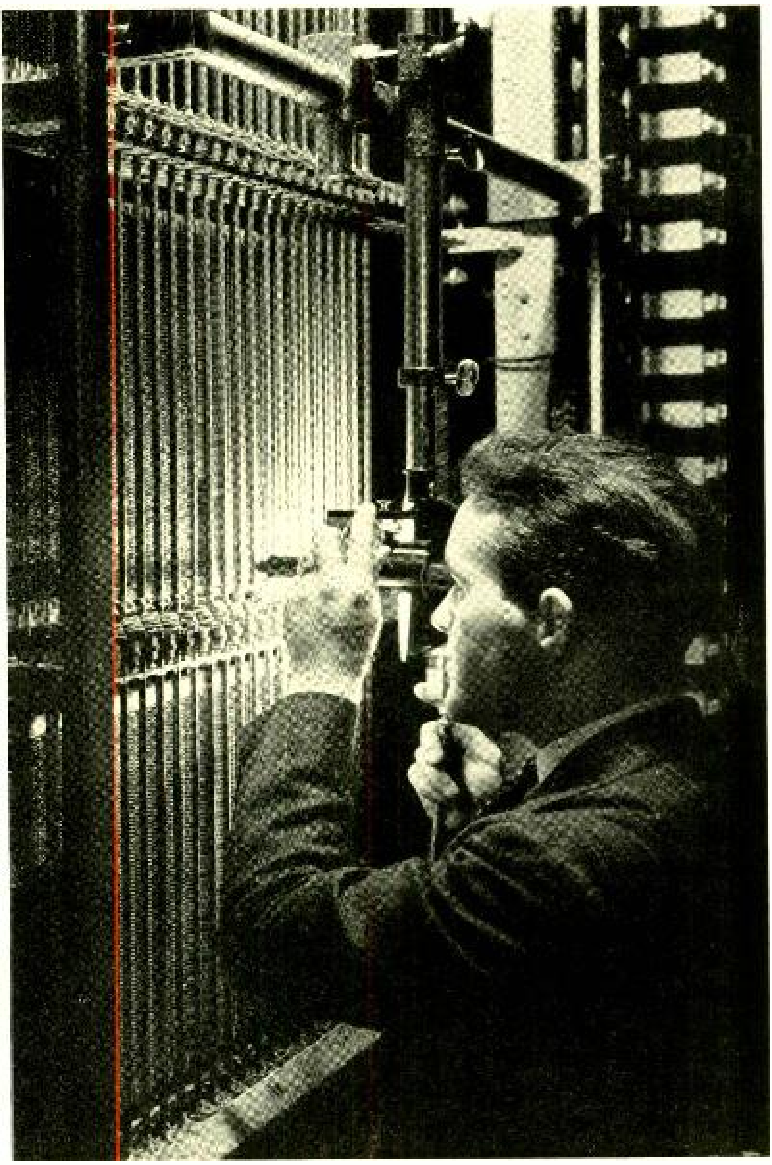
BELL LABORATORIES RECORD

MARCH
1941

VOLUME XIX

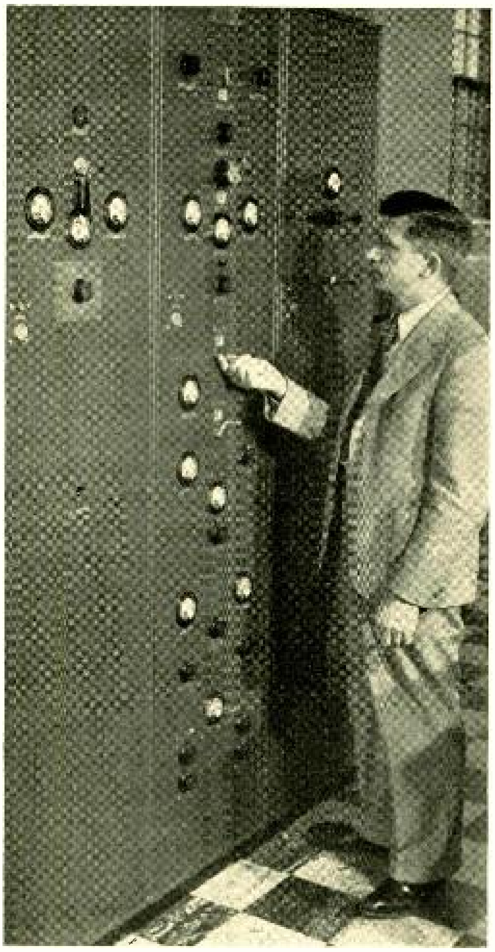
NUMBER VII



Field investigation of terminals in a dial central office.

A Twin-Channel Single-Sideband Radio Transmitter

By K. L. KING
Radio Research Department



THE advantages of single-sideband transmission, and the receiver designed for this system, have already been the subject of several articles in the RECORD.* To carry on studies of this type of short-wave transmission between England and the United States, an experimental single-sideband transmitter was built, and installed in England in 1934. A somewhat modified design was made later. Two transmitters of this latter type are now installed at Lawrenceville, New Jersey, for trans-atlantic service, and one is used at each end of the San Francisco-Honolulu circuit. To take advantage of the experience gained, further modifications have recently been made in the design of the transmitter, which has been changed also so that it may be used for either single or double-sideband transmission. Several of these new equipments, known as the D-156000 radio transmitter, are now in service at Lawrenceville, Ocean Gate, Panama, Buenos Aires, and Switzerland and others are projected.

One of the interesting features of this new single-sideband transmitter is that it can transmit simultaneously two independent single-sideband signals. An accompanying carrier is transmitted at reduced amplitude so that the major part of the output is in the two sidebands. When the two sidebands are used as two separate channels, the voice-frequency bands extend from 250 to 3000 cycles, but one of them is translated to the band from 2250 to 5000 cycles by a modulator and filter system in the terminal equipment preceding the transmitter. Thus the two telephone channels are separated by an interval of 2500 cycles into which the major products of distortion fall. This results in substantial reduction of crosstalk between channels.

Although this transmitter provides two channels for single-sideband transmission with voice bands 2750 cycles wide, it will also provide a

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*May, 1936, p. 303; Aug., 1936, p. 405; Nov., 1939, p. 84.

single channel for a voice band from 100 to 6000 cycles wide. This wide, high-quality band may be transmitted as either single or double sideband. The change from single to double sideband may be made either locally or by remote control, since the operation of a single relay is all that is required to change from one type of transmission to the other. This feature is of particular advantage when the transmitter is to be used for service to several points, some of which are not equipped for single-sideband reception.

A block schematic of the transmitter is shown in Figure 1. Three modulating steps are used. The first two conversion frequencies, of 125 and 2500 kc, are both derived from a single 625-kc oscillator—the 125 kc through a multivibrator, and the 2500 kc through a harmonic generator. For two-channel single-sideband transmission, the two voice bands are supplied to modulators 1A and 1B together with the 125-kc conversion frequency.

These units are balanced modulators, and thus the output of each consists only of the two sidebands of 125 kc, the carrier itself being suppressed by the balanced circuit. The two filters following the modulators, however, select opposite sidebands—filter A selecting the upper, and filter B, the lower. The two single sidebands passed by these filters, combined with a reduced carrier, form the input to the second modulator, which uses the 2500-kc conversion frequency. The upper sideband of this modulation is

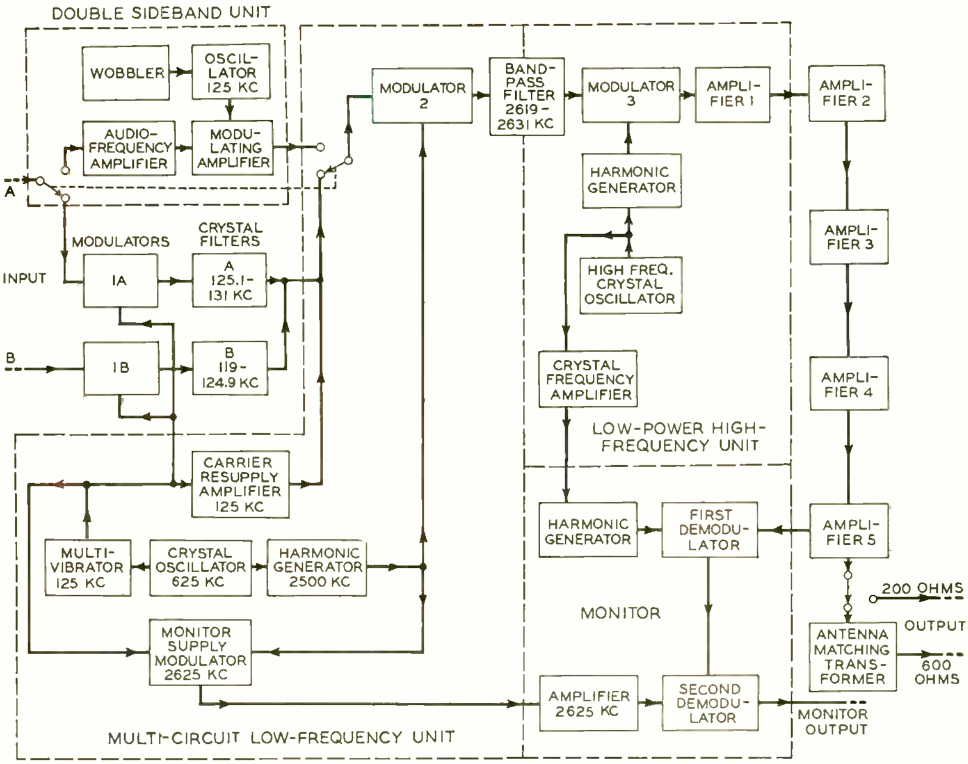

Fig. 1—Block schematic of the D-156000 radio transmitter

selected by the following filter, and passed to the third modulator.

The transmitter is arranged for operating on any of six predetermined frequencies between 4½ and twenty-two megacycles, and the third conversion frequency must be chosen to give the desired final frequency. The oscillator is arranged for control by any one of six quartz plates, and these, as well as the proper tuned circuits for the associated harmonic generator, are selected from the front of the panel. Five amplifier stages follow the third modulator, and give the transmitter an output of 2 kw for the envelope peak. As used at Lawrenceville, the transmitter drives a water-cooled amplifier with an envelope peak output of 60 kw.

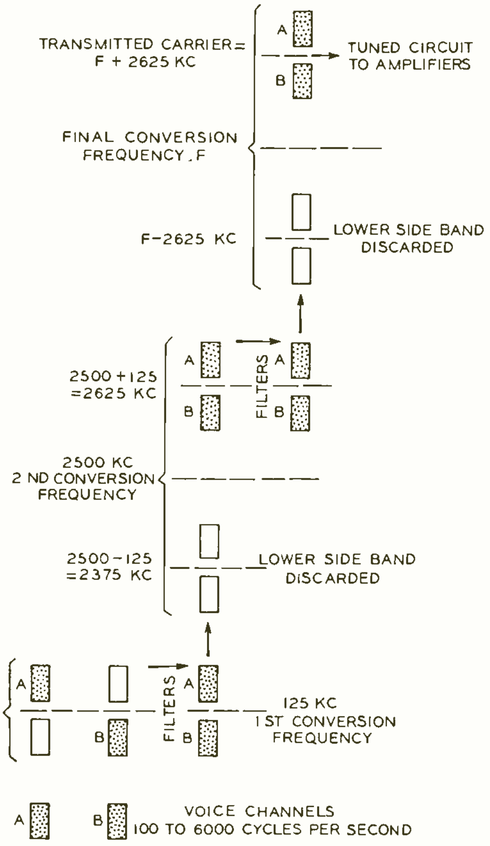

Fig. 2—Frequency diagram for the single-sideband transmitter

A frequency diagram of the transmitter is given in Figure 2. It shows the various conversion frequencies and the relative positions of the sidebands. Sidebands transmitted are shown cross-hatched, while those discarded are shown clear.

When used for double-sideband transmission, a separate first oscillator and modulator are employed. This part of the circuit is shown at the upper left of Figure 1. From the second modulator on, it is the same for both types of transmission.

To give the operators of the transmitter an opportunity to measure distortion when using single-sideband transmission, a built-in monitor is provided. A small amount of the out-

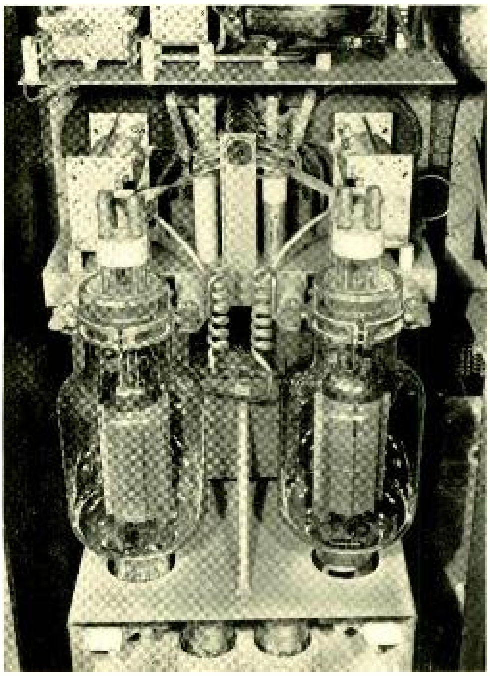

Fig. 3—Close-up of fifth amplifier panel showing switch that is used for cutting in additional capacitance

put of the transmitter is fed to a two-stage demodulator. The first stage is supplied with the third conversion frequency through a separate harmonic generator, while the final stage is supplied with a conversion frequency of 2625 kc, which is derived by combining the first and second conversion frequencies of the transmitter in the monitor-supply modulator.

The transmitter consists of three panels shown from the front in the photograph at the head of this article, and from the rear in Figure 4. The right-hand bay in Figure 4 includes most of the power-supply equipment, while the left-hand bay includes all the equipment up to the filter between the second and third modulator. Rectifiers for the filament supply of the medium-power amplifiers are also on this bay. The middle panel includes the third modulator with its oscillator and harmonic generator, the five subsequent amplifiers with their tuned circuits, and the monitoring equipment. This latter equipment is on the lowest panel, evident in Figure 4, while on the panel immediately above it is the oscillator and its associated equipment, the third modulator, and the first of the following amplifiers. The next three panels, equal in size, include the second, third, and fourth amplifiers with their tuned circuits. Above them is the fifth amplifier and its tuned circuit.

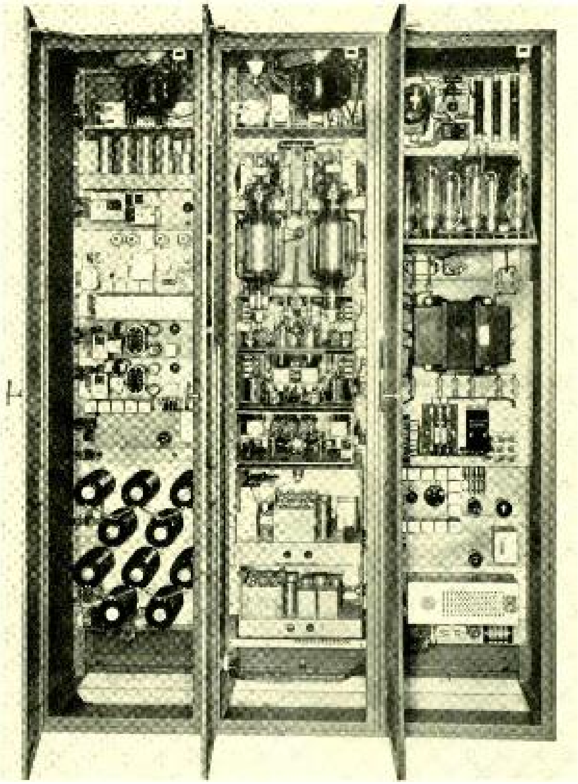
*Fig. 4—Rear view of the D-*156000 *transmitter*

Since the frequencies are all fixed up to the third modulator, no operating adjustments are required. Beyond this point, however, any of six frequencies may be employed, and switching arrangements are provided to select the proper oscillator crystal, and the pretuned circuits in the harmonic generator, the third modulator, and the first two amplifiers. In amplifier stages 3, 4, and 5, the variable inductances employ a rider wheel to short-circuit the end turns of a rotating coil, similar to those described in connection with the 16A radio transmitter.* The two inductances for each stage are geared together and driven by a single handle. The number of turns of inductance in use is shown by indicators visible from the front. Because of the larger currents encountered in amplifier 5, the inductance range is smaller, and additional capacitance must be added for the lower carrier frequencies. This is done by a cam-operated switch.

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*Record, *Sept.*, 1935, *p.* 17.

Handling DSA Traffic at Toll Boards

By D. F. JOHNSTON

Switching Development Department

A SUBSCRIBER in a dial area has access to both an outward toll operator and a "DSA" operator.* The latter is usually reached by dialing zero. She assists in completing calls that for some reason or other the subscriber has not been able to complete; she may handle directly the shorter distance toll calls; and she may take also reports of trouble conditions, fires, or other emergencies. She also handles calls from any manual lines in the area, and in addition is connected to the subscriber lines over intercepting trunks when a line has been dialed on which no service is available, either because it is an unassigned number or because there is trouble on the line. The outward toll operator, on the other hand, sets up all outgoing toll calls except those shorter ones handled by the DSA operator, and is reached by dialing some number such as 110, which is the number used in the step-by-step system. These two types of operators have generally been located at different switchboards, and often in different buildings. The toll operators are at the toll office, and the "DSA" operators at one or more of the local offices. Studies have shown that in some cases more economical handling of calls would be brought about if arrangements were made to enable the toll operators to handle DSA calls as well as toll calls. This would do away with the DSA boards, and obtain the economies of combined service.

To provide DSA service at a toll board, however, certain modifications are required, and the necessary circuit arrangements have been developed by the Laboratories for the

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*Dial System "A" operator.

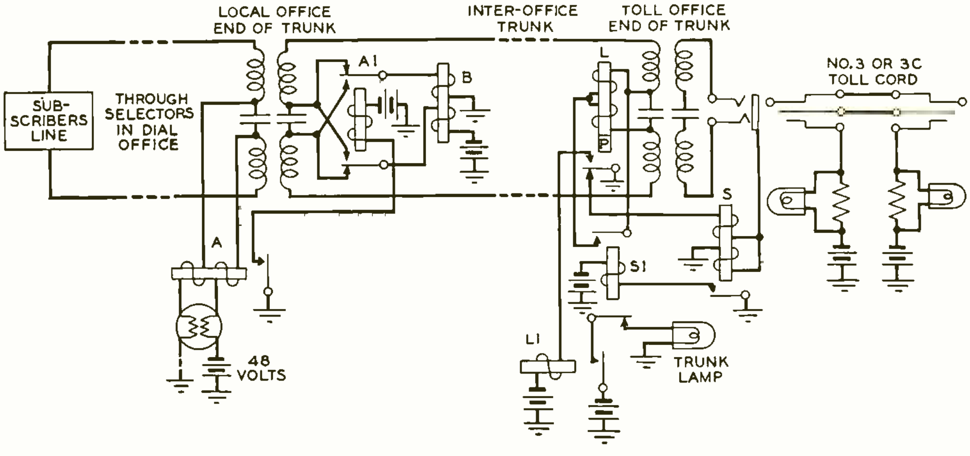

Fig. 1—A recording-completing trunk and toll cord circuit at a No. 3 or 3C toll position

Nos. 1, 3, and 3C toll boards. Since it is desirable to keep the transmission losses in a toll system as low as possible, no apparatus is connected to the talking leads of the toll cords at the switchboard except at No. 1 toll positions, where a high-impedance bridge is used at the line end for receiving a-c signals, and another high-impedance bridge at the office end for receiving d-c signals. The equipment for supplying talking battery to subscribers is placed in the local office end of the recording completing trunks, over which the subscribers reach the toll office. The circuit arrangement of such a trunk, and a toll cord at a No. 3 or 3C position, is shown in simplified form in Figure 1. At the DSA boards, on the other hand, this battery supply is placed in the cord circuit as shown in Figure 2. When DSA service is to be given at toll positions, therefore, the calls must be routed to the board over a recording completing trunk, so that battery supply will be available.

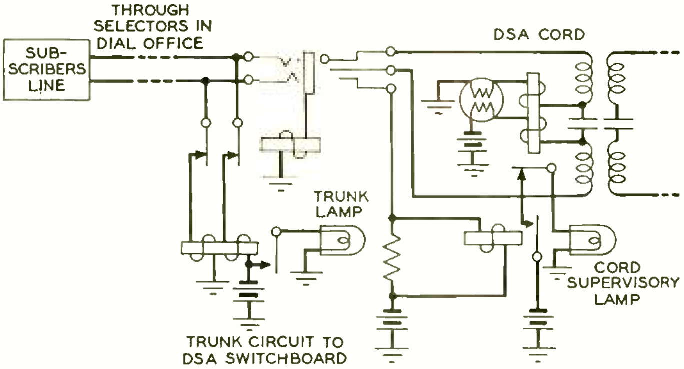

Fig. 2—A subscriber's line and DSA cord circuit at a DSA position showing location of battery supply

In a dial area there are commonly a number of manual lines for subscribers who for some such reason as physical disability need manual operation. Such lines are normally terminated at DSA positions, where the battery is supplied from the cord circuits. When toll positions are used for DSA service, these lines must be brought to the toll board, and a battery supply must be provided in the line circuit. Where there are a large number of manual lines, the cost of equipping all of them with the necessary battery-supply circuit may make the use of toll positions uneconomical for this purpose.

Another change required in giving DSA service at the toll board is the provision of intercepting trunks. These also must supply the features which at regular DSA positions would be supplied from the intercepting cords.

In addition to these changes required to provide battery supply, others are needed to permit proper signalling and dialing. DSA cords are designed to use d-c supervisory signals, and to dial over either end. The Nos. 3 and 3C toll cords also have these provisions, and thus no changes in these respects are required for them. The No. 1 toll cords, however, are not arranged to receive d-c signals on the toll end. It was necessary, therefore, to add a d-c signalling bridge at this end also, and to insert condensers in the talking conductors to separate the two d-c bridges. Then to avoid the severe shunting effect of the added bridge on the a-c bridge, the connections of the a-c bridge were arranged so that there would be only one condenser in the path to the supervisory relay.

To provide dialing at both ends of the No. 1 cord, considerable modification was required, since the dial circuit had to be changed, and a new position circuit added. The cord, when changed, differed so much from the regular cord that it was given a distinctive designation, and is now known as the type-A toll cord.

Besides these changes, consideration also had to be given to the matter of ringing. DSA positions are equipped to ring on individual lines, two-party lines, or four-party lines either semi or full-selective. All these types of ringing are not required at toll positions, since ordinarily there is no need for the operator to ring the subscriber back on the line over which the subscriber calls. On delayed calls, where the subscriber must be recalled, the toll operator dials the subscriber's number, and ringing is supplied from the dial-office equipment. A toll operator has need to ring back on an answering cord only to coin stations and PBX's, and thus the toll positions are equipped for ringing only on single-party lines, no provision being made for ringing over the various types of multi-party lines. So far as normal service is concerned, therefore, the ringing facilities at a toll board, although less extensive than at the DSA positions, would be entirely sufficient.

There are times on rare occasions, however, when the operator at a DSA position could render greater service if she could ring back on any type of line. Suppose, for example, that a subscriber dials "operator" to report that his house is on fire, and then before giving his number, abandons the call either by hanging up or by leaving his receiver off the hook. The operator has no way of knowing the number because she is connected to the line over a trunk that might be used by any line in the area, but since her cord is connected to the trunk, she could call the subscriber back if she had the proper ringing facilities. If it were a two or four-party line, and the

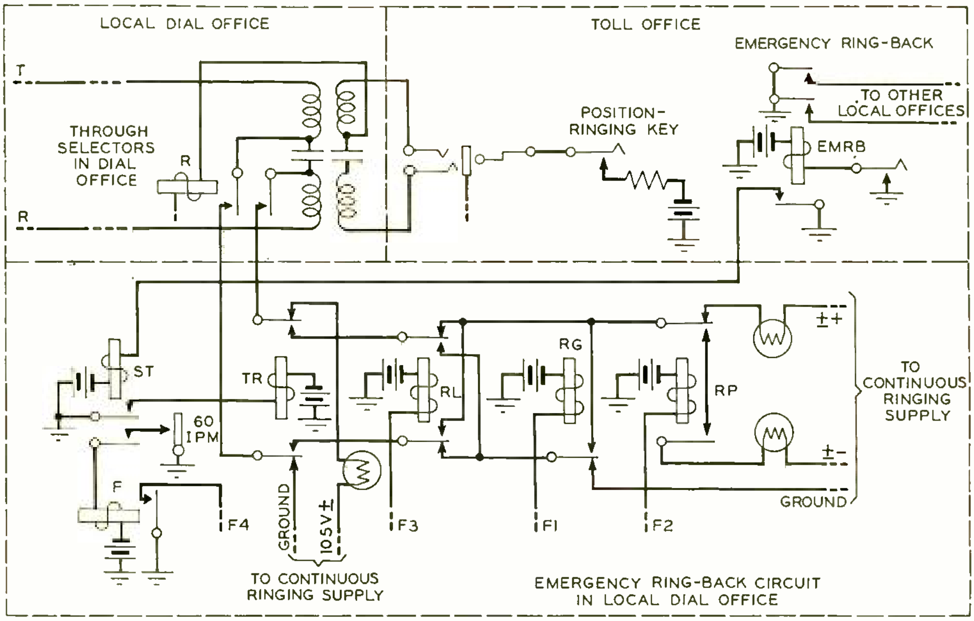

Fig. 3—Simplified schematic of emergency ring-back circuit at a toll position

receiver had been left off the hook, the operator could ring the other parties on the line and determine the number by a process of elimination. The ringing facilities at the regular DSA boards permit this to be done. The operator does not, of course, know the type of line, but she applies one type of ringing after another until a response is obtained.

To make this emergency ring-back available at toll positions used for DSA service, a new emergency ring-back circuit has been developed. The toll position is normally equipped with a ringing key that operates a ringing relay in the trunk circuit, and when the key is operated, the relay connects ringing voltage to one side of the line and ground to the other. The new circuit adds an emergency ring-back key that operates relays, first to transfer the leads from the ringing relay to an emergency ringing supply, and then to apply, in successive half-second intervals, the various types of ringing to the line. In this way all the parties on the line, regardless of type, will hear ringing at least once every 2½ seconds. Although no attempt is made to give code ringing, it is felt that the attention of all subscribers will be attracted by the unusual timing of the emergency ringing, and that they will answer their telephones. The circuit is shown in simplified form in Figure 3.

The ST relay, which is operated by the emergency ring-back relay, operates the TR relay to transfer the leads from the ringing relay to the emergency ringing circuit, and also makes a connection to an interrupter circuit, which alternately applies open-circuit and ground at half-second intervals to relay F. The leads from the TR relay, over which the emergency ringing is to be sent, pass through contacts on relays RL, RG, and RP which when operated singly or in various combinations transmit all the needed types of signals from the three ringing leads marked ± −, ± +, and ground. Relays RL, RG, and RP are operated in rotation in various combinations by a

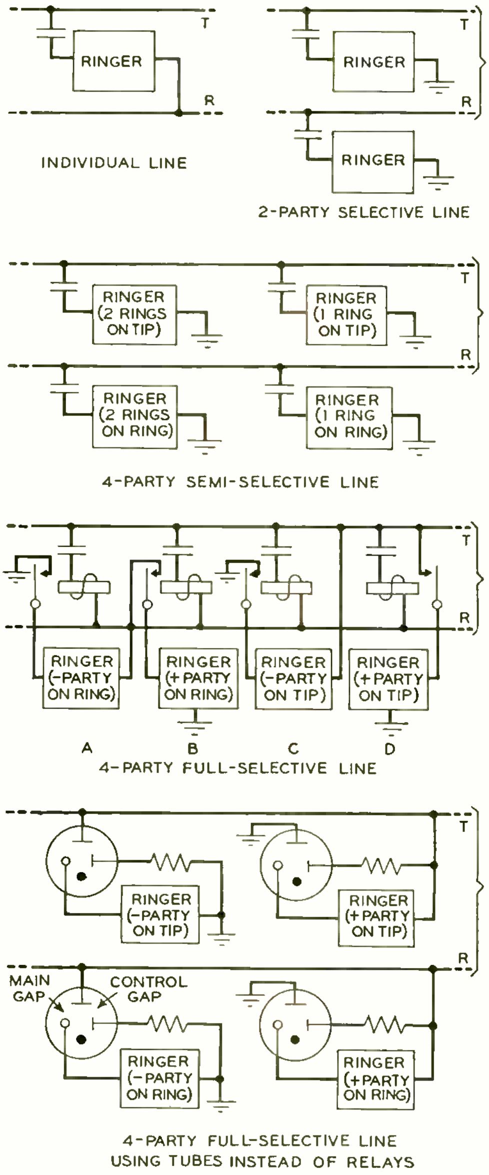

Fig. 4—Various types of ringing circuits over which the emergency ring-back circuit has been designed to operate

group of four relays associated with leads F1, F2, F3, and F4. As a result of the action of the interrupter circuit, which alternately grounds lead F4 and removes ground from it through relay F, these four relays put ground on leads F1, F2, and F3 to operate relays RG, RP, and RL, respectively, and thus to send out ringing that is changed in type every half second for as long as the emergency ring-back key is held operated. The arrangements of the ringers on various types of lines are shown in Figure 4.

Relays ST, TR, RL, RG, RP, F and those associated with leads F1, F2, F3, and F4 are installed in each of the local dial offices, one set being required for each office. The emergency ring-back relay is in the toll office, and is operated by an emergency ring-back key at each position. The operation of this key and relay operates the ST relays in all the local offices and thus transfers all ringing to the emergency condition. This does not interfere with the normal ringing being done at other positions of the toll board because all of the combinations but one provide individual line ringing.

This emergency ring-back circuit, as already noted, is not essential to the provision of normal DSA service at toll positions. It has been developed by the Laboratories to make available facilities for giving this added service whenever local conditions make it seem advisable. The other provisions, however, are always needed, and with their adoption there has been a rapid trend toward the consolidation of the DSA service with the toll service.

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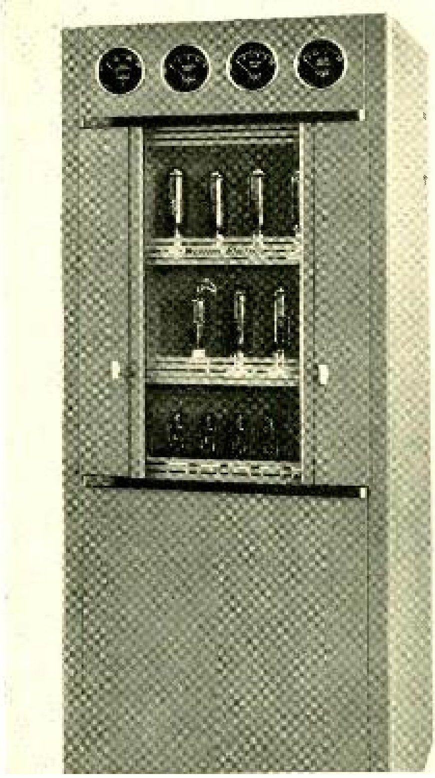
451A-1 RADIO TRANSMITTER

Developed by Bell Telephone Laboratories, this new radio transmitter is intended for applications where power in excess of 250 watts is not contemplated. It effectively covers the broadcast, police, and emergency-communication services in the frequency range from 550 to 2750 kilocycles. Like the 1-kw transmitter, described in the RECORD for September, 1931, and the frequency-modulation transmitter described in September, 1940, this new transmitter has all its electrical components assembled on a central unit, around which the enclosing cabinet is placed. All the important controls are behind the two narrow doors at the sides of the front. This construction gives ease of assembly, maintenance, and control without detracting from safety of operation or appearance.



Autotransformer for Emergency Repair of Open-Wire Carrier Circuits

By H. H. FELDER

Toll Transmission Development

WHEN unusually severe sleet storms and high winds destroy sections of open-wire lines, the telephone companies are confronted with a real problem in maintaining the continuity of telephone service. Considerable time may be required to put the lines back into their normal condition, and to avoid a lengthy interruption of telephone service it has been customary to bridge the break in the lines with twisted pairs, which may be placed on temporary supports, tied to trees, or laid along the ground. The wire used for restoring toll lines in this manner is known as HC drop wire. It is 14-gauge, twisted pair, rubber insulated, and carries weatherproofed braid for mechanical and sunlight protection. It can easily be stored in a central location, and after use can be reclaimed, and returned to the storehouse for future use.

In recent years there has been a considerable increase in the use of carrier systems on open-wire lines, and with the introduction of the new J-carrier system* in a frequency band above the type-C system, as many as fifteen two-way telephone circuits in addition to the usual voice-frequency circuit may be provided by a single pair of wires. Under such conditions, it becomes even more desirable to restore service promptly, but unfortunately the transmission characteristics of the HC drop wire are not such that it can be connected directly to open-wire lines and permit satisfactory communication over the wide frequency range used by the C and J-carrier systems. Its impedance differs so greatly from open-wire impedance that severe reflections would occur at the junctions. The most serious effect would be a prohibitive increase in reflection crosstalk† in parallel carrier systems on the same pole line, by

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*Record, *April*, 1940, *p.* 226.

†Record, *Nov.*, 1934, *p.* 66.

the conversion of near-end to far-end crosstalk. Moreover, the loss due to impedance mismatch at the junctions combines with the attenuation loss of the drop wire to substantially increase the insertion loss.

To secure the maximum advantage of this simple method of line repair for carrier systems, therefore, an autotransformer has been developed for use at the junctions of open wire and HC drop wire. This device greatly reduces the junction reflections so that the reflection crosstalk effects become tolerable for all lengths of drop wire that are satisfactory as regards insertion loss. The component of the insertion loss due to junction reflections, moreover, is practically eliminated, leaving only the attenuation loss of the drop wire plus the small transformer loss. These very desirable improvements in carrier transmission performance are obtained with some, but usually tolerable, impairment in the other services routed over the open-wire lines. This impairment includes the restriction of direct-current telegraph service to one grounded circuit per open-wire pair.

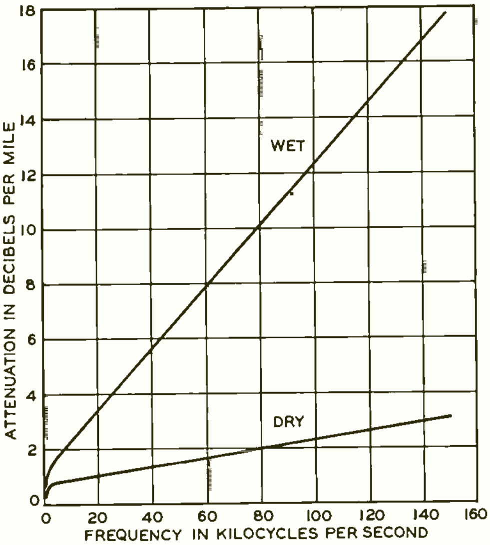


Fig. 1—Attenuation characteristics of HC drop wire

The curves of Figure 1 show the large variation in the attenuation of HC drop wire with frequency and moisture conditions. This variation is due to the moisture absorption properties of the weatherproofed braid, which is included for mechanical protection. The data on Figure 1 are of special concern in the line repair method under consideration because the lengths of autotransformer-terminated drop wire that can be allowed in an open-wire carrier line are basically determined by the losses at high carrier frequencies, in relation to the available reserve amplification in the carrier repeaters.

The characteristic impedance of HC drop wire is shown in Figure 2. Over the frequency range of the J-carrier system, the reactance is essentially zero, and the resistance is practically constant with frequency, although it varies between about 150 and 80 ohms depending on the weather. The characteristics of an open-wire line are similar in form; that is, it has essentially zero reactance and a flat resistance, but the resistance—which varies with the type of line rather than with weather conditions—is between 500 and 650 ohms. The impedance-matching transformer must thus increase the impedance of the HC drop wire to make it approximately the same as that of an open-wire line. An autotransformer is employed, and to enable it to meet a variety of conditions, it is designed with a compromise impedance ratio.

To permit d-c tests to be made on the open-wire line after the drop wire has been installed, a condenser is inserted at the midpoint of the autotransformer. This condenser resonates with the inductances of the low-impedance and high-impedance sections of the transformer winding to form two cut-off frequencies which will vary in value depending on the size of the condenser. Between these two frequencies is a suppression band, above and below which are pass-bands. Carrier, voice, and 135-cycle frequencies fall in the upper pass-band, but the 20-cycle signalling is transmitted in the lower pass-band.

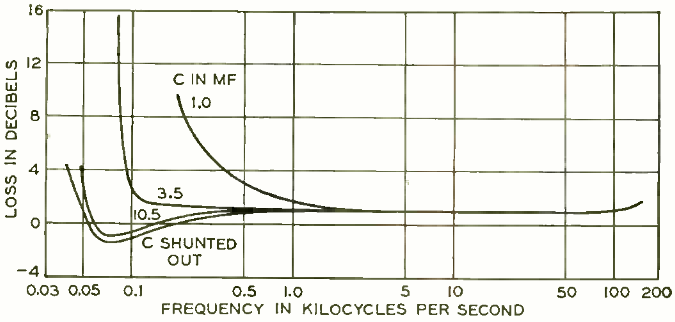


Fig. 3—Insertion-loss characteristics of two 24A autotransformers with different values of capacitance

To meet the various conditions encountered, three values of capacitance are provided. With a 3.5 mf capacitance the lower boundary of the upper pass-band is below 135 cycles and the autotransformer is satisfactory for 135-cycle and voice-frequency signalling as well as for the voice and carrier-frequency telephone channels. It is relatively unsatisfactory for 20-cycle signalling, however. In the lower pass-band where 20-cycle signalling occurs, the autotransformer functions as a simple series impedance in the line and the condenser is shunted across the line at one end of this impedance. For efficient 20-cycle signalling, it is essential that the shunt impedance be increased and therefore 1 mf is used. This raises the lower boundary of the upper pass-band and slightly impairs transmission in the voice-frequency channel. For this reason 1 mf is used only when 20-cycle signalling is employed. When the circuit is used for program transmission it would be desirable to short-circuit the condenser so as to eliminate the suppression band and allow the low program frequencies to be satis-

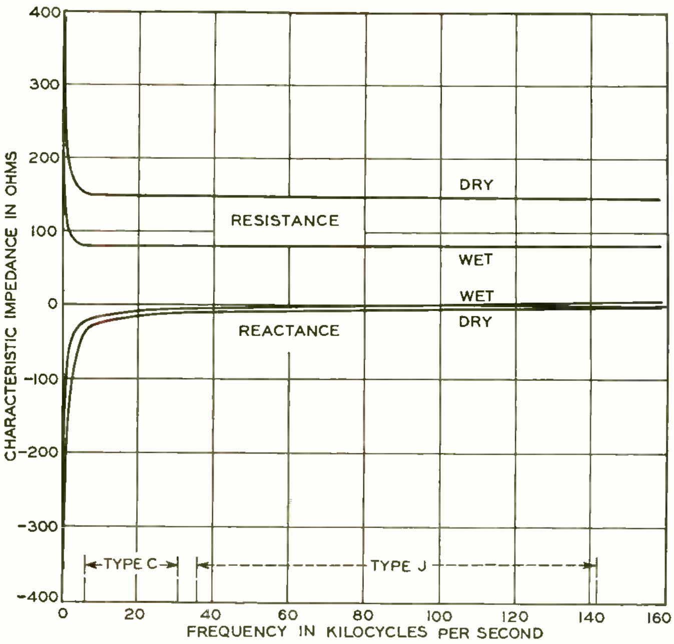


Fig. 2—Characteristic impedance of HC drop wire: resistance component, above, and reactance component, below

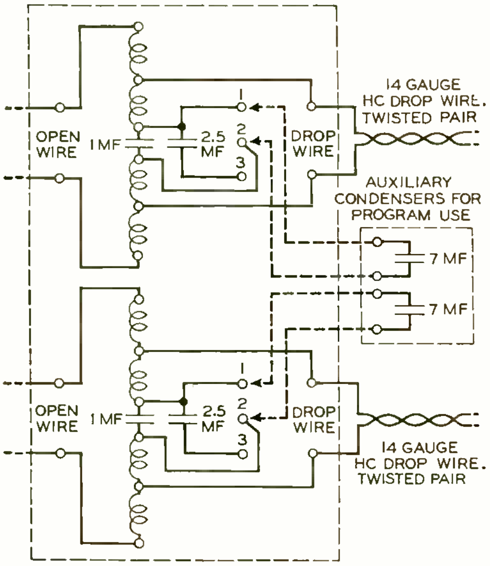


Fig. 4—Circuit diagram of the 24A autotransformer for open-wire circuits

factorily transmitted. This would make d-c testing impossible, however, and so when the ability to make d-c tests cannot be dispensed with, or when a recent form of program reversal circuit is employed, a 10.5 mf condenser is employed, which is large enough to give program transmission only slightly poorer than when the condenser is short-circuited. The insertion-loss characteristics for these various arrangements are shown in Figure 3. The losses shown are for two autotransformers with zero length of drop wire; the loss that occurs in the drop wire itself must be added to obtain the overall loss.

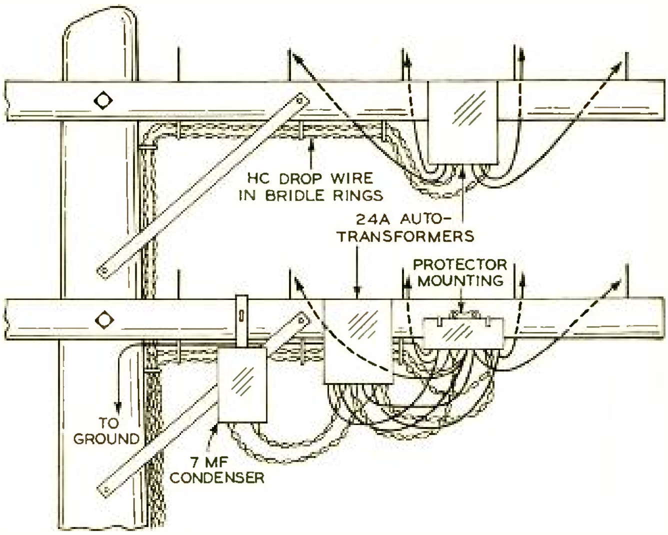


Fig. 5—Method of mounting 24A autotransformers on cross-arms, with and without protectors

These various capacitances are secured by providing a 1-mf condenser connected at the midpoint of the transformer, and 2.5 and 7-mf condensers that may be connected in parallel with it as required. The 2.5-mf condenser forms part of the transformer unit, but the 7-mf condenser is furnished as a separate element, and is installed only when it is required.

The complete transformer assembly, known as the 24A autotransformer, consists of two autotransformers each with a 1 and a 2.5-mf condenser arranged in a single metal container. The circuit diagram is shown in Figure 4, where the leads to the 7-mf condensers are dotted lines to indicate an optional arrangement. By strapping terminals 2 and 3 together, the capacitance is made 3.5 mf, and when in addition the 7-mf condenser is connected to terminals 1 and 2, it becomes 10.5 mf. The physical arrangement of the apparatus is shown in Figure 8 and in the photograph at the head of this article. The two transformers and four condensers are mounted on a panel through which their terminals project into the terminal compartment. A terminal strip in this compartment provides seven main terminals for each of the two transformer units. A strap fastened to the bottom of the terminal compartment is used to suspend the unit from a crossarm, and a cover slips over the assembly and is held to the bottom of the terminal compartment by a clamping screw. When installed on a crossarm, it appears as shown in Figure 5. Here a 24A autotransformer alone is installed on the upper arm. This arrangement is used where program circuits are not involved and where because of seasonal factors, protection from lightning or other high voltages is not required. The arrangement on the lower arm in Figure 5 shows suitable locations for the installation of the 7-mf condenser, and the protector mounting when required.

The improvement in reflection coefficient to be expected when autotransformers are used is indicated in Figure 6. The upper curve shows the reflection coefficient at one end of an 0.8-mile section of drop wire inserted in an open-wire line without autotransformers, while the lower curve shows the results when autotransformers are employed at the two junctions. It will be noticed that with transformers the coefficient is under 0.10 over practically the entire frequency range, increasing somewhat only at very low frequencies. This increase arises partly because the impedance ratio of the transformer is far from ideal at these frequencies and partly because the transformer and condensers contribute impedance distortion. Under wet conditions, the coefficient may rise to about .20 in the carrier range, but a lower value will be resumed as the drop wire dries out.

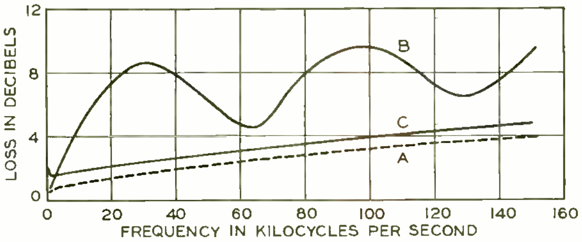


Fig. 7—Improvement in insertion loss when 24A autotransformers are employed

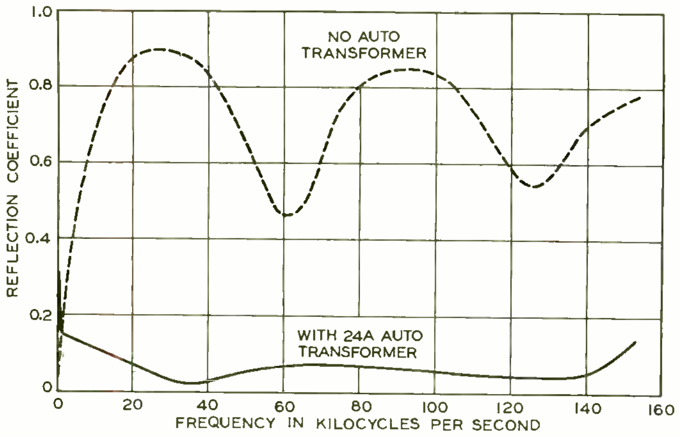


Fig. 6—Improvement in reflection coefficient when 24A autotransformers are employed

The improvement in insertion loss secured by the autotransformer under dry conditions is shown in Figure 7. Curve B shows the loss when 0.8 mile of drop-wire is connected between open-wire lines without transformers, and curve C, when transformers are employed. Curve A shows the characteristic loss of the drop wire by itself, and serves as a basis of comparison for the other two curves. The data apply for "dry" drop wire. With "wet" or partially wet drop wire, the losses would be greater, so that even under favorable conditions with respect to reserve amplification, it will seldom be practicable to use more than about two miles of HC drop wire in an "average" repeater section in type-C or J carrier-frequency systems.

When installing the drop wires on a pair-for-pair basis, it is desirable to have some separation between them to minimize possible crosstalk. It has been found, however, that if the wires are tied together only at the supports, and allowed to hang loosely between supports, the crosstalk between pairs will be small compared to that resulting from the junction reflections and from local disruptions in the open-wire transposition systems.

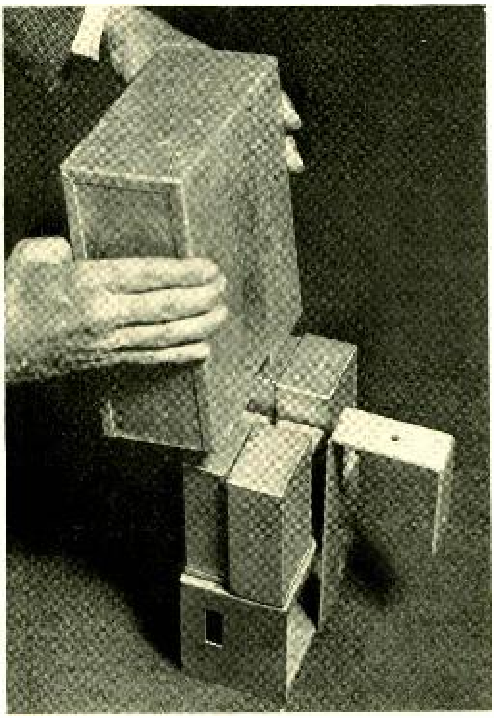
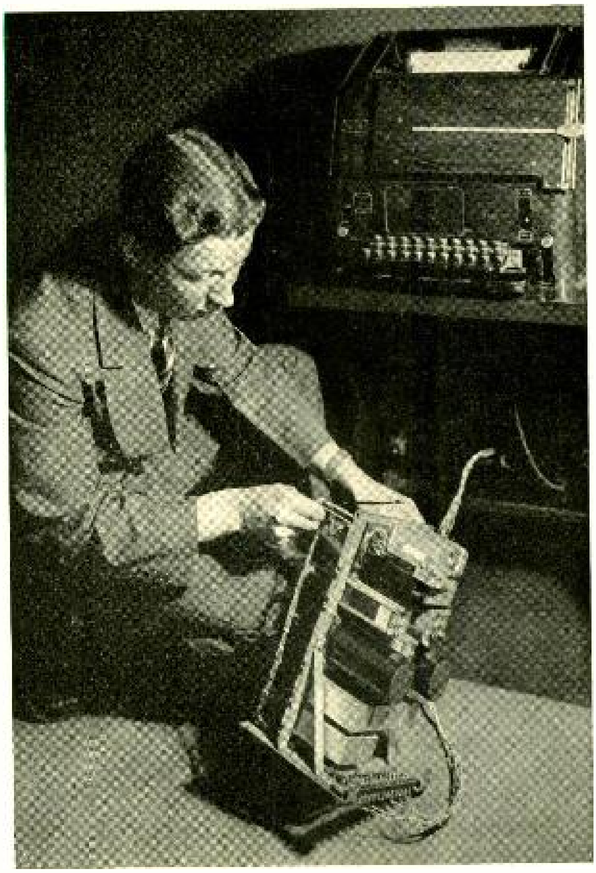


Fig. 8—A cover slips over the autotransformer unit, with the rear side between it and the suspension bracket

Polarential Telegraph Operation

By ALLAN WEAVER
Systems Development



GROUNDED telegraph circuits are sensitive to changes in the weather, since those changes bring about variations in line leakage and in line resistance. Where telegraph relays are located at subscribers' premises frequent readjustment is impractical; to avoid it, a new method of operation has been developed. It is called "polarential," and differs from "differential duplex" in that it operates in one direction on differences in current and in the other on reversals in current. It includes two types of circuits: one, type A, minimizes the effect of variations in line resistance, and is used on cable circuits; the other, type B, which is applied to open-wire lines, greatly minimizes the effect of variations in leakage.

In the type-A system the battery voltages at each end of the line are chosen so that the current in the line, although in opposite directions for marking and spacing conditions in either direction of transmission, has the same magnitude for both. A given change in line resistance will, therefore, affect both marking and spacing currents equally and cause no bias at the receiving relays. In the type-B system the voltage to ground at the middle of the line reverses but has the same magnitude for marking and spacing. A given leakage at the middle of the line will, therefore, cause a current to ground which is the same for marking and spacing and hence the change in the receiving relay current will be the same for these two conditions. These systems are used only on circuits that require the transmission of signals in one direction at a time, which is the type of transmission used on a large percentage of the circuits used in the Bell System.

The operation of the first system, designated type A, is explained more fully by Figure 1, which shows the sending and receiving relays of a west repeater connected over a line to the sending and receiving relays of an east repeater. When no transmission is taking place the relay contacts are as shown in Figure 2. To transmit from west to east, the armature of the W sending relay moves between M and S (marking and spacing contacts). When it rests on M, current flows from the positive pole of the M battery through ground to the east end, through the M contact of the sending relay and the No. 1 winding of the E receiving relay (which it holds on M) thence over the line and through the No. 3 winding of the W receiving relay back to battery. An equal current is drawn through the artificial line AL_1 and winding 4 by the same battery but windings 3 and 4 are oppositely poled and their currents have no net effect on the relay. However, a local current in winding 5 holds the relay on M. If temperature variations change the line resistance the currents through windings 3 and 4 will no longer be equal but the unbalance is not enough under ordinary conditions to operate the relay falsely on outgoing signals.

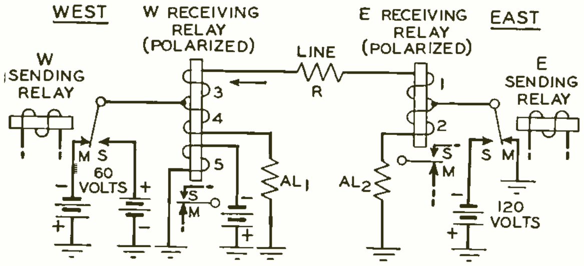


Fig. 1—Schematic of telegraph circuit for type-A polarential operation as used on cable lines

When the W sending relay armature rests on S the line current flows in the opposite direction and the E receiving relay closes its S contact. Windings 3 and 4 are still in opposition and the W receiving relay remains on M. For transmission in the opposite direction (E to W), the M contact of the W sending relay remains closed. Current from a 60-volt battery flows steadily through winding 4, and the artificial line AL_1. The current through winding 5 is so adjusted that its magnetomotive force annuls that of winding 4. As the E sending relay operates its armature between M and S it alternately makes the net voltage on the line 60 volts E to W and $60-120=-60$ volts W to E. The resulting currents being equal and opposite will act through winding 3 to move its armature between M and S. Since they both flow through the line, any change in its resistance will affect them alike.

The line currents for the type-A operation normally have values shown by the *a* trace of Figure 2. When the cable becomes warm its resistance increases and the currents may have values shown by the *b* trace. The operating values for the receiving relay are shown by the upper and lower horizontal dotted lines respectively. Signals repeated by the receiving relay are shown by the *a*-1 trace and the *b*-1 trace. A comparison of trace *a*-1 with *b*-1 shows that the signals

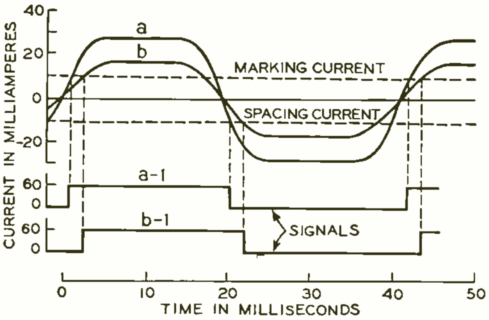


Fig. 2—Line currents and repeated signals of type-A polarential telegraph system. Curve (a) is for normal operation and Curve (b) when the cable is warm

are of equal length and thus are undistorted but that they have been displaced with respect to each other, which does no harm.

The other polarential system, designated type B, is shown schematically in Figure 3. Transmission from west to east is the same as in the type-A arrangement; when sending from east to west, ground is used for the marking condition as before but positive instead of negative 120-volt battery is applied to the line for the spacing condition. The net voltage around the whole circuit for the spacing condition in E-W transmission is therefore three times that for marking and in the same direction. The spacing current is also unchanged in direction but three times as great. When it flows in winding 3 of the west receiving relay it overpowers the current in windings 4 and 5, which oppose it, and pulls the armature to the spacing position. As in type-A polarential operation both receiving relays have balanced windings which are connected to the line and artificial line respectively, thus preventing false operation of the telegraph system on outgoing currents.

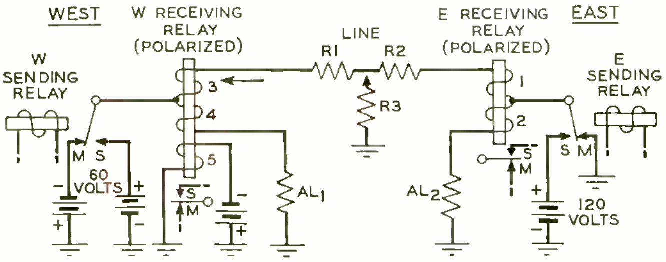


Fig. 3—Schematic of telegraph circuit for type-B polarential operation as used on open-wire lines

The effect of leakage on the type-B system can be shown by assuming that this occurs at the middle of the line and then considering the voltages in the circuit. With both senders in a marking condition and no leakage the voltage distribution along the line is shown by the lower solid line of Figure 4. When the east sender is operated to spacing the voltage distribution is that shown by the upper solid line. The marking voltage at the center of the line is equal to the spacing voltage but opposite in sign. If a leak is added at this point, the marking and spacing voltages will be reduced to new values, shown as $+e'$ and $-e'$, and these will also be equal to each other but op-

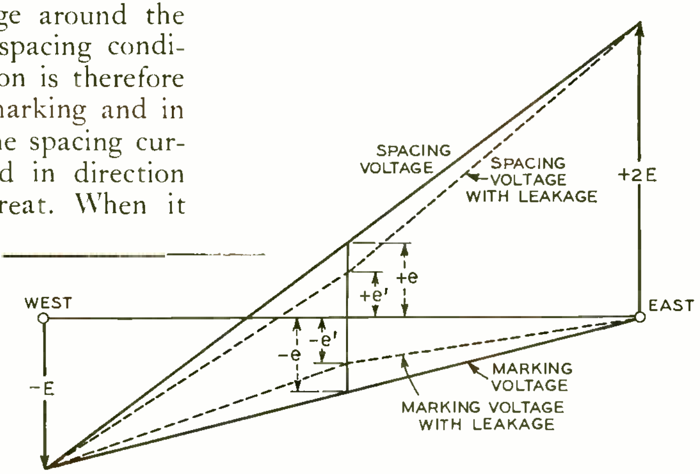


Fig. 4—The voltage distribution along the telegraph line for type-B polarential operation is shown by the upper and lower full lines of the figure when there is no leakage. With leakage the marking and spacing voltages will both be reduced as indicated by the dotted lines. In this description of polarential operation voltage drops through apparatus resistances have been ignored to simplify the diagram

posite in sign. When these voltage conditions prevail at the center of the line the signals received at the west end will be unbiased.

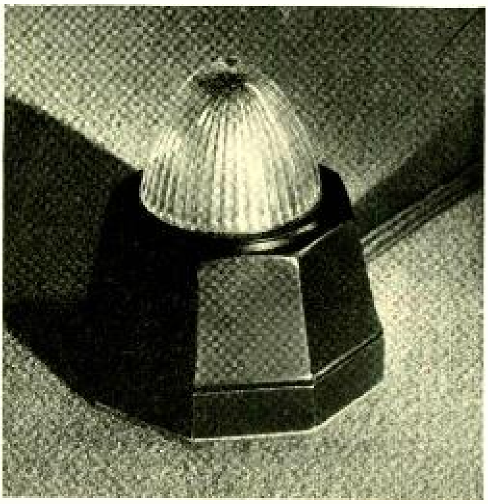
Referring again to Figures 3 and 4 the current received by the west relay is the algebraic sum of the voltage to ground at the center of the line e, and the terminal voltage, E, divided by the resistance of the line between the center and the west terminal, R_1, i.e. $\frac{E \pm e'}{R_1}$. The e' is minus for marking and plus for spacing and the biasing current will be set at the average of the two currents, or at E/R_1. The net effect on the relay will therefore be the difference between the biasing current and the line current, or $\frac{E}{R_1} - \frac{E \pm e'}{R_1} = \frac{\pm e'}{R_1}$. The net marking and spacing effects will therefore be equal to each other in magnitude but opposite in sign whatever the leakage. The actual magnitude of both the marking and spacing effects have, of course, been reduced by the leakage.

In the above considerations it has been assumed, for the sake of simplicity, that the leakage is lumped at one point in the middle of the line, while in a real line the leakage will be distributed along the line. For ordinary values of leakage this assumption gives results which closely agree with actual measurements, but when the leakage is very large a small amount of bias is introduced. Even in this case, however, the bias is very much smaller than it would be in previous grounded telegraph systems.

Type-A and type-B polarential methods of operation are now available in many Bell System open-wire and cable telegraph repeaters. These improved methods of controlling leakage and resistance-change losses have reduced considerably the rebalancing and readjusting requirements on grounded telegraph circuits.

Visual Ringing Signal

A new visual signal, recently developed to supplement the audible ringing signal in subscribers' lines, utilizes a cold cathode discharge tube and operates directly from the ringing current without relay or auxiliary power supply. It is more economical both in first cost and in maintenance than any visual signal heretofore available. A metal housing with a glass top protects the tube. The indicator can be mounted against a wall or equipped with a cord and placed on a desk or table. A composition pad on the base minimizes slippage and prevents marring of the surface on which it is placed. This signal can be used in manual, panel, step-by-step or crossbar areas and should find considerable application among subscribers with impaired hearing, and in locations where it is necessary to distinguish between several lines or extensions.



Noise from Shunt Capacitors on Power Systems

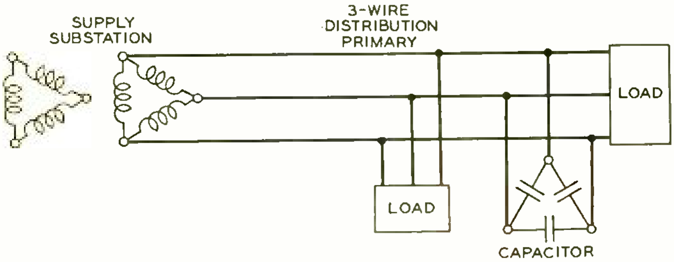
By R. M. HAWEKOTTE

Inductive Coördination

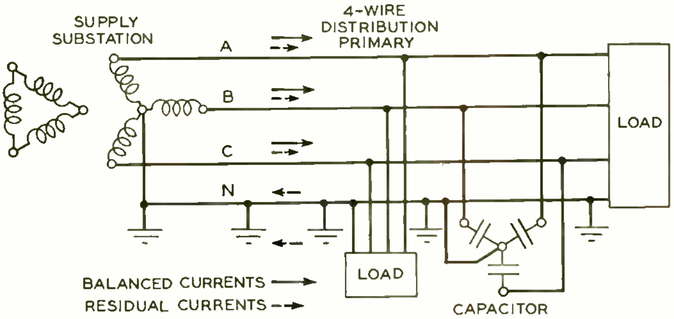
DURING the last few years, the extensive use of shunt capacitors for improving power factor and voltage conditions on power-distribution circuits has, in some instances, required that steps be taken to prevent an increase in noise in paralleling telephone circuits. Situations of this sort are being studied as they arise by Project Committee 1A of the Joint Subcommittee on Development and Research, which is composed of representatives of the Edison Electric Institute and the Bell System. In these studies, the committee has had the coöperation of the local power and telephone companies and, in several cases, of the manufacturer of the capacitors. The present article is based upon the results of the committee's work to date.

In themselves, capacitors are not sources of harmonics. When a capacitor is connected to a primary power distribution feeder, however, it may form a resonant circuit at some harmonic frequency with the inductive reactance of the line, voltage regulators, supply transformers, and source of supply, and thus greatly increase the currents caused by harmonic potentials which are present in the system's voltage at or near this resonant frequency.

Typical applications of three-phase shunt capacitors to distribution primaries are illustrated schematically in Figure 1. Depending upon the type of connection, such capacitors may have marked effects on either the "balanced" or "residual" harmonic cur-



(a) Δ-CONNECTED CAPACITOR



(b) Y-CONNECTED CAPACITOR, MULTI-GROUNDED NEUTRAL

Fig. 1—Three-phase shunt capacitors connected to power circuits may have marked effects on harmonic currents

rents on the circuit or on both. The balanced currents in a power system are those components of the phase currents that are equal and add up vectorially to zero. Thus balanced currents are confined to the phase conductors. Where the phase currents at any frequency do not add up vectorially to zero, their vector sum is termed the residual current. Residual currents flow in a circuit consisting of the three line conductors in parallel as one side and the earth in parallel with any multi-grounded neutral conductors present as the other side, as illustrated in (b) of Figure 1.

The most prominent residual currents are likely to occur at frequencies that are odd multiples of the third harmonic of the fundamental because, at these frequencies, the currents in the three line conductors of a three-phase circuit are in phase and thus add up arithmetically. Residual currents also occur at other frequencies, however, because of inequalities in the phase currents caused by unbalances that may occur in the system, such as unequal loads connected between the phases and neutral of a four-wire circuit or unequal lengths of single-phase branches. About sixty per cent of the residual current in a circuit operating with multi-grounded neutral flows in the earth; the remaining forty per cent returns in the neutral conductor. It is the sixty per cent that returns by way of the ground that has the greatest effect on telephone circuits.

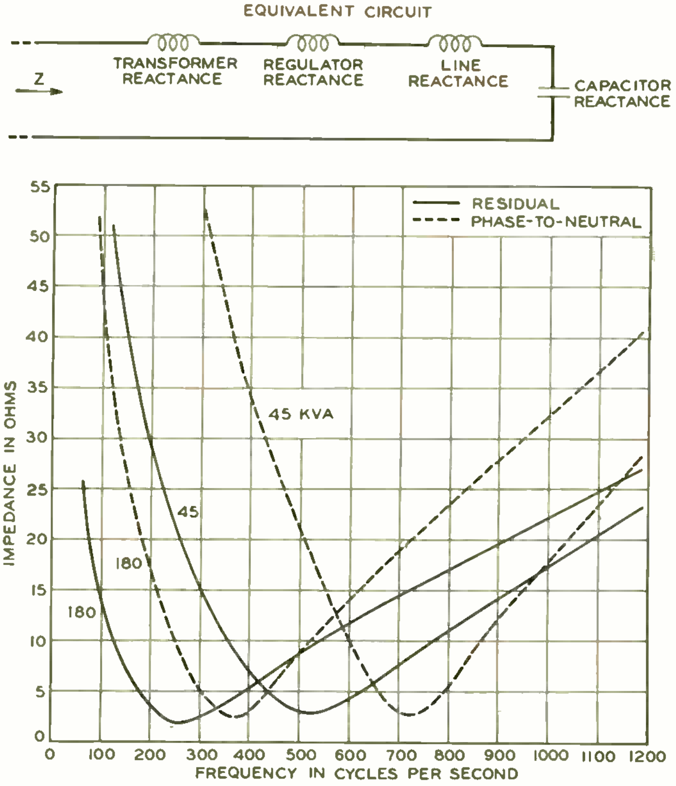


Fig. 2—Equivalent circuit of power system with corrective capacitors, above; and the effects of 45- *and* 180-*kva, three-phase, grounded-Y capacitors on circuit impedances of a two-mile, four-kv line, below*

Where three-phase capacitors are associated with the phase conductors only, that is, where they are connected in Δ, as in (a) of Figure 1, or in Y with isolated neutral, they have no effect upon the impedance of the residual circuit and thus can produce resonance in the balanced circuit only. When they are connected in Y with grounded neutral, however, as in (b) of Figure 1, they form a part of both the balanced and residual circuits, and may cause resonance in either or both.

A simple equivalent circuit for a power circuit with a capacitor connected is shown in the upper part of Figure 2. This type of circuit may be used to represent the phase-to-neutral circuit for computing the effects of the capacitor on balanced harmonic components, or the residual circuit for calculating the effects on residual components. Below this diagram are curves illustrating the effects of 45- and 180-kva, three-phase, Y-connected capacitors on the impedance of the residual and phase-to-neutral circuits of a particular 2-mile, 4-kv line. The magnitudes of the balanced and residual harmonic currents under such conditions depend upon the harmonic potentials present and on the impedances of the balanced and residual circuits, as shown in Figure 2.

TABLE 1—I·T IN POWER CIRCUIT BETWEEN SUBSTATION AND CAPACITOR LOCATION ON THREE-PHASE, 4-WIRE, MULTI-GROUNDED-NEUTRAL POWER CIRCUIT

Power System Arrangement	*I·T Product*	
	Balanced	*Residual*
No capacitors	1400	290
Y-connected capacitors with grounded neutral	3500	745
Delta-connected capacitors	3300	295

The inductive influence of a power line current on neighboring telephone lines is determined by its I·T product, which is the product of the current and its telephone influence factor. The effect of a capacitor installation on the I·T product in one particular case involving a three-phase, four-wire power line operated with a multi-grounded neutral is indicated in Table 1. It will be noticed that there was a substantial increase in the I·T product of both balanced and residual currents where Y-connected capacitors with grounded neutral were employed, while the increase was confined to the balanced current for the Δ-connected capacitors. In the balanced circuit, the larger I·T product resulted from an increase in the fifth and seventh harmonic currents, while in the residual circuit, it came from the increase in the third harmonic, or 180-cycle current.

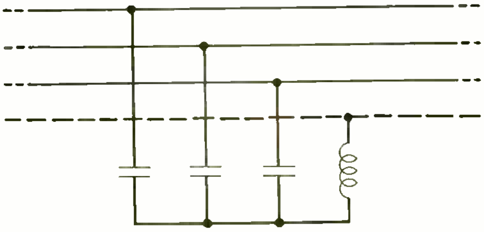


Fig. 3—Capacitor bank with reactor in neutral connection

To what extent this increased I·T product will increase the noise in a telephone circuit depends upon the coupling between the power and telephone lines, the type of telephone circuit involved, and the apparatus with which it is equipped. The effects of the above harmonics on the noise in the receiver of a sidetone-connected station set on an exposed line are indicated in Table 2. With a grounded-ringer set, it will be noticed that the noise was materially increased when the capacitors were connected in grounded

TABLE 2—EFFECT OF POWER CIRCUIT CURRENTS ON NOISE IN EXPOSED TELEPHONE CIRCUITS

Power Circuit Arrangement	*Noise in Receiver of Sidetone Station Set (Db)*	
	Bridged Ringer	*Grounded 8A Ringer*
No capacitors	Less than 6	21.0
Y-connected capacitors with grounded neutral	6	40.5
Delta-connected capacitors	Less than 6	23.0

Y, but not appreciably affected when they were connected in Δ. With bridged ringer sets, the noise was not important in either case.

The tests indicated that for this particular situation the noise results chiefly from the effects of longitudinal voltages to ground on the telephone circuit, induced by the ground-return components of the residual current in the power circuit. The induced voltages acting on the unbalances to ground in the telephone circuit and equipment produced the noise in the receiver as already described in the RECORD.* With Δ-connected capacitors, the ground-return currents in the power circuit were relatively small, and the induced noise was increased only slightly, while with grounded Y-connected capacitors, there was a relatively low impedance path for the residual current, and the increase in noise was substantial.

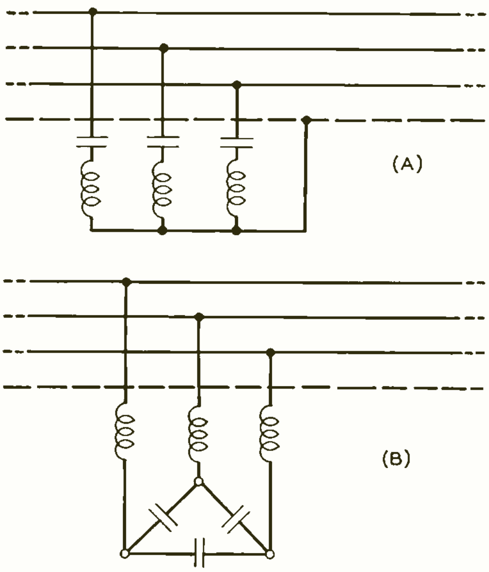


Fig. 4—Capacitor bank with reactors in phase wires. Y-connected bank at A, *and Δ-connected bank at* B

TABLE 3—EFFECT OF NEUTRAL REACTORS ON POWER CIRCUIT INFLUENCE AND TELEPHONE CIRCUIT NOISE

	Power Circuit I·T Product		*Noise in Receiver of Sidetone Station Set with Grounded 8A Ringer*
Power Circuit Arrangement	*Bal.*	*Resid.*	*(Db)*
No capacitors......	1400	290	21.0
Y-connected capacitors:			
(a) with grounded neutral....	3500	745	40.5
(b) with reactor in grounded neutral....	3000	215	30.0

There are several measures that may be taken to limit the noise in any given situation. Some of these require modifications in the power system, and others in the telephone system. In the power circuit, where ground-return currents control the inductive effects, Δ-connected capacitors might be employed in place of Y-connected units with grounded neutral. The effectiveness of this measure has already been illustrated in Table 1. A similar effect might be obtained if the neutral of the Y-connected bank were not grounded, but this is not generally desirable because a fault in one of the capacitors might result in high potentials across the other two.

It has been found, however, that a small reactor inserted in the neutral connection is effective in breaking up the resonant condition in the residual circuit. Such an arrangement is indicated in Figure 3. A reactor is usually selected that will form a resonant circuit with the capacitors at 180 cycles. This, of course, prevents resonance with the system at 180 cycles, and above that frequency results in a

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*RECORD, *September*, 1939, *p.* 2.

net inductive reactance in the residual circuit. A trial of such a reactor was made, and its effect in reducing the I·T product and the noise is indicated in Table 3. This measure does not, of course, affect the balanced components. Furthermore, it does not reduce the residual I·T product to zero, but to a value of the same order of magnitude as with Δ-connected capacitors, Table 1. Although the noise is reduced appreciably from that with the directly grounded capacitors, it is not so low as with the Δ-connected capacitors, as may be seen by comparison with Table 2. With the Δ-connected capacitors the residual I·T product and noise were controlled by frequencies in the range above 540 cycles, while with the Y-connected capacitors and neutral reactor the frequencies below 540 cycles predominated. The greater relative importance of these lower frequencies in the receiver noise, as compared to the residual I·T product, is reflected in the higher receiver noise remaining under the latter condition.

Resonance in the balanced circuit may similarly be prevented by inserting a reactor in series with the capacitor in each phase, as indicated in A of Figure 4. If the capacitors were Δ-connected, the arrangement would be as shown in B. One arrangement of this sort that has been tried experimentally makes use of reactors which resonate with the capacitors in the phase-to-neutral circuit at about 270 cycles. A reactor of this magnitude increases the voltage across the capacitor units by only about 5 per cent, which in most cases is unimportant. If a larger reactor were employed, which would resonate at a lower frequency, the 60-cycle voltage rise would be larger and too close to the operating limits of the capacitor. This arrangement could be combined with a suitable neutral reactor, as indicated in Figure 5, so as to combine the effects of both Figures 3 and 4A, and thus prevent resonance in either the balanced or residual circuits.

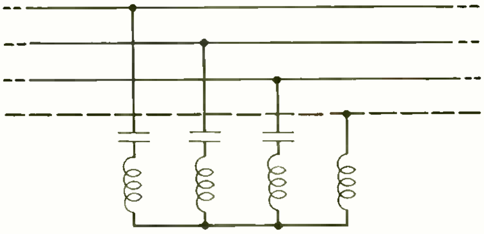

Fig. 5—Capacitor bank with both phase and neutral reactors

TABLE 4—NOISE IN THE RECEIVER OF PARTY LINE STATION SETS FOR SEVERAL POWER CIRCUIT ARRANGEMENTS

	Noise in Receiver (Db) Y-connected Capacitors on Power Circuit	
	With Grounded Neutral	*With Reactor in Grounded Neutral*
Sidetone Station Set		
8A Ringer..........	43.5	34.0
8J Ringer*.........	17.5	8.0
Anti-Sidetone Station Set		
8A Ringer..........	32.5	22.5
8J Ringer..........	20.0	10.0

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*Double condenser station set

There are also several measures applicable to the telephone plant for reducing the noise in situations involving capacitors. As pointed out above, it has been found that the greatest increase in noise on exposed telephone circuits has been that in the receivers of party line station sets, in which the ringer is connected between one line wire and ground. The noise has been found to vary materially with different ringers employed. This is indicated in Table 4. These data are confined to measurements on a set equipped with a 337 transmitter and 144 receiver, since the noise-weighting factors for the newer types are still under development. The results indicate that material reductions in receiver noise may be obtained either by converting sidetone sets with the lower-impedance 8A ringer to anti-sidetone sets with the same ringer or, preferably, with the 8J ringer. Other measures applicable in the telephone plant to reduce the effects of longitudinal induction have been discussed in detail in the article already referred to. These include cable-sheath shielding, longitudinal chokes, and drainage circuits.

Where the exposed telephone circuits are of open-wire construction, coördinated transpositions offer a means of noise reduction where the direct-metallic induction is an important contributor. This measure, for example, would be most effective on toll circuits, which are well balanced, and on subscriber circuits equipped with bridged ringers or with grounded ringers of the higher impedance type. Where numerous discontinuities are present, however, the effectiveness of telephone transpositions is reduced.

It is evident from the foregoing discussion that there are a number of factors involved in noise coördination problems resulting from installations of power system capacitors. The measures appropriate for any specific case will depend upon the circumstances surrounding that situation, there being no unique or universal solution yet available for coördination problems of this type. In the cases thus far studied, the solutions have involved the application of measures to both the power and telephone systems singly and in combination.

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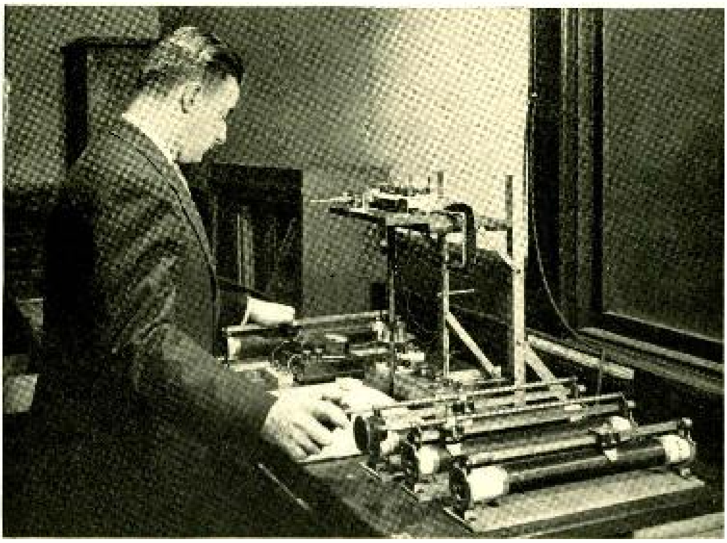
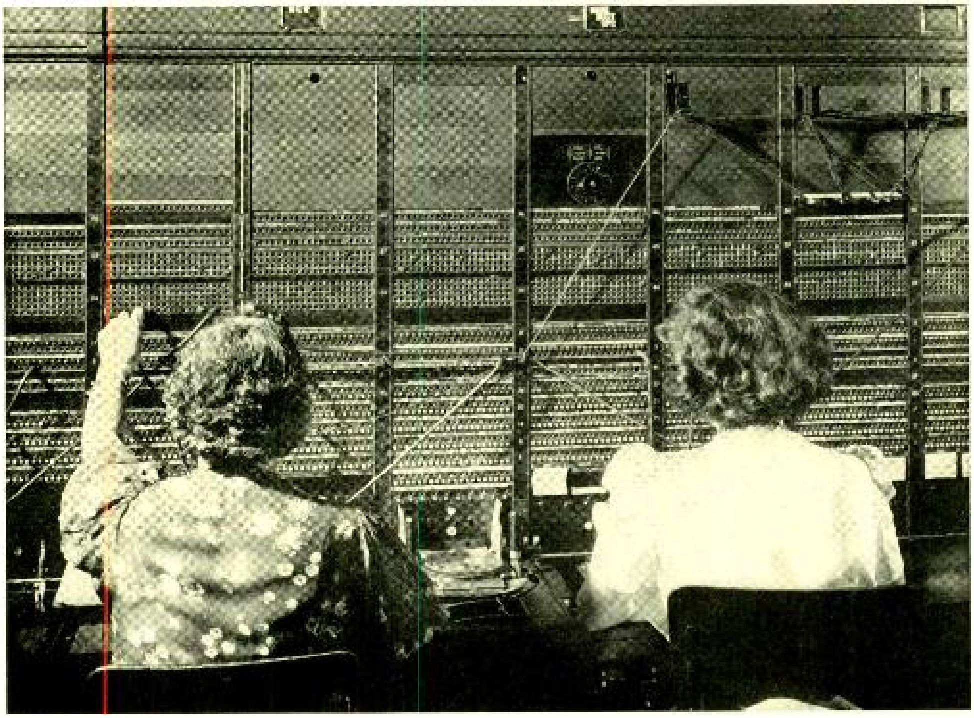


G. W. Galbary determines the pulling characteristics of a holding magnet of a crossbar switch vertical unit



An Answering-Time Recorder

By H. G. W. BROWN

Switching Development Department

THE interval of time between the origination of a telephone call and the operator's answer is called the "answering time." Since this interval is one criterion of the service given by a central office, it should be kept as small as is consistent with economical operation. Answering time depends on a number of factors such as the size and proficiency of the operating force and, in certain types of office, on the proper distribution along the switchboard of the lines of various calling rates. The rate at which calls come into the board, and thus the number of operators required to answer them properly, varies from hour to hour and from season to season. One of the important tasks of the supervisory force is to see that the number of operators at the board is adequate for the calling load at all times. Long experience has proved that the most satisfactory and economical service is given when the average answering time is kept constant throughout the day and year.

Studies made at each office show the variation in load both in its daily cycles and in its seasonal trends, and this information furnishes data for arranging the schedules of the operating force. To ensure that the schedules are satisfactory, it is desirable to obtain records of the answering time, and to provide such records an

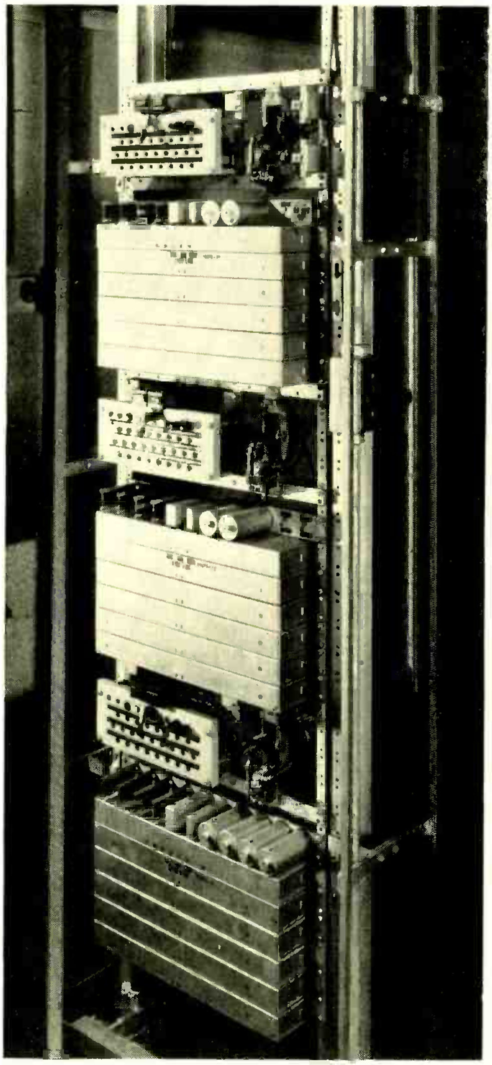


Fig. 1—Three answering-time recorders in the Long Lines building in New York City

answering-time recorder has recently been developed. It is designed for use with manual switchboards, dial system "A" boards, toll boards, or such auxiliary and miscellaneous equipments as intercepting and information desks.

The new instrument makes a record of the total number of calls handled by the recorder and the number of these calls that were not answered within a specified time. It is arranged for connection to twenty-five lines, and the lines associated with it at any one time may be distributed over an entire switchboard, so as to give a representative sample of the service at the board, or they may be confined within narrower limits, as occasion may indicate desirable.

Fundamentally the recorder consists of two electrically operated registers with the necessary connecting and control relays. One is known as the total-calls register, and operates each time a call obtains control of the circuit. The other is known as the delayed-answer register, and operates each time an observed call is not answered within the time for which the recorder is set. The indications of these registers are read periodically. If, for example, the readings are taken

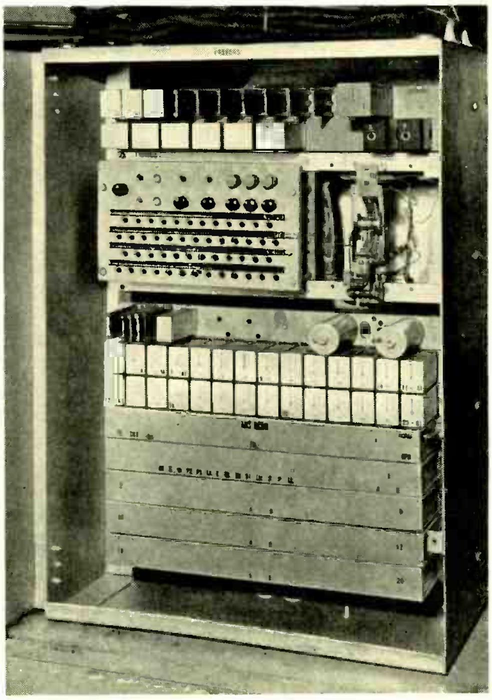


Fig. 2—An answering-time recorder in portable form installed in the "information" office at Paterson, New Jersey

every hour of the day, or every half hour as is done in some places, a complete record is available of the variations that occur in the answering times during both light and heavy load periods.

When a call comes in on one of the lines connected to the recorder, a series of relays operate. These first operate the total-calls register, and then arrange the circuit so that subsequent "flashing" by the subscriber will not cause false operation of the register. They then connect a lead from the 120 i.p.m. office interrupter to a rotary selector, which acts as a counting mechanism. It moves ahead one step on each pulse from the interrupter and operates the delayed-answer register on reaching a step that corresponds to the delay time to be measured. The recorders are arranged to count time intervals of almost any duration up to 20 seconds with a maximum deviation on any one observation of +0.5 second. Any type of interrupter available in the office may be used; when the interrupter lead is closed, the magnet of the selector is operated, and when the interrupter lead is opened, the armature of the selector advances the brush one step as the armature releases.

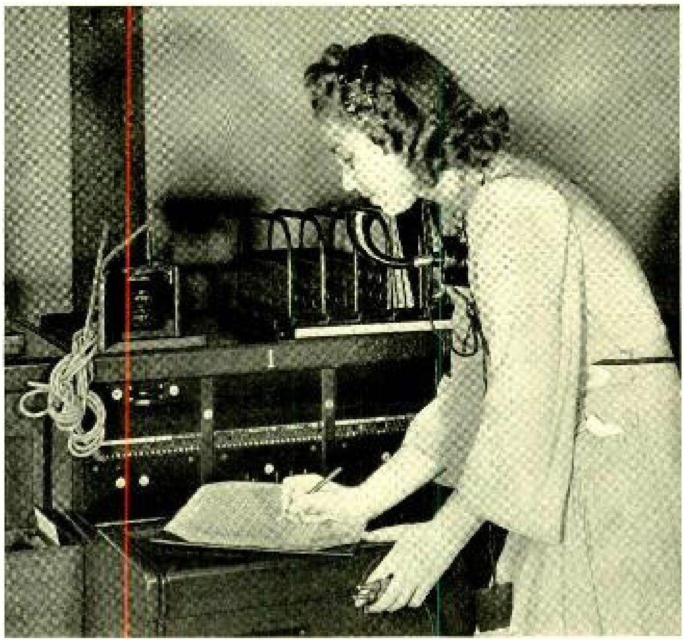


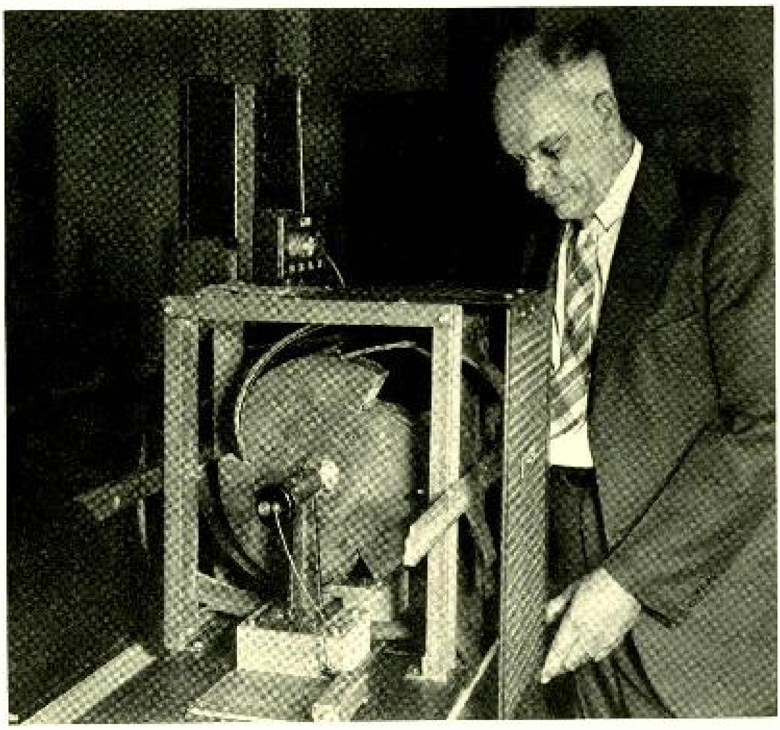
Fig. 3—The "total-calls" and "delayed-answer" registers used with the portable unit are installed in a separate box in the operating room

If the call is answered before the delayed-answer register has been operated, the selector is advanced to the normal position, all operated relays are released, and the circuit is made available for the next call. The circuit similarly releases and restores to normal after the delayed-answer register has been operated. The equipment is thus never held on a single call longer than the delayed-answer period.

As already noted, the recorder is accessible to twenty-five lines, but the answering time can be measured on only one line at a time. A chain of relays is therefore provided so that while one call is being timed, all the other lines are excluded from the register. A further precaution is taken to prevent the recorder from timing calls which might have started while it was busy. Hence not all calls originated on the twenty-five lines are timed, but the result has been found to give a fair sample of the answering time on the group of lines that are being observed.

The recorder is arranged in two forms: one for permanent mounting on a relay-rack, and one in a small cabinet for portable use. An installation of three recorders of the former type at the Long Lines building in New York City is shown in Figure 1. The "chain" and other relays are on the lower part of the unit, and the selector that does the timing is at the upper right. The jacks are used primarily for testing purposes. When recorders are installed in a large office, where there are many trunk groups to be studied, a switching arrangement is provided that enables the recorder to be transferred from one group to another as desired. This circuit is operated by a small dial switch, which permits as many as ten groups of trunks to be associated with the recorder one at a time. This switch, installed just above the multiple on one of the switchboard lines at the Long Lines building in New York City, is shown in the photograph at the head of this article.

A portable unit, installed at the "information" office in Paterson, New Jersey, is shown in Figure 2. There are slight differences in equipment and arrangement of the two forms because of the differences in the type of service, but all the main features are the same. In either form, the use of the recorders materially reduces the effort required to obtain answering time data, and the equipment greatly increases the quantity of data obtained in an equal observing interval.



In this life test for telephone booth treads, leather and metal flaps attached to a rotating drum simulate the scuffing action of shoe leather and nails. The treads, attached to the front and back vertical members of the frame, are being inspected by W. A. Krueger

Contributors to this Issue

R. M. Hawekotte graduated from Purdue University in 1924 with a B.S.E.E. degree, and at once joined the Department of Development and Research of the A. T. and T. He was engaged chiefly in the development of special measuring apparatus used in tests on inductive interference, and in investigations of inductive coördination problems involving voice-frequency noise on telephone circuits resulting from wave-shape distortion on power circuits. He has also studied frequency-selective devices applicable to the power system as a means of correcting the wave-shape distortion. In 1934, with the D & R, he transferred to the Laboratories where he has continued inductive coördination studies. A considerable amount of this work was with the Joint Subcommittee on Development and Research of the Bell System and Edison Electric Institute.

K. L. King graduated from the State College of Washington in 1929, and soon after joined the Radio Research Department of these Laboratories. Since then he has been engaged primarily in the development of radio equipment. At first he assisted in the development of transmitters for ship-to-shore service, and then took part in the design of the first single-sideband transmitter for transoceanic short-wave telephone communication. He later went to England for an extensive series of tests of this new transmitter, and has since worked on the various designs leading up to the transmitter described in this issue.

Allan Weaver was graduated from the University of Nebraska in 1921 with the degree of B.Sc. in E.E. He joined the Department of Development and Research of the A. T. and T. that year to work on the engineering requirements and the design of direct-current telegraph repeaters. For five years beginning in 1924 he was concerned with the engineering requirements of telephotograph systems. Since 1929 Mr. Weaver has worked on teletypewriters and associated repeater equipment. In 1934 he transferred to the Laboratories with the D & R.

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as night operator, but later transferred to central-office maintenance work. His ability and wide experience in this field led to his transfer to the Engineering Department of the Western Electric Company in 1920. Here he engaged in laboratory testing and circuit design. With what is now the Switching Development Department he has engaged in a wide variety of activities, concerned primarily with manual switchboards and their associated and auxiliary circuits.

H. H. Felder was graduated from Clemson A. and M. College in 1918 with a B.S. degree in electrical and mechanical engineering. After some months in the U. S. Signal Corps he joined the Engineering Department of the A. T. and T. in January, 1919, and became a member of the Department of Development and Research upon its formation later that year. He has been engaged in general transmission problems in connection with telephone repeater development and toll circuit layout and switching. Recently he has been engaged also in work on some of the phases of cable loading as applied to entrance cables for type-J open-wire carrier systems.

D. F. Johnston received the B.S. degree in electrical engineering from The Catholic University of America in 1922, and at once joined the Technical Staff of these Laboratories. With the Systems Development Department he at first associated with the method-of-operation group, but later transferred to the panel switching laboratory, and still later worked on the design of circuits for local test desks. In more recent years, he has devoted his time to the design of circuits for toll switchboards.