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The Voder

PEDRO *the* VODER

A Machine That Talks

WHEN the Emperor of Brazil after listening to Bell's telephone at the Philadelphia Centennial Exposition exclaimed, "My God, it talks!" he somewhat overstated the facts; for the telephone didn't talk, it carried talk. But there is a machine that does talk which will be exhibited by the Bell System at the San Francisco Exposition and at the World's Fair in New York. It creates speech. It is the first machine in the world to do this. It looks like a little old-fashioned organ with a small keyboard and a pedal. It is played by a girl operator. It takes a good deal of practice and some time to learn—not as much time as it takes the human to learn the mechanisms he is born with, but still quite a while. And it talks with what might be called a slight electrical accent. Nevertheless a skilled operator can make it say what she wants.

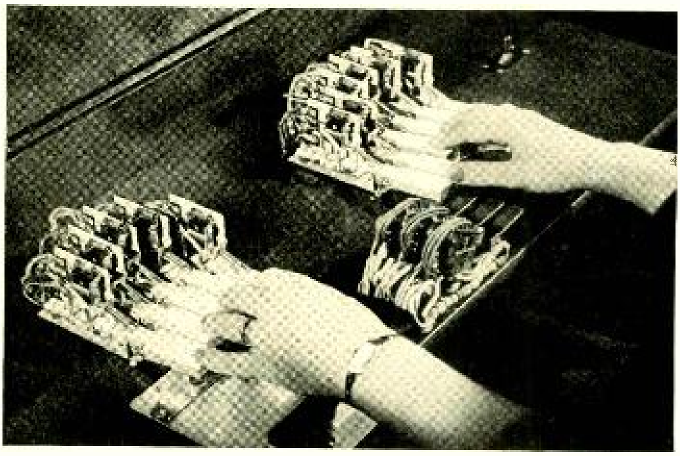
The device is an electrical arrangement which corresponds to the mechanism of human speech in all the essentials of kinds of sound and of the completeness of their control. It was designed in Bell Telephone Laboratories as a scientific novelty to make an interesting educational exhibit; and it is built entirely, except for its keys, of apparatus used in everyday telephone service.

The last part of the name, Pedro the Voder, comes from the key letters of the words, "*V*oice *O*peration *DE*monstrato*R*," because it is a device which shows electrically the operation of the human voice. The first part is taken from the name of Dom Pedro, the emperor who so promptly recognized the marvels of Bell's "speaking telephone."

In human speech there are two kinds of sound and the Voder has electrical equipment corresponding to each of these. One kind of sound is made by forcing the breath through the mouth, past tongue and teeth and lips, while shaping the mouth cavity. That is the way in which are made consonant sounds like "s," "th" and "f." And that is the way in which are made all the sounds of speech when one whispers. In the Voder there is an electrical source which contains all the sounds which enter into whispered speech. By choosing the proper combination of keys the operator can let through to the loudspeaker an electrical current to make any of them.

The other kind of sound which enters into human speech comes from the vocal cords. The most important of these sounds are those of the vowels like "a," "o" and "u." The human vocal cords give off a very complex and somewhat musical sound. When one talks one shapes his mouth cavity so that some particular parts of this complex sound come through clearly, while other parts are suppressed and unheard. In the Voder, therefore, there is an electrical source of sound corresponding to the vocal cords; this is a "relaxation oscillator" which gives a saw-tooth wave of definite pitch. There is a pedal for changing this pitch and for giving to speech a rising or falling inflection as desired. When the operator wants the sounds made by the vocal cords, instead of whispered sounds or consonants, a switch is depressed by her wrist to bring this oscillator into play. Then the particular parts of the sound which are wanted are selected by playing the proper keys. Each key operates a variable attenuator to control the current in a definite frequency range. The source of current for each attenuator is an electrical filter which picks from the saw-tooth wave one particular group of its overtones.

The Voder, an outgrowth of fundamental researches, is based on a development by Homer W. Dudley of a speech synthesizer which is controlled electrically by a speech analyzer. (This was described in the RECORD for December, 1936.) It is an adaptation of that synthesizer with manual instead of automatic electrical controls. The first model was built in the Research Department by Messrs. Dudley, R. R. Riesz, R. L. Miller, and C. W. Vaderson. Its further development was carried out by F. A. Coles and E. H. Jones of the Apparatus Development Department. Meanwhile the difficult task of working out its linguistic possibilities and its technique of operation was undertaken by S. S. A. Watkins, who also developed a course of training for its operators.



Black keys for "g," "p," and "t"; one white key for "th" and "f"; the remainder of the keys control filter output

The Crossbar System

By R. C. DAVIS
Local Central Office Switching Development

THE crossbar switch* has given the Telephone Systems engineer a valuable tool for use in the complex problem of completing dial subscribers' connections. This tool has been found to have advantages in many respects over switching mechanisms used in other systems, but its application also has presented many problems. Both the step-by-step and the panel systems employ selectors for establishing a connection between two subscribers. These selectors are radically different both in their construction and their method of control, but they are alike in employing a brush or wiper that moves over a large number of terminals until the desired one is reached. The crossbar switch is not of this nature at all; it is a group of magnetically operated contacts, any desired one being made by the operation of two magnets in rapid sequence. Since there is no passing of a brush over a sequence of terminals, an entirely different method of controlling selections has been developed, so that the crossbar system differs from previous dial systems not only in the type of apparatus employed, but in the method of control.

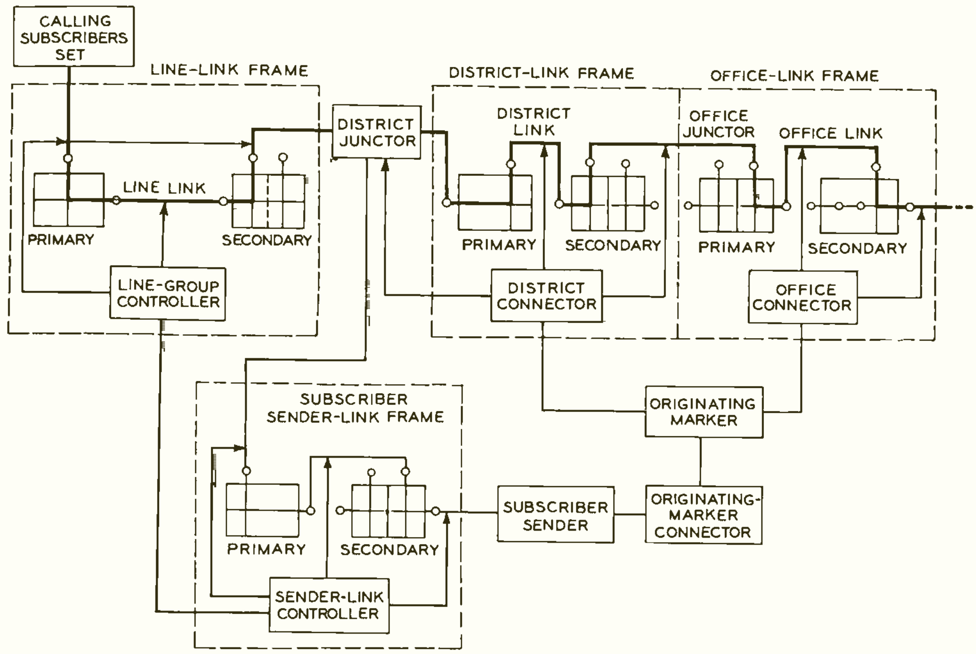
In the step-by-step system the operation of the subscriber line relay causes a line finder to connect itself to the line. The line finder has a first selector directly connected to it, and the first digit dialed by the subscriber causes the first selector to step vertically up to the level corresponding to the digit dialed, after which it rotates horizontally to find an idle trunk to a second selector. Each successive selection is made in this fashion with the selectors directly responsive to the subscriber's dial. In the panel system the operation of the subscriber line relay also causes a line finder to find the calling line and the line finder is directly connected to a district selector. In this system, however, a subscriber's sender is also connected to the line through the district selector and a link circuit, and the digits dialed by the subscriber are recorded in the sender. The sender then is connected through a connector to a decoder, which translates the office code into brush and group selections of the district and office selectors. The sender then proceeds to set up the call through the district, office, incoming, and final selectors to the called line, after which it is released. Control of these selections is over the trunk conductors which are later used for speech transmission.

The selectors in both the step-by-step and panel systems are provided with control equipment individual to the selector for selecting the brushes or groups of bank terminals and for moving the brushes over the terminals by impulse control, directly by the dial in the step-by-step system and by the sender in the panel system. Individual equipment is also provided in these selectors for moving their brushes over the terminals to hunt for

*Record, *July*, 1937, *p.* 338 and *June*, 1938, *pp.* 332 and 336.

idle trunks. This necessarily means that considerable equipment is provided in these circuits which is used for only a few seconds at most in setting up the connection; and since this equipment is individual to the circuit, it is not used again until disconnect by the subscribers takes place and a new call is set up. In the crossbar system, however, economic advantage is taken of the high-speed relay-like operating characteristic of the crossbar switch by putting all of the selecting and trunk-hunting features in a few common control circuits. This greatly simplifies the individual district and incoming trunk circuits, and entirely eliminates individual relay equipment in the crossbar circuits corresponding to the office and final selector circuits in the panel system.

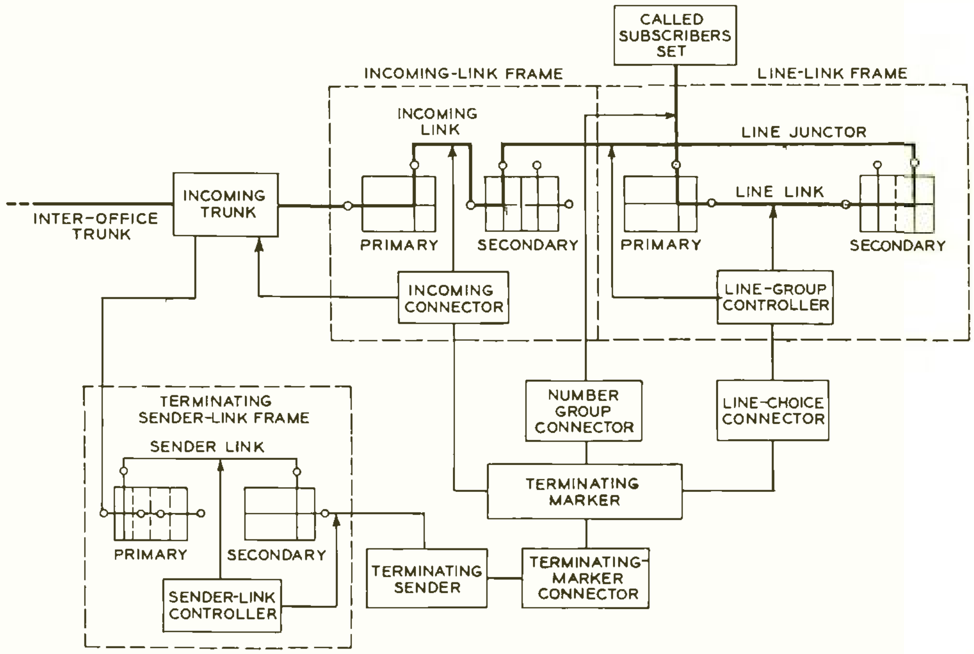
The switching frames of the crossbar system are known as the line link, the district link, the office link and the incoming link frames. The district, office, and incoming link frames perform the same switching functions as the district, office, and incoming selector frames of the panel system, but the line link frames are used for connecting the lines to districts on originating calls and for connecting the trunks from incoming frames to the lines on terminating calls, thereby performing the functions of both the line finder and final frames of the panel system. Each of these crossbar frames consists of primary and secondary switches. The connections from the primary to the secondary switches of the same frame are known as "links" and the connections between frames are known as "junctors." Each primary switch has links to each of its associated secondary switches, and the junctors outgoing from each district and incoming frame are distributed evenly over all office and line link frames respectively. Similar primary-secondary switching arrangements are used in the sender link frames for connecting subscriber senders to district junctors and terminating senders to incoming trunks.



The path of a subscriber-to-subscriber call through the various elements of the crossbar system is shown in the diagram. When the calling subscriber removes his receiver, the operation of his line relay actuates a line group and a sender link controller circuit, each of which is common to an entire frame. These controller circuits select an idle line link, district junctor, sender link, and sender, and operate the necessary select and hold magnets to establish the connections. Approximately 0.6 second is required to complete this connection, after which dial tone is sent to the subscriber, and the control circuits are free to serve another call.

The subscriber sender in the crossbar system is fundamentally the same as the panel subscriber sender except that it does not itself control the district and office selections. The sender picks an idle originating marker and passes the code of the called office as is done in the panel system, and in addition also passes other information on to the marker which will be needed by its added function peculiar to crossbar operation. This added function is known as a marker operation and consists of picking an idle trunk to the called office and then picking idle paths through the district and office link frames for connecting the district junctor to the trunk selected. When these functions have been performed the marker operates the proper select and hold magnets to close the cross-points and establish the connection to the selected outgoing trunk. After getting its check signal that the cross-points are properly closed, the marker is available for the next call that comes in. The marker completes its function in approximately 0.5 second.

After the district junctor has been connected to a trunk to the called office, which we will assume is a crossbar office, the subscriber sender closes a bridge across the trunk conductors, which operates the line relay of the incoming trunk circuit and causes



a sender link controller circuit to connect a terminating sender to the trunk through a crossbar link in a manner similar to that in which the line group controller circuit operates. When the terminating sender is connected to the trunk, the record of the called subscriber's number is transferred to it by the subscriber sender over the trunk conductors.

The terminating sender then passes the record of the called subscriber's number to a terminating marker, which in turn tests the called line for busy and, if it is found idle, picks idle paths from the incoming trunk to the subscriber's line in a manner similar to the connecting of the district junctor to the selected out trunk by the decoder marker. The marker makes the busy test and determines on which line link frame the line is located through a frame known as the Number Group connector frame, and then connects to the desired line link frame through a frame known as the Line Choice Connector frame. The subscriber sender is released when the record of the called number has been passed to the terminating sender, and the terminating sender and marker are released when the connection has been established. The marker completes its function in about 0.5 second.

There are a number of reasons why those engineers who have followed the development of the crossbar system feel that it will render a grade of service superior to any previous system. The switches themselves are provided with split springs equipped with noble metal contacts so as to provide double assurance of making contact. Practically all of the control relays used in this system are also equipped with the split-spring contacts. Experience shows that such contacts very greatly reduce circuit failures caused by contact trouble.

Marker operation, which is made especially attractive with this switch on account of its high speed of operation, is also an important element of the crossbar system. With this operating method it is possible to make a second attempt on many of the trouble conditions encountered, and on many such calls the connection can be established on the second attempt over another path with such speed that the subscriber is not aware that any trouble has occurred. In addition to serving the call on the second attempt, a record is made of the failure of the first attempt on a trouble indicator which attaches itself to the marker on all circuit failures. This trouble indicator will be of considerable aid to the maintenance man in quickly removing conditions causing circuit failures. In other dial systems where connections are established by moving brushes over bank terminals many time elements enter into the proper functioning of the system. Due to the simplicity of the crossbar switch itself and the marker method of operating it, many of these time elements are entirely eliminated. These factors are important in reducing maintenance effort.

In addition there are many new operating features in the crossbar system. With marker operation, the desired trunk or line is tested before the connection is set up, which permits rerouting the call when it is desirable to do so. This is advantageous for rerouting interoffice calls to alternate trunk groups through a tandem office where the regular group is all busy, and thus permits the use of smaller direct trunk groups by routing peak-load traffic through tandem. In the step-by-step and panel systems it is necessary to wire all unused subscriber line numbers to trunks to the intercepting operator, but in the crossbar system calls for unused line numbers are rerouted to intercept trunks merely by the absence of the regular jumpers on the line number terminals. It is possible to spread large interoffice trunk groups over all office frames, and large and busy PBX trunk groups over all line frames for better balancing of loads. The system can be introduced into a panel area without change in the connecting offices or subscriber sets.

The design of the crossbar switch and multi-contact relay is such that less adjustment is necessary after they are assembled. The crossbar switch frames can be equipped with all apparatus and wired and tested in the shop, by progressive straight-line manufacturing methods, thus completing a large proportion of the work before shipment to the job.

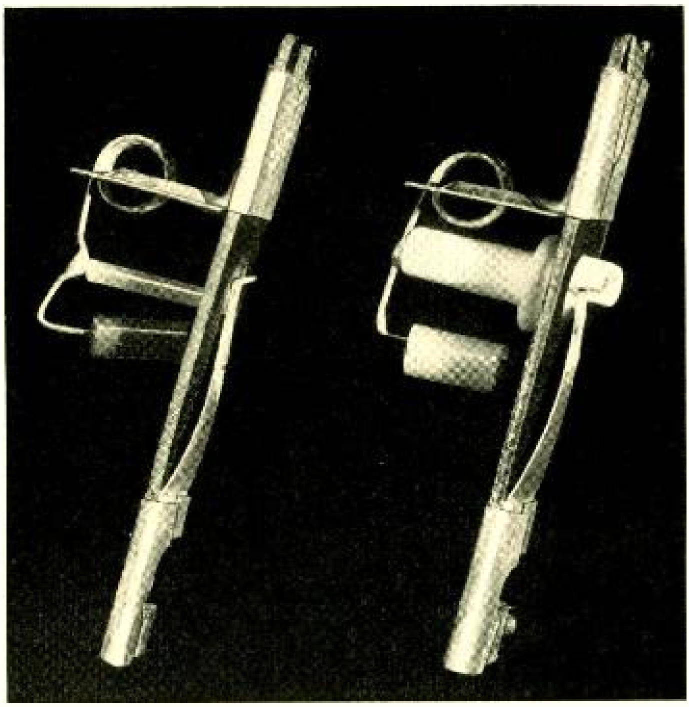
Because of the flexibility of the sender, decoder, and marker, and the simplicity of operation of the crossbar switch, together with its precious metal twin contacts, it is quite certain that the apparatus and the principles developed will find many uses in future switching problems.

"My God, It Talks!"

"In the closing days of the Philadelphia Exposition of 1876 Dom Pedro of Brazil stopped before Alexander Graham Bell's booth, put a telephone receiver to his ear, heard human speech and gasped in awe, 'My God, it talks!' Those who heard the Voder utter intelligible sentences—the first time that the feat has been performed by a machine which is not a mere recorder of sound—were undoubtedly similarly impressed. The scientists among them must have come away with a heightened respect for their own vocal organs and with the conviction that the greatest of all human inventions is language. Only a highly developed brain can perform the miracle of making throat, oral cavity, vocal cords, lips work together to shout a command or croon a cradle song. If men could not speak and sing, there would have been no Voder.

"The Bell physicists and engineers have reason to be proud of their strange instrument. College professors who still cherish the wrong idea about industrial research look upon them as hirelings whose sole function it is to make money for their corporation employers. But here they are devising not only new telephones but delving into the mysteries of human speech and hearing with a thoroughness and success never before even remotely matched. The result is that the final authorities on the mechanics of speech and hearing are not the laryngologists and otologists but the creators of telephones. Out of the effort to develop the crude instrument that overwhelmed Dom Pedro has come a richer knowledge of sound. Looked at in this way the Voder is something more than an interesting toy which will delight the tens of thousands who will visit the World's Fair and stand transfixed as skillful girls play upon keys and make electrical circuits respond with pleasantries scarcely distinguishable from those that come from living lips. Science has taken a day off to perfect a remarkable invention which is intended to amuse but which is actually the summation of decades of fine research."

—Editorial in the New York Times.



Telephone Alarm Fuses

By FRANK HARDY
Telephone Apparatus Development

ALARM fuses, sometimes called "grasshopper" fuses because of their acrobatic behavior, have been used for many years to protect telephone circuits against abnormal currents originating within the system. Early fuses of this type were designed for twenty-four and forty-eight-volt circuits, but higher voltages for vacuum-tube and telegraph circuits, and the increased capacity of storage batteries, have required the development of additional fuses to meet new requirements.

In fuses of the alarm type the fuse element holds under tension a coiled indicating spring to which a colored glass bead is attached, and a flat alarm spring. These are mounted on opposite sides of a fibre strip about 1⅝ inches long and ½ inch wide and connected by the fuse element through a hole in the strip. When the fuse blows, both springs are released. The indicating spring gives a visible signal by projecting the glass bead outward and the alarm spring makes contact with an alarm bus bar. This lights a lamp on the fuse panel and actuates a relay which in turn operates the central-office audible and visible alarm system. Glass beads of different colors are used to help identify fuses of different capacities and slots of different sizes for corresponding fuse posts minimize the chances of using fuses of larger capacity than required.

With the general usage of vacuum

tubes in the telephone system a demand arose for a low-capacity alarm fuse which would operate satisfactorily in circuits of 160 volts direct current. This called for some means of extinguishing the flash which could occur and blow adjacent fuses if the ordinary alarm fuse were used. Investigation showed that a glass sleeve mounted over the fuse wire prevented it from harming adjacent fuses. This modified fuse, the 35J, which has one-half-ampere capacity, is shown in the headpiece, at the left. The 35P three-quarter-ampere fuse, which is a more recent development, is identical except for capacity.

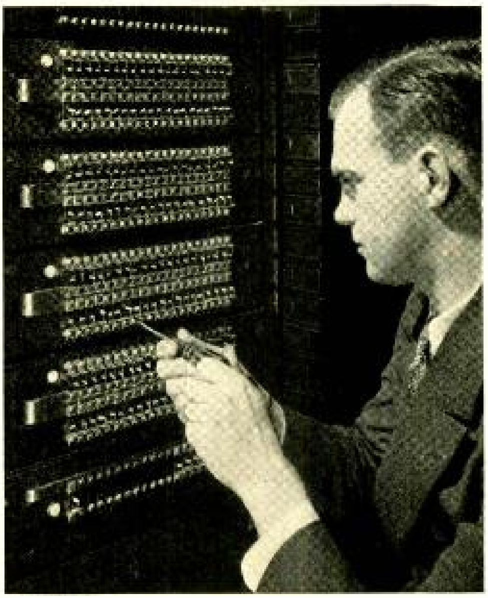


Fig. 1—J. Michal is shown replacing a blown alarm fuse. These fuses flip up a small glass bead as a visual signal and ring a gong at the time they blow

To simplify the fuse arrangements of power equipment for telephone exchanges, a demand arose for alarm-type fuses of higher capacity than the one-half-ampere 35J, which would operate satisfactorily on the short-circuit current from 150-volt storage batteries. This problem involved not only reducing the side flash, but also preventing an arc from forming between the terminals. With small-capacity fuses, the resistance of the wire element prevents the current from reaching an excessive value when a battery is short-circuited. Fuses of larger capacity, however, have proportionally greater cross-sectional area and the resistance of the element is correspondingly decreased. A fuse of five-ampere capacity may be called upon to open circuits with a short-circuit current of as much as 300 amperes because the total resistance of the circuit may be only a few tenths of an ohm. A fuse designed to operate under these severe conditions is shown in the headpiece, at the right. The fuse element is enclosed in a porcelain tube. A flange at the bottom forms a baffle between the tip of the alarm spring and the opposite terminal to prevent the establishing of an arc. Fuses of this description which will rupture satisfactorily the short-circuit cur-

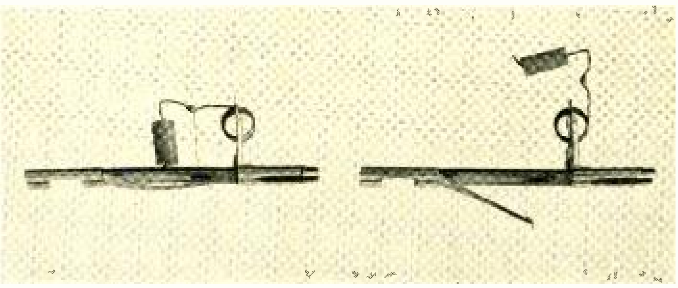


Fig. 2—An alarm fuse before and after the fine fuse wire has blown. As shown on the right, blowing releases the spring (above) which supports the glass bead and the one (below) which closes the alarm circuit

rent from 150-volt storage batteries are now available in capacities from one and one-third to five amperes.

A more recently developed fuse of the alarm type is the 35R, which is

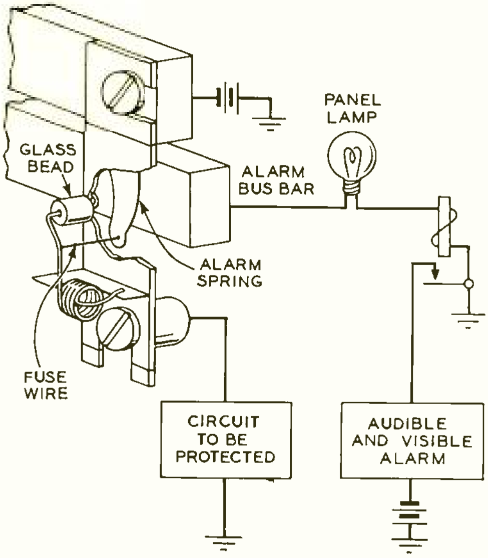


Fig. 3—When the fuse blows the alarm spring makes contact with a bus bar. This lights a lamp on the fuse panel and actuates a relay which in turn operates a centralized audible and visible alarm

designed for a capacity of only 0.18 ampere and will rupture the short-circuit current from 130-volt storage batteries. With the exception of the element the fuse is identical with the common alarm fuse. The fuse element required special development to meet the condition that it be capable of being soldered and able to withstand, without stretching, a constant tension of 70 grams applied by the fuse springs. Tests showed that the element would have to have a minimum tensile strength of 230 grams to avoid breakage during manufacture, and sufficient ductility to withstand wrapping around the indicating spring. If made of Advance wire or copper-nickel resistance wire, which is used in most other alarm-type fuses, an element for the 0.18-ampere fuse would have a tensile strength of only about fifty grams and would be too fine for commercial handling. Although some materials showed promise, wire made of them was brittle, could not be soldered or was sufficiently affected by atmospheric conditions to cause breakage. An investigation showed that Nichrome wire could be drawn by special methods so that it would be three times as strong as commercial Nichrome wire, without materially affecting its brittleness. This met the requirements. A protective sleeve is not needed over the element of this fuse to prevent side flash or arcing because its high resistance, approximately 6.6 ohms, limits the maximum current when the fuse blows to a reasonable amount, and the fineness of the wire provides little material for volatilizing and establishing an arc.

Long-Distance Conference System

By H. A. ETHERIDGE
Toll Transmission Development

A NEED often arises for a conference between several people located at widely separated points. If all could be simultaneously connected together by telephone the conference could be quickly held at a considerable saving in time and money. To provide standard equipment enabling this service to be given quickly and economically, a toll-conference system has recently been developed by the Laboratories.

It might seem off-hand that conference service could be given simply by connecting the telephone lines together; but there are several reasons why this cannot be done. One is that the power flowing from the talker's telephone divides among all the connected lines, and thus each receives less than it normally would. For this reason it is not generally desirable to use more than the two telephones for any one call unless special provisions are made. While on some very short circuits the added loss would not be serious for a single extra telephone, it rapidly becomes so as the number of connected instruments is increased. It is not difficult to overcome this loss by the addition of properly connected repeaters and they form a regular part of the new conference system.

A much more serious difficulty is the disturbing effect of echoes. Just as sound echoes always occur whenever sound waves traveling in air meet some object which differs from air in its ability to transmit sound, so electrical echoes occur whenever the electrical waves traveling along telephone wires meet some line discontinuity or piece of apparatus that has different transmission characteristics. There is always such apparatus in any telephone line, particularly at repeater stations and at terminals. Also, these echoes become more serious as the distances involved and consequently the delays in the echo path become greater. By careful design and some-

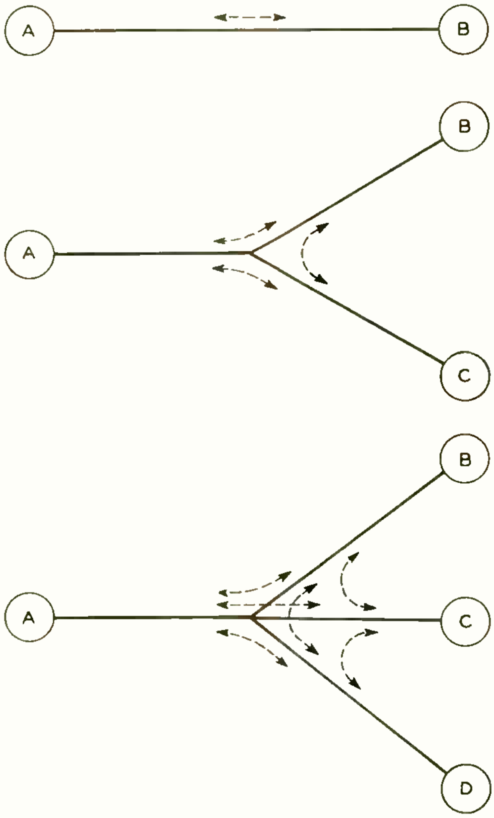


Fig. 1—Echo paths multiply rapidly as the number of connected lines increases

times by the use of echo suppressors the echoes are held to values that are unobjectionable between two terminal telephones on the usual toll connection, and for the most part subscribers are not conscious that these echoes exist.

When several lines are connected together the number of echo paths is greatly increased, and as a result the total volume of echo increases rapidly. Also, echo paths of greater delay become more important. This is illustrated in a simple manner in Figure 1. The upper sketch shows only two telephones in the circuit, and a talker at A may receive only a single echo caused by reflection at B. With three telephones, as in the central sketch, there is an echo path from A to B and back to A, and from A to C and back. There are also multiple-circuit paths by way of A, B, C and A, or by way of A, C, B and A. With four telephones, as in the lower sketch, there are three simple paths—to B and return, to C and return, and to D and return; but there are a large number of multiple paths, such as A, B, C, A; A, C, D, A; A, B, C, D, A; and so on. These large numbers of echo paths would soon make the circuit unusable, and therefore the provision of a conference arrangement for interconnecting a large number of telephone circuits without serious trouble from echoes is difficult.

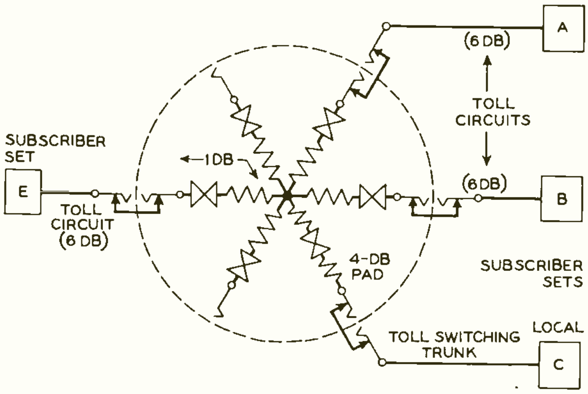


Fig. 2—Schematic representation of the toll-conference bridge

The toll-conference system is based on a grouping or "bridging" circuit that will connect six lines together. In simplified form, the arrangement can be shown as in Figure 2. Each of the six branches includes a resistance and a repeater. In designing this circuit an extensive study has been made of possible echoes and their effect on transmission. With a six-branch system such as this, there are five two-circuit echo paths, twenty three-circuit paths, and a rapidly increasing number of paths as the number of circuits traversed increases. The number of ten-circuit paths is more than one million.

It would be desirable to operate such a conference bridge at zero loss, or even at a net gain. A study of the echo situation, backed up by actual experience, has shown that for six outlets a loss per branch of about 1 db is about the minimum that can be employed with the present toll plant. This gives an added loss between any two subscribers of 2 db, but under these circumstances it is advantageous to accept this loss since it is very effective in reducing echoes. The reason is that while the direct-voice current undergoes the loss but once in passing from talker to listener, the echo undergoes it twice even for the simplest echo path back to the talker. For the multi-circuit paths, the echo has to suffer this amount of loss for each circuit traversed.

Each of the six branches of the conference bridge is arranged as shown in Figure 3. On the switchboard side of the repeater there is a switching pad L, and a termination T, which are designed to be cut into or out of the circuit by relays. The pad is removed when the branch is connected to a toll circuit, and is inserted when it is connected to a local circuit. The termination is connected across the branch only when no connection is made to it. The purpose of the pads is to equalize transmission between subscribers to a certain extent, and also to reduce impedance variations, while the termination serves to terminate an idle branch in its proper impedance. The gain of the standard two-wire repeaters is adjusted so that the outlet-to-outlet loss is 2 db when the switching pads are cut out.

This circuit has been carefully designed to reduce echoes. The 600-ohm nominal impedance of the bridge is one of the means taken, since the circuits to which it will be connected have this nominal 600-ohm impedance, and it is at changes in impedance that reflections occur. Another step is to reverse the connections to the hybrid coil of alternate branches at the switchboard's ends. This reverses the phase of the reflected currents and tends to annul certain of their effects.

Although a six-branch bridge was selected as being adequate to handle a large part of the conference demands, there are times when more than six connections are desired. Under these circumstances two of the bridge circuits are connected together. This has the effect so far as echoes are concerned of increasing the number of branches to the bridge circuit, and thus requires additional steps to reduce the echoes.

To accomplish this a voice-operated device called a volcas has been developed. The word is formed from the initial letters of the words "voice-operated loss control and suppressor." This device, shown schematically in Figure 4, consists essentially of voice-controlled relays that cut out a moderate loss in one direction and insert a larger loss in the other when speech reaches it. When no current is being received, resistance shunts R1 and R2 are connected across the monitoring windings of the output coils on each side of the associated repeater, thus introducing a loss of about 3 db each. When speech currents are received, say from east to west, they flow to the EW amplifier-detector and thence through windings on relays ME and MW. The windings on these relays are so designed that this cur-

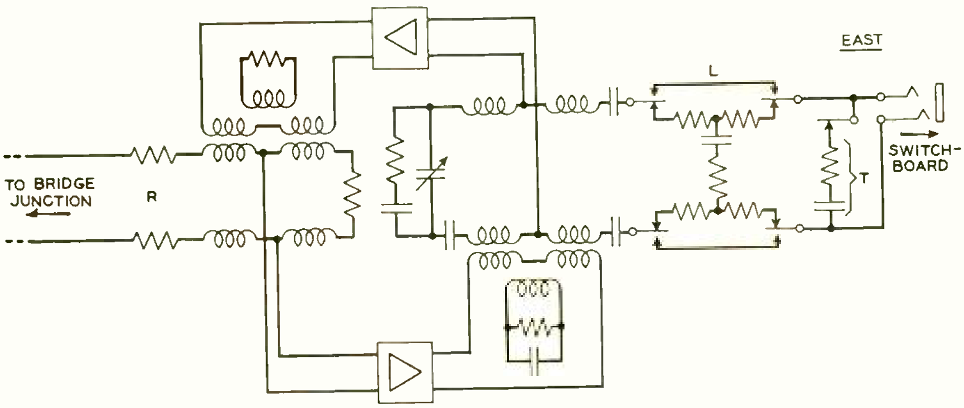


Fig. 3—Schematic diagram of a single-bridge branch

rent operates relay ME and biases relay MW so that it will not operate should current flow through its other winding. Operation of ME, in turn, operates HE, which removes the 3-db loss in the EW path, and by connecting R4 across the WE path increases its loss by 10 db. The operation of HE also short-circuits the WE amplifier-detector. When east ceases talking, the relays return to the unoperated positions, and when west begins to talk, a similar set of operations will remove the 3-db loss in the WE path and increase the loss by 10 db in the EW path. Thus echoes through the volcas-equipped branch are greatly reduced.

In general it is expected that each conference bridge will be equipped with a volcas in two of its branches, although at important centers more branches may be equipped. When two or more of the conference bridges are to be connected together over a toll line, they are joined through the branches equipped with volcases. The effect of the volcases is essentially to isolate the bridges from each other, so that the echoes remain about the same as with a single bridge. Also, the gains of the volcas-equipped branches are different from the non-equipped branches and are such that the loss of the interconnecting toll circuit is neutralized and the transmission between all subscribers on the circuit is the same as if they were connected over a single bridge.

To set up a conference connection, the subscriber asks for the toll-conference operator, and gives her the names or numbers of the telephones he wants included. They are called, notified of the desired conference, and asked either to hold the line or to remain near their telephone. To enable the subscribers to be connected together at the same time, a holding and disabling feature is provided in the standard circuit. This includes a special jack at the switchboard into which the toll line of the first subscriber reached is connected. The insertion of the plug into this jack short-circuits the bridge so that as the other subscribers are connected to it, talking cannot proceed. After all have been connected, the plug of the first subscriber's circuit is removed from the holding and disabling jack and inserted in the bridge jack, and the conference begins.

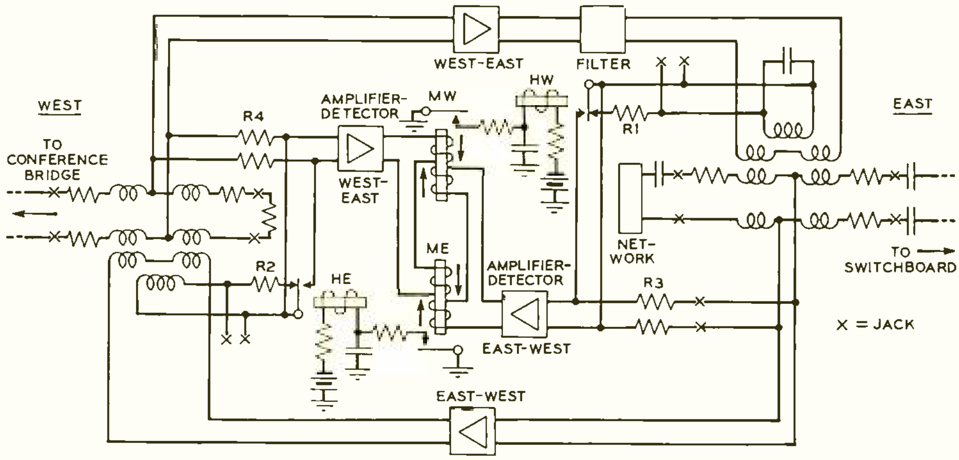


Fig. 4—Simplified schematic of the volcas circuit

Crosstalk Balancing for the Type-K Carrier System

By LESTER HOCHGRAF
Noise Prevention

THE application of carrier channels to conductors in existing toll cables has introduced many new problems in the prevention of crosstalk. Previously the cables had been arranged exclusively for voice-frequency channels. By careful construction of the cable and associated apparatus, and matching of the quads at splices, both near-end and far-end crosstalk at voice frequencies have been kept within limits permitting the operation not only of two-wire circuits but of four-wire circuits with both directions of transmission in the same sheath. Crosstalk increases rapidly with increasing frequency, however, and for the type-K system, with an upper frequency of 60,000 cycles, different methods for its control are required.

Between each pair of a cable and every other pair there is both a capacitive and an inductive coupling. If the conductors of the pairs were laid parallel to each other and to the wires of other pairs, the crosstalk resulting would be so large as to make the circuits unusable. Actually, however, the conductors of a pair are twisted together, which has the effect of continuously changing the relative positions of the wires of a pair so that the current induced in a short length is opposed by the current induced in the opposite direction in the next short length. Under ideal conditions there would be no crosstalk, because crosstalk currents induced in one wire of a circuit would be exactly offset by those induced in the other. This ideal condition is never attained, but the crosstalk is greatly decreased by the twisted construction. A further reduction is obtained by using a number of different lengths of twists which are not multiples of each other. Additional compensation is obtained by measuring certain of the unbalances and splicing in such a way as to have the unbalances over one section counteract those over an adjacent one.

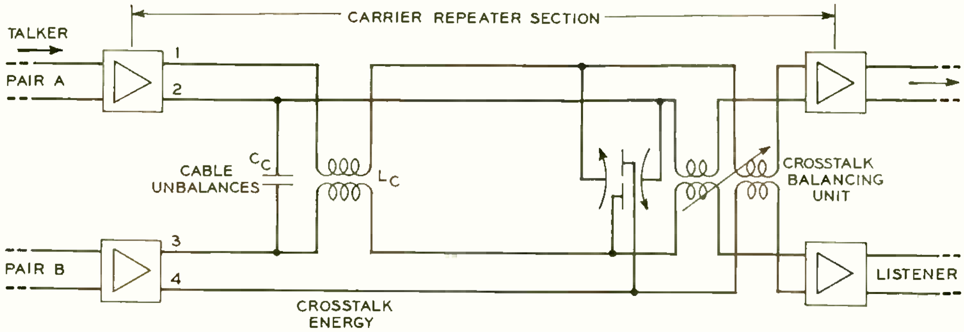


Fig. 1—Schematic representation of far-end crosstalk and its method of balancing

It is as a result of such methods as these that the crosstalk of voice-frequency cables is held within satisfactory bounds. There still remain residual unbalances because of imperfect stranding, and irregularities in the relative positions of the pairs in the cable. These unbalances cannot be completely eliminated, and if uncorrected they would be large enough to make carrier channels unusable. A distinctly different solution of the problem was needed and studies were made of all factors to determine how the problem could best be met.

In general, the crosstalk is of two kinds: near-end and far-end, near-end being heard at the same end of the circuit as the talker and far-end at the distant end. The limit for the near-end coupling is much more severe than for the far-end coupling. It was found impractical to reduce the near-end

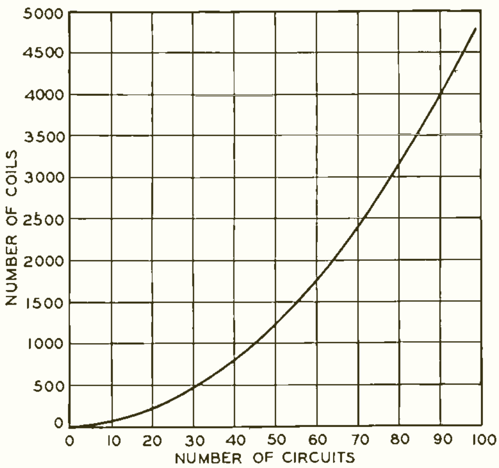


Fig. 2—The number of balancing units required increases approximately as the square of the number of circuits

coupling within existing cables enough to meet the crosstalk requirements. Since the type-K is a four-wire system, however, the pairs for opposite directions of transmission can be placed either in different cables or in separate shielded compartments in the same cable. Both of these arrangements are in use, and as a result the near-end crosstalk is made negligible by the shielding. Within the cable, therefore, it is only far-end crosstalk that must be contended with.

The situation existing between two pairs of a cable for one repeater section is shown in Figure 1. There is, of course, different capacitive and inductive coupling between each wire of pair A and each of pair B and the variations of these couplings are random along the length of the circuit. For the moment, imagine that Figure 1 represents a very short length of cable. The net capacitive and inductive unbalances between the two pairs may be represented respectively by a single condenser and a single mutual inductance between a wire of pair A and a wire of pair B. It is assumed for this particular illustration that the condenser is between wires 2 of pair A and 3 of pair B, and that the mutual inductance is between wire 1 of pair A and wire 3 of pair B. These net couplings are indicated by C_c and L_c. The crosstalk balancing unit, shown at the right of the section, provides both capacitive and inductive coupling between the two pairs. It is possible to adjust the balancing unit so that a net excess of capacitive coupling will exist between wires 1 of pair A and 2 of pair B, and between 2 of pair A and 4 of pair B, so as to neutralize exactly the coupling C_c. A similar adjustment of the inductive coupling would complete the balancing of the pairs. Of course, it would be possible to provide a large number of balancing units distributed along the length of the pairs, but since far-end crosstalk only is to be balanced it is possible to make a great reduction in the number of balancing units required to compensate for the cable unbalances.

With similar pairs, the crosstalk currents travel down the line along with the inducing currents, and thus suffer the same attenuation and phase shift. Crosstalk induced at the beginning of a section, for example, may readily be corrected at the end of the section, since, although the inducing current will have been attenuated and shifted in phase at the end of the section, the induced crosstalk will have been similarly attenuated and shifted. It is therefore possible to make one balancing unit compensate for the algebraic sum of all the unbalances in a repeater section, and the net cable unbalance shown in Figure 1 represents the algebraic sum of all the cable unbalances in the carrier repeater section.

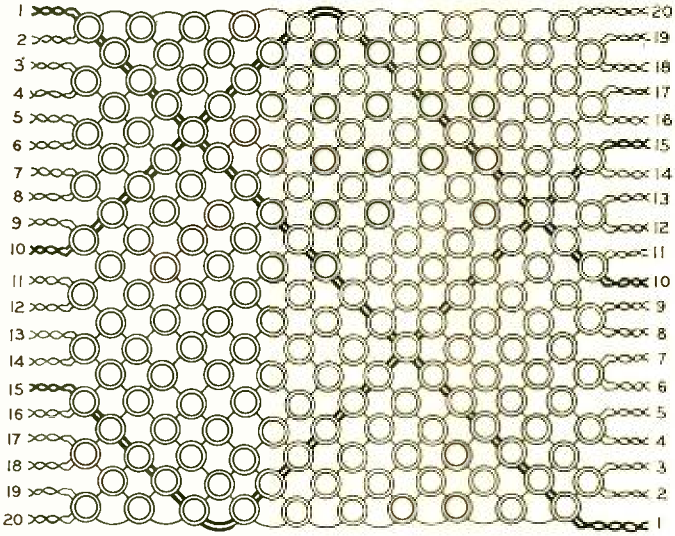


Fig. 3—Schematic arrangement of coupling units in the complement for 20 circuits

Such a system was tried on an experimental line near Morristown, New Jersey, and it was found possible to reduce the crosstalk over the type-K frequency range by 20 db. This is more reduction than is needed for the number of circuits anticipated, and since the system is an elaborate one at best, it seemed desirable to take advantage of the excess improvement by introducing some simplification. The relative amounts of crosstalk caused by capacitive and inductive unbalance varies with the voltage of the circuit. On the comparatively high-voltage, high-impedance, voice-frequency circuits, the capacitive coupling is predominant. The type-K circuits, however, are of much lower impedance and thus of lower voltage than the voice circuits, and as a result, the inductive coupling becomes dominant. It was found by actual test that while correction by capacitive coupling alone would give only 11 db improvement in crosstalk, correction by inductive coupling alone would give 16 db. As a result it was decided to simplify the crosstalk balancing units by using inductive coupling alone, and suitable units have been designed and built for the first field trial of the type-K system.

Each is a four-winding adjustable unit for balancing the couplings between two pairs. The number of units required for each repeater section goes up almost in proportion to the square of the number of pairs, as shown in Figure 2. For 100 circuits, which is the largest number planned for the present time, 4,950 coils would be needed. Where only a few type-K circuits are to be employed, it would obviously be uneconomical to provide

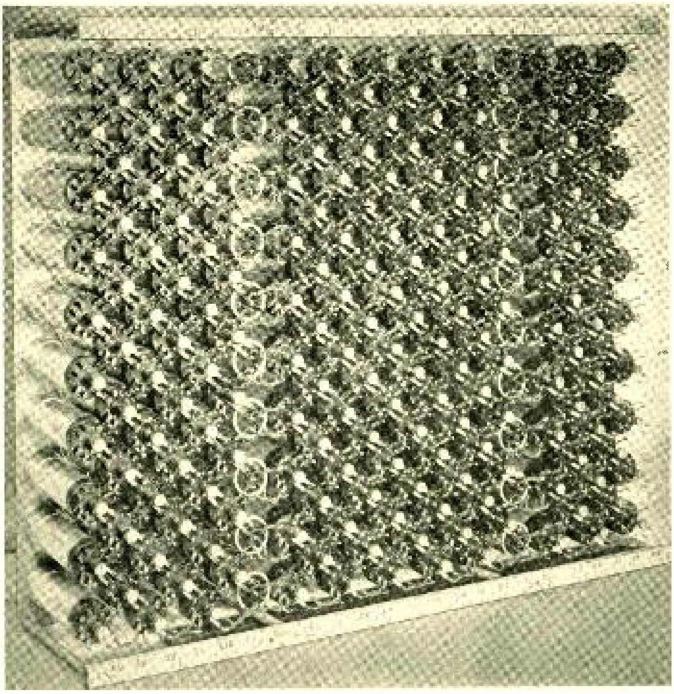


Fig. 4—A complement of 200 coupling units for balancing a group of twenty circuits

groups and ten of the 400-unit groups.

As mentioned before, the position of the coupling units in the repeater section makes little difference if there is a good impedance match between the line and the repeaters at the ends of the section. For the Morristown trial, the coupling units were actually located at the middle of the section because otherwise the comparatively poor impedance matches at the ends of the section would have introduced additional crosstalk because of reflection. Before the first commercial trial, however, the impedance match was improved, and the coupling units on all commercial circuits are installed at the ends of the sections where they can be housed in the repeater building.

coils for the full 100 circuits at the time of the initial installation, and as a result the balancing units have been arranged in two sizes of groups—one of 200 and one of 400. To balance a group of 20 pairs, there must be 19 units connected to each pair, and thus 190 altogether. The 200-unit group will thus handle 20 pairs. The purpose of the extra 10 coils is described on page 190. Forty pairs would require 780 units; two 20-unit groups would handle the balancing of each group of 20 pairs among themselves, and a 400 group would handle the balancing between pairs of the two groups of twenty pairs, since each pair of a group would require twenty coils to balance them against the twenty pairs of the other group. This same scheme is carried out as the number of pairs increases; 100 pairs would require five of the 200-unit

The coupling units themselves, however, produce a phase shift, and although the shift is small per coil, the total will take on quite appreciable values because of the large number of units connected to a particular pair. It is important, therefore, that they be connected to their respective pairs so that the phase shift suffered by the inducing current up to the point of coupling is the same as that suffered by the crosstalk that it is to offset.

In a group of twenty pairs, for example, each pair will connect to nineteen coupling units—one to link it with each of the other nineteen pairs. If each of these units produces a phase shift of θ degrees, the current will have been shifted 19 θ degrees after leaving the last one, while after leaving the first one it is shifted only θ degrees. To assume the worst case, suppose the first unit on pair 1 coupled it to pair 20, and that pair 20 passed through all its other eighteen units before it reached the one coupling it to pair 1. At the entrance to the group of coupling units the signal current in pair 1 will be in phase with the crosstalk current induced by it in pair 20 because both have passed over the same length of line. The crosstalk current, however, will be shifted by 18 θ degrees before it reaches the unit coupling it to pair 1, while the signal current which is to compensate it will not have been shifted at all, since it acts through the first coil in line 1. There will thus be 18 θ degrees difference in phase between the correcting current and the crosstalk current, and the correction may be ineffective.

It is desirable, therefore, to devise some connecting scheme for the coupling units so that the current in each pair when it reaches a particular unit will have passed through the same number of units as the crosstalk current in the pair to which that unit couples it. No way has been found of meeting this desired end perfectly, but the scheme employed keeps the number of units equal, or within one of being equal, for all pairs. The arrangement is indicated schematically in Figure 3. Here the circles represent the coupling units—each of which couples two lines together. The units are assembled compactly on a rectangular frame as shown in Figure 4, and are strapped together with short connections.

Where there are more than twenty pairs, this equality of coils passed through by the inducing and crosstalk currents must be maintained for the entire assembly of 200- and 400-coil groups. Arrangements have been worked out for accomplishing this for any number of lines up to 100. The 200-coil groups require a panel about thirty by thirty inches, and the 400-unit complement, a panel about forty-two by forty-two inches. They are mounted in steel lockers, each holding two of the larger and one of the smaller complements. Such a cabinet is shown in Figure 5.

To adjust the coils an actual crosstalk coupling measuring circuit is set up. An oscillator, representing a talker,

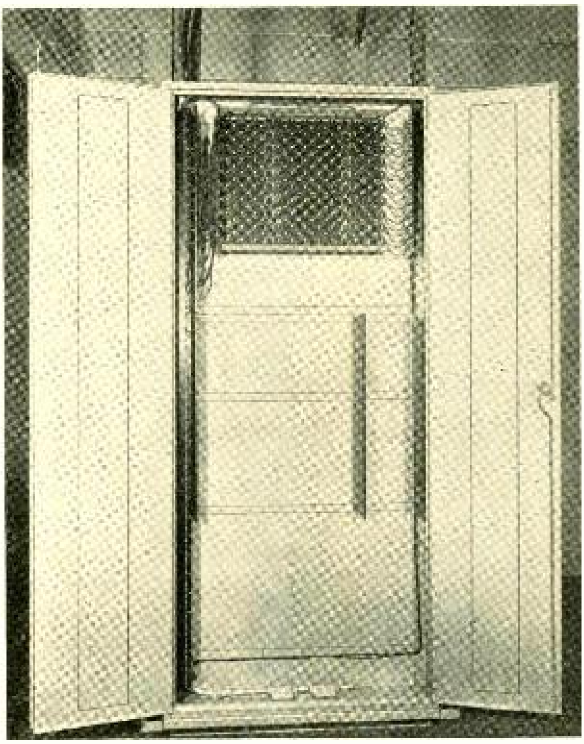


Fig. 5—A cabinet for holding two 400-coil complements and one 200-coil complement

sends on one pair from the cable terminal of one carrier repeater section through to the other terminal. On a second pair a detector amplifier, representing a listener, receives the crosstalk at the distant terminal and indicates the crosstalk magnitude by meter to a man stationed in front of the balancing coil panel. If the oscillator were sending on pair 1 and the receiving amplifier were plugged in on pair 2, the man adjusting the units would change the coupling of the coil numbered 1-2 until the minimum crosstalk setting is reached as indicated by a reduced reading of the meter. The receiving amplifier is then plugged in on pair 3, and coil 1-3 is adjusted for minimum crosstalk, the adjusting thus proceeding from coil to coil until all the combinations in one panel have been completed. A frequency is chosen for the sending oscillator which lies between two of the channels of the type-K system to enable the adjusting to be done while other pairs in the same cable have carrier circuits in operation.

Since in the existing cables the wires are usually laid up into quads, the two pairs comprising a quad are in very close relationship and, in general, have much higher crosstalk than other pair combinations. This crosstalk has been reduced by a splicing procedure known as "poling" described in an accompanying article*, but even with this reduction the crosstalk still tends to be larger than other pair combinations. For this reason each group of twenty pairs is provided with ten additional coupling units to provide an extra one for each of the ten quads. It is for this reason that the small complements have 200 coils instead of 190, which would be sufficient to provide one coupling between each pair and any other. Thus, if one coil does not have sufficient coupling to compensate for the high crosstalk on these combinations, the adjuster goes to the second coil with the same combination number and brings the crosstalk down to a minimum by using the combined coupling of two coils.

With the adjustments completed, a check run is made at a different frequency, and if the crosstalk is satisfactory the coils are locked in adjustment and the locker closed. It is expected that only when cable trouble has made it necessary to replace a section of the cable will it be necessary to readjust the coils.

*Page 191, this issue.

Crosstalk Poling for the Cable Carrier System

By F. W. AMBERG
Noise Prevention

TO meet the more severe crosstalk conditions arising from the application of carrier frequencies as high as 60,000 cycles to existing voice-frequency cables, a number of new methods of crosstalk control have been required. The new type-K system employs a four-wire circuit, and one of the basic changes is to route the pairs for each direction of transmission in separate cables. Where the traffic does not warrant two cables, separate shielded compartments within the same sheath may be used for the two directions of transmission. Where quadded cables are used for carrier, the phantom circuit, derived from the two pairs of the quad in voice-frequency practice, is not used, and thus the more difficult crosstalk conditions associated with phantoms are avoided. Additional improvements required for pairs in the same cable or compartments is secured by two methods used jointly; the first method, described in an accompanying article on page 185, is known as crosstalk balancing, and the other, as crosstalk poling.

The need for two methods arises from the fact that existing toll cables are composed of quads rather than of pairs of conductors. A quad consists of two pairs twisted together. A "side" circuit is obtained from each of the pairs and a "phantom" circuit from the two pairs in combination. Phantom circuits are not used for carrier operation because their transmission characteristics are inherently different from those of side circuits, and because crosstalk couplings involving phantom circuits are much greater than those involving side circuits only. Because of the twisting to form the quad, however, the two side circuits are closer together throughout the length of the cable than are the pairs of different quads, and, as a result, the crosstalk between them is greater.

Crosstalk improvement by balancing employs small transformers to couple every type-K pair of the cable to every other, and the large number of them required makes it very desirable to have them all alike and as small as possible, so that they may be manufactured economically. The more crosstalk reduction they must provide, the larger they must be, however, and if they had to be large enough to correct for the crosstalk between the side circuits of a quad they would have to be much larger than if they had to correct only the crosstalk between the pairs of different quads. Since there are 190 pair-to-pair combinations in a group of ten quads, only ten of which are side-to-side, it would be very uneconomical to allow the side-to-side requirements to determine the size of the 190 coils. Because of this situation it seemed advisable to use crosstalk poling to reduce the crosstalk between the side circuits of a quad to about the same value as that between pairs of different quads. As a result of the poling, the crosstalk reduction provided by the balancing coils need be only about sixty-five per cent on the average of that which would be required without poling. Poling is naturally less effective in some repeater sections than in others. To insure, therefore, that satisfactory crosstalk results can be obtained in all sections, two balancing coils are provided for each side-to-side combination, making a total of 200 coils for a ten-quad group. If a new type of cable were developed especially for the type-K carrier system, it might be possible to avoid poling, but present plans indicate that the type-K system will be largely applied to existing quadded cables.

Crosstalk from one pair to another is induced by the magnetic and electric fields that interlink the pairs, and in general there is some crosstalk due to each type of induction. Moreover the crosstalk current of both types may be either positive or negative, that is, it may be flowing in either direction around the circuit. Crosstalk poling consists in measuring the side-to-side crosstalk of each quad in a repeater section from each repeater station to the mid-point, and then in re-splicing the quads at the mid-point in such a manner that the crosstalk in one half section tends to neutralize that in the other. Since the conditions may be different for the two kinds of

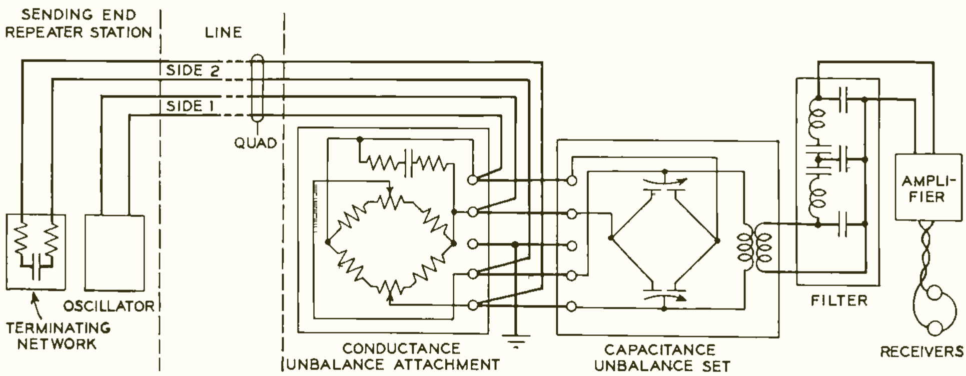


Fig. 1—Schematic diagram of the measuring circuit used for crosstalk poling

Fig. 2—Crosstalk poling as actually carried out in the field

crosstalk, poling will not in general eliminate all the crosstalk, but by selecting the type of crosstalk that is predominant for that quad, a very considerable reduction is possible.

The method of measuring is indicated schematically in Figure 1. Each repeater section is divided into two approximately equal sections, with the measuring equipment in the middle. This equipment consists of a capacity unbalance set and a conductance unbalance set, with which the two components of the unbalance between the side circuits may be measured. At the end of the section being measured, one of the side circuits of the quad is connected to an oscillator, and the other is terminated in its characteristic impedance for the test frequency. Instead of using a carrier frequency for these measurements, 850 cycles is employed since this simplifies the testing apparatus required and permits the use of existing apparatus units. The unbalance is essentially the same as it would be at the carrier frequencies, so that there is no appreciable loss in overall effectiveness of the poling method. Noise, however, will be present on the test pairs due to cross-induction from voice-frequency circuits in the same cable. To prevent this from causing difficulty in securing a balance, a narrow-band filter is employed in the test set, which eliminates most of the undesirable disturbances.

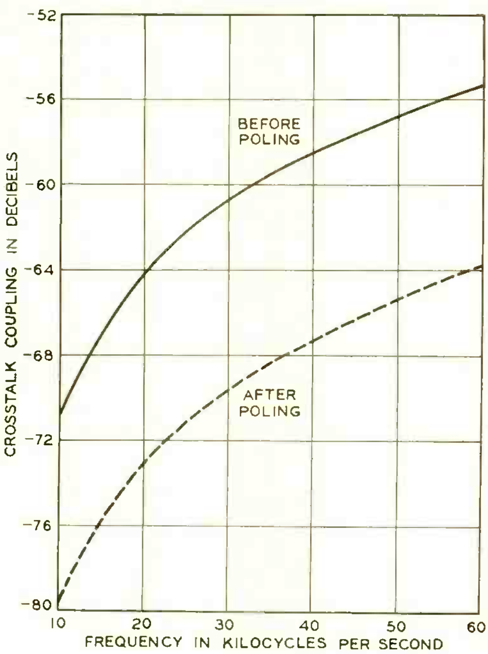


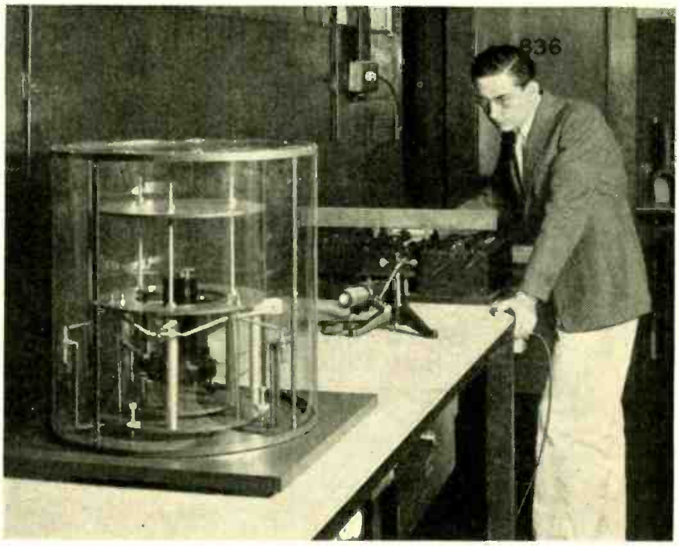
Fig. 3—Results of side-to-side crosstalk measurements before and after poling on the cables between Toledo and South Bend

The measurements consist in adjusting the two unbalance sets until no tone is heard in the receiver, the sensitivity of which is increased by the use of an amplifier. The readings of the two unbalance sets then give the magnitude and sign of the two types of crosstalk coupling. After measurements have been made over one half section, similar readings are made over the other. The measurements for each half section are then compared and quads selected for splicing that have approximately the same unbalance. In splicing them together, the side circuits are connected so that the crosstalk in one half of the repeater section is opposite in phase to that in the other, thus reducing the crosstalk. If the crosstalk in the two halves is of opposite phase, the wires of both pairs are spliced without transposition, i.e. tip to tip and ring to ring, while if the crosstalk is of the same phase the wires of one pair are transposed, i.e. tip to ring and ring to tip. For certain side-to-side combinations the magnetic component may be predominant while for others the electric component may be most important. A particular poling scheme, therefore, may not reduce both types of crosstalk in the same degree. In such cases that poling scheme is used which will reduce the predominant component, thus resulting in the least crosstalk at carrier frequencies.

As shown in the photograph at the head of this article, these measurements are generally made on the ground near a cable splice that has been opened for the measurements. Figure 2 shows a splicer on an aerial cable being given splicing instructions. After the quads have all been connected together in accordance with the splicing plan determined from the results of the measurements, check measurements are made by sending at one repeater station and receiving at the other. These reveal any errors in splicing that have been made and permit them to be corrected. As a result of this poling, the crosstalk between the two side circuits of quads is reduced by about 9 db over the frequency range that is employed for the type-K system, as shown by Figure 3.

The Lawrence Sperry Award for 1938

has been awarded by the Institute of the Aeronautical Sciences to Russell Conwell Newhouse of the Radio Development Department "for the development and first practical application of the terrain clearance indicator"



Anti-Vibration Support for Sensitive Portable Galvanometers

By W. S. GORTON
Physical Research

ANTI-VIBRATION supports are a necessity for sensitive galvanometers whenever these instruments are to be used in laboratories which are subject to mechanical shocks. Most widely used is the Julius suspension in which the galvanometer rests on a platform hung by three wires from the ceiling. This arrangement protects against horizontal vibrations; where vertical vibrations must be considered, helical springs replace the wires. In these Laboratories the most successful support is that shown in Figure 1; it consists of a series of triangular iron frames connected by crossed helical springs which are damped by a wrapping of friction tape. These hanging supports, while effective, are heavy, bulky and relatively immobile. To meet a need for a compact and easily portable support there was developed a new design which embodies results of recent experience in investigating vibration in central-office apparatus.

Since vertical vibrations are usually not directly harmful the new support was designed to protect the galvanometer chiefly against horizontal vibrations. This is done by making the natural frequency of vibration in the horizontal direction considerably less than that of the vibrations to be guarded against. The method of suspension finally adopted is shown schematically in Figure 3. Its essential features are the support of the galvanometer platform on three steel rods*, each pointed at both ends, and the stabilizing of the platform by helical springs. Three of these springs are connected radially between the plat-

*Theory requires the rods to be so shaped that the upper point of each is a center of percussion with respect to the lower point. In practice, the mass of the galvanometer and platform is so large compared with that of the rods that this requirement is of negligible importance.

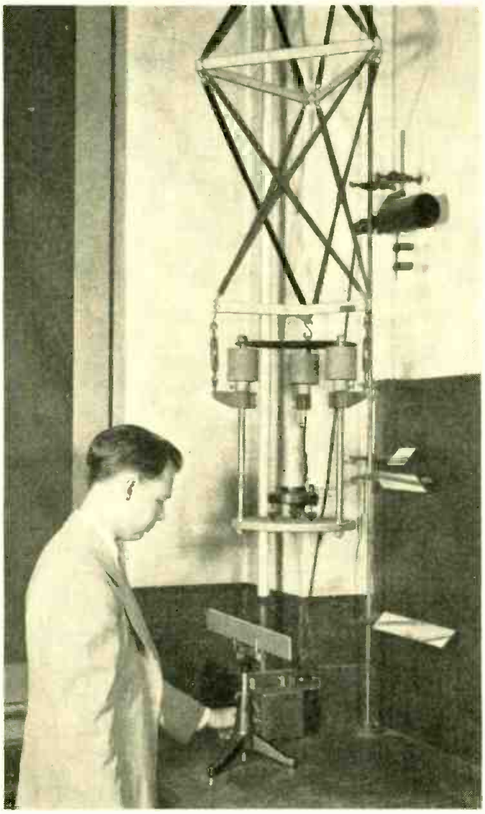


Fig. 1—A. W. Treplow observing with galvanometer suspension frequently used in Bell Telephone Laboratories

form and vertical supports, and other springs are arranged in pairs tangentially. A natural frequency of 0.3 cycle per second can be obtained without making the equilibrium too delicate. A low natural frequency in the horizontal direction can also be obtained by resting the platform on the upper ends of three thin rods of suitable dimensions with clamped lower ends, but the present arrangement was chosen because of its greater compactness and the greater flexibility in design and adjustment that are thereby attained.

Damping is secured, without the use of liquids, by having a camel's-hair brush rub on the galvanometer platform—a device which has long been successful in marine galvanometers. To secure the greatest possible freedom from disturbances tending to tip the galvanometer, the point of suspension of the moving element should be at the center of mass of the galvanometer and its supporting platform. A sheet of sponge rubber about ½ inch thick is put under the whole arrangement to diminish shocks which might otherwise break the suspension of the moving element of the galvanometer. No other protection against vertical vibrations has been necessary.

This support has been found satisfactory where building vibration was considered exceptionally bad. With the scale one meter from the galvanometer no motion of the spot greater than 0.1 millimeter could be detected. These tests were made with a sensitive galvanometer having a period of five seconds. The support has also protected satisfactorily a high-sensitivity ballistic galvanometer with a period of twenty-five seconds.

When the support was on a bench on a concrete floor, the galvanometer was unaffected by movement in the

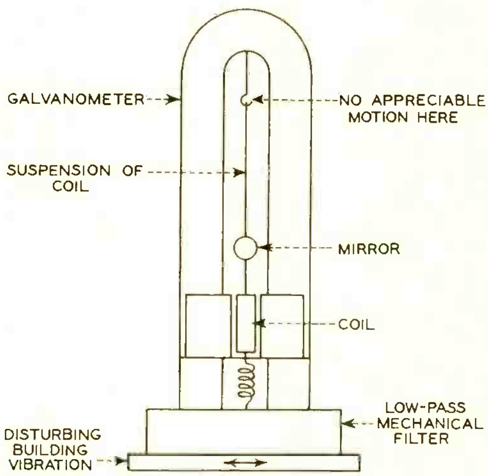


Fig. 2—Elements of a D'Arsonval type of galvanometer

room. With the bench on a wooden floor, however, the galvanometer was sometimes disturbed by persons coming close to one of the bench legs. This caused a small change in the level of the support and perceptible motion, which could not be protected against, since it has a frequency lower than the natural frequency of the galvanometer support. The remedy is to avoid having anyone step within about eighteen inches of the bench legs while measurements are being made, or to support the galvanometer

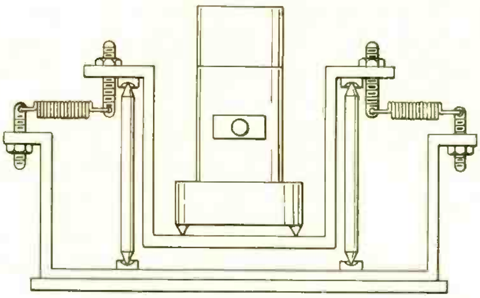


Fig. 3—The galvanometer platform is supported on three steel rods. Three radial springs connect the platform to vertical supports and other springs are arranged in pairs that are arranged tangentially

on a tripod made of iron pipe, with legs going through holes bored in the wood floor down to the concrete of the building. In the case of the ballistic galvanometer, no particular trouble has been caused by the moving of persons in the room, although the floor is of wood, and measurements can be

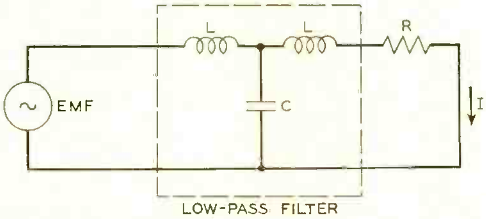
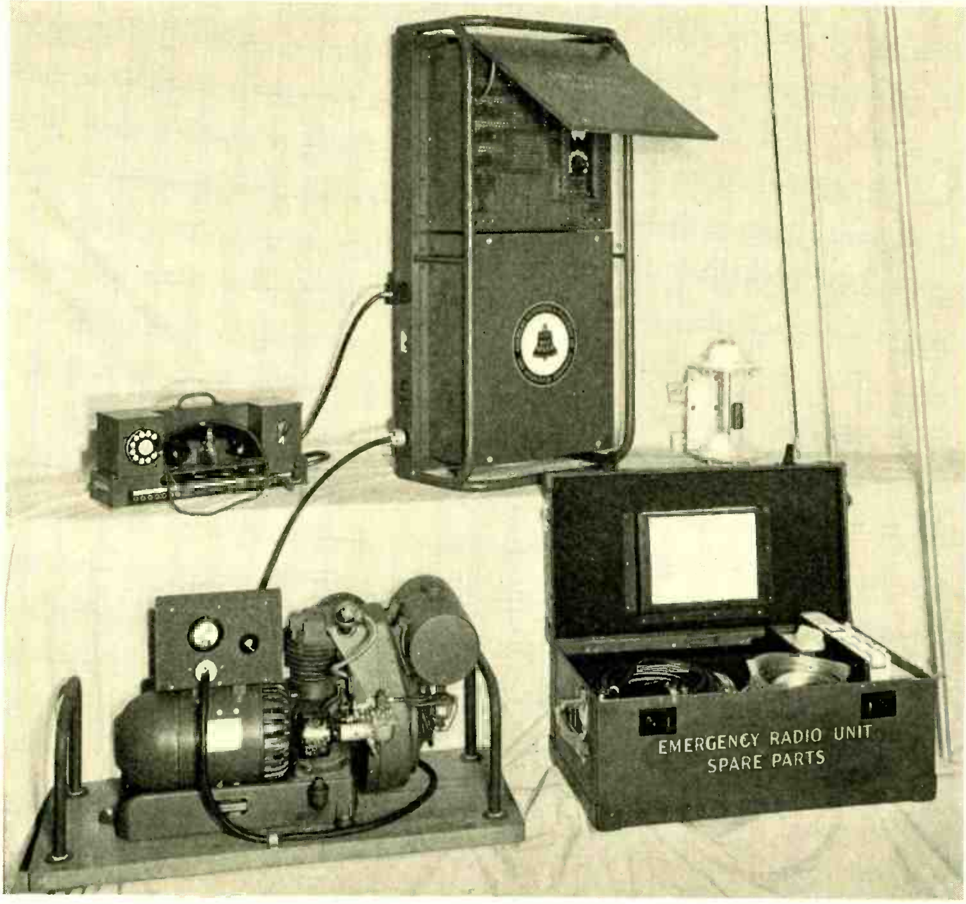


Fig. 4—Electrical analog of the mechanical elements of the new suspension. Electromotive force corresponds to building vibration; capacity to springs and gravity; inductance to the masses of the galvanometer and platform; resistance to damping and current to motion of the galvanometer. The springs and mass form a low-pass filter

made even when work is being done on the far end of the long bench on which the galvanometer rests, provided the disturbance is not too violent.

The galvanometer support here described is relatively light and compact, and performs satisfactorily on a bench resting upon the floor under unfavorable conditions of building vibration. Its use permits practically complete freedom in selecting a location for a galvanometer and makes change of location easy and quick.



Portable Emergency Radio-Telephone Equipment

A combined radio transmitting and receiving equipment has been made available to the Associated Companies for the sole purpose of handling emergency situations where telephone wires are unavailable. The damage to communication systems in the New England hurricane last September demonstrated its value.

The apparatus is known as the 221A emergency radio-telephone equipment and consists of a 24-type transmitter, a 23-type receiver, a 32-type control unit, a 600-watt portable gasoline-driven generator, and a demountable antenna, together with tools, spare parts and ground system materials. Operating frequencies in the 2 to 3 megacycle band are employed. The entire equipment weighs approximately 500 pounds and can be easily transported by light truck or passenger car.

If a storm or flood destroys a section of open-wire line or cable, these sets may be used to bridge the gap until the damage can be repaired. When commercial power is not available the gasoline-driven generator is used. The range of the emergency radio system is in the neighborhood of 25 miles although under favorable conditions considerably greater distances may be attained.

Contributors to this Issue

R. C. DAVIS was associated with the Indiana Bell Telephone Company in their Plant and Engineering Departments from 1912 until 1921 when he came to these Laboratories. For the next four years he participated in the development of circuits for manual switchboards, and in 1925 became a supervisor of one of the manual-circuit development groups. In 1927 he took charge of a group engaged in the development of circuits for dial systems, and much of the early crossbar development was done in this group. He is now in charge of the groups developing senders, markers, and routine-test circuits for all sender dial systems.

F. W. AMBERG, after attending Carnegie Institute of Technology and the University of Alabama, joined the Western Electric Company at Kearny in 1928. The following year he transferred to the Department of Development and Research of the American Telephone and Telegraph Company, where he engaged in development work connected with cable crosstalk and noise problems at both voice and carrier frequencies. Since the consolidation of the D. & R. with the Laboratories in 1934, Mr. Amberg has continued this work, particularly as applied to the type-K carrier system.

W. S. GORTON received the A.B. degree from Johns Hopkins University in 1908; the A.M. in 1910 and Ph.D. in 1914 from the same institution. He was Instructor in Electrical Engineering at the Massachusetts Institute of Technology from 1911 to 1913; Physicist with the Brady Urological Institute of Johns Hopkins Hospital from 1914 to 1917; and Associate Physicist at the Bureau of Standards from 1917 to 1919. In 1919 he joined the Laboratories where he has since been engaged in problems relating to voice-operated telephone repeaters; the development and manufacture of submarine telegraph and telephone cables; and the properties of base metal telephone contacts.

H. A. ETHERIDGE left Princeton to serve in the U. S. Army in 1917, but returned on receiving his discharge, and received the B.S. degree in 1919. For a short period he was in business for himself, but in 1921 he joined the Southern Bell Telephone and Telegraph Company. His work

R. C. Davis

F. W. Amberg

W. S. Gorton

H. A. Etheridge *Frank Hardy* *Lester Hochgraf*

there was with the Transmission Department, until 1923, when he transferred to the Department of Development and Research of the American Telephone and Telegraph Company where he was concerned chiefly with transmission problems arising from the use of repeaters on long telephone circuits. Since 1934, when the D. & R. was consolidated with the Laboratories, Mr. Etheridge has continued this work in the Toll Transmission Development Department.

FRANK HARDY took special courses in mechanical and electrical engineering at The Royal Technical College, Glasgow, and Paisley Technical College, Scotland, after military service in France. He came to the Laboratories in 1923. For several years he was engaged on toll development problems and later in sound picture development work. Recently he has been concerned with the testing and developing of apparatus in the Apparatus Analysis Department.

LESTER HOCHGRAF received the E.E. degree from Rensselaer Polytechnic Institute in 1926 and the degree of D.Eng. in 1929. He then joined the Department of Development and Research of the American Telephone and Telegraph Company, where, with the Toll Transmission group, he engaged in studies of crosstalk on open-wire lines. Since his transfer to the Laboratories early in 1934, he has continued his crosstalk studies but with the cable group. More recently much of his attention has been given to crosstalk reduction on the type-K carrier system.