BELL LABORATORIES RECORD

MAGNETIC MATERIALS
I. C. PETTIT

CAPE COD RADIO LINK
F. F. MERRIAM

GAIN CONTROL OF CARRIER SYSTEMS
L. M. ILGENFRITZ
D. M. TERRY

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In this Issue

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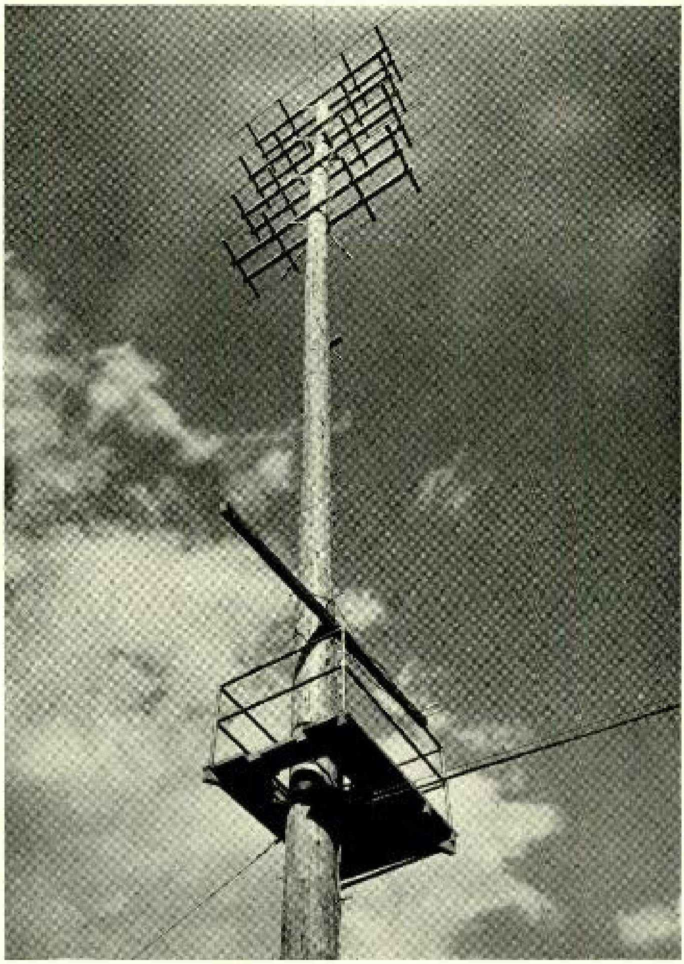

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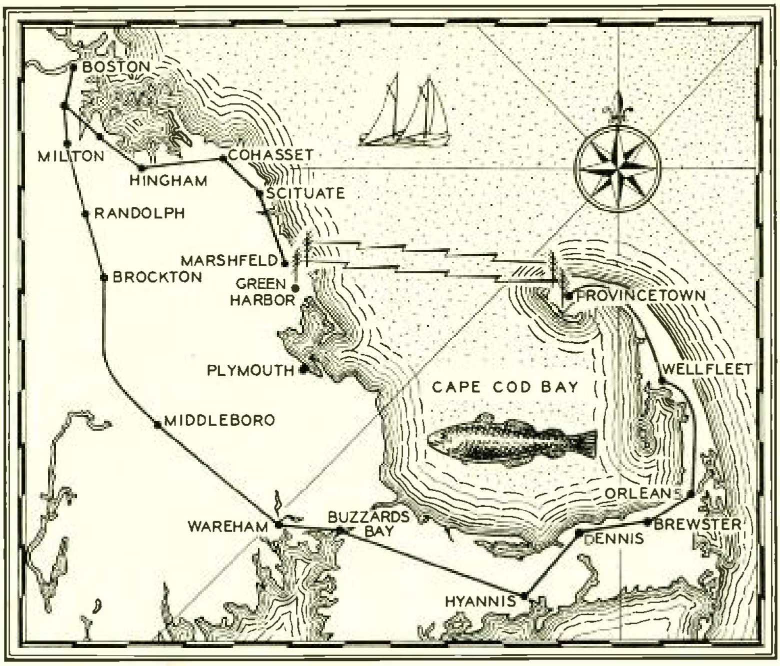


An Extension of Land Telephone Lines By Ultra-Short Wave Radio

By F. F. MERRIAM
Radio Research

FOLLOWING the commercial application of short waves to transoceanic telephony in 1928 and 1929, attention was directed by Bell Telephone Laboratories toward determining the properties and usefulness of ultra-short waves. The short-wave transoceanic circuits are operated at frequencies between 5 and 21 megacycles while the ultra-short waves are at frequencies above 30 megacycles, which is generally taken as the upper limit of the short wave range. It had previously been discovered that these higher frequencies were not in general reflected from the Kennelly-Heaviside layer. They were, therefore, considered primarily suitable for short-distance communication, where the waves followed essentially an optical or straight-line path from the transmitter to the receiver. In the telephone plant there are instances where natural barriers so separate points only a short distance apart that it is difficult and expensive to construct ordinary telephone lines or submarine cables to connect them. It seemed that for such conditions ultra-short wave radio extensions might be a satisfactory means of giving telephone communication. To be economically feasible, however, such radio circuits must be inexpensive both in first cost and in operation.

During the last few years, the Laboratories have been experimenting with an ultra-short wave circuit between Deal and Holmdel, New Jersey, with the thought of developing equipment capable of unattended operation. Some time ago this development reached the stage where it seemed desirable to carry out a trial of a two-way circuit under conditions approximating commercial use to gain experience with the problems involved in regular operation. In particular, it was desired to design and install the radio stations for operation without direct attendance, so that the apparatus could be located remotely from a central office.

After a study of possible locations, it was decided in cooperation with the New England Telephone and Telegraph Company to carry out the trial installation across Cape Cod Bay, between Green Harbor and Provincetown, Mass. The coastal station of the New England Telephone and Telegraph Company, already existing at Green Harbor, made a convenient place in which to install one end of the system. The physical conditions are also favorable for an ultra-short wave link between that point and Provincetown, 25 miles away. The sand dunes near Provincetown, rising about 100 feet in height, make it possible to secure an optical path across the bay. Furthermore, Provincetown is fairly accessible by motor car around the Cape and is already provided with wire circuits, so that the radio link need not be completely depended upon. This location is thus a good proving ground for this new type of telephone circuit.

Accordingly, the radio link has been established across the bay, as indicated on the map, and extended at Green Harbor by wire to Boston, to form a direct Boston-Provincetown toll circuit. At Boston and at Provincetown the circuit appears at a jack in the switchboard alongside the jacks of other toll circuits. The insertion of a cord into the jack starts the radio transmitter at that end of the radio link. The receivers at both ends are kept in constant operation while the circuit is available for traffic. Ringing is accomplished by sending a 1000 cycle tone interrupted at twenty cycles over the radio circuit. Since the radio transmitter requires less

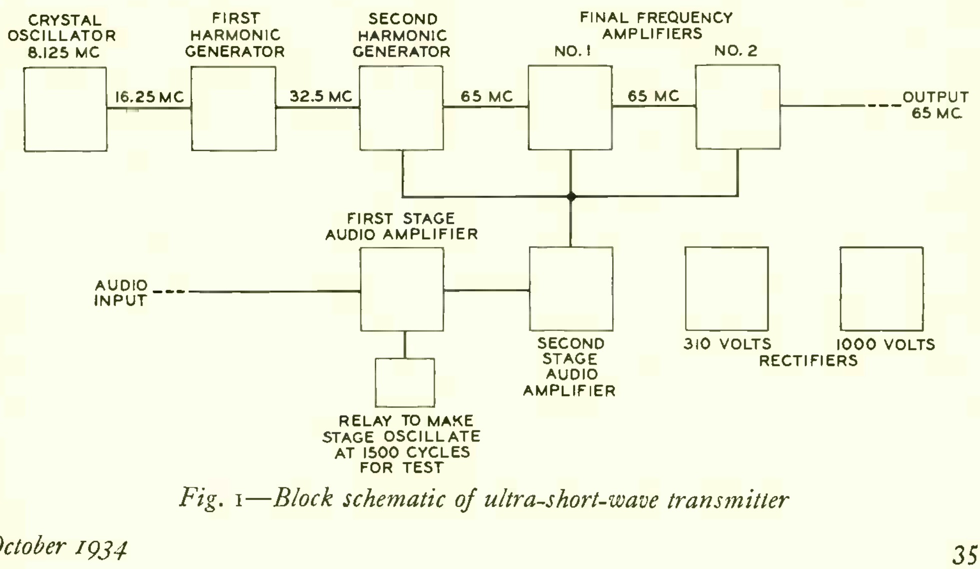


Fig. 1—Block schematic of ultra-short-wave transmitter

than one second to start, the operator may ring immediately after inserting the cord. Privacy equipment, similar to that used on the transatlantic short wave channels, is installed.

The receiver is started and stopped by the operation of a key at the local test board. The power supply is arranged so that when the receiver is in operation, current is also applied to some of the filaments of the transmitter. Provision is also made for testing the overall operation of the transmitter and receiver at each end from the local test board. A tone is generated which modulates the transmitter, and if both transmitter and receiver are operating properly, a side-tone will be produced in the local receiver which can be heard by the test board operator.

The transmitter, developed by R. W. Friis and L. M. Klenk under the supervision of N. F. Schlaack, is crystal controlled, and is capable of delivering 15 watts of carrier power which can be completely modulated. A block schematic for the Green Harbor transmitter is shown in Figure 1. The Provincetown transmitter is the same except that the output frequency is 63 megacycles. A quartz crystal oscillator is followed by two harmonic generators, a push-pull modulating amplifier, and a push-pull power amplifier. Modulation is accomplished by supplying audio-frequency modulating power to the plate and screen of the modulating amplifier and to the screens of the second harmonic generator and the power amplifier.

Two rectifiers employing hot-cathode mercury-vapor tubes supply plate and screen potentials for all tubes. Grid bias potentials are obtained from cathode resistors and grid leaks. Grid and plate circuits of each stage are shielded from each other to prevent extraneous coupling and interstage feedback. The transmitter operates entirely on standard commercial 110-volt, 60-cycle current.

The radio receivers, developed by G. Rodwin and C. H. Swannack under the direction of F. A. Polkinghorn, also operate from a 110-volt, 60-cycle circuit, and are of the double detection type. A block schematic is shown in Figure 2. To make unattended operation possible, a crystal oscillator is used as a source of beating frequency. A single-stage harmonic generator produces sufficient voltage of the eighth harmonic of the crystal fre-

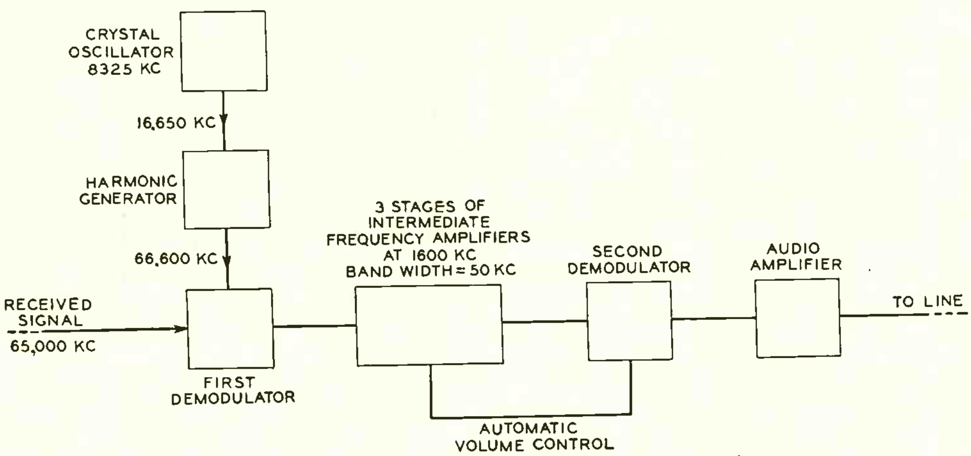


Fig. 2—Block schematic of ultra-short-wave receiver

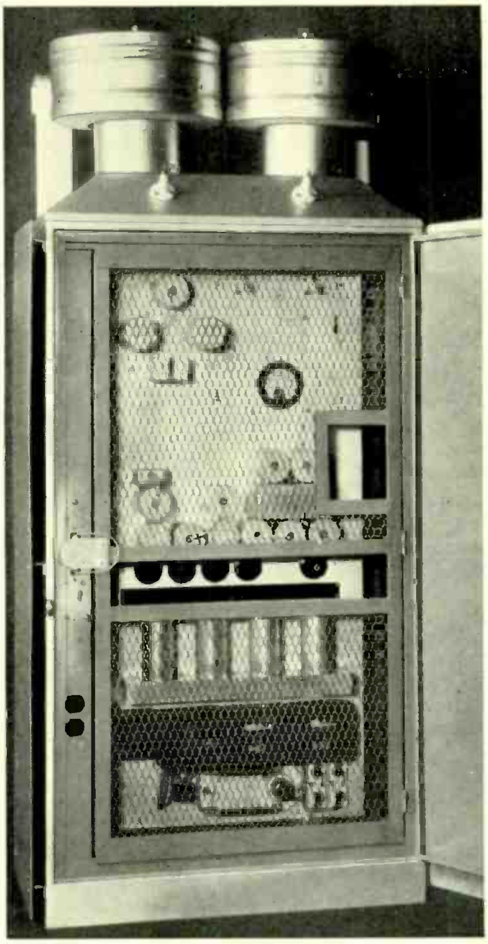


Fig. 3—The ultra-short-wave transmitter is mounted in a metal container suitable for pole mounting

quency for satisfactory operation of the detector. The intermediate frequency amplifier consists of three stages of amplification at 1600 kilocycles, and has a band width of approximately 50 kilocycles. A small amount of automatic volume control is provided to compensate for slight variations in received voltage caused by variation in humidity and other factors.

The receiving and transmitting antennas are identical and are mounted on 100 foot poles fifty feet apart. Horizontal exciter and reflector elements are supported on standard cross-arms. Four pairs of half-wave exciter elements, each comprising two half-wavelength conductors, are spaced one-half wavelength apart in a vertical plane on one side of the pole. Reflector elements are similarly arranged on the opposite side of the pole, the spacing between exciters and reflectors being one-quarter wavelength. The transmitter and receiver are each mounted in a metal container suitable for mounting on the antenna poles at a later date. At the present time they are installed in a small building lo-

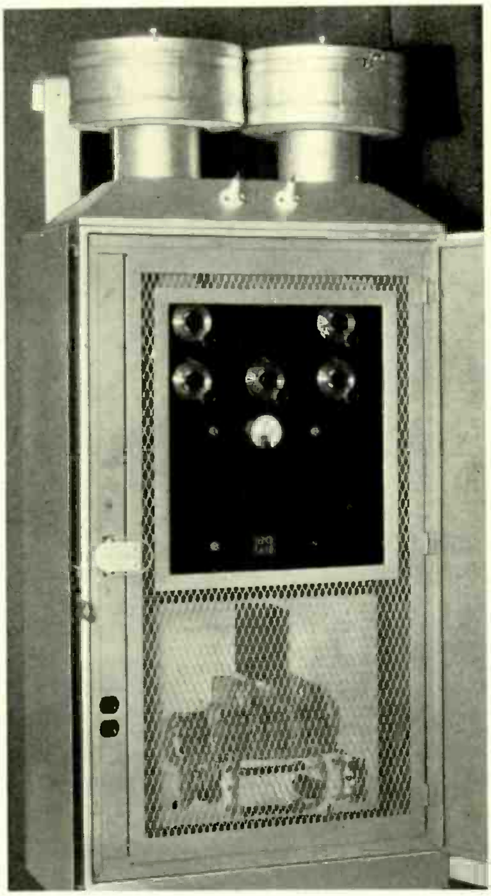
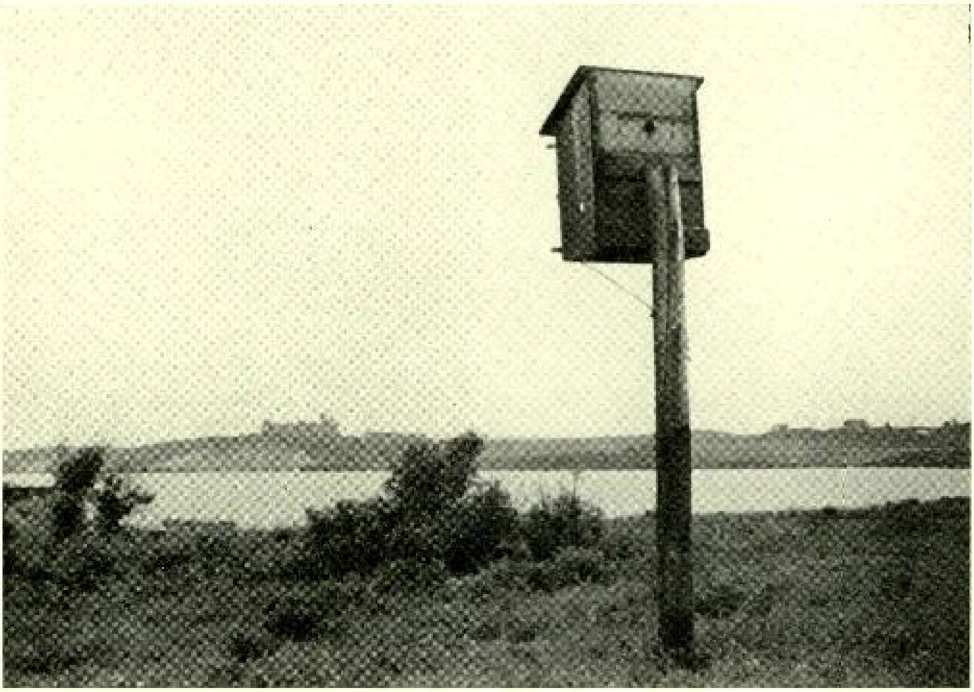


Fig. 4—The receiver is mounted in a similar container and both incorporate safety provisions to prevent maintenance men from coming in contact with high potentials

cated between the transmitting and receiving antennas. The mechanical design of the transmitters and the station layout were made by M. E. Fultz and J. L. Mathison.

The entire development and installation of the project has been under the direction of A. A. Oswald. The system was put into trial service early in July. It was found to yield a high-grade, two-way telephone circuit and is adding to our knowledge of the practical problems and capabilities of such a system.



This picture shows all that remains in evidence today at Montauk, Long Island, of the experimental radiotelephone station which was erected there by the Bell System in 1915 *and shown on page* 512 *of the* Record *for July* 1931. *This was the first radiotelephone effort of the Bell System and, indeed, was the first vacuum-tube radiotelephone transmitter ever built. Its successful transmission to Wilmington and to St. Simon's Island, Georgia, were preliminaries to the famous experiments later that year, in which the voice was first projected across the oceans. All that remains is this box on a stub pole. It housed the switch which threw the antenna lead-in either to ground or to the apparatus within a building which stood nearby*

Magnetic Materials

By I. C. PETTIT
Telephone Apparatus Development

WHENEVER a telephone call is made—from the moment the receiver is lifted from the hook to the instant it is returned—magnetic forces play a very important role. The relay which closes the lamp circuit and thus attracts the attention of the operator; the transformer, called a repeating coil, through which the speech current flows from one subscriber's circuit to another or to a trunk; the ringer which summons the called subscriber and the receiver itself which transforms the speech currents into sound waves—all depend upon magnetic materials for their operation. What material is the best for each purpose has been the subject of continuous inquiry and development in the Laboratories.

In a very general way magnetic materials divide into two classes: those which can be easily magnetized but will lose their magnetism when subjected to small reverse magnetizing forces; and those which, although more difficult to magnetize, retain a large part of their magnetism even under the action of considerable demagnetizing forces. The first class comprises the so-called magnetically soft materials used for electromagnets, among which are magnetic iron, silicon steel, the permalloys, cobalt iron, perminvar and permalloy dust. In the second class, of magnetically hard materials for permanent magnets, are found low chrome steel, high chrome steel, tungsten steel, and cobalt steel.

In the selection of a magnetic material there are five properties which serve as criteria of its quality. The first is the ease with which it may be magnetized, a quality known as "permeability", which is measured by the ratio of the flux density to the magnetizing force which produces it. Not only do materials differ in permeability, but the same material itself has different values of permeability under different magnetic conditions. The ease of magnetization, in other words, depends upon the intensity of magnetization. One of the permalloys, for example, has a very high initial permeability which increases rapidly until a flux density of 5,000 or 6,000 gausses is reached. From this point the permeability falls rapidly to a flux density of about 11,000 gausses when it becomes practically saturated. For moderately high values of magnetizing force and, correspondingly, of flux density, magnetic iron on the other hand has a relatively high permeability, although for small magnetizing forces its permeability is only a small fraction of that of permalloy.

Another property of importance in a material is the continuance of the magnetized condition when the magnetizing force has been removed. This quality is measured by the residual induction, that is, that value of flux density remaining in a completely closed core of the material when a given magnetizing force is removed. Another very important quality is the coercive force—the magnetizing force which must be applied in the

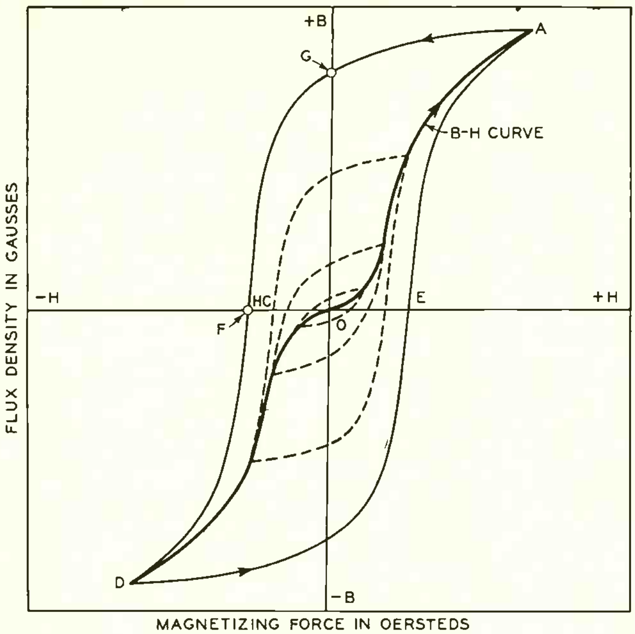


Fig. 1—A group of magnetization curves. The heavy line OA shows the behavior of the sample when first magnetized. The ordinate G indicates the residual induction; the abscissa F the coercive force. The area included by A G F D E measures the energy loss due to hysteresis; hence its designation "hysteresis loop." Dotted lines are for lesser degrees of magnetization

opposite direction to remove the residual induction: that is, to demagnetize the material. These last two qualities are of course most important in the selection of materials for the production of permanent magnets such as are used in polarized relays, in telephone receivers and in magneto-generators. The existence of the qualities of residual induction and coercive force means that the flux density within the magnetized core depends at any instant not only upon the magnetizing force then acting, but also upon the previous magnetic history of the core.

In attaining its successive values the flux density lags behind a changing magnetizing force much as if the magnetic elements of the core were being rearranged against the opposition of frictional resistance. This phenomenon, known as "hysteresis" gives rise to the term "hysteresis loss" which represents the energy used up in such a rearrangement whenever the material undergoes periodic reversals in magnetization, as in an alternating current transformer.

Another loss under the same conditions arises from the existence of eddy currents which are induced within a magnetic core when it is energized by an alternating current. This loss, like the hysteresis loss, manifests itself by heat. Sectionalizing the core by laminations insulated from one another reduces this loss. Similarly, using a material of a high electrical resistivity means feebler eddy currents and smaller losses. Hysteresis loss and electrical resistivity are therefore two qualities of importance in the design of apparatus for alternating currents.

The fact, for example, that the electrical resistance of magnetic iron is relatively low, hence, that its eddy current loss is large, practically limits its use in the design of telephonic equipment to cores for electromagnets which operate on direct currents. The fact that its coercive force is fairly low and its permeability quite high, even at relatively high flux densities, indicates that it may be used for relays in which the armature is attracted when a current is sent through the windings and falls away again under gravity or spring pressure when the current ceases. "Magnetic iron" is a term applied to the material which is as nearly pure as it is possible to obtain commercially.

In silicon steel, which may be considered a 4% silicon alloy of magnetic iron, the resistivity is about five times that of magnetic iron. Eddy currents are greatly decreased in consequence, and the material is therefore adapted for use in cores of apparatus operating within the audio frequency range. This steel also has the advantage of a considerably higher permeability than magnetic iron at the low flux densities which are usually produced in telephone apparatus operated by speech currents. It is used largely in cores of transformers, and induction and retardation coils.

A material physically superior to silicon steel for the cores of audio frequency apparatus is "45 permalloy". The name "permalloy" covers certain alloys of nickel and iron developed in these Laboratories and possessing remarkable magnetic properties. Different combinations of these materials are designated by the amount of nickel which they contain. The "45 permalloy" has a resistivity nearly as high as silicon steel and a permeability at low or moderately high flux densities two or three times greater. Its coercive force is also considerably lower. Its cost however is considerably greater and in designing apparatus this factor must be balanced against its better magnetic properties. It is used largely in transformers and certain types of relays.

The "78 permalloy" is a material having remarkably high permeabilities. Its initial and maximum permeabilities are more than ten times those of silicon steel while its coercive force is only about one-tenth. Although its hysteresis loss is very low, its resistivity which is only about one-third that of silicon steel makes it less suited than some of the other permalloys for audio frequency apparatus. It is used mainly for the cores and armatures of sensitive relays.

To adapt permalloy for high frequency use about 4% of the iron content of the 78 permalloy was replaced by a like amount of chromium. This gave us "3.8-78 chrome permalloy" which has been used for general purposes. This material has a resistivity somewhat higher than 4% silicon steel and an initial permeability about ten times as great while its coercive force is only about one-tenth as large. While it is relatively expensive, it is largely used, in audio frequency transformers and in some carrier frequency coils. In the form of thin tape a chromium permalloy has been used for the continuous loading of a number of submarine telegraph cables.

In distinction from the permalloys there has been developed in the Laboratories a material which, unlike the permalloys that saturate at relatively low flux densities, does not reach practical saturation until the flux density reaches about 24,000 gausses. This is an alloy of iron and cobalt in approximately equal proportions. To aid in its fabrication 2% of vanadium has been added. Its initial permeability is three or four times that of magnetic iron while its maximum permeability is only about one-third as high; but above a flux density of about 12,000 gausses, its permeability is about four times as great as that of magnetic iron. The high cost of this material has greatly limited its application, but it is finding a field in the pole tips of electromagnets producing highly concentrated magnetic forces.

Another development of the Laboratories is "perminvar", whose remarkable magnetic qualities bid fair to extend the usefulness of magnetic materials. This name has been applied to the alloys of iron, nickel and cobalt which when properly heat-treated are distinguished by their constancy of permeability over a region of flux density from zero to about one thousand gausses. Since their permeability is substantially constant and their hysteresis loss small in this region, the perminvars are superior to the permalloys, and to the other magnetic materials previously discussed, in respect to the amount of distortion produced in transmitted speech currents. Hence the use of coils with perminvar cores will result in distinctly superior transmission circuit characteristics. This is of especial importance in carrier systems. A perminvar which, over the region mentioned, exhibits great constancy in permeability, contains 45% nickel, 25% cobalt, and 30% iron. When properly heat-treated this perminvar has a permeability of about 400; this value is sensibly constant up to a flux density of 1000 gausses. Other compositions have been found more desirable for specific purposes. For example, the perminvar containing 70% nickel, 7.5% cobalt, and 22.5% iron and designated "7.5-70 perminvar" has a permeability of about 800 and its constancy is limited by specification so that its permeability increase must be less than 1% over a range of flux density from zero to 500 gausses. One of the greatest drawbacks at present to the wide extension of the use of perminvar is its permanent loss of the perminvar characteristics if carried even momentarily to flux densities of only a few thousand gausses. Ordinary methods of demagnetization are only partially successful. Due to this characteristic and its high cost it has had application to only a few coils in which drastic reduction of modulation effects was demanded.

For apparatus such as the loading coils which are inserted in long telephone lines to improve transmission, a core material is required which will introduce very small transmission losses and wave-form distortion. More specifically, the hysteresis and eddy

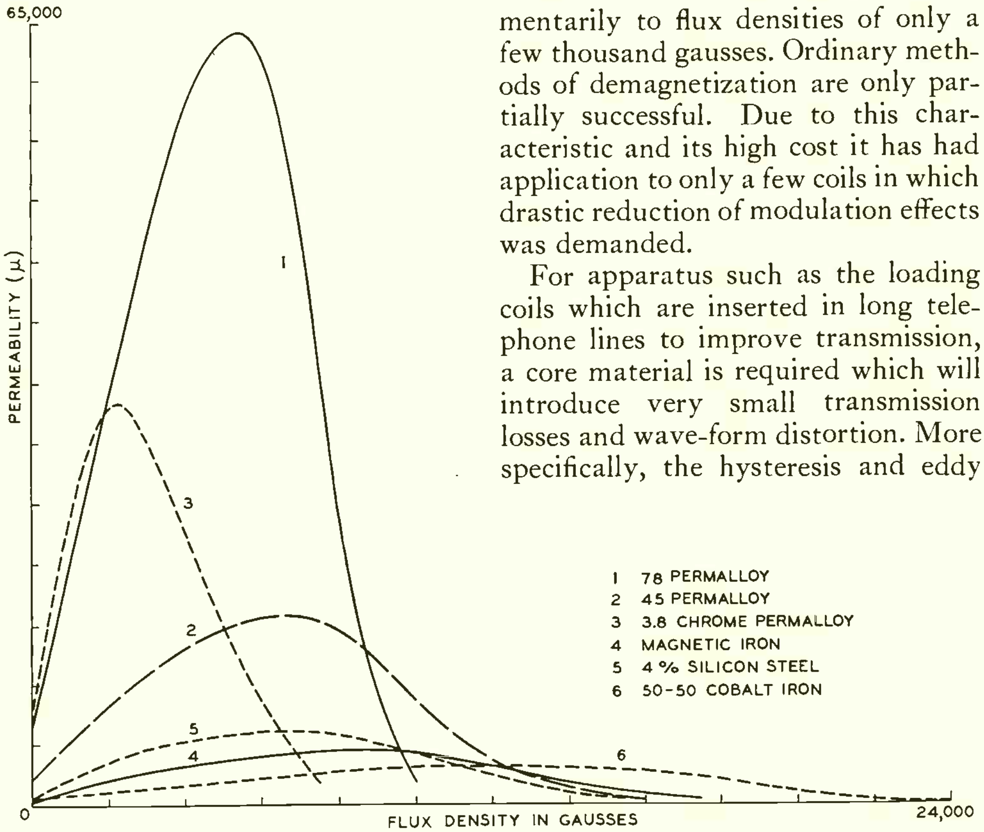


Fig. 2—Permeability curves of electromagnet materials

current losses as well as the distorting modulation effects must be small over a wide range of magnetizing force. To accomplish this it can be demonstrated that the effective permeability of the loading coil core must be kept low relative to the intrinsic permeability of the materials discussed in other sections of the paper. By finely dividing the core material and using 80 permalloy which intrinsically has a low hysteresis loss, coils peculiarly suited to the loading of transmission circuits may be produced. The fine dust particles are coated with a thin insulating film and are compressed into suitable ring cores under a pressure of about 200,000 pounds per square inch. The coils made from these permalloy dust cores have extremely small losses and their characteristics continue very constant in service. These cores are also used in audio frequency filter coils.

By the addition of certain elements to ordinary carbon tool steel, materials of varying degrees of excellence for permanent magnets have been produced. One per cent of chromium added to ordinary carbon steel increases somewhat its coercive force and permits it to be hardened by quenching in oil instead of water. This is of considerable advantage in the elimination of quenching cracks. The coercive force of this steel is usually between 40 and 50 oersteds. It is the least expensive of the magnet steels and is largely used whenever weight is not of such importance as to preclude a magnet of sufficient length to retain its strength. This steel is largely used in magneto-generators, coin collectors and ringers.

By the addition of approximately 4% instead of 1% of chromium a magnet steel of still higher coercive force is produced. Its coercive force is in the neighborhood of 70 oersteds. This is also an oil hardening steel and because of its freedom from quenching cracks and its lower cost it has largely replaced the earlier 5% tungsten steel which is a water quenching steel and which has similar characteristics. This steel is also largely used where the slightly higher cost is not a determining factor or where a somewhat shorter and consequently lighter magnet is demanded, for example, in polarized relays and some of the more recently designed ringers.

Cobalt steel, invented by Professor K. Honda of Japan, marked a decided advance in permanent magnet steels. It contains about 35% cobalt, 7% or 8% tungsten and 3% chromium. The carbon content is about the same as that in other magnet steels. The coercive force of this steel is more than three times that of the 4% chrome steel and consequently it is very resistant to demagnetization. Magnets made of it may be very short and still be of satisfactory strength. It is employed extensively in receivers and other high class instruments. The only drawback to its more extended use is its cost which is some twelve or fifteen times that of the 4% chrome steel.

In the processes of rolling or drawing soft magnetic materials their structure is strained and distorted, and this greatly decreases their permeability and increases their coercive force. This condition may be relieved and the normal magnetic qualities obtained by a proper heat treatment which differs somewhat with different materials. In general, the process consists in heating them at the proper temperature for a given time, sealed in metal boxes which are then allowed to cool slowly. As might be expected, the magnet steels require hardening by quenching in water or in oil from a definite temperature.

In the investigation of all these magnetic materials there has been in the past an immense amount of work which is the basis of our present design information on magnetic apparatus. All of the materials have been improved in their properties, but the most remarkable achievements have been in the development of the permalloys for high permeability and of cobalt steel for high coercive force.

A new day has thus come in design and a new field for improvement has opened before the designer with each development of magnetic materials. The continuation of present investigations which are relating more completely the physical condition and the chemical constituents of a material to its magnetic properties gives promise of even greater developments in the future.

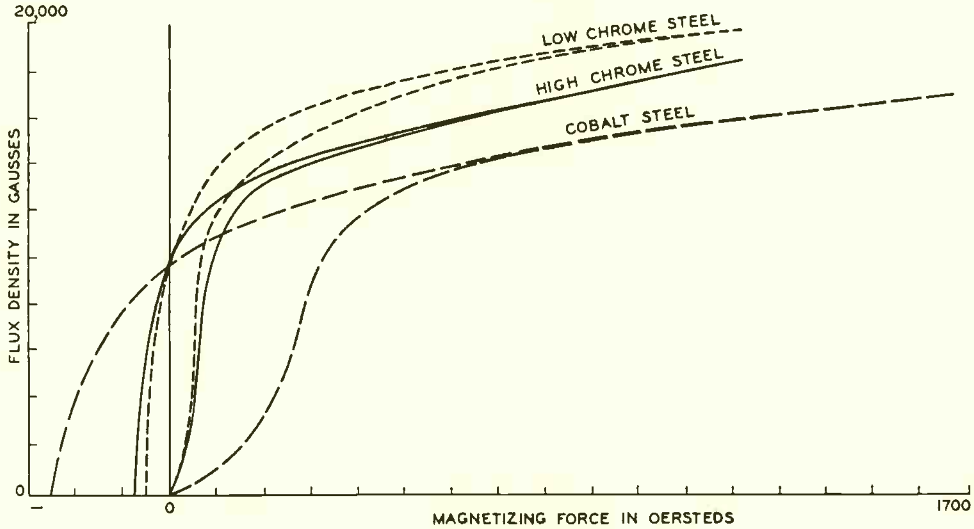
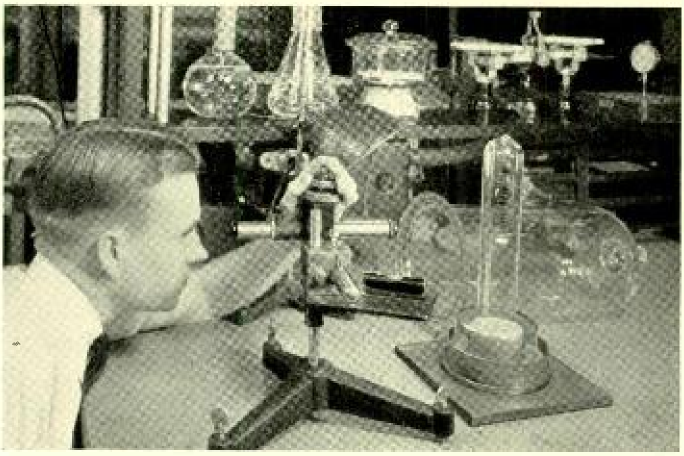


Fig. 3—Characteristic curves of permanent magnet steels



Diffusion of Water through Organic Insulating Materials

By D. B. HERRMANN
Chemical Laboratories

WATER has remarkable penetrating power. No organic substance is known to be entirely impervious to it. The life of plants and animals may be said to depend on the diffusion of water through their cell walls, and it is a familiar fact that the water which permeates the human body forms its largest single constituent. Water passes through materials often considered water-proof such as rubber, asphalts and waxes.

In the Bell System a number of organic materials are used as insulations which often are exposed to moisture. Although the actual quantity of water which diffuses through most organic substances is small, this small amount becomes important in condensers, coils and terminal boxes and other apparatus which must be protected over a period of years.

One of the methods used to evaluate insulations which are to be exposed to moisture is the measurement of the quantity of water absorbed. Such measurements do not always give a complete picture of water-proofing characteristics, since a considerable amount of water may diffuse through a layer of material into some interior space and only a small amount remain absorbed in the outer layer. Differences in molecular structure, phase relationships, and crystalline state may play important roles in diffusion, and often the absorption of water does not appear to be the principal controlling factor.

Of the general methods for determining the rate of diffusion of water through a layer of a substance, probably the most simple and direct is to establish on one side a concentration of water vapor, maintain on the other side a lower concentration, and measure the amount of water which passes

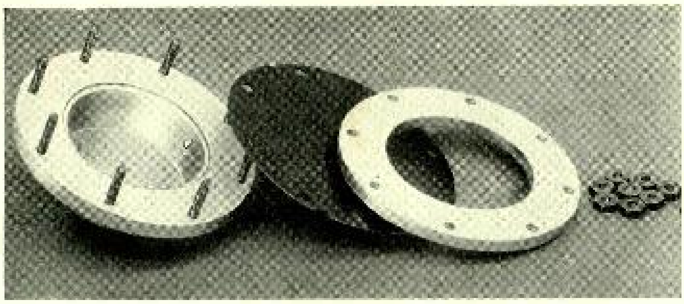


Fig. 1—Water vapor passes from the interior of the aluminum cell through the rubber sample into a drying agent outside

through the material in a given time. A convenient way to do this is to seal a sheet of the material across a cup or cell in such a manner that moisture passes from the cell through the sample into a drying agent outside. For such measurements several types of cells are used in these Laboratories depending on the nature of the material.

For rigid and semirigid substances like soft and hard rubber, phenol fibre, cellulose derivatives, and many plastics, an aluminum cell is used in which the sample is held in place by an aluminum pressure ring, the seal being completed by suitable washers coated with petrolatum (Figure 1). The cell is placed in a dessicator containing a drying agent and maintained at 25° C. by immersion in a water bath (Figure 2). The loss in weight of the entire cell combination is taken as the amount of water which has diffused through. Moisture absorbed by the material does not change the total weight.

For substances having a tendency to cold flow, such as asphalts, the cell shown in Figure 3 is used. The asphalt is supported by a thin alundum disc, and the drying agent is supported on a calibrated quartz spring whose elongation indicates the amount of water which has passed through.

A third type of cell is used for materials having a very low diffusivity and which require an extremely tight seal. Such a cell may be constructed

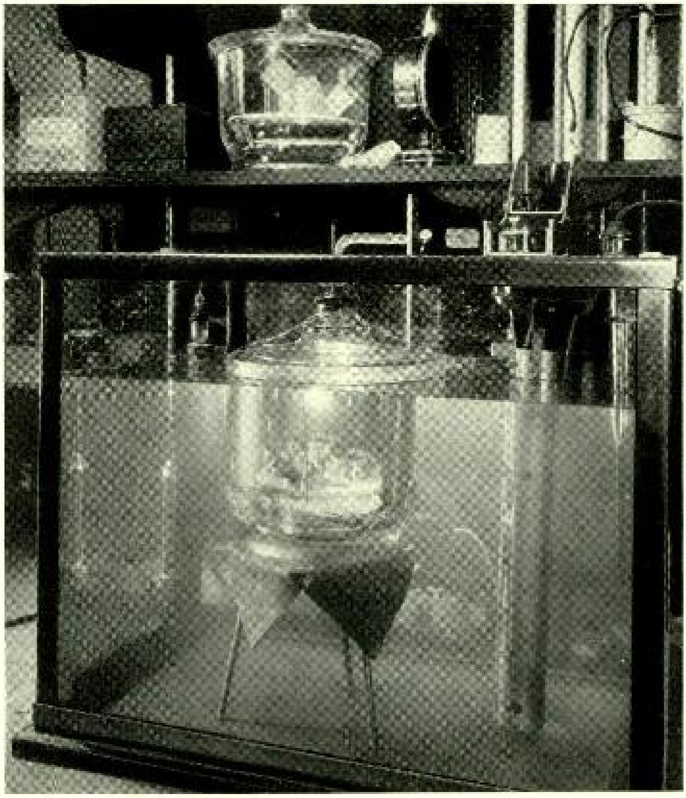


Fig. 2—The temperature is held constant during a diffusion test, often by keeping the cells in a desiccator immersed in a water bath

by making a thick-walled wax cup across the mouth of which a thin disc of the material to be measured may be sealed. The sealing is accomplished by melting together the edges of the cup and the disc, if the disc is of wax, or by melting the cup around the edge of the disc if the latter cannot easily be melted. The water which passes through is collected by a drying agent attached to a calibrated quartz spring, as shown in the picture at the head of this article. The temperature is kept constant by placing the apparatus in an air bath or constant temperature room.

Most materials obey quite closely the linear diffusion law established by Fick, and since the factors which enter into linear diffusion are definite and measurable, the law is particularly applicable from an engineering standpoint. It states substantially that the amount of vapor diffusing through a unit area of a material in unit time is proportional to the difference in vapor pressures on the two sides and inversely proportional to the thickness. The constant of proportionality, or diffusivity, constant depends principally on the nature of the material. The law is somewhat analogous to Ohm's law; the differential vapor pressure corresponds to the electromotive force, and the flow of water molecules driven by it is checked by the "resistance" of the material. Diffusivity is thus analogous to conductance.

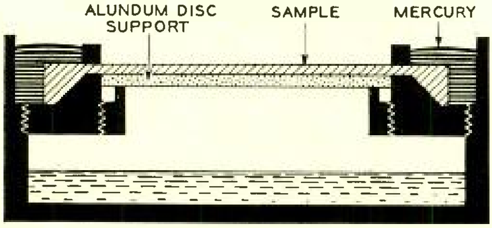


Fig. 3—When a material with a tendency to cold-flow is placed in a diffusion cell, it is usually supported by an alundum disc

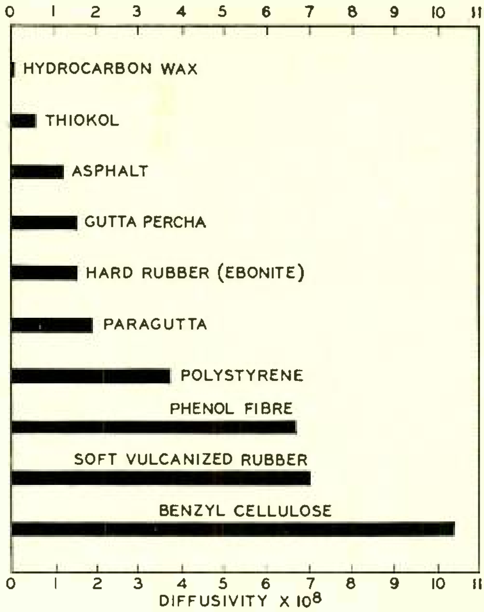


Fig. 4—The diffusivities of organic insulating materials differ considerably. That of cellulose acetate, if plotted on this chart would appear as a bar extending to 160

The diffusivity constant of a material is taken as the number of grams of water which pass through a one centimeter cube in one hour under a vapor-pressure difference of one millimeter of mercury at a definite temperature.

Organic materials whose diffusivity constants at 25°C. have been measured in the Laboratories include soft and hard rubber compounds, submarine cable insulations, phenol fibre and similar materials, cellulose acetate and related substances, asphalts, and pure hydrocarbons such as polystyrene. The amount of water which diffuses through a centimeter cube of material at 25°C. ranges between 10^{-9} and 10^{-5} grams per hour when the difference in vapor pressures is one millimeter of mercury (Figure 4).

Measurements of this sort have proved especially valuable in dealing with rubber, asphalts, and waxes, which are used extensively in the Bell System as insulating materials, primarily to provide protection from water. The amount of material needed for protection has hitherto been determined largely empirically, but a knowledge of the rate at which water passes through an insulation now makes it possible to estimate the thickness needed to protect a piece of apparatus for a specified length of time under known conditions of temperature and humidity. The minimum thickness of rubber sheath necessary to protect a dry-core paper cable can be calculated, for example, and the amount of material required in sealing apparatus with an organic substance can be estimated.

The mechanism by which water diffuses through solid materials is not definitely known. There are some data on the diffusion of gases through inorganic substances, however, which help to explain similar processes in organic materials.

There are indications that sorption* plays an important part in some cases of the diffusion of gases through inorganic materials. Hydrogen diffuses into copper only after it has first been adsorbed on the copper surface, and palladium sorbs hydrogen so strongly as to indicate that they combine chemically. On the other hand, diffusion independent of adsorption seems to be exemplified by the passage of inert gases through fused silica, where the gas molecules are believed to enter extremely minute cracks in the film directly from the gas phase.

The diffusion of moisture through certain organic substances such as polystyrene and hydrocarbon wax, is associated with very little absorption. The amount of water absorbed by polystyrene is extremely small, although the diffusion of water through it is comparatively large. The water absorption of the wax is also small, yet its diffusivity is only about one fortieth of that of the polystyrene. Both materials are homogeneous, nonpolar compounds. The difference between their diffusivities appears to be due to differences in their physical and chemical structure of some other sort than those determining sorption. In sharp contrast is the case of cellulose acetate, through which moisture passes 1600 times as fast as through hydrocarbon wax. Here the sorption of water is strong and probably borders on chemical union, as does the interaction of palladium with hydrogen. It is very likely that the higher sorption affects the diffusivity, and that both are largely accounted for by the same features of chemical structure.

To arrive at a true picture of the mechanics of moisture diffusion through organic substances much additional work is required. The measurements made in these Laboratories form only a beginning in this direction.

*"*Sorption*", *and the corresponding verb*, "*sorb*", *describe a process in which both absorption and adsorption takes place.*

The Regulation of Transmission Over Open-Wire Lines at Carrier Frequencies

By L. M. ILGENFRITZ
Transmission Development

SATISFACTORY transmission requires, among other things, that the overall loss of the telephone circuit must remain reasonably constant over long intervals of time. This constancy of transmission loss, unfortunately, is not an inherent property of most transmission lines that are in use, and so it has been found desirable on the longer lines to provide means for the regulation of transmission loss within suitable limits.

The attenuation of open-wire line conductors increases with frequency. The rate of increase is proportional to the a-c resistance of the pair and to the conductance. Both of these factors increase with frequency and as a result the transmission loss does so also. At the higher frequencies, which are used for carrier transmission, the loss is considerably greater than at voice frequencies. Of more importance, however, is the fact that both the resistance of the pair and the conductance between wires do not remain constant but vary considerably from time to time with the prevailing weather conditions, and the variation in attenuation is of sufficient magnitude to require correction.

This variation in transmission loss is due to two causes. First and most important is the change of leakage at the insulators. Of secondary importance is the change of conductor resistance with temperature. The former is peculiar to the open-wire form of line construction in which the insulators are fully exposed to weather, while the latter effect is present in all copper line conductors. Already important strides have been taken to reduce the change of insulator leakage with weather by the design of improved types of insulators, but considerable remains to be done before this source of variation can be eliminated.

Occasionally, the insulator problem is aggravated by unusual weather conditions which are sometimes encountered in certain parts of the country. These conditions may be caused by sleet building up a wet ice coating over the insulators, thus forming a wet path between the wires at each crossarm. Another serious condition encountered in small areas in the far west is the building up of a frost coating on wires and insulators. This coating sometimes becomes several inches thick and increases the line loss per unit length tremendously. Still another is the effect of sudden fogs in regions such as the part of the central transcontinental line normally subject to salt dust deposits on the surfaces of insulators. The dampening of this salt dust by the fog on the insulator surfaces causes a large increase of leakage and consequently of transmission loss.

While these unusual effects are interesting and now and then quite serious, the variations of transmission

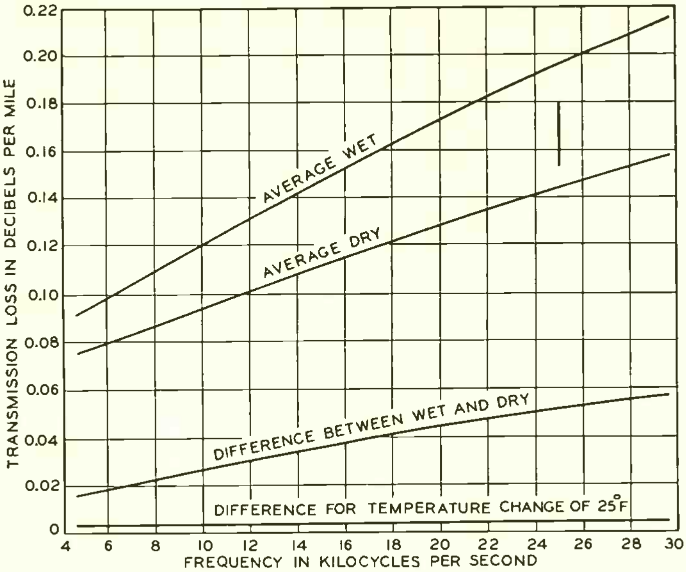


Fig. 1—*Attenuation-frequency characteristics of an open-wire pair*

the attenuation change from the wet to dry condition is much more important than the variation due to temperature. Figure 2 shows a record of attenuation taken at a single frequency on a line 150 miles long, equipped with S.P. insulators, and gives a continuous measurement for a 36-hour period. The weather conditions at one end of the line are noted along the time scale. Evidently the attenuation varies almost continuously and sometimes quite rapidly. In this case the total range of variation is nearly 4 db, which occurs within a 12-hour interval. To show how this range of variation compares with the average curves of Figure 1, the broad black vertical line at 25 kilocycles between the wet and dry curves has been drawn in after being reduced to the variation per mile. During the period shown in Figure 2, the line was not entirely dry nor did it show as large an increase in attenuation during wet weather as may frequently occur. The S.P. insulators used on this line are an old type and show about three times the normal variation with weather changes exhibited by the modern C.S. type which are now standard for new construction.

loss even with ordinary change of weather are sufficient to present a real problem, especially in the longer systems. To illustrate the amount of these variations, Figure 1 shows the attenuation of an open-wire pair in db per mile at different frequencies in the range employed for carrier transmission. One curve, the highest in the figure, shows the average attenuation during wet weather. The next lower curve is the same characteristic during average dry weather. It will be noted that not only the transmission loss of the line increases with frequency but also the change in loss with the change from wet to dry weather increases with frequency. This differential is plotted below the dry-weather attenuation curve. At the bottom of the illustration is shown the change in attenuation with temperature for a representative day. The maximum change per day throughout a period of a year might amount to twice this in some localities.

It is evident from these curves that

The length of line measured to produce Figure 2 was about average for the spacing of repeaters on a type-C carrier system. Evidently for a carrier system operating over many sections of line in tandem, averaging 150 miles per section, the problem of varying line attenuation is important. There are a number of carrier systems employing 10 or more of such sections. If the variations shown in Figure 2 were multiplied by 10, it would amount to 39 db for the whole line. Fortunately, these line sections, when connected together, extend over such wide areas that it is very unlikely the same weather conditions will prevail along the entire line and this reduces the probability of obtaining large variations of total line attenuation. It is the reason, however, why a more continuously and rapidly varying attenuation can be expected on long carrier systems, and makes more important the matter of providing suitable level indicators for the transmission maintenance forces so that proper level corrections can be made.

Of course, there are other sources of transmission variations which may occur in the repeaters and terminals, but these can and have been made a small part of the total by suitable design and maintenance.

Ever since carrier systems a thousand miles or more in length have been placed in service, an indicator of level for maintenance purposes has been employed. Nearly all type-C carrier systems have been equipped with this indicator, the so-called 1A pilot channel. A single-frequency pilot current is located between channel bands and as near the central part of the transmitted range of carrier channels as possible. To measure this pilot frequency properly, tuned-rectifier meters are provided at all intermediate carrier repeaters and at the receiving terminals. These meters are calibrated in db and are adjusted to indicate "Normal" level when normal levels are transmitted on all channels including the pilot. Deviations of level can be noted and corrected manually by the amplifier gain-control potentiometers. Periodical observations of the meter readings at each office are required as part of the regular maintenance procedure. At receiving terminals a sensitive marginal relay is connected in series with the

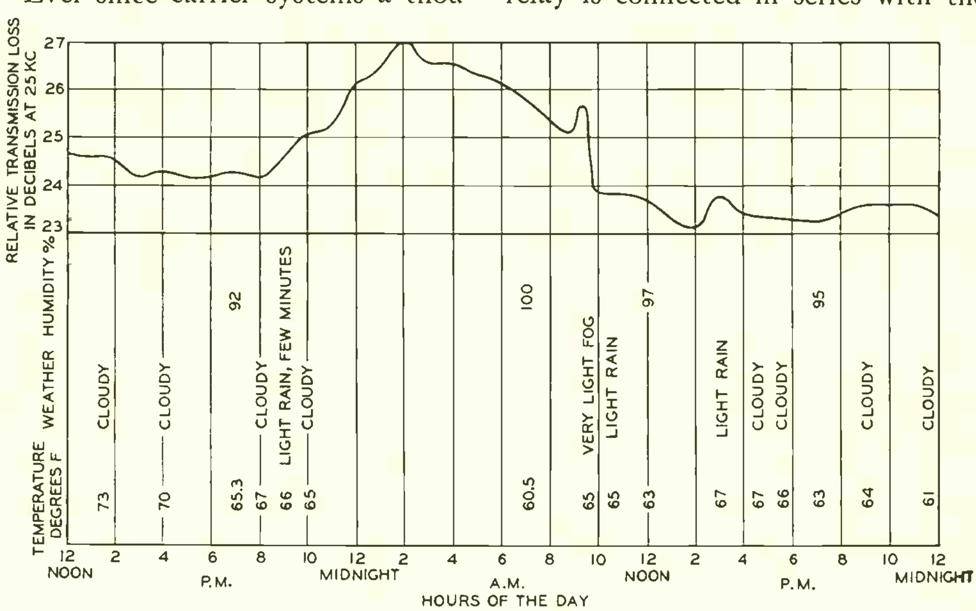


Fig. 2—Variation of transmission loss of a section of open-wire line at 25 kilocycles due to weather changes

indicator meter to give an alarm when the pilot deviates too far from normal. By this means the maintenance personnel at the receiving terminal is notified as soon as a major deviation of the pilot level has occurred. In a long system, after an alarm has been sounded, it is not known where the fault is located, and to avoid making the gain correction at the wrong point, it is necessary to get in touch by an order wire with each repeater office to determine where a gain correction should be made, and then to authorize the proper adjustment. This does not complete the adjustment. It merely insures that the repeater gains are correct at the pilot-channel frequency.

Referring back to Figure 1, one may note that the variation of line loss is different at different frequencies. The gain correction by means of the repeater-amplifier potentiometer, on the other hand, is uniform at all frequencies. This gain adjustment, therefore, is correct only at the pilot frequency and leaves small differentials to be added or subtracted at adjacent channel frequencies.

When the change of line loss is large and requires a number of consecutive steps from time to time, the error at adjacent channel frequencies will also become large. To avoid accumulation of excessive errors from this cause, the receiving terminal maintenance forces are required to keep accurate account of the steps of gain correction which have to be made at all repeaters in the system, and when these have accumulated sufficiently to justify correction of the equivalents of the individual channels, the corrections are made. This can be done by manipulating potentiometers at the individual channel receiving terminals. A table is employed for the corrections of this kind, which is based on the attenuation differential curve given in Figure 1.

Very fortunately, this curve has practically the same shape for all gauges of line conductors and types of insulators, so the same basic table can be applied to all open-wire systems of the same frequency allocation regardless of the facilities over which the systems operate. Of course, the correction in the individual channel depends upon the frequency of the pilot and the frequency of that channel, so the use of different frequency allocations calls for different tables.

This transmission maintenance procedure is open to the objections that it is complex and requires much time to carry out, and that the smaller variations of transmission must be neglected. Under certain conditions these small variations can add up to become larger than is sometimes allowable. Difficulties with the older system such as this have led to the development of an automatic control system which is described in more detail in a com-

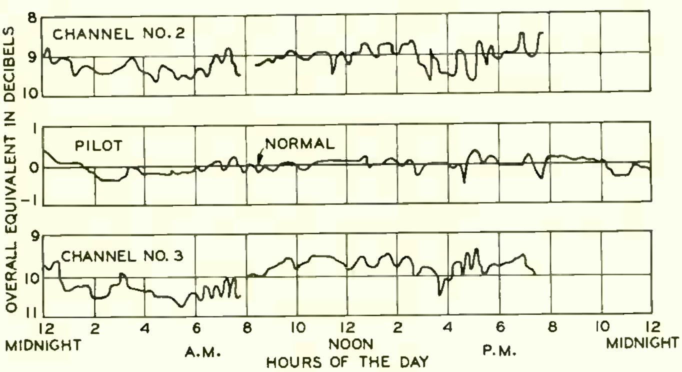


Fig. 3—Record of transmission variations over a period of 24 hours

panion article.* In this system, designated as the 2A pilot channel, the table of corrections has been replaced by networks having the basic characteristic shown in Figure 1.

Automatic control has the advantage that it makes adjustments in much smaller steps and makes communication between offices for the maintenance of levels unnecessary. It also provides level correction at all frequencies at all repeater offices as well as terminals and this is an important advantage for the longer systems. Records of the operation of systems using 1A manual pilot-channel control indicate that the maintenance of channel equivalents is ordinarily within the range of about 3½ db either way from normal for any channel of a system. With the automatic control, this range is reduced to 2 db, and generally a much better figure even than this can be realized.

Figure 3 shows the variation in loss on two channels of the Washington-West Palm Beach type-C system on which the trial of the automatic pilot channel was made. The recorded net loss of channels 2 and 3 are shown together with the pilot level which was automatically adjusted as soon as that level departed more than ½ db from normal. Evidently a much better grade of transmission maintenance can be obtained with the use of the automatic pilot regulator.

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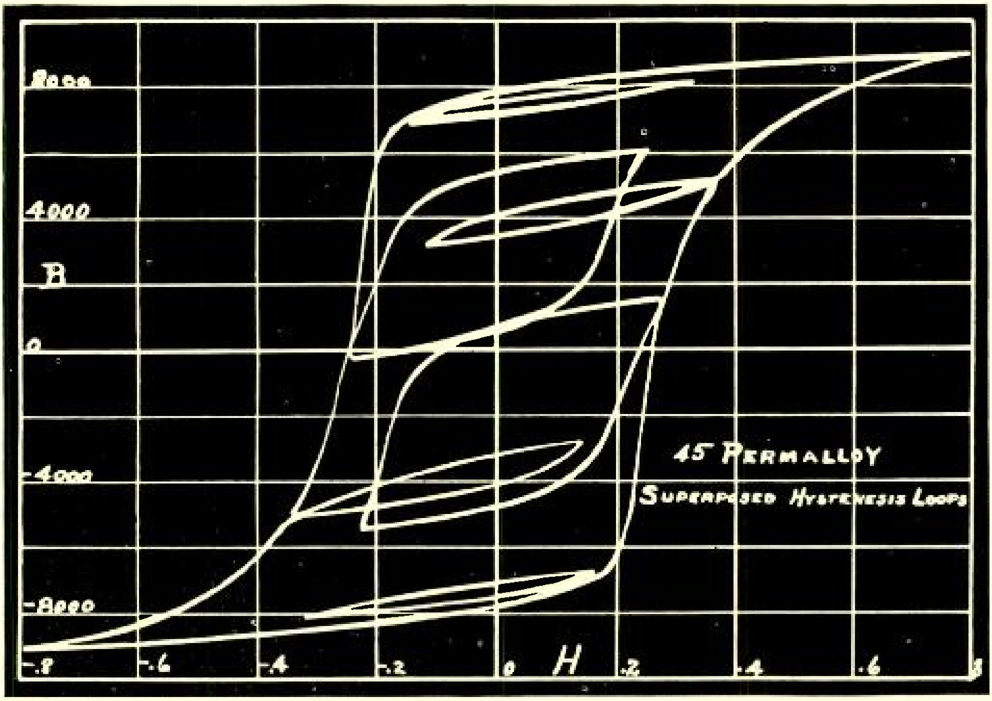


Hysteresis Loop with superposed incremental loops taken on a ring specimen of 45 permalloy. Curves were made with Haworth Magnetic Curve Tracer. At intervals in the process of tracing the hysteresis loop the rate of change of the magnetizing force was reversed for a predetermined increment and then the forward tracing of the loop continued

CS system are diagrammed in Figure 1.

The equipment required for the two pilot channels, and its location in the circuit, both at a terminal and at a repeater station, is shown in the block schematics of Figures 2 and 3. At the terminal station the pilot oscillator is located in the transmitting side just ahead of the transmitting amplifier. In the receiving side are the pilot indicator, the pilot alarm, the control equipment, and the regulating network. At intermediate stations there are in each branch a pilot indicator, the control equipment, and the regulating network. The pilot alarm at intermediate stations is optional.

The oscillator, a schematic of which is shown in Figure 4, must be very stable in frequency and of constant output. It may be tuned to the desired location between channels, and the output is set to the proper value by an adjustable resistance network. The pilot indicator circuit, shown schematically in Figure 5, has a high-impedance input circuit which is bridged across the output of the receiving amplifier. Since the pilot current is between adjacent channel bands, the indicator circuit must be sufficiently selective to prevent serious interference into the pilot channel

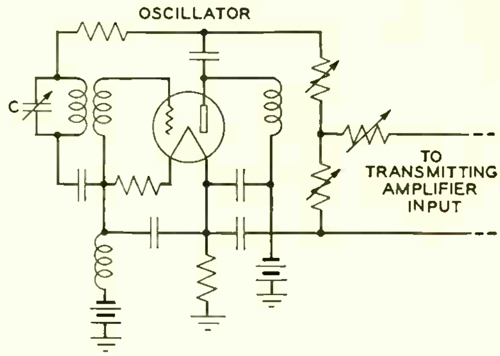


Fig. 4—Simplified schematic of oscillator for 2A pilot channel

from speech on the adjacent telephone channels. This is accomplished by two loosely coupled tuned circuits between the transformer and vacuum tube. As shown in Figures 2 and 3, the indicator circuit is tapped on the output side of the main amplifier while the regulating network is connected in the circuit on the input side of the amplifier. Any change made

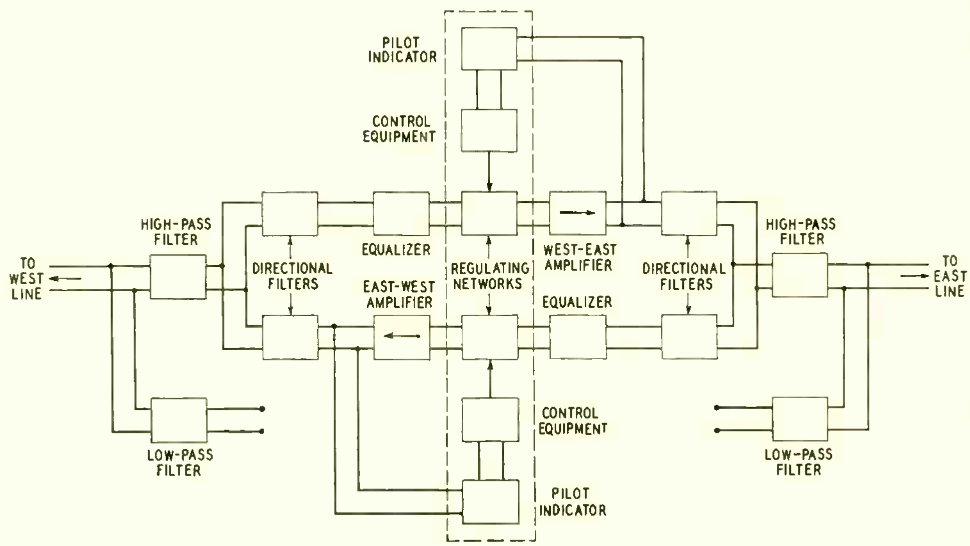


Fig. 3—Schematic of intermediate station showing location of 2A pilot channel equipment

in the network as a result of the action of the indicating controller will therefore act immediately to bring the indicator back to the proper reading.

The regulating network is composed of eight separate units. Four of them each produce a nominal loss of four db, one of two db, one of 1 db, one of ½ db, and one of ¼ db. They are connected in the circuit in series and the control equipment acts to remove from the circuit those that are not needed. The attenuation units, with the exception of the two smaller sizes, introduce losses that simulate an actual length of open line—the loss increasing with frequency. The regulating network thus builds out the line attenuation to a fixed value for any weather condition. This fixed attenuation (line plus regulating network), increasing with frequency, is then closely equalized to an overall loss-frequency characteristic that is uniform with frequency by a base equalizer network which is normally a part of the repeater. This attenuation correction with frequency equalization is illustrated in Figure 6.

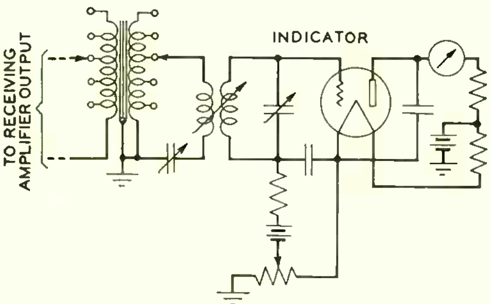


Fig. 5—Simplified schematic of pilot indicator circuit

The control equipment consists of three rotary type selectors, designated A, B, and C, a group of eight relays to cut in or out the units of the regulating network, an indicating controller, and certain other auxiliary relays. A simplified schematic showing the regulating network, the indicator, and control equipment in their relation to the amplifier and line circuits is given in Figure 7. In the indicating controller on the right are shown the high and low contacts, one or the other of which is closed by the meter every 15 seconds if the level differs from normal by as much as ½ db. A third switch, marked trigger, is also closed every fifteen seconds, 10 seconds after the operation of the level meter, and completes the change in the attenuation that has been shown necessary by the previous operation of either the high or low contact. If neither the high nor low contact has closed, the subsequent trigger operation produces no change in attenuation, but if one of them has closed, the circuit acts to increase or decrease the loss introduced by the network by ¼ db. This sequence is repeated every fifteen seconds and the correction, if required, is always made in ¼ db steps.

The B selector controls the operation of the relays that cut in or out the 1, ½, and ¼ db units. As the selector is moved from positions 1 to 8

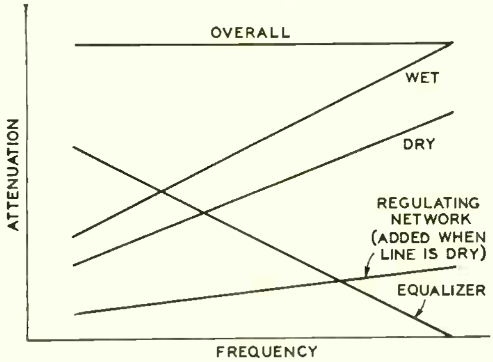


Fig. 6—The attenuation of the regulating network plus that of the line when dry is equal to that of the line alone when wet, and this attenuation is compensated by the base equalizer

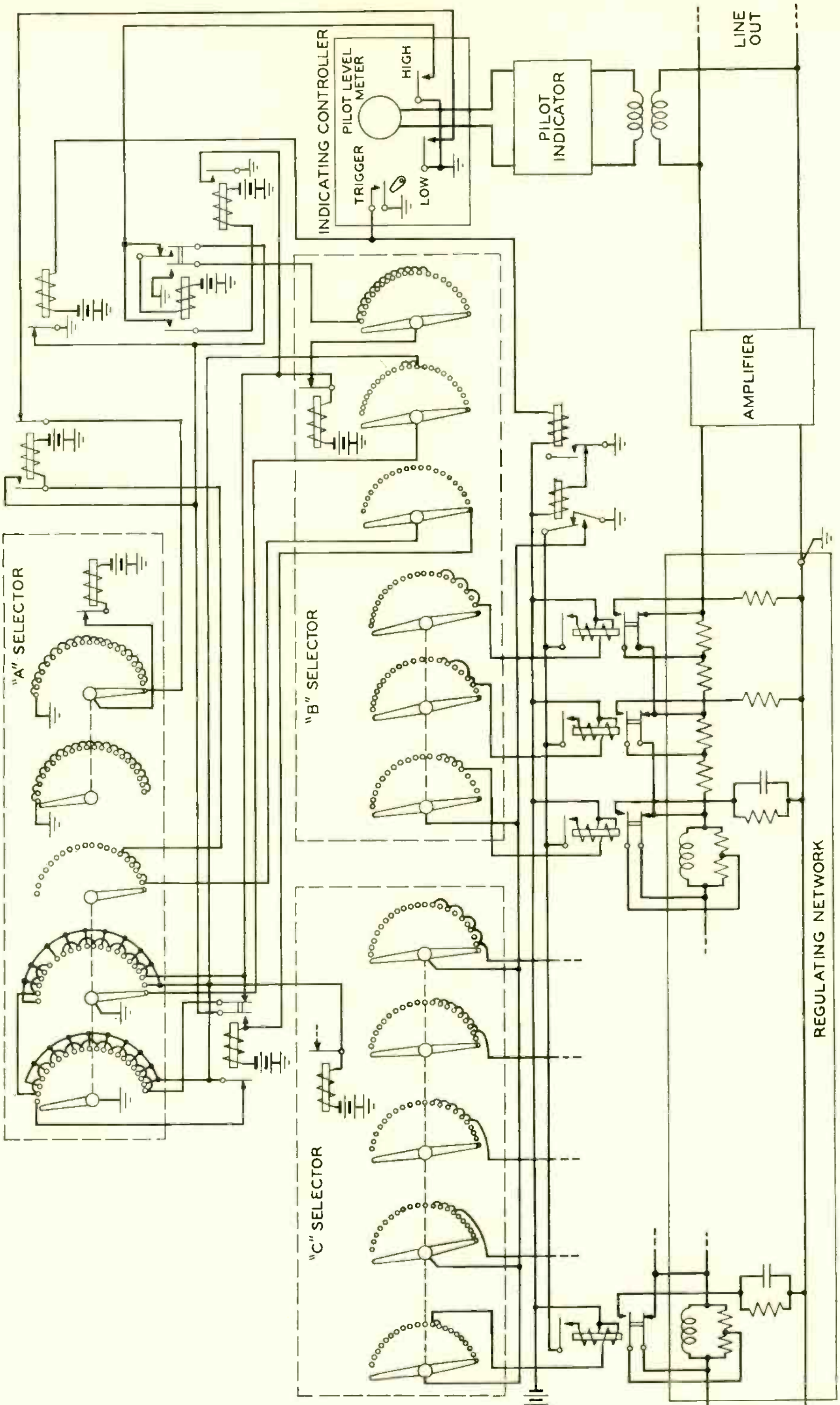


Fig. 7—Simplified schematic of control circuit

inclusive, with intervening trigger contacts, the total loss introduced by these units increases from 0 to 1¾ db in quarter db steps. The C selector on the other hand, controls the relays that cut in or out the 2 and 4 db units, and as it is moved from steps 1 to 10 inclusive, with intervening trigger contacts, the loss inserted increases from 0 to 18 db in 2 db steps. By selecting the proper combination of steps of these two selectors, therefore, any loss from 0 to 19¾ db may be obtained. The A selector is employed only when effective backward stepping of the B or C selector is required in reducing attenuation by a ¼ db step. Since the selectors will operate in only one direction, the A selector, making one revolution, acts as a master selector to give the right number of pulses or steps to the B or C selector to step it forward one-half revolution minus one step. Then when the trigger contact operates, the attenuation will be reduced by ¼ db.

If, for example, at some particular time there is 8 db inserted and the high contact of the controller closses, the B selector will move forward one step. Then at the end of the 15 second interval when the trigger switch operates, an additional ¼ db loss will be inserted in the circuit. Had the low instead of the high contact closed, the B selector would step under self-interruptions from the 0 db position to the 1¾ db position, while the C selector, receiving pulses from the A selector, would have been moved to reduce the loss by 2 db. As a result a net change of −¼ db would be brought about when the trigger switch operates.

The control circuit is also arranged to give an alarm when the pilot current suddenly becomes excessively low, as would happen from an open or a short on the line, and also on failure of the automatic control. Provision is also made for manual operation in emergencies. With the 2A carrier pilot control it is possible to hold the overall loss between terminals to within 2 db of the normal value.

Acoustic Spectrometer

By C. N. HICKMAN
Physical Research

IF a beam of white light is passed through a prism it will spread out into a continuous colored band spectrum, shading from red to violet. This shows that white light is composed of a great number of colors, and that the wave length for each color is different. An instrument called a spectrometer is used to separate any kind of light into its different colors or wave lengths, and the process is known as spectrum analysis.

In like manner the various complex sounds which we hear are composed of a number of simple tones of different wave lengths, but each wave length has a different pitch or frequency. The acoustical research department of Bell Telephone Laboratories has recently developed an instrument which separates complex sounds into their simple component tones and at the same time indicates their approximate amplitudes. By analogy it is called an acoustic spectrometer.

The separation of complex tones into their components is not new in itself. With one method employed, the component frequencies were detected one at a time. Such a method of analysis is applicable only to complex tones that remain constant in every respect while tests for the desired frequencies are being made. Another method, and the oldest one, was to obtain a record of the wave form, such as a tracing on smoked glass or an oscillogram, and then by mathematical analysis or by mechanical means, determine the combination of simple tones that would produce the complex wave. This latter method has the advantage that it is possible to analyze tones of short duration. The former method, while applicable only to tones of relative long duration, is much faster.

The acoustical spectrometer recently developed, is applicable to tones of very short duration, and shows all the components at the same time. Instead of having a single selective element which must be successively adjusted to all the desired frequencies, it has a large number of selective elements each responding to frequencies within a narrow range,

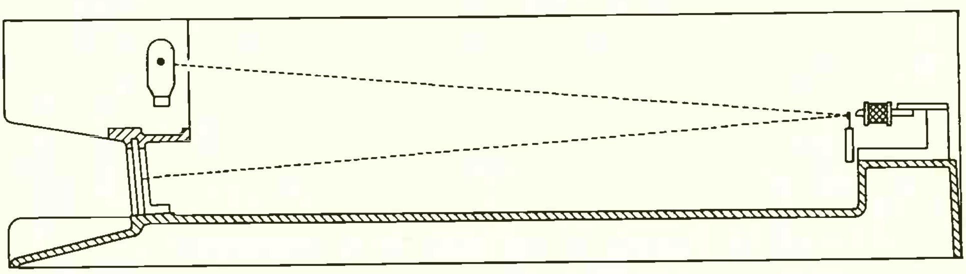


Fig. 1—Small spherical mirrors mounted on vibrating reeds reflect a ray of light to indicate on a screen the component frequencies and their magnitudes

and all acting simultaneously. With this new apparatus it is therefore possible to read or record at any moment all the components present in any complex tone. The analysis is accomplished by first converting the complex sound waves into corresponding complex electric currents. Tuned reeds, electromagnetically driven, are then caused to vibrate—each reed responding to components in a different part of the frequency range.

Figure 1 shows a schematic arrangement of the spectrometer. Light from a lamp filament passes through a slit and falls on concave mirrors which are mounted on the tuned reeds. An image of the slit is brought to a focus on a screen by each mirror. As a reed vibrates, the mirror moves the spot of light up and down on the screen forming a vertical line. The length of the line is a measure of the amplitude of the component, and the position of the line along the screen indicates the frequency.

In the present spectrometer, which was developed largely for demonstration purposes, there are 24 reeds per octave and six octaves—covering the frequencies from 50 to 3200 cycles per second by quarter tone intervals. The reeds comprising each octave are driven by a single long narrow electromagnet with a permalloy core. The sound is picked up by a suitable microphone, passed through an amplifier and then on to the six magnets—one for each octave. All the frequency components that were in the original sound will be represented in the magnetic flux, and the reeds will be set in vibration when there is a frequency component that corresponds or is close to their resonance frequency. As the machine is now arranged, the spectrum may be watched, or the glass screen may be replaced by sensitized paper and photographic records made. A motion picture camera might also be employed to photograph a changing spectrum.

The appearance of the record made is illustrated by Figure 2, which shows

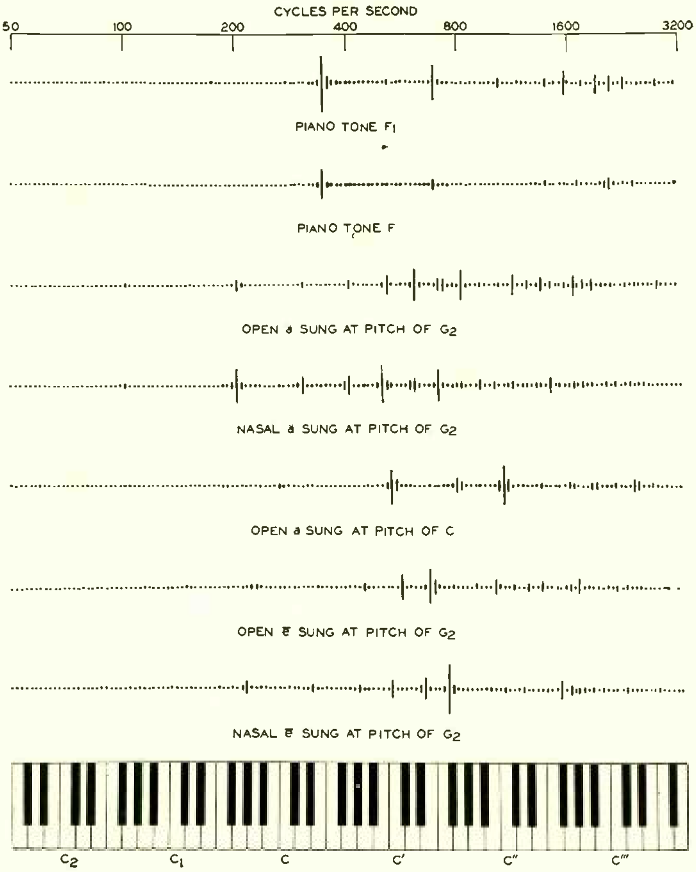


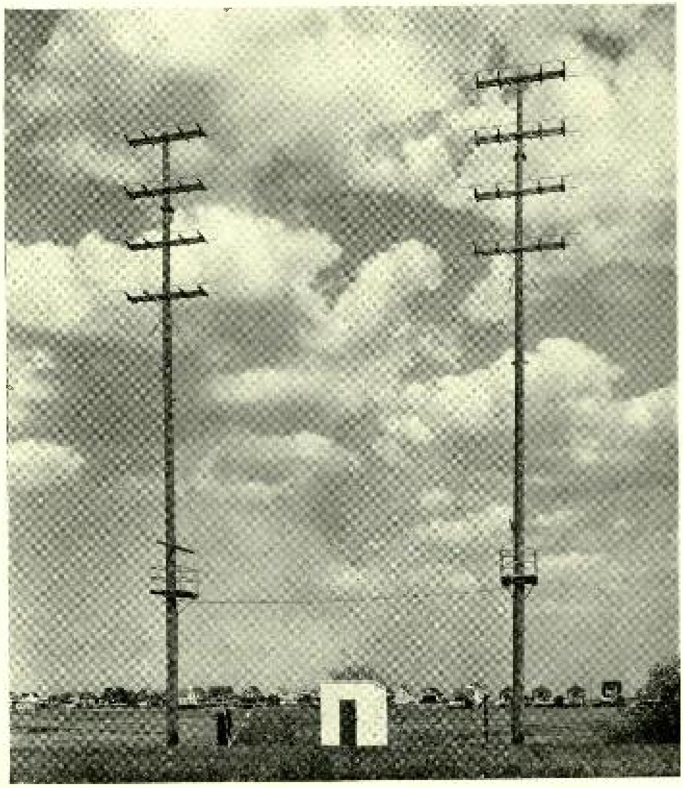
Fig. 2—Spectrograms of various sounds indicate the different magnitudes of the various harmonics

a group of spectra for sounds of various types and pitches. In each case there is a fundamental of low frequency and a series of harmonics. The amplitudes of the harmonics vary, and it is this variation in the relative magnitudes of the harmonics that gives the difference in quality between tones of the same fundamental pitch.

In the design of the apparatus, provision has been made for tuning each reed accurately to its correct frequency, and also for tilting the mirrors so that the dots of light from successive reeds fall at equally spaced intervals along a straight line. Their amplitudes of vibration are also adjusted so as to be the same for the same input voltages to the amplifier.

The method and design that has proved so satisfactory in this demonstration apparatus is easily applicable to wider frequency ranges and smaller frequency ratios between adjacent reeds. With 48 reeds per octave, which is readily obtainable, it is possible to detect components with frequency differences of only ¾ per cent.

This development provides a long-wanted tool for studying the frequency components of sound of all types. The rapidity with which results can be obtained by its use will, it is expected, make it useful in the acoustic studies carried on in these Laboratories.



Ultra-short wave antennas at Green Harbor, Massachusetts

Contributors to this Issue

C. N. Hickman received the A.M. degree at Clark University in 1917, and then engaged in ballistic research for the U. S. Government. At the close of the war he was employed at the Bureau of Standards in the Inductance and Capacitance Laboratory. He then returned to Clark University and received the Ph.D. degree in 1922 under Dr. A. G. Webster. Following a short period of service with the Navy Department designing submarine mines, he joined the Department of Development and Research of the A. T. and T. Company in 1924. In 1930 he joined the Technical Staff of the Laboratories where he has been making a study of magnetic recording.

F. F. Merriam left Georgia Tech during the war to engage in aircraft radio work as a second lieutenant in the Army Air Service. After the armistice he returned to his studies, and completed the course in electrical engineering in 1919. Coming directly to the Laboratories he worked on various electrical tests in the Apparatus Development Department until December 1919. He then transferred to the Research Department and assisted in the first ship-to-shore radiotelephone development during 1920 and 1921. The following year he left the Laboratories to engage in radio merchandising in Atlanta, Ga. and later in geophysical research in Oklahoma and Texas. In 1927 he returned to the Research Department of the Laboratories, where he has since been engaged in short wave and ultra-short wave antenna development. He is at present in charge of the group which is engaged in this work.

D. M. Terry received the B.E.E. degree from Ohio State University in 1920, and at once joined the Technical Staff of the Laboratories. Here he was first associated with the Research Department, where he worked on fundamental carrier research and on the development of picture transmission. He was in charge of the transmitting apparatus in Cleveland for the first public demonstration of this system in 1924. Two years later he transferred to the toll group of the Systems Department. His work here has been chiefly on the development of automatic control of trans-

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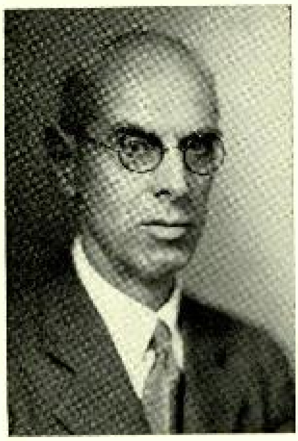

I. C. Pettit

L. M. Ilgenfritz

mission level for carrier telephone lines.

D. B. Herrmann entered the Laboratories in 1923. After a short time in the messenger service, he transferred to the Patent Department and then to the Chemical Laboratories as a laboratory assistant. In 1925 he left to attend the College of the City of New York, returning to the Laboratories for two summers. He joined the staff of the Laboratories in 1928, and continuing his college work received the B.S. degree in 1930. Here he has been concerned with general problems of organic chemistry, particularly those relating to rubber, balata, gutta percha and like ingredients of submarine cable insulation, and with measurements of the dielectric properties of this and other types of insulation. Recently he has been occupied with studies of the diffusion of water through organic insulating materials, and of the deterioration of various substances by light.

After graduation by Cornell in 1903, I. C. Pettit was for the next several years an instructor in engineering for his alma mater. On entering the Engineering Department of the Western Electric Company in 1910, he at once began the work on magnetic materials which has occupied him almost continuously since. Among his activities have been early measurements on magnetic alloys; the application of silicon steel to repeating coils; and design of permanent magnets for telephone receivers. He also participated in the development work preceding the introduction of the porcelain protector block. Within recent years in the Materials Development group Mr. Pettit has been responsible for tests and specifications of all magnetic materials; for studies of the large number of new magnetic materials which have been invented in the Laboratories and elsewhere, and for their recommendation to design groups for incorporation into telephone apparatus.

L. M. Ilgenfritz received a B.S. degree in electrical engineering from the University of Michigan in 1920, and at once joined the Department of Development and Research of the American Telephone and Telegraph Company. Here, with the Transmission Development Group, he worked on the development of all types of carrier telephone and telegraph systems, and of gain control systems employing carrier pilot channels. With the recent merging of the D. and R. and Bell Telephone Laboratories, Mr. Ilgenfritz becomes a member of the Technical Staff of the Laboratories with the Transmission Development Department, where he continues his studies in carrier problems.