flow

Sound is caused by air in vibration, and its electrical analog is an alternating current. It is found that the opposition to the flow of an alternating current, which is called impedance, is not constant, but varies with frequency. An impedance has two components: a reactance, which may be either positive or negative and which varies in value with the frequency; and a resistance, which for any single element is approximately independent of frequency. At zero frequency (direct current) the impedance is equal to the resistance because the reactance component becomes zero.

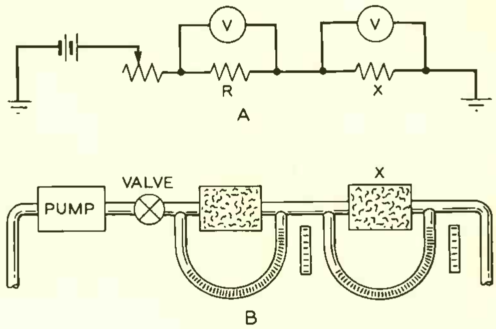


Fig. 2—The ammeter of Figure 1 consists of a fixed resistance and a voltmeter, as indicated at A. In the fluid circuit, B, this corresponds to a fixed resistance and a manometer

In the acoustic analog there is a closely similar set of factors: an acoustic reactance, which becomes zero at zero frequency, and an acoustic resistance which does not. An acoustic impedance at zero frequency is the acoustic resistance, but it is here that the apparent paradox enters, because sound at zero frequency is no longer sound, but a steady flow of air. Thus an arrangement like that of Figure 2B, which measures resistance to a steady flow of air, really measures an acoustic resistance.

The design of transmitters, receivers, handsets, and all acoustic apparatus requires that the acoustic reactances and resistances of all parts be known. While apparatus for measuring acoustic impedance is available, it is more elaborate than the acoustic resistance meter, and more time is consumed in making a measurement. For many purposes, moreover, a measurement of resistance alone is sufficient. Often it is desired to compare the acoustic impedances of pieces of apparatus which have the same general form of impedance curve. In such cases a measurement of resistance alone, which establishes the point at which the curve crosses the axis of zero frequency, is sufficient to indicate the relative values of the impedances. Also, it is sometimes possible to calculate the values of reactance, so that a measurement of resistance alone is sufficient to permit the impedance to be determined. A simple acoustic resistance meter is thus very useful, and several of them are in use in the Laboratories.

One form is shown in use in the photograph at the head of this article. Its general arrangement is illustrated in more detail in Figure 3. A compressed air supply is admitted through a valve at the extreme left and passes through two resistances with a by-pass valve between them. This arrangement permits a fine control of air pressure at the input to the meter proper. The capillary tube has a very small bore and serves as the fixed resistance for measuring flow. A manometer, bridged across it, measures the pressure drop, which—divided by the resistance of the tube—gives the actual flow in centimeters per second. The air then passes through the resistance under test. A second manometer measures the pressure at this resistance. The scale of this manometer is marked along an inclined portion of the tube to permit accurate measurement of very small pressures. A rubber tube connection allows the adjusting reservoir to be raised or lowered so as to bring the level of the liquid in the inclined tube to the zero point of the scale.

With the instrument shown, and a flow of 5.1 cc per second, one centimeter on scale F will correspond to 10 ohms resistance. To make a measurement it is necessary only to raise or lower the reservoir to adjust the zero position of scale F, and then to adjust the flow by the valves until the proper reading on scale A is obtained to indicate 5.1 cc per second. The resistance

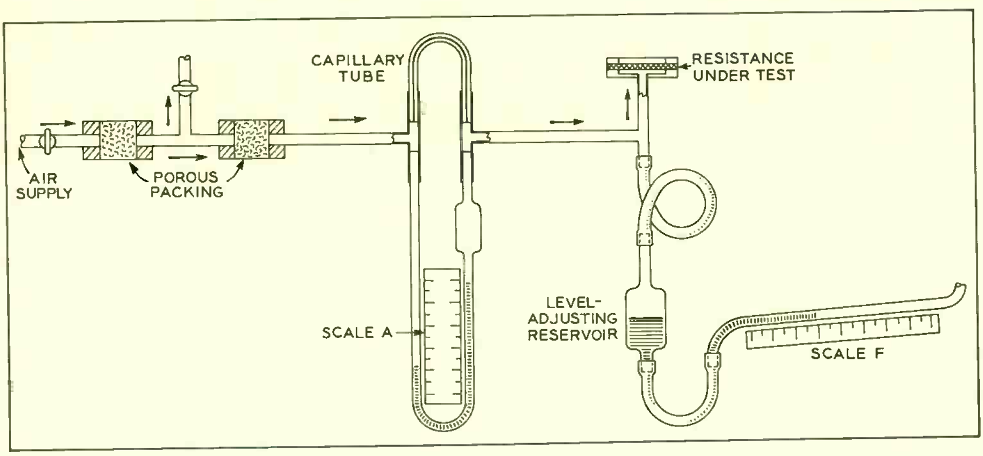


Fig. 3—One form of acoustic resistance meter used in the Laboratories

may then be read directly on scale F. The instrument is adapted to measuring the acoustic resistance of almost any type of element from a piece of fabric, as in Figure 3, to a complicated piece of apparatus. An application to the measurement of microphone parts has already been mentioned in the RECORD.* The arrangement shown in the photograph at the head of this article employs two fixed resistances (capillary tubes), either of which may be connected into the circuit.

*RECORD, *May*, 1932, *p.* 320.

Dr. H. B. Williams, Dalton Professor of Physiology and Executive officer of the Department of Physiology of the College of Physicians and Surgeons of Columbia University, and Dr. B. G. King, Instructor in Physiology at Columbia University, who coöperated with L. P. Ferris and P. W. Spence of Bell Telephone Laboratories in the investigation of the effect of electric shock on the heart reported in this issue of the Record.

Contributors to this Issue

E. L. Owens graduated from Virginia Polytechnic Institute in 1924 with the B.S. degree in Electrical Engineering. He then entered the Engineering Department of the Western Union Telegraph Company and remained with them for some five years. In 1929 he became a member of the Technical Staff of the Laboratories. Here, with the Radio Development Department, he has been engaged in the development of speech input equipment for radio broadcasting transmitters.

L. P. Ferris received the B.A. degree from the University of Colorado in 1908 and the B.S. degree in electrical engineering from M.I.T. in 1911. Immediately thereafter he joined the Engineering Department of the A. T. and T. Company, his first assignment being the capacity unbalance testing of the first cable laid between Philadelphia and Washington. After about two years in transmission engineering he was sent to California where he was engaged for five years in a joint investigation with power engineers of inductive interference with communication circuits by power circuits. In 1919, when the Department of Development and Research was formed, his work in that department included carrier and telegraph transmission problems. In 1920 his work was transferred to inductive interference, crosstalk and measuring devices. Later when his organization was transferred to the Laboratories he became Inductive Coördination Engineer. Questions as to the effect of foreign voltages on telephone circuits arose many times in connection with Mr. Ferris' work and led to the joint study of electric shock with Dr. H. B. Williams and Dr. B. G. King, of Columbia Medical School, and P. W. Spence, of the Laboratories, which is summarized in this issue of the Record.

P. W. Spence joined the Engineering Department of the American Telephone and Telegraph Company in 1914 and worked for a year on safety codes. He then severed his connection with the company temporarily to study at Columbia University where he received the B.S. degree in 1918 and that of E.E. in 1921. In the latter year he returned to the American Telephone and Telegraph Company and engaged in studies of inductive interference in the Long Lines Department.

E. L. Owens

L. P. Ferris

P. W. Spence

L. E. Abbott

J. B. DeCoste

W. H. Doherty

From 1922 to 1927 he was with the Operations Department, working on problems in broadcasting development, new services and patent licensing. Since 1927 he has been largely occupied with the studies on the effects of electric shock which are reported in this number of the RECORD.

L. E. ABBOTT was graduated from the Brooklyn Polytechnic Institute with the degree of M.E. in 1928, and obtained his M.S. degree from the same institution in 1931. As a member of the Materials group he worked on various problems connected with the physical properties of metals until 1930, when be began his present work. This is concerned with the use of welding in telephone apparatus fabrication, and the application of X-ray technique to telephone problems.

J. B. DECOSTE entered the Commercial Department of the Laboratories in 1928. In the same year he was transferred to the Chemical Research Department where he has been engaged in the development of organic finishes, synthetic resin plastics and resinous adhesives. In 1933 he received a B.S. degree in chemical engineering from Cooper Union.

T. J. Pope

W. H. DOHERTY received the B.S. degree in electric communication engineering from Harvard University in 1927, and the M.S. degree in engineering in 1928. He spent a few months in 1928 with the Long Lines Department in Boston as a technical employee and then became a research associate with the radio section of the Bureau of Standards, where he engaged in a study of radio wave phenomena. In June, 1929, he joined the Radio Development Department of the Laboratories where he has been engaged ever since in the development of high-power transmitters for transoceanic radio-telephony and broadcasting.

T. J. POPE received the B.S. degree from the University of Illinois in 1927 and at once joined the Technical Staff of the Laboratories. Here, with the Research Department, he has worked chiefly in the field of acoustics, devoting a large part of his time to the study of acoustic impedance and its measurement. While with the Laboratories he has also studied at Columbia University, and received his M.A. degree in 1934.