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DUPLEX AND QUADRUPLEX TELEGRAPHY
MULTIPLEX TELEGRAPHY
TESTING OF CIRCUITS
PRINTING AND MESSENGER-CALL SYSTEMS
SUBMARINE TELEGRAPHY
HIGH-SPEED TELEGRAPHY

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PREFACE

The International Library of Technology is the outgrowth of a large and increasing demand that has arisen for the Reference Libraries of the International Correspondence Schools on the part of those who are not students of the Schools. As the volumes composing this Library are all printed from the same plates used in printing the Reference Libraries above mentioned, a few words are necessary regarding the scope and purpose of the instruction imparted to the students of—and the class of students taught by—these Schools, in order to afford a clear understanding of their salient and unique features.

The only requirement for admission to any of the courses offered by the International Correspondence Schools, is that the applicant shall be able to read the English language and to write it sufficiently well to make his written answers to the questions asked him intelligible. Each course is complete in itself, and no textbooks are required other than those prepared by the Schools for the particular course selected. The students themselves are from every class, trade, and profession and from every country; they are, almost without exception, busily engaged in some vocation, and can spare but little time for study, and that usually outside of their regular working hours. The information desired is such as can be immediately applied in practice, so that the student may be enabled to exchange his present vocation for a more congenial one, or to rise to a higher level in the one he now pursues. Furthermore, he wishes to obtain a good working knowledge of the subjects treated in the shortest time and in the most direct manner possible.

In meeting these requirements, we have produced a set of books that in many respects, and particularly in the general plan followed, are absolutely unique. In the majority of subjects treated the knowledge of mathematics required is limited to the simplest principles of arithmetic and mensuration, and in no case is any greater knowledge of mathematics needed than the simplest elementary principles of algebra, geometry, and trigonometry, with a thorough, practical acquaintance with the use of the logarithmic table. To effect this result, derivations of rules and formulas are omitted, but thorough and complete instructions are given regarding how, when, and under what circumstances any particular rule, formula, or process should be applied; and whenever possible one or more examples, such as would be likely to arise in actual practice—together with their solutions—are given to illustrate and explain its application.

In preparing these textbooks, it has been our constant endeavor to view the matter from the student's standpoint, and to try and anticipate everything that would cause him trouble. The utmost pains have been taken to avoid and correct any and all ambiguous expressions—both those due to faulty rhetoric and those due to insufficiency of statement or explanation. As the best way to make a statement, explanation, or description clear is to give a picture or a diagram in connection with it, illustrations have been used almost without limit. The illustrations have in all cases been adapted to the requirements of the text, and projections and sections or outline, partially shaded, or full-shaded perspectives have been used, according to which will best produce the desired results. Half-tones have been used rather sparingly, except in those cases where the general effect is desired rather than the actual details.

It is obvious that books prepared along the lines mentioned must not only be clear and concise beyond anything heretofore attempted, but they must also possess unequaled value for reference purposes. They not only give the maximum of information in a minimum space, but this information is so ingeniously arranged and correlated, and the indexes are so full and complete, that it can at once be made available to the reader. The numerous examples and explanatory remarks, together with the absence of long demonstrations and abstruse mathematical calculations, are of great assistance in helping one to select the proper formula, method, or process and in teaching him how and when it should be used.

This is the second of a set of three volumes covering the subject of telegraphy. In it are treated the more complex forms of telegraphy, such as the duplex, quadruplex, multiplex, printing, submarine, and high-speed systems and the methods of testing circuits. The operation of many of these systems involves the most ingenious applications of electrical and magnetic laws and; therefore, the utmost care has been taken to make comprehensive the explanations of the actions of the devices employed. Circuit diagrams and illustrations of apparatus are freely employed, the former being of especial value as aids to the proper understanding of the operations of the systems as a whole. A very complete treatment is accorded the adjustment of apparatus and the location of troubles both within the office and on the line. A high order of technical knowledge and skill are required to operate and to maintain in efficient condition modern telegraph systems, and there are no textbooks printed better fitted to help the ambitious operator to advance than those provided in this set of volumes.

The method of numbering the pages, cuts, articles, etc. is such that each subject or part, when the subject is divided into two or more parts, is complete in itself; hence, in order to make the index intelligible, it was necessary to give each subject or part a number. This number is placed at the top of each page, on the headline, opposite the page number; and to distinguish it from the page number it is preceded by the printer's section mark (§). Consequently, a reference such as § 16, page 26, will be readily found by looking along the inside edges of the headlines until § 16 is found, and then through § 16 until page 26 is found.

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MULTIPLEX TELEGRAPHY

DUPLEX AND QUADRUPLEX TELEGRAPHY

(PART 1)

DIFFERENTIAL DUPLEX SYSTEM

INTRODUCTION

1. Definition of Terms.—Methods of transmitting single messages over a line are frequently called **simplex** to distinguish them from those systems, known as **multiplex**, by which two or more messages are transmitted over a wire at the same time. The advantage of the multiplex system lies in the fact that as one line can do the work of two or more lines, the expense of erecting and maintaining the other lines is saved. A good ground return, though, is necessary for the successful working of this system. Multiplex systems for sending two messages simultaneously in opposite directions over one wire are termed **duplex systems.** Sometimes these systems are termed **contraplex telegraphy,** to imply that the messages are being sent in contrary or opposite directions. On a duplex system there is one sending and one receiving operator at each end or office, that is four operators in all. There are three systems of duplex telegraphy: the *differential*, *polar*, and *bridge*.

The transmission of two telegraphic messages simultaneously in the same direction over the same wire is called the **diplex system**; this term is the opposite of contraplex. On a diplex system there are two sending operators at one end and two receiving operators at the other end, or four operators in all.

The simultaneous transmission of four independent messages, two in one direction and two in the other, is termed the **quadruplex system.** This system requires two sending and two receiving operators at each end, eight operators in all.

2. Method of Indicating Various Circuits.—Whenever it is not especially inconvenient or confusing to do so, the following system of drawing in the various circuits in the diagrams for multiplex systems will be used: The main-line circuit will be drawn in full lines; the artificial-line circuit, in two dots and one dash; the local receiving circuit, in dots; the local sending circuit, in dashes; and the balancing ground-coil

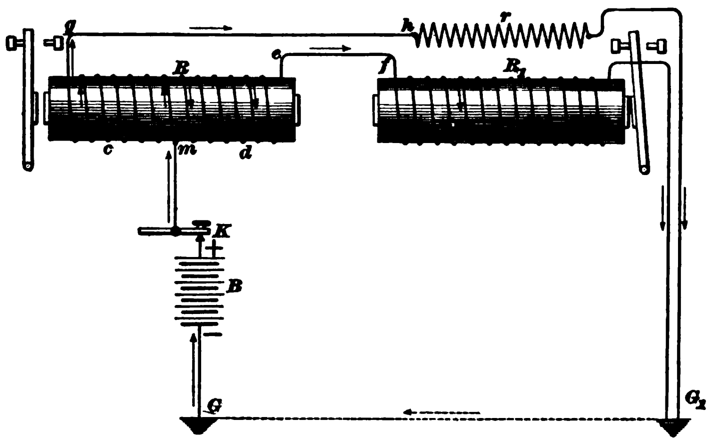


FIG. 1

circuit in the polar, duplex, and quadruplex systems, in one dot and one dash. This plan will make it possible for one to readily distinguish and trace out the various circuits.

PRINCIPLES OF OPERATION

3. Neutral Relay.—The essential feature of the **differential duplex system,** which is also known as the **Stearns duplex,** is the differentially wound relay. In the case shown in Fig. 1, the two outside ends of the differential relay *R* are extended to a distant station through two line wires *g h* and *e f*.

A relay R_1 is connected in one line $e\,f$ and a resistance r equal to the resistance of this relay R_1 is connected in the other. Both circuits are grounded at G_1.

The winding on the differential relay R is divided into two parts, c and d, which have an equal number of turns and an equal resistance, by a connection made at its middle point m. As the two line wires $e\,f$ and $g\,h$ have equal resistances and equal electrostatic capacities, the resistance and electrostatic capacity from the middle point m through $d-e-f-R_1-G_1$, is equal to that through $c-g-h-r-G_1$. Therefore, when the key K is closed, the current will divide equally at m, one-half flowing to G_1 through each of the two circuits, and the relay core R will not be magnetized because two equal currents flow around it in opposite directions. The magnetizing effect of one coil is completely neutralized by that of the other coil. Such a differentially wound nonpolarized relay is commonly called a **neutral relay.**

4. Not only will the steady or final current strength in both coils be the same, but as the capacities and the resistances in the two circuits are equal, the currents in both coils of the neutral relay will rise and fall at exactly the same rate. If the current should reach its maximum value or fall from its maximum value to zero much quicker in one coil than in the other, the armature of the relay would be momentarily affected every time the home key was closed or opened. By the arrangement shown in Fig. 1, however, the home relay R is not affected by the operation of the home key K. This is one of the conditions that must be fulfilled in any successful duplex system. At the distant end, the current that flows over the line $e\,f$ will flow through the relay R_1, and, consequently, that relay will respond every time the key K at the other end is closed, provided, of course, that the current has sufficient strength.

5. The Condenser.—Instead of extending the end of the coil c through the line $g\,h$ and the resistance r to the ground G_1 at the distant end, let it be grounded at G at the home station, as shown in Fig. 2, and include between g and G a resistance r equal to the resistance from e through the line $e\,f$ and the coil d_1

to the ground G_1, also a condenser C having a capacity equal to that of the line $e f$ and so arranged that it will charge and discharge at the same rate as the line. Then the opening and closing of the home key K will have no effect on the home relay R, but it will operate the distant relay R_1. The condenser C is a very necessary part of this equipment. For if no condenser is used, the current will rise to its maximum value in one coil of the home relay R before it does in the other, causing a movement, or momentary *kick*, as it is called, of the armature every time the home key K is opened or closed. This kick of the armature would cause *false signals* every time the home key was operated and would seriously interfere with incoming signals and render the method useless, except, perhaps, on very short lines.

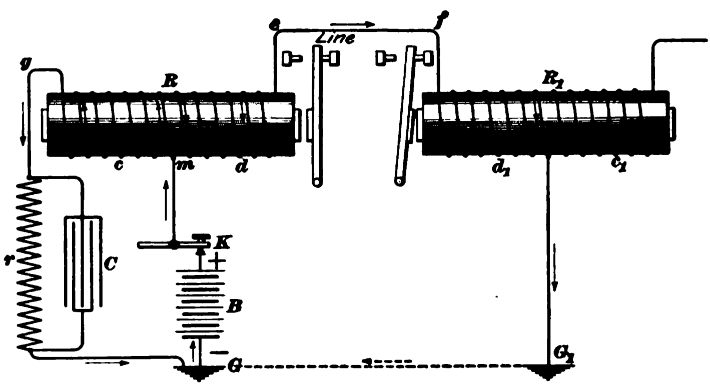


FIG. 2

The application of the condenser to the artificial line in order to give it a capacity equivalent to that of the line, was first made, in 1872, by Stearns, who was a pioneer inventor in duplex telegraph work. Without this discovery the duplex and quadruplex systems at present in use would not be practicable.

6. The capacity of the condenser C should be arranged to resemble the distributed capacity of the line wire. A simple condenser will charge and discharge more quickly than a line wire, in which the capacity is distributed throughout its length. The longer the line and the larger its capacity, the more care must be taken to make the artificial line resemble it. The way in which this is accomplished will be explained in connection with the practical arrangement of the various systems.

7. Artificial Lines and Line Coils.—In order to transmit messages in both directions simultaneously, the arrangement of apparatus at each end must be similar, as shown in Fig. 3. The keys K, K_1 have rear and front contacts and, normally, the levers of the keys rest on the rear contacts a, a_1, which are connected to the ground. Thus the key arrangement resembles that used on the Morse open-circuit system. The resistance

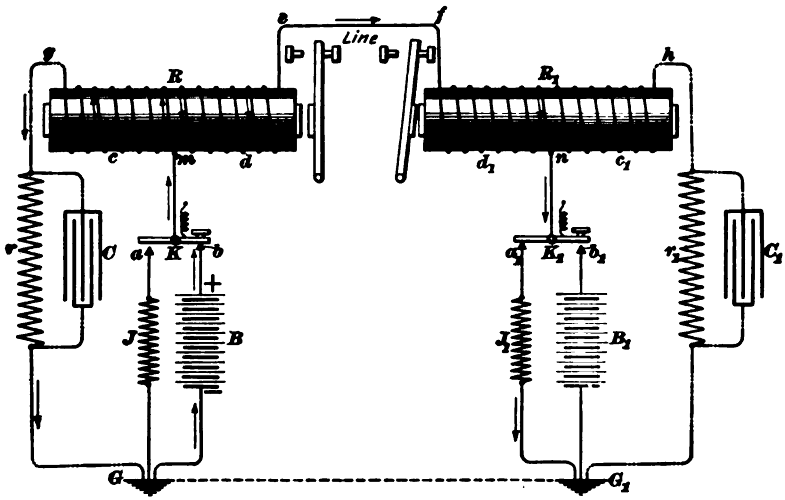


FIG. 3

and capacity of the circuit from the middle m of the home relay R through the coil c and the resistance r and condenser C to ground G should be equivalent to the resistance and capacity of the circuit from m through $d-e-f-d_1-n-a_1-J_1-G_1$. Similarly, the resistance and capacity of the circuit from the middle n of the distant relay R_1 through the coil c_1 and the resistance r_1 and condenser C_1 to ground G_1 should be equivalent to that of the circuit from n through $d_1-f-e-d-m-a-J-G$. The circuit from the end g of the home relay R to the ground G, containing the resistance r and the condenser C, and the circuit from the end h of the distant relay R_1 to the ground G_1, containing the resistance r_1 and the condenser C_1, are called the **artificial lines.** The coils c and c_1 are called the **artificial-line coils** and the coils d and d_1, the **line coils** of the relays.

8. Battery Resistance.—A resistance J, Fig. 3, equal to the internal resistance of the battery B must be inserted between the ground plate G and the rear contact a of the key K. This will give a path of equal resistance from m to the ground G, whether the key K rests on the front or rear contact; J_1 is a similar resistance, equal to the internal resistance of the battery B_1. If such resistances are not used, the home relay R, assuming the distant key K_1 to be closed, will be more strongly magnetized when the home key K is open than when closed, because the current through the line coil d of the home relay R will be greater when the home key K is open than will be the current through the artificial-line coil c when the home key K is closed. The unequal magnetization of the relay would produce an inequality in the signals that it is very desirable to avoid.

POSITIONS OF TWO KEYS

9. When messages are being transmitted simultaneously in both directions, the two keys may be in such positions as to form any one of the following four combinations: Both keys may rest on their rear contacts, both may be on the front contacts, the home K may be on the rear and the distant K_1 on the front contact, and vice versa. No matter which position the home key K occupies, the operation of the distant key K_1 will not affect the distant relay R_1 but it will operate the home relay R. Similarly, no matter which position the key K_1 occupies, the operation of the other key K will not affect its home relay R but will operate the distant relay R_1.

10. One Key Closed.—Suppose that one key K_1 rests on the back contact a_1 and that the other key K is pressed against the front contact b, or **closed,** as it is called. Current then flows from the positive pole of the battery B, charging both the line and the condenser C. When it reaches its maximum value, it flows steadily through the contact b to the middle point m of the relay R, where it divides equally, one half flowing through the artificial-line coil c and the artificial-line resistance r back to the battery B. The other half flows through $d-e-f-d_1-n-a_1-J_1-G_1$ to the ground plate G, and back to the battery B. There is also a closed circuit from the middle point n of the relay R_1 through the artificial-line coil c_1 and the artificial-line resistance r_1 to the ground plate G_1; but the resistance of this path is so very large, compared to that of the path through a_1 and J_1 to G_1, that it need hardly be considered. Moreover, even if there is an appreciable current in the artificial-line coil c_1, it flows in the proper direction in this case to help, and not to oppose, the magnetizing influence of the current through the line coil d_1. Thus the closing of the home key K will not magnetize, temporarily or permanently, the home relay R, because the currents through the two coils c and d are equal and circulate in opposite directions around the iron core of the relay, producing, therefore, no resultant magnetizing force. However, the distant relay R_1 is magnetized because the currents through the two coils c_1 and d_1 are not equal and opposite in direction, and, furthermore, the current in the coil d_1 is strong enough to cause the armature to be attracted. Hence, the home relay R is not magnetized, but the distant relay R_1 is magnetized when the home battery B is connected in the circuit by closing the home key K. In like manner, when the distant key K_1 is closed only the home relay R is affected.

11. Both Keys Closed.—If, while the home key K is against the front contact b, the distant key K_1 is closed, the batteries B and B_1 will be in opposition in the circuit $B-b-K-m-d-e-f-d_1-n-K_1-b_1-B_1-G_1-G-B$. These two batteries contain the same number of cells and have the same electromotive force; consequently, in the circuit just traced, the current will be zero, as the electromotive forces of the batteries are opposed to one another. With both keys closed, the currents in the artificial-line circuits, that is, in $B-b-K-m-c-g-r-G-B$ and in $B_1-b_1-K_1-n-c_1-h-r_1-G_1-B_1$, are due to the electromotive force of only one battery in each circuit; hence, these currents will have their normal strength. Consequently, while there is no current in the line coils d and d_1, there is sufficient current in the artificial-line coils c and c_1 to magnetize both relays R and R_1; therefore, when both keys are closed at the same time, both relays will be closed. Although current from the home battery B closes the home relay R, it is the distant key K_1 that controls the opening and closing of the home relay R. The home key K has no control over the home relay R.

As it has been shown that the distant relay R_1 is energized and the home relay R unaffected when only the home key K

TABLE I

COMBINATIONS OF KEY-AND-RELAY POSITIONS

West Key K	East Key K_1	Western Office				Eastern Office			
		Current in		Difference	Relay R	Current in		Difference	Relay R_1
		Coil d	Coil c			Coil d_1	Coil c_1		
Open	Open	0	0	0	Open	0	0	0	Open
Closed	Open	+1	+1	0	Open	−1	0	1	Closed
Open	Closed	−1	0	1	Closed	+1	+1	0	Open
Closed	Closed	0	+1	1	Closed	0	+1	1	Closed

is closed, and that both relays are energized when both keys are closed, it follows that the relay R is energized and R_1 unaffected when only K_1 is closed, and that neither relay is magnetized when both keys are open, because both batteries are then cut off.

12. Key-and-Relay Positions.—Let us consider that whenever a current flows from the home key through the two coils on the home relay toward the line and artificial line, respectively, it is a positive current; and, conversely, that whenever the current flows from the line or artificial line through the coils of the home relay toward the key, it is a negative current. Furthermore, let the current flowing through one artificial-line circuit that is due to one battery be considered as having a strength of 1 unit. Then the four possible combinations of key and relay positions and the currents in each coil may be summarized as shown in Table I. It will be noticed that whenever the difference between the currents in the two coils of one relay is not zero, the relay is closed and, furthermore, that the distant relay is open or closed corresponding to whether the home key is open or closed.

13. Cause and Prevention of False Signals.—If, at the same moment, both keys should be in an intermediate position, touching neither the front nor the rear contact, there would be no current in any of the relay coils. Consequently, both relays would open every time this occurred, causing false signals and confusion, if means were not taken to prevent them. When gravity cells are used, false signals may be easily avoided by using a continuity-preserving transmitter that is so constructed that when it is moved, contact is made with one stop before the contact with the other stop is broken. A continuity-preserving transmitter that is much used in repeaters and in duplex and quadruplex systems was described in connection with telegraph repeaters. Where dynamos that furnish current at a high potential are used, such a transmitter is not very satisfactory, on account of the injurious sparking that occurs every time the transmitter opens the short circuit it has made around the dynamo.

If the transmitter used does not perfectly preserve the continuity of the circuit, the false signals may be avoided by connecting a repeating sounder in a circuit through the back stop of the differential relay, and an ordinary sounder in another circuit through the back stop of the repeating sounder. This arrangement will give the signals properly, provided the interval of no current in the relay, although long enough to allow its armature to break contact with the regular front stop, is still too short to allow the armature to cross the gap and make contact with the back stop; for the circuit of the second sounder is not closed until the armature of the repeating sounder touches its own back stop. This arrangement, which was first devised by Edison, is successfully used on the neutral-relay side of some quadruplex systems, in connection with which it will be more fully explained.

PRACTICAL ARRANGEMENT

14. The practical arrangement of the Stearns, or differential, duplex is shown in Fig. 4. The arrangement at the two ends is slightly different in order to show both in one figure. R and R_1 are the differential relays; S and S_1, the local sounders; T and T_1, continuity-preserving transmitters; and K and K_1, ordinary telegraph keys connected in local circuits with batteries and the magnet coils of the transmitters. By using the ordinary key and a transmitter connected as shown, operators can send better and faster than by using a double-contact key as is shown in Fig. 3. In all multiplex systems where manual transmission is employed, except perhaps on cables, an ordinary key connected in a local circuit is used to control some form of a transmitter or pole changer. The circuit containing the transmitter, or pole-changer magnet, and the telegraph key is called the **sending circuit**, the **sending side**, or the **sending leg** when it is extended to a branch office. The resistance of the transmitter magnet is usually about the same as the sounder magnet, and the local transmitter circuits are supplied with current in the same manner as are the sounders.

15. The diagram is drawn to show the condition of affairs when both keys K and K_1 are closed, causing both relays R and R_1 and both sounders S and S_1 to be closed. The arrows represent the direction and the figures on the arrows the relative magnitude of the currents in the various parts of the circuit. Practically, it makes no difference which pole of the main-line battery is connected to the home ground. The positive of one and the negative of the other main-line battery may be connected to the ground, or the positive or negative terminals, as shown in Fig. 3, of both batteries may be grounded.

16. Adjusting Artificial Line.—The rheostats Rh and Rh_1, Fig. 4, usually contain between 6,000 and 7,000 ohms and

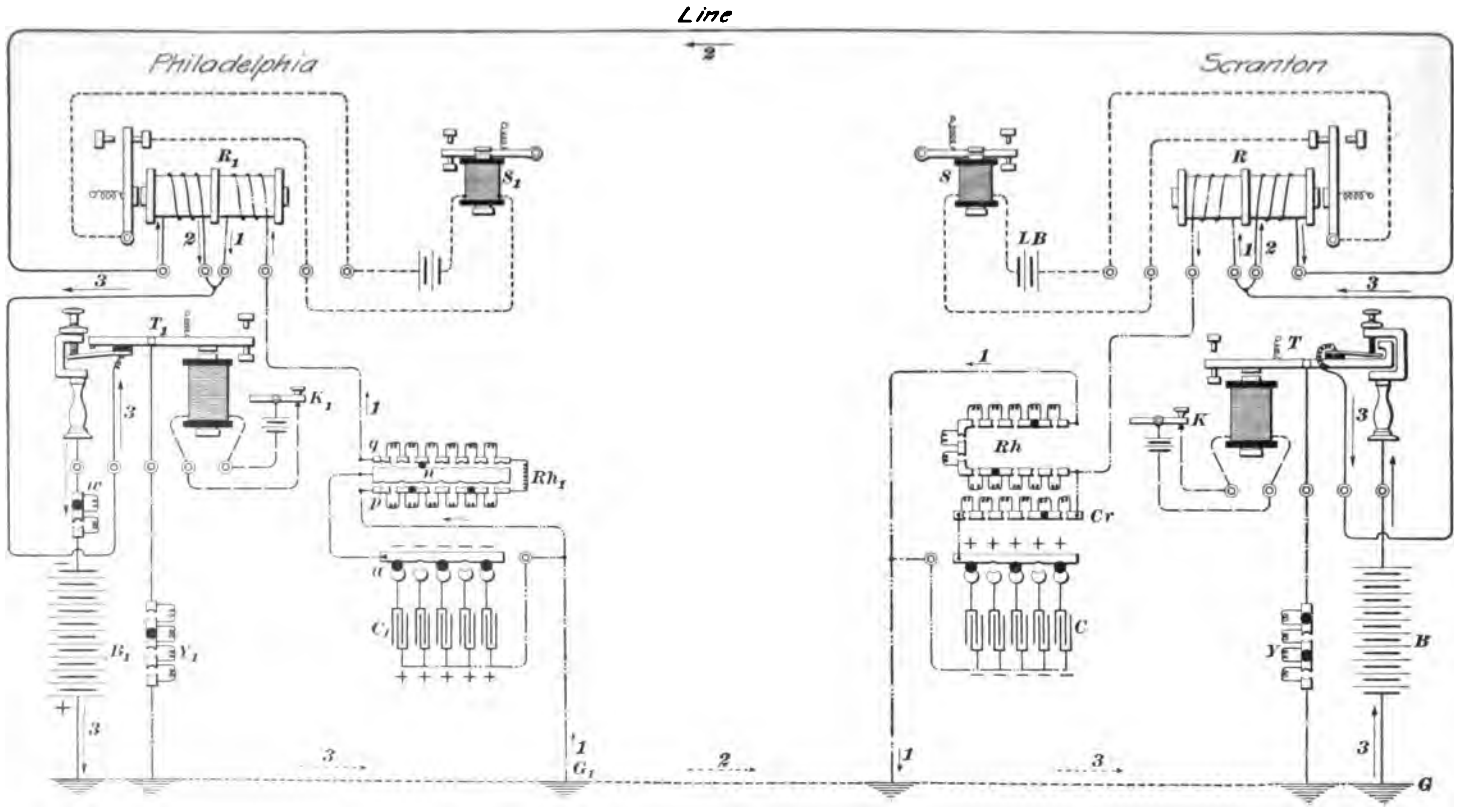

Line
2
Philadelphia
Scranton
R_1
S_1
S
LB
R
1
2
3
T_1
K_1
T
K
w
q
n
p
Rh_1
Rh
Cr
a
C_1
C
B_1
Y_1
Y
B
G_1
G

FIG. 4

are adjustable by steps of 100 ohms or less, thus permitting them to be used on lines of No. 6 B. W. G. iron wire that do not exceed about 600 miles in length. For a No. 6 B. W. G. line wire 600 miles long, as much as 9 microfarads may be required in the condenser C. At the Scranton end, an adjustable resistance Cr, called a *retarding coil*, is placed in series with the condenser in order that the artificial line may be made to charge and discharge as slowly as does the line. If the condenser discharged before the line, although the total discharge may be exactly the same, there would be a false signal due to the inequality in the rate of discharge of the two circuits. To avoid making this false signal the artificial line must be arranged and adjusted to charge and discharge at exactly the same rate as does the line, neither faster nor slower.

17. At the Philadelphia end, the condenser and resistances are arranged without this coil, but there the adjustable rheostat Rh_1 has a brass center strip n to which one terminal of the condenser is joined. In this case a plug may be placed, as shown at n, so as to connect one terminal of the condenser to any coil in the rheostat and thus control the rate and total discharge of the condenser through the relay.

When a current of electricity is flowing through a wire, the difference of potential between two points that are near together is less than that between the points that are farther apart. Hence, as the charge that a condenser receives depends on the difference of potential at its terminals, the charge that the condenser C_1 will take may be regulated by connecting the terminal a of the condenser to different coils of the rheostat Rh_1. At the Philadelphia end, in Fig. 4, this terminal is shown connected to a coil through the plug at n. The nearer this connection is made to the line, the greater will be the resistance between the terminals of the condenser; and, hence, the greater will be the charge taken by the condenser. The nearer it is made to the ground, the less will be the charge taken by the condenser. If the plug is placed in the hole q, the condenser receives the largest charge possible in this arrangement, while if the plug is placed in the hole p, the condenser will receive no charge, as both terminals of the condenser are, practically, connected together. Thus, by adjusting the number and position of the plugs along *a* and the position of the plug *n*, and, further, by adjusting the total amount of resistance in the rheostat Rh_1, this artificial line may be adjusted to charge and discharge at exactly the same rate as the line and, furthermore, to have the same total resistance and capacity.

18. Spark Coil.—The resistance *Y*, Fig. 4, which corresponds to *J* in Fig. 3, is adjusted to equal the internal resistance of the battery *B*, so that the resistance from the tongue of the transmitter to the ground at the same station will be the same in both the open and closed positions of the transmitter. This is the purpose for which the resistance *Y* is used, but it is usually

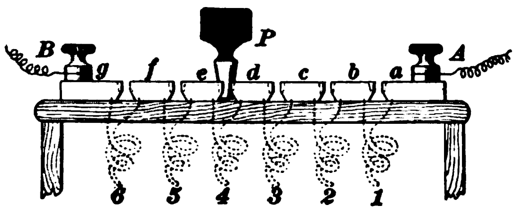


FIG. 5

called the **spark coil** because it also diminishes the intensity or quantity of current in the spark when the short circuit around the battery is broken at the continuity-preserving transmitter *T*. The resistance *w* is necessary when low internal-resistance batteries or dynamos are used in place of the battery B_1, in order to prevent too large a current from flowing, especially in case of a short circuit, and injuring the dynamo or contact points of the transmitter. In case such a resistance *w* is used, the resistance Y_1 of the balancing ground-coil circuit must be equal to that of *w* plus the internal resistance of the battery B_1. In this arrangement *w* is sometimes called the spark coil, or the *protective resistance*, and Y_1 the **ground coil.**

19. Adjustable rheostats are made in various forms. In Fig. 5 is shown the construction and arrangement of the coils in one form of rheostat in which the adjustment is made by means of brass plugs, or pegs. The coils are wound back upon themselves on wooden spools so they shall have no inductance. When wound in this manner, they are called **non-inductive resistance coils.** If they were wound continuously around the spool in one direction, like an ordinary relay coil, their inductance would often be a very serious and annoying factor. It will be evident that the insertion of the plug *P* in the hole between the brass blocks *e* and *d* short-circuits the fourth coil, or "cuts it out" as it is frequently expressed. Thus, by the use of enough plugs, any number of coils may be cut out, thereby reducing the resistance as much as may be desired. The blocks are usually mounted on hard rubber and the resistance of each coil in ohms is usually stamped on the cover opposite the hole,

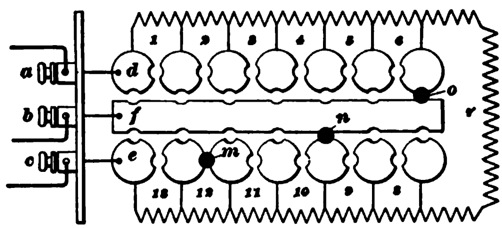


FIG. 6

or on the adjacent brass block or disk. Fig. 5 shows only one row of coils, but the boxes frequently contain several rows.

20. In Fig. 6 is shown the top of a very convenient form of adjustable rheostat for use in artificial-line circuits. Between the two binding posts *a* and *c*, when all plugs are removed, there will be the resistance of the thirteen coils in series; that is, the sum of all the coils whose values are stamped on the brass disks or on the ebonite cover opposite the holes. If a plug is inserted at *m*, for instance, coil *12* is cut out. If a plug is inserted at *o* and another at *n*, the intervening coils *7*, *8*, and *9* are cut out. Where this box is used on duplex and quadruplex systems, the middle brass strip *f* is connected through the middle binding post *b* to a condenser. By means of a plug, the strip *f* and, hence, one terminal of the condenser may be connected to any coil in the rheostat. In such a case, *f* would usually be connected to one disk and coil by plugging only one hole, the resistance being adjusted by plugging between disks.

21. Adjustable Condenser.—One form of adjustable condenser used in connection with various telegraph systems is shown in Fig. 7. The total capacity is divided into five sections; the capacity of the first section is 4 per cent. of the total capacity. The percentage capacity of each section is plainly marked on the disk to which the section is joined. If the total capacity of the condenser is 2.5 microfarads, then, by placing a plug in the hole *b*, Fig. 7 (*n*), the capacity of the condenser

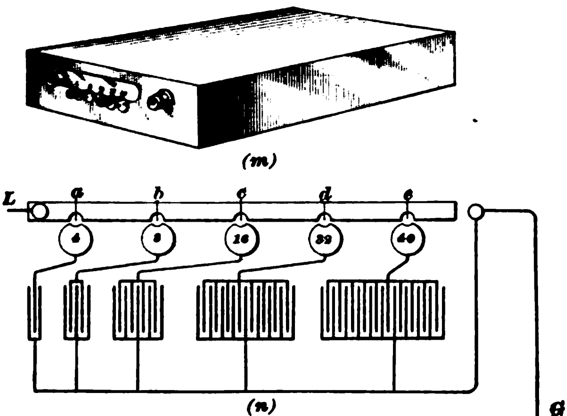


FIG. 7

between *L* and the ground *G* will be 8 per cent. of 2.5; that is, .2 microfarad. By placing plugs in the holes *a*, *c*, and *d*, the capacity will be $4+16+32=52$ per cent. of 2.5, that is, 1.3 microfarads. The condenser can be adjusted by steps of .1 microfarad from .1 up to 2.5 microfarads. The finished appearance of the condenser is shown at (*m*). Sometimes the actual capacity of each section is marked on the disk to which it is connected.

22. Differentially Wound Neutral Relays.—Neutral and polarized relays may be differentially wound in several ways. The idea to be kept in mind is to so arrange the two coils that the resistance and the number of turns in each winding will be exactly equal, and the effect of equal currents in each coil on the movable part of the relay will be the same in intensity. The best way would be to wind the coils with two wires, side by side, as shown in Fig. 8 (*a*). Then the two wires, being insulated from each other, would form two coils as nearly alike in every way as it is possible to get them. The wires composing the two windings on each core, being side by side, would cause the differential action to be, largely, between currents in the windings rather than between magnetisms produced in the cores by such currents. But this is not a con-

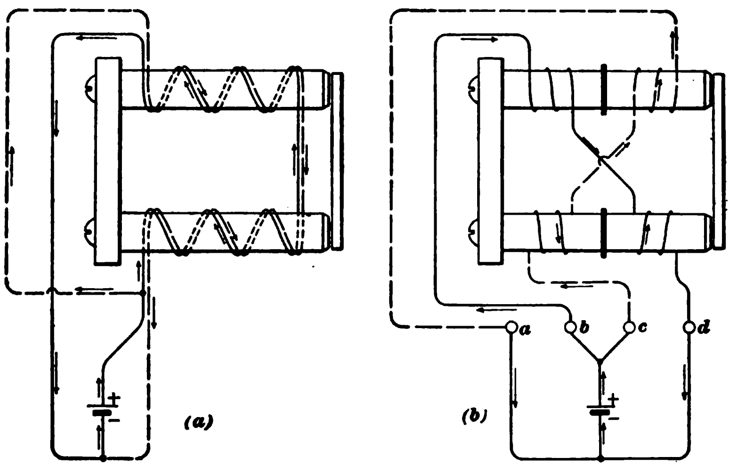


Fig. 8

venient nor a profitable way to wind them. The other extreme is to wind one coil on each core of the magnet. This is not a good way, because, although the two coils may be very much alike, they would not neutralize each other very well. A compromise that has proved satisfactory consists in winding four coils, two on each core, the rear coil on one core, together with the forward coil on the other core, forming one half of the differential winding, and the forward coil on the first core, together with the rear coil on the second core, forming the other half. This method of winding is shown in Fig. 8 (*b*). When the current circulates in the coils in the direction shown by the arrows, the magnetizing forces due to equal currents in the two windings neutralize each other. The ends of the coils are brought out to the binding posts *a*, *b*, *c*, and *d*. Evidently, an excess of current in one winding over that in the other will magnetize the relay. The Stearns differential relay, which is somewhat larger than the ordinary relay, has about 200 ohms in each winding.

BALANCING DIFFERENTIAL DUPLEX

23. Balancing a duplex or quadruplex system includes the adjustment of the various instruments and of the resistance and the capacity of the artificial line to equal exactly that of the main line, so that sending on the home key will not interfere in any way with the signals that are received at the home office from the distant office.

To balance the differential duplex, ask the distant office to open his key. If Philadelphia, Fig. 4, is the distant office, the line will then be grounded through the transmitter T_1 and the rheostat Y_1. Now, turn down the retractile spring of the home relay *R* and adjust the magnets, as would be done with an ordinary relay, for a weak current, in order to make the relay sensitive to the slightest inequality in the division of the current through its two coils. Make dots with the home key *K* and vary the resistance in the home rheostat *Rh* until the home relay no longer responds to the home signals. Then ask the distant office to make dots and readjust the home relay *R* to properly respond to the signals from the distant office as would be done with any ordinary relay. If a momentary kick follows each signal, it may be eliminated by varying the capacity of the condenser *C* and the resistance of the rheostat *Cr*.

To eliminate the kick at an office where the arrangement is like that shown at the Philadelphia end, the capacity of the condenser is adjusted and the position of the plug *n* varied until the kicks disappear. Leakage from the line wire to the ground is equivalent to a line wire of lower resistance, and when the leakage from the line increases, the resistance in the rheostat *Rh* will have to be diminished and the condenser may, also, need readjusting. If the signals from the distant office are stronger when the home key is open than when it is closed, there is not enough resistance in the home rheostat *Y*, and vice versa. The adjustment is not complete until the incoming signals are perfect with the home key held open or closed, or when writing with it.

POLAR DUPLEX SYSTEM

DISTINGUISHING FEATURES OF THE POLAR DUPLEX

24. A polar duplex telegraph system is one by means of which two messages may be sent simultaneously in opposite directions by controlling, at each end, the polarity of the potential connected toward the line. The essential devices in the polar-duplex set located at each end are a differentially wound polar relay, an artificial line, a potential reversing device called a *pole changer*, and a battery or dynamo, whose connections in the circuit are reversed by the pole changer.

25. Superiority of Polar Duplex.—In good weather, the differential, or single-current, duplex gives satisfaction, but its efficiency falls in proportion to the increase in the current that leaks from the line wire down every pole and support to the earth. If this leakage current would disappear when the distant key was open, all would be well; but it does not, and, consequently, the effective, or surplus, current in wet weather becomes too weak to overcome the already high tension of the retractile spring attached to the armature of the relay. The polar duplex overcomes this difficulty to a great extent, and will continue to work satisfactorily long after rain storms have rendered the single-current systems useless. On account of using currents flowing in opposite directions, the capacity of the line should give less trouble.

26. Differential Polarized Relay.—An essential feature of the polar duplex is the differentially wound polarized relay. Fig. 9 represents a polarized, or **polar**, relay, as it is also called, with the two coils connected in three different ways with the same battery. In (*x*) the current circulates only in the coil *c*. The direction of the current and the resultant direction of the lines of force and the polarity of the poles are as indicated. Although there is no current in the coil *d*, the lines of force created in the core by the current in the coil *c* will return to their original starting point through the path offering the least resistance to them, which is through the soft iron, as shown by the

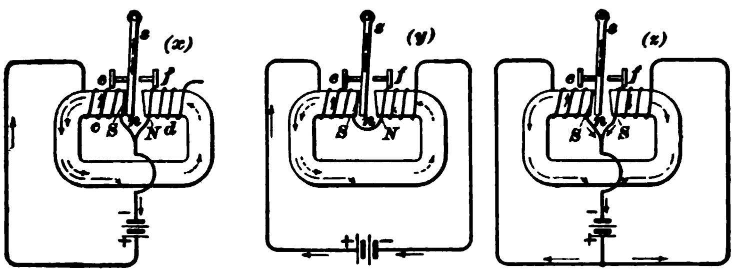


FIG. 9

dotted arrows, and not through the steel magnet, which has been omitted in this figure for the sake of simplicity. Thus the necessity of using the best quality of soft iron for this part of the relay is evident. On account of the lines of force produced by the permanent magnet, shown by arrows drawn with dashes, which make a north pole at *n* on the tongue, and those produced by the current in the coil *c*, shown by dotted arrows, there will be a strong south pole at *S*, and a weaker north pole at *N*. This will cause the armature to rest against the stop *e*. If the battery is reversed, the tongue will be drawn against the stop *f*.

27. In Fig. 9 (*y*), the same battery is connected so that the current flows through both coils, but the strength of the current will only be about one-half what it was in (*x*), because the two coils will have twice the resistance of one. The currents circulate through the two coils around the iron in the same direction, tending, therefore, to help and not to oppose each other in magnetizing the soft-iron core. Therefore, the intensity and direction of the magnetism produced in (*y*) will be the same as that in (*x*) and the armature will be held against the stop *e*.

28. In Fig. 9 (*z*), the two coils are connected differentially, so that the current from the battery divides into two equal portions, one portion flowing through each coil, but in opposite directions, around the iron. Consequently, the coils tend to magnetize the iron with equal forces in opposite directions, and they thus neutralize each other and produce no magnetism; but the permanent steel magnet polarizes the soft-iron parts the same as if there was no current in either coil. Hence, both cores equally attract the armature and it remains against whichever stop it happened to be previously. If the battery, in this case, is reversed, the two coils will still oppose and neutralize each other. Consequently, when connected as shown in view (*z*), the coils have no influence at all on the tongue, no matter what may be the strength or the direction of the current through the two coils.

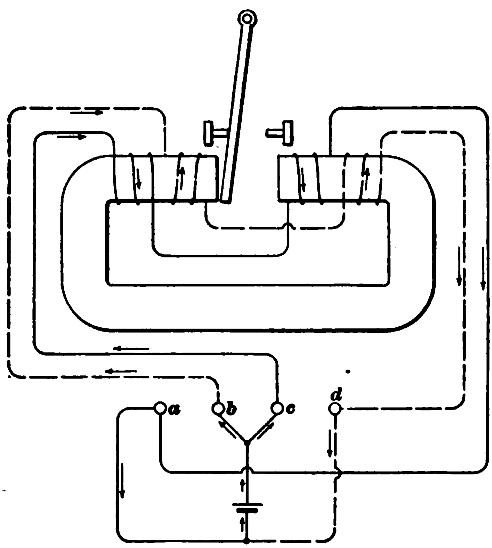


FIG. 10

29. Method of Winding a Differential Polar Relay. The differential polar relay is wound with two coils on each core in the same manner and for the same reasons as the differentially wound neutral relays. In the diagrammatic view of a differentially wound polar relay given in Fig. 10, the ends of the coils are brought out to the binding posts *a*, *b*, *c*, and *d*. When current circulates in the coils in the direction shown by the arrows, the magnetizing forces due to the current in the two windings neutralize each other and an excess of current in one winding over that in the other will magnetize the relay.

Each of the four coils of a Western Union polar relay has about 2,780 turns of 36 B. & S. wire and a resistance of 200 ohms. Thus the line winding, or *line coil*, as it is called, although it consists of two coils, has a resistance of 400 ohms, and the artificial-line winding, which also consists of two coils, has, likewise, a resistance of 400 ohms. Polarized relays on duplex circuits require about 25 milliamperes, while on quadruplex circuits the minimum current required to work them varies from 15 to 18 milliamperes.

Some polar relays are wound with 300 ohms of enamel wire. Reversing a current of 3 milliamperes should properly work such a relay when the magnetic air gap, with the armature centered between cores, is from .035 to .04 inch on each side and the travel between contact points is .003 inch. The same conditions apply to the 400-ohm, silk-covered wire relay, as the latter possesses very few if any more turns. There is a flat multi-blade pocket-knife device, each blade differing in thickness and marked in thousandths of an inch, which is very useful in quadruplex departments for determining such distances.

30. Connections of Polar Duplex.—The connections of the polar duplex when dynamos are used to supply all current are shown in Fig. 11. PR and PR_1 are differentially wound polarized relays, the adjustable resistances Rh and Cr and the condenser C form the artificial line at the left-hand stations while Rh_1 and C_1 form the artificial line at the right-hand station. The artificial-line circuits are arranged in a slightly different manner at the two stations, in order to illustrate two methods used. The resistance Cr, called a *retarding coil* because it retards the discharge of the condenser, is placed in series with the condenser C and is adjusted until the artificial line charges and discharges neither slower nor faster than the line.

When a current is flowing through a wire, the difference of potential between two points near together is less than that between two points farther apart. As the charge that a condenser receives depends on the difference of potential at its terminals, the charge that the condenser C_1 receives may be regulated by connecting the upper terminal of the condenser to different coils of the rheostat Rh_1. The nearer this connection is made to the line, the greater will be the resistance and potential difference between the terminals of the condenser; and, hence, the greater will be the charge taken by the condenser. The portion of the rheostat Rh_1 between the condenser connection and the line acts also as a retarding coil. This is the later and better arrangement.

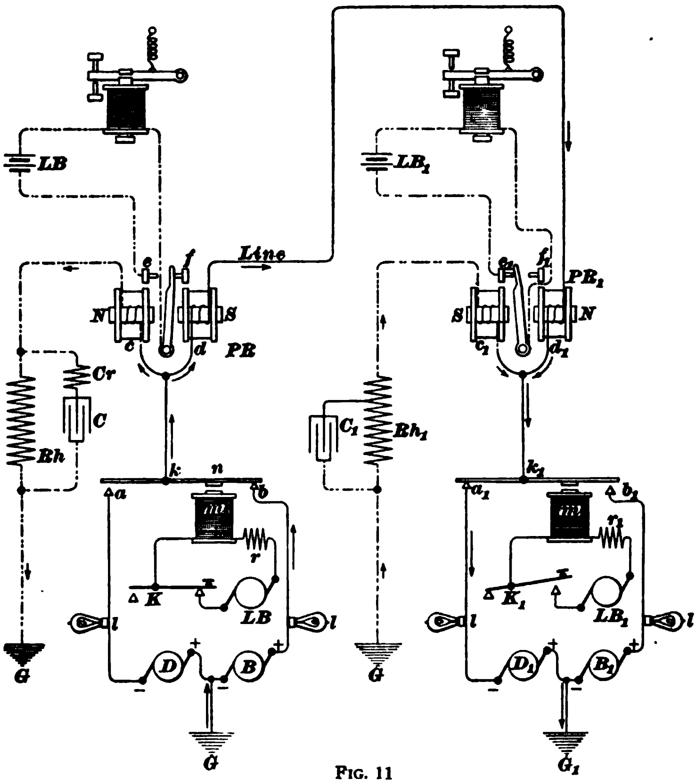


FIG. 11

31. The dynamo, or *walking-beam pole changer*, which is shown in Fig. 11, consists of a lever, or beam, *k* to which is fastened the iron armature *n*, two adjustable stops *a* and *b*, an electromagnet *m*, the current through which is controlled by the operator's key *K*, a 23- to 40-volt dynamo *LB*, and a resistance *r* that allows just sufficient current to flow to operate properly the pole changer. When the key K is closed, the positive pole of dynamo is connected through contact b to the beam k; when it is open the negative pole of dynamo D is connected through contact a to the beam k. The beam k, in moving from one position to the other, momentarily opens the circuit when in its intermediate position and the dynamos are never short-circuited.

In circuit with each machine is a non-inductive resistance l, which is either an incandescent lamp or a non-inductively wound coil of German-silver, or other high-resistance, wire. This resistance serves two purposes: It reduces sparking at the contact points, because it limits the strength of the extra current when the pole changer opens the circuit, and it prevents injury to the dynamo due to overheating in case there is a short circuit. For duplex and quadruplex circuits, this resistance varies from about 300 to 800 ohms. All four dynamos, D, B, D_1, and B_1, generate current at the same voltage. The connections at the two ends are identical, except for the slight difference in the artificial lines that has already been explained.

OPERATION OF POLAR DUPLEX SYSTEM

32. Both Keys Open.—When both keys K and K_1 are open, the beams k and k_1 of the pole changers rest on the rear contacts a and a_1, and, as the negative poles of two equal dynamos, one at each end, are, in this open position of the two keys, connected to the line, there will be no current flowing in the line coils d and d_1. However, there will be current in the two artificial-line coils c and c_1 and the direction in which the current flows around the soft-iron cores and the polarization of the armatures will be such as to hold the armatures of both polarized relays against their back stops f and f_1. The current in either artificial-line coil due to the home dynamo may be represented as having the strength of 1 unit.

33. Key *K* Closed.—If the western operator commences to send by pressing his key K, the positive pole of one dynamo B will be connected to the relay and line, in place of the negative pole of the other dynamo D. This will reverse the direction of the current through the artificial-line coil c, but its strength will remain the same, namely, 1 unit. The current in the line coils d and d_1 will now have a strength of 2 units, because the two dynamos B and D_1, which generate equal electromotive forces are now connected in series in the line circuit. Hence, a current of 1 unit flows through the artificial-line coil c and a current of 2 units through the line coil d, but the direction of the currents in the two coils, as indicated by the arrows, is such that their magnetizing forces oppose each other, and the result is equivalent to a current of 1 unit flowing only through the line coil d in the direction shown by the arrow at that coil. This will produce a north pole at the left-hand end of the core on which the coil d is wound and a south pole at the right-hand end of the core on which c is wound and, consequently, the tongue, assuming it to have a south pole between the two cores, will remain against the back stop f. Thus, the closing of the home key K does not affect the home relay PR as long as K_1 the distant key remains on the rear contact a_1.

At the east end, the current in the artificial-line coil c_1 has not changed in strength or direction; it has a strength of 1 unit. In the line coil d_1, however, there is now a current of 2 units. The direction of the currents in the two relay coils d_1 and c_1, as indicated by the arrows, is such that their magnetizing forces oppose each other, and the result is equivalent to a current of 1 unit through the line coil d_1 in the direction shown by the arrow in that coil. This will produce a south pole at the left-hand end of the core on which the coil d_1 is wound and a north pole at the right-hand end of the core on which the coil c_1 is wound. Consequently, the tongue, assuming it to have, as before, a south pole between the two cores, will move against the front stop e_1 and close the local sounder circuit at the eastern office. Thus, the closing of the home key K, when the distant key K_1 is open, operates the polar relay PR_1 at the distant office, but does not affect the home polar relay PR.

34. Both Keys Closed.—If the key K_1 is now closed, the relay PR will be closed and the relay PR_1 will continue to remain closed until the key K is released. For when both keys are closed and the levers of the pole changers rest on thier front contacts, the two dynamos B and B_1 are connected in opposition in the line circuit. Consequently, no current flows in either of the line coils d or d_1. The current in the artificial-line coil c_1 is reversed and will produce a north pole at the right-hand end of the core on which it is wound, and a south pole at the left-hand end of the core on which the coil d_1 is wound. But this polarity is the same as before and, therefore, the tongue of the polar relay PR_1 remains against the front stop e_1, being unaffected by the change in the currents caused by closing the home key K_1, although it has reversed the polarity applied to the circuit by the home dynamos.

At the western office the current in the artificial-line coil c has not changed in strength nor direction, but there is now no current in the line coil d. The direction of the current is such that it reverses the polarity of the cores, producing a north pole at the right-hand end of the core on which c is wound and a south pole at the left-hand end of the core on which d is wound. Consequently, the tongue of the home relay PR moves against the front stop e and closes the local sounder circuit. Thus, the closing of the distant key K_1 when the home key K is closed, closes the home relay PR, but does not affect the distant relay PR_1.

35. Key K_1 Closed.—If the western key K is now released, the distant K_1 remaining closed, the two dynamos D and B_1 will be in series in the line circuit, the current in the line coils of both relays will have a strength of 2 units, and the current through the artificial-line coil c will be reversed in direction, but will have the same strength as before, namely, 1 unit. The direction of the currents in the coils c and d is such that their magnetizing forces oppose each other, and the result is equivalent to a current of 1 unit flowing from the line through coil d. This produces a south pole at the left-hand end of the core on which the coil d is wound and a north pole at the right-hand end of the core on which c is wound. Consequently, the polarity is such that the tongue of the home relay PR remains against the front stop e when the home key K at the western office is released.

Thus, the opening of the home key K does not change the polarity of the home relay PR. At the eastern station the effect of a current of 2 units flowing from the dynamo B_1 through the coil d_1 to the line, and a current of 1 unit from the same dynamo flowing through the coil c_1 to the artificial line, is equivalent to a current of 1 unit flowing from the same dynamo B_1 through only the line coil d_1. This produces a north pole at the left-hand end of the core on which d_1 is wound and a south pole at the right-hand end of the core on which c_1 is wound, thus causing the tongue of the relay to move from the front stop e_1 to the rear stop f_1. Thus, the opening of the home key K, while the distant key K_1 is closed, produces no effect on the home relay PR, but does open the distant relay PR_1.

It has, therefore, been shown that no matter what may be the position of the distant key, the operation of the home key does not affect the home relay, but that it does properly operate the distant relay.

36. Keys in Intermediate Positions.—It may be well to consider what happens to the relay during the short interval between the opening of the circuit at one contact of the pole changer and the closing of the circuit again at the other contact of the same pole changer. Suppose that the lever of the distant pole changer k_1 rests on the rear stop a_1, and that the lever of the home pole changer k, in moving from the rear to the front contact, remains in an intermediate position, touching neither a nor b. In this position only the dynamo D_1 is in the circuit. It supplies a current of 1 unit to the coil c_1. The artificial line Rh at the western office, the coils c and d, the line and the coil d_1 are in series with the dynamo D_1. The resistance of this circuit is double that of the line and the two line coils d and d_1, and, consequently, the current in this circuit will have a strength of $\frac{1}{2}$ unit. The current of a strength of $\frac{1}{2}$ unit in coil d_1 will oppose the current of 1 unit in c_1, but the magnetism due to a resultant current of $\frac{1}{2}$ unit flowing from the artificial line through coil c_1, produces a south pole at the right-hand end of c_1 and, therefore, tends to hold the tongue of the distant relay PR_1 against the back stop f_1, where it is already. Thus, the distant relay PR_1 will not be affected until the lever k of the pole changer touches the front stop b. A current of ½ unit flows in the same direction through both coils c and d, so that their magnetizing forces help each other and produce a resultant magnetism of the same polarity and strength as when the lever k of the pole changer rested on the rear stop a. Consequently, the home relay R is not affected, and the tongue remains stationary against the rear stop f.

Suppose that the levers of both pole changers are in an intermediate position at the same instant. Evidently all four dynamos are cut off and there is no current in any part of the system.

TABLE II

COMBINATIONS OF KEY-AND-RELAY POSITIONS

West Key K	East Key K_1	Western Office				Eastern Office			
		Current in		Difference	West Relay PR	Current in		Difference	East Relay PR_1
		Coil d	Coil c			Coil d_1	Coil c_1		
Open	Open	0	−1	+1	Open	0	−1	+1	Open
Closed	Open	+2	+1	+1	Open	−2	−1	−1	Closed
Open	Closed	−2	−1	−1	Closed	+2	+1	+1	Open
Closed	Closed	0	+1	−1	Closed	0	+1	−1	Closed

But, now, the magnetism produced in the soft iron by the permanent steel magnet will hold the tongues on whichever side they happen to be, thus preventing any false signals.

37. Key-and-Relay Positions.—Let the current flowing from the home pole-changer lever through either coil on the home relay toward the line or artificial line be called a *positive current;* and the current flowing from the line or artificial line toward the home pole-changer lever be called a *negative current.* Furthermore, let the current that flows through one artificial-line circuit due to one dynamo be considered as having a strength of 1 unit; and let the end of the tongue between the cores of the polar relay be assumed to be a south pole. Then the four possible combinations of key-and-relay positions and the currents in each coil may be summarized as shown in Table II.

The quantities in the difference column are obtained by subtracting the quantities in the c or c_1 column from the quantities in the d or d_1 column, respectively. It will be noticed that whenever the current in the line coil minus the current in the artificial-line coil of the same relay is $+1$, the relay is open; and that whenever it is -1, the relay is closed. Furthermore, it will be noticed that the eastern relay is open or closed according to whether the western key is open or closed.

POLE CHANGERS

38. A very essential instrument in the polar duplex and quadruplex systems is the **pole changer.** This is a device for reversing the battery and, consequently, for reversing the direction of the current in the circuit. It shifts the line from one pole of a battery to the opposite pole, and, simultaneously, does the same with the wire connected to the ground. Where dynamos are used, it shifts the line from one pole of one dynamo to a pole of opposite polarity on another dynamo. Poles of opposite polarity of the two dynamos are permanently grounded. Thus the operation of a pole changer changes the direction of the current in some part, at least, of the circuit.

A device that will reverse the direction of the current in the circuit without opening the circuit is called a **continuity-preserving,** or **circuit-preserving, pole changer.** Such a pole changer is preferable to one that opens the circuit when shifting the line from one pole of the battery to the opposite pole. While continuity-preserving pole changers are generally used where gravity cells are employed for main-line batteries, they are not practicable, and are not used where dynamos have replaced gravity batteries.

39. Continuity-Preserving Pole Changer.—The principle of continuity-preserving pole changer is shown in Fig. 12. The battery B is connected to two movable spring contact strips a and d. The line wire is connected to the lever of the key K, and the fixed piece *b* is connected to the ground. In the normal, or open, position of the key, as shown in (*x*), the positive pole of the battery is connected through the strip *a* and contact *c* to the key lever and to the line; the negative pole of the battery is connected through the strip *d* and the fixed contact piece *b* to the ground *g*. In this position of the key, the direction of the current through the circuit is as shown by the arrows. If the key is depressed, or closed, as shown in (*y*), the direction of the

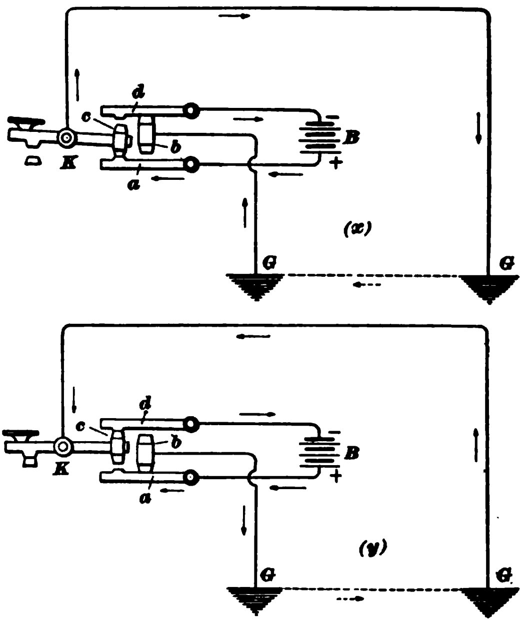


FIG. 12

current in the line and in the ground circuit, as shown by the arrows, is the reverse of that shown in (*x*).

In passing from one extreme position to the other, the key momentarily short-circuits the battery. For the spring strips *d* and *a* may be made flexible enough and so adjusted that as the key in (*x*) is pressed down and the contact *c* moves up, the moving contact *c* first touches the spring strip *d*. Then the spring strip *a* touches the fixed contact *b*, next the moving contact *c* parts from the spring strip *a* and finally pushes the spring strip *d* away from the fixed contact *b*, giving the position of the contacts shown in (*y*). The reverse happens when the key moves in the opposite direction. Thus, the contact *c* momentarily short-circuits the battery and preserves an uninterrupted path from the line to the ground. This short-circuiting does not injure a gravity battery, on account of its rather high internal resistance. It may be a little hard on the contacts,

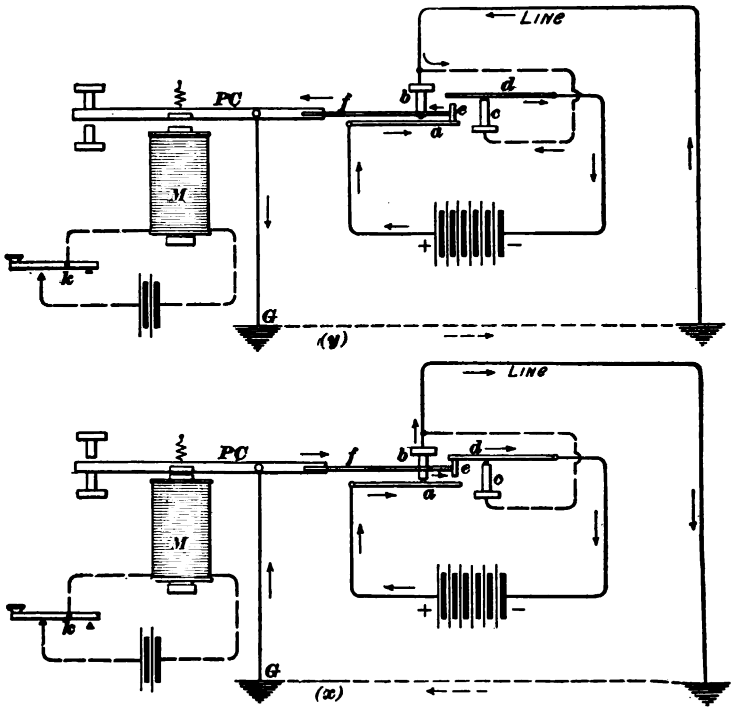


Fig. 13

due to the arc that is formed when the short circuit is opened, but it is not so serious as to render the method impracticable. The desirable feature of this pole changer lies in the fact that the battery is reversed with the least possible interference with the line current. In practice, the lever of the key is never manipulated directly by hand, but by means of an electromagnet.

40. B. & O. Pole Changer.—In Fig. 13 are shown the two positions of a pole changer known as the **B. & O.** (Baltimore and Ohio Railroad) **pole changer.** The contact screw *b* is placed behind the lever *f* and never touches it. When the key *k* is open, the position of the contacts and the direction of the current is as shown in (*y*). When the key *k* is closed, the magnet *M* draws down the forward end of the lever *PC* of the pole changer, causing the moving contact *e* to push the spring strip *d* away from the contact screw *c*, and allowing the other spring strip *a* to rest against the contact screw *b*, thus giving the position of the contacts shown in (*x*). The springs *d* and *a*

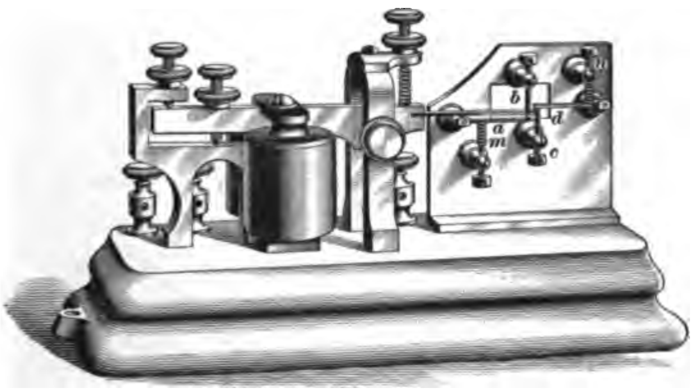


FIG. 14

may be made long and flexible enough and so arranged that, as the lever *f* moves up, the spring *a* first touches the screw *b*, then the moving contact *e* touches the other spring *d*, next the moving contact *e* parts from spring *a*, and, finally, the contact *e* pushes the spring *d* away from the contact screw *c*. The arrows show the direction of the current. This is a so-called continuity-preserving pole changer. It momentarily short-circuits the battery because *e* touches *d* before it leaves *a*.

This pole changer, as made by Bunnell & Co., is shown in Fig. 14. The contact springs *a* and *d* have bearing upon them adjustable springs *m* and *n*. The stop-screws *b* and *c* are also adjustable. These screws and contacts are not enclosed and are easy of access for the purpose of adjusting and cleaning. The rest of the instrument resembles an ordinary sounder.

41. Western Union Gravity-Battery Pole Changer. The so-called clock-face pole changer used by the Western Union Telegraph Company, where gravity main-line batteries are employed, is shown in Fig. 15. The contacts are enclosed in a case having a glass front, so that as much dirt and dust may be kept from them as is possible. The glass front enables one to observe the operation and condition of the contact points.

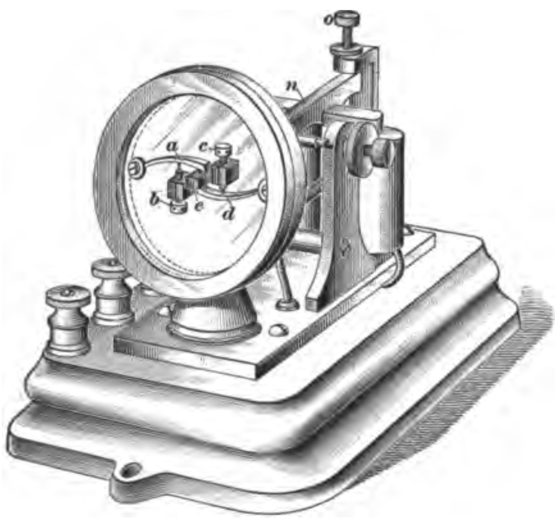


FIG. 15

The principle of this pole changer may be understood by referring to Fig. 16. The centerpiece e is fastened to the end of an armature lever and moves up and down. When down, as shown in (x), the positive pole of the battery B is connected through the strip a and the stop b to the line; the negative pole of the battery is connected through the strip d and the movable contact e to the ground G. The arrows show the direction of the current flowing in the various parts of the circuit. The reverse position is shown in (y).

This is a continuity-preserving pole changer. It momentarily short-circuits the battery in the intermediate position and preserves a closed circuit at all times between the line and the ground *G*. As contact *e* moves upwards, the spring *d* touches the stop *c*; then the contact *e* touches the spring *a* and pushes it away from the stop *b*; finally, the contact *e* parts from the spring *d*. However, the movable piece *e* is in contact with both springs *a* and *d* only momentarily; in fact, all these changes

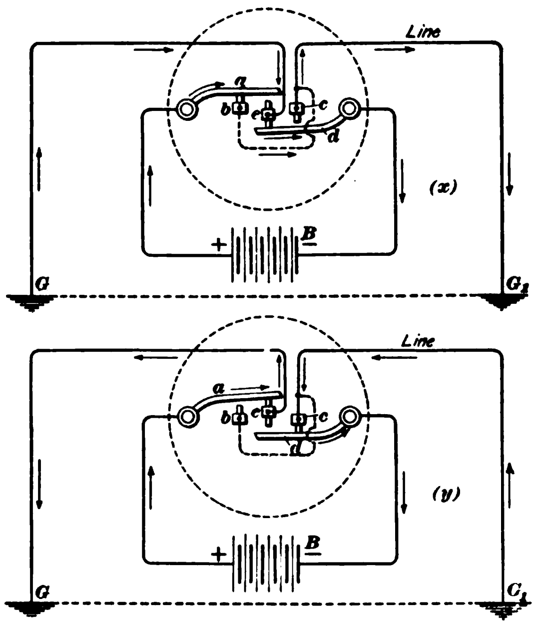


Fig. 16

follow one another very rapidly and the battery is short-circuited for only an instant. When the contact *e* moves downwards, the contacts are made and broken in a similar manner. The parts shown in both Figs. 15 and 16 are similarly lettered. In Fig. 15, *n* is the armature lever, on the front end of which is fixed the movable contact *e*. The stops *b* and *c* are in contact with the case and are connected to one binding post on the base. The springs *a*, *d* and the *e* end of the lever *n* are all insulated and connected to separate binding posts.

42. Dynamo Pole Changers.—Theoretically, there should be no difference in the efficiency of a duplex or quadruplex circuit whether it is supplied with current by a dynamo or by gravity cells in first-class condition. But in practice, the dynamo has been found to be the more economical and reliable source of energy. The use of gravity batteries, however, permits the employment of the continuity-preserving pole changer, for as each line has its own battery the direction of the current in any line can be reversed without interfering with the working of any other line. Besides, the continuity-preserving transmitter is less liable to interfere with the signals on the neutral relay in the quadruplex system than the walking-beam pole changer. But continuity-preserving pole changers cannot be used with dynamos because one dynamo furnishes the current to all lines requiring the same polarity and voltage; therefore, it is not practical to reverse the connections of the dynamo in one circuit without reversing it in all the others. A separate dynamo is therefore required for each polarity at each end, but not for each multiplex set at each end, and one pole of each machine is permanently grounded.

43. With dynamos it has been found advisable to use a pole changer that does not short-circuit the machines, but which opens the circuit connected to one pole of one dynamo slightly before it connects the circuit with the opposite pole of the other dynamo. If a continuity-preserving pole changer were used, it would at every reversal, where 350-volt machines are employed, short-circuit 700 volts and cause the formation of bad arcs at the contact points. This would soon put the contact points in very bad condition, and perhaps damage the dynamo on account of the heat produced.

To avoid these difficulties, the so-called **walking-beam pole changer,** shown in Fig. 17, is used. The line is connected to the beam *a b*; the positive pole of one dynamo *C* is connected to the contact stop *e* under one end *a* of the beam, and the negative pole of the second dynamo *D* is connected to the contact stop *f* under the other end *b* of the beam. The positive pole of one dynamo *D* and the negative pole of the other *C* are permanently grounded at *G*. Thus, when the key *K* is closed, the positive pole of dynamo *C* is connected to the line through the beam *a b*, and when the key is open, the negative pole of *D* is connected to the line. The beam *a b* in moving from one position to the other, momentarily opens the line circuit when in its inter-

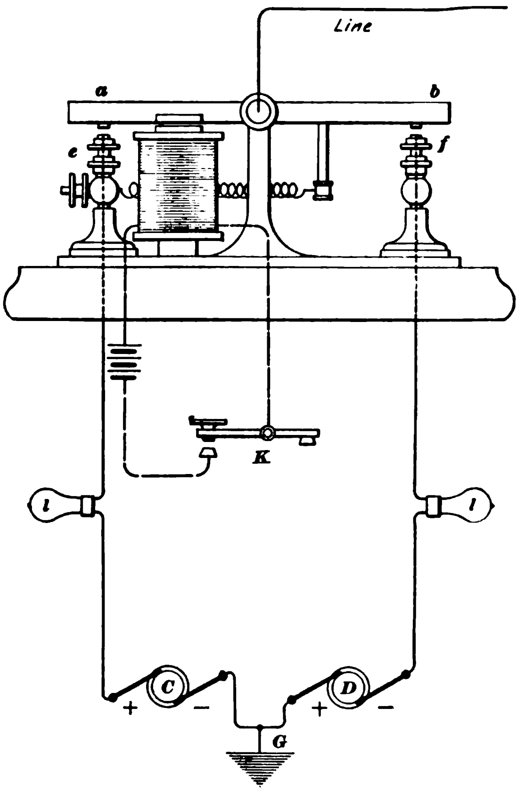


FIG. 17

mediate position, as is shown in this figure, but the dynamos are never short-circuited.

In circuit with each machine is a non-inductive resistance *l*, either an incandescent lamp or a non-inductively wound coil of German-silver, or other high-resistance, wire. This resistance serves two purposes: it reduces sparking at the contact points, because it limits the strength of the extra current when the pole changer opens the circuit, and it prevents injury to the dynamo due to overheating in case there is a short circuit. For quadruplex circuits, this resistance varies from 300 to 800 ohms.

TABLE SWITCH

44. A form of switch that is extensively used on the tables, or desks, in connection with duplex and quadruplex systems is shown in Fig. 18. Along the top is a row of seven screws, or binding posts, to which all wires running to the switch are fastened. Along the bottom is a row of six contact buttons. The buttons *1*, *3*, *4*, and *5* are connected under the switch to the binding posts, as shown by the dotted lines. The buttons *2* and *6* are idle buttons; that is, they have no wires connected to them. The switch arm *A* may rest on button *1* or button *2*, *B* on *3* or *4*, and *C* on *5* or *6*. This makes a very convenient switch; its use will be apparent when diagrams for the dynamo duplex and quadruplex systems are given. A similar switch, that is extensively used, has only two arms, which are mechanically joined together by a cross-bar having on it a handle by means of which both arms are simultaneously moved to the right or left.

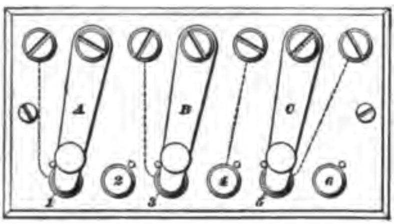


FIG. 18

POLAR DUPLEX OPERATED BY GRAVITY BATTERY

45. The practical arrangement of a polar duplex set at an office where gravity cells are used is shown in Fig. 19. All the apparatus and connections have already been explained except the use of the switch *H* and the resistance *Gc*, called the ***ground coil***. This resistance need not necessarily be adjustable; it may be simply a coil having a fixed resistance. The resistance from *r* through the ground coil *Gc* to G_2 should be equal to that of the circuit from *p* through the pole-changer contacts and main battery *B* to the ground *G*. When the duplex set is in operation, the switch *H* rests on *p*; but in order to balance the set, it is desirable to cut off the pole changer and the battery *B*, but to keep the resistance of the circuit the same. This is accomplished by turning the switch *H* to *r*. The resistance of *Gc* should be equal to the internal resistance of the main battery *B*. Here *PC* represents a continuity-preserving pole changer suitable for use with gravity cells, such as has been shown in Figs. 14 and 15; *K* is the sending key and *S* is the receiving sounder.

POLAR DUPLEX OPERATED BY DYNAMOS

46. In Fig. 20 is shown the arrangement of the polar duplex when dynamos are used to operate the system. The walking-beam type of pole changer and the switch *M* replace the continuity-preserving pole changer and the simple switch *H* shown in Fig. 20 in which gravity main-line batteries were used. In order to avoid confusion, the local receiving and sending circuits are shown separately in Fig. 21. The contact buttons *u* and *z* on the switch *M*, Fig. 20, are idle, or insulated, and are used merely to rest the arms *o* and *q* upon when it is desirable to entirely cut off the main-line dynamos *D* and *F*. When the system is in operation, the switch arms *o*, *p*, and *q* rest upon the buttons *t*, *v*, and *r*, respectively. When the arm *p* rests upon the button *w*, the main circuit is connected through the ground coil *Gc* to the ground at G_2 instead of through the pole changer and dynamo *F* or *D* to the ground *G*. Thus, the polar relay is entirely disconnected from the home dynamos. This is the position of the switch arm *p* for balancing the system. The resistance of the circuit from the button *w* through the ground coil *Gc* to the ground G_2 is made equal to that of the circuit from the button *v* through the pole-changer contacts, one lamp *l* and one dynamo to the ground *G*. The switch *Gc* is practically equal in resistance to that of one of the lamps *l*. At *N* is shown the form of switch used where a dynamo is employed to operate the local sending and receiving circuits.

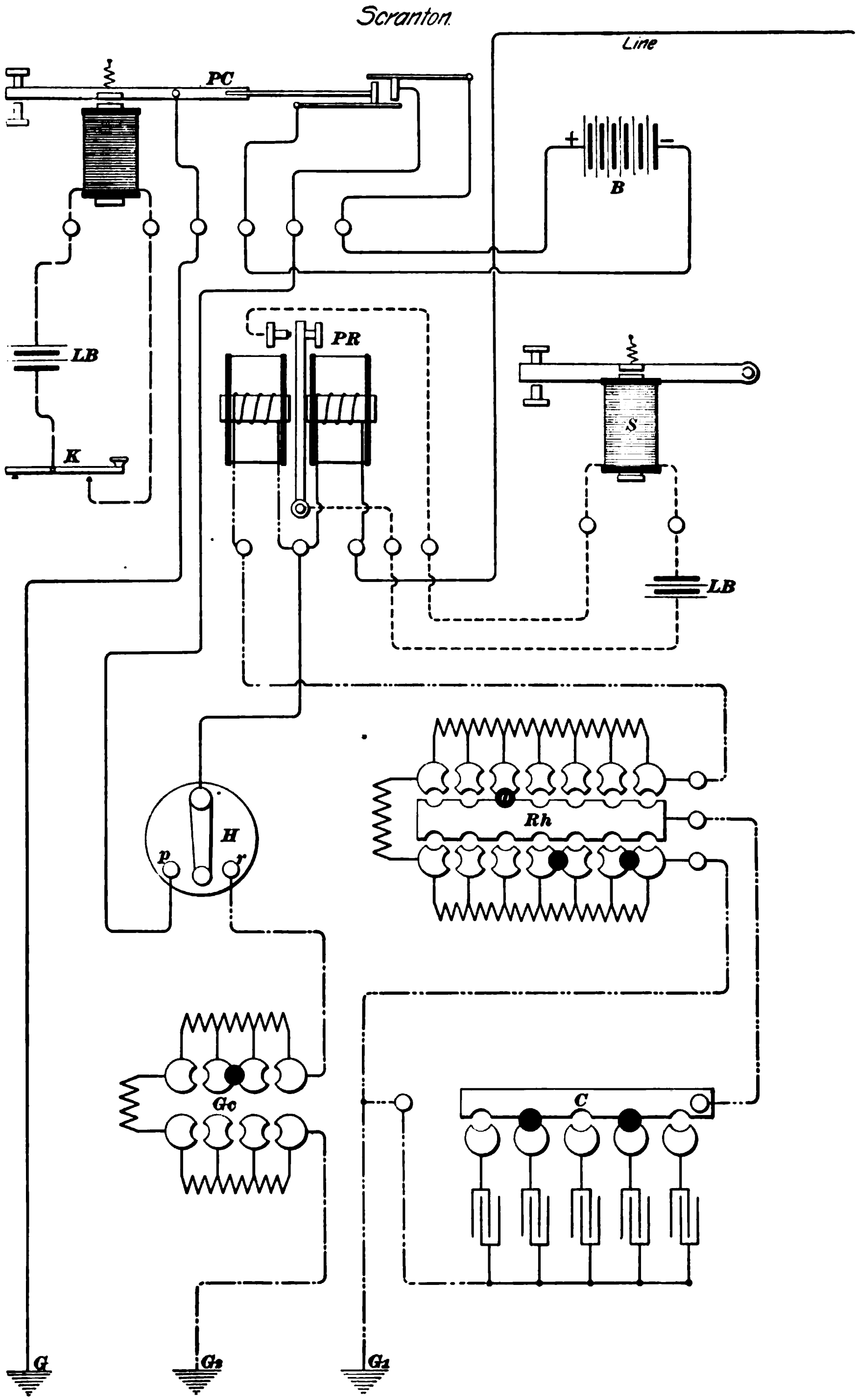
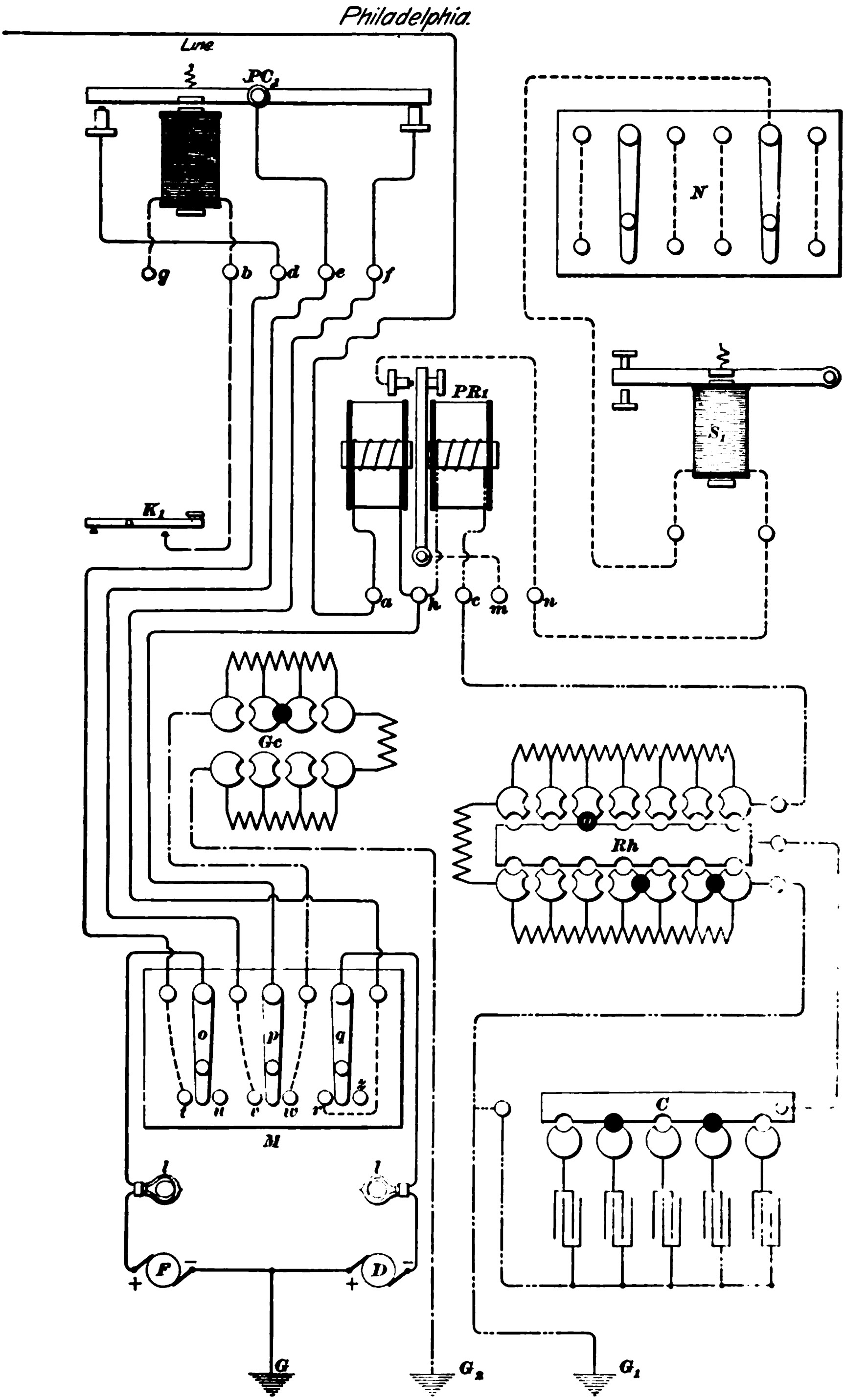


FIG. 19



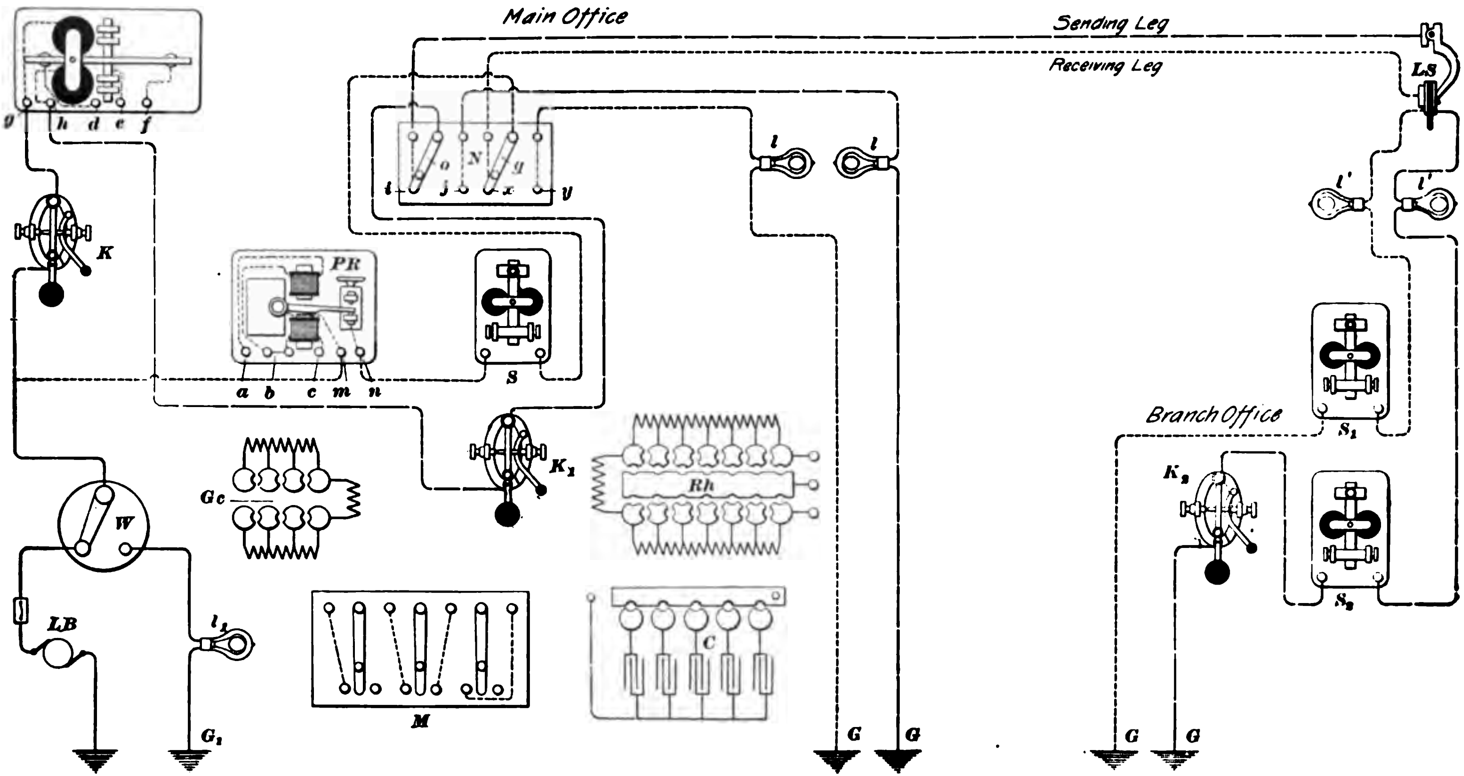
Philadelphia
Line
PC1
g
b
d
e
f
N
K1
PR1
S1
a
h
c
m
n
Gc
Rh
o
p
q
t
u
v
w
r
z
M
C
l
l
F
D
G
G2
G1

FIG. 20

47. Local Circuits Supplied From One Dynamo. In Fig. 21 is shown the connections for the sending and receiving circuits in Western Union offices where a 23-volt dynamo *LB* is used to supply current for the pole changer and sounders in both the sending and receiving sides of the circuit. All sounders in the receiving side are controlled by the polar relay *PR*, and the pole changers and sounders in the sending side are controlled either by the key *K* or K_1 at the main office, or by the key K_2 at the branch office. By means of the switch *W*, the 23-volt dynamo *LB* may be cut off and the circuit connected to the ground G_1 through the lamp l_1. This is convenient when there is a battery or dynamo in the circuit at the loop switch or elsewhere, or when another duplex set connected to this same dynamo is repeating into this set.

48. Sounders are included in the sending circuit at the branch office to enable the branch-office sending operator to hear his own writing and, also, to enable the main-office and branch-office operators to communicate with each other over the sending side. Sometimes a sounder is placed in the sending circuit at the main office, especially when the pole changer is adjusted so close that it is difficult for the main-office operator to read from the sounds made by it. The receiving side cannot well be used for communication between the main and branch offices, and, consequently, no keys are included in that side. For the convenience of the operator on the receiving side at the main office, the sending side is often extended over to the receiving table, where an extra key K_1 is inserted in the sending circuit. This enables the receiving operator to communicate, without leaving his desk, with the distant main office. Of course, he cannot do this if the sending side is in use at that time. The pole-changer and sounder coils have the same resistance, usually 4 ohms, in each instrument.

The branch-office loop, containing on the receiving side, or *receiving leg*, as it is called, the sounder S_1, and on the sending leg the sounder S_2 and the key K_2, is connected through a wedge and spring jack *LS* at the loop switchboard in the main office with the table switch *N*. When the switch arms *o* and *q* rest



Main Office
Sending Leg
Receiving Leg
LS
l'
l'
g
h
d
e
f
K
PR
a
b
c
m
n
S
o
N
g
i
j
x
y
l
l
K1
Gc
Rh
W
LB
l1
G1
M
C
G
G
Branch Office
S1
K2
S2
G
G

Fig. 21

on the buttons i and x, respectively, the main-office sending and receiving circuits are in series with the branch-office sending and receiving circuits respectively. By means of various resistance lamps l', all loop circuits are made to have about the same resistance, so that any branch office may be connected through the loop switch to the duplex set, and the 23-volt dynamo will still furnish the proper amount of current. The branch-office loop may be readily cut off by moving the switch arm o to contact j and arm q to contact y. This substitutes two locally grounded circuits, each containing a lamp l, for the branch-office sending and receiving legs. These lamps l have the proper resistance, so that shifting the switch arm o from contact i to contact j and the switch arm q from contact x to contact y does not change the strength of the current.

49. Several Loops in One Circuit.—It is practicable to connect several offices in one local circuit on either or both the sending or receiving legs of a duplex or quadruplex circuit. In Fig. 22 the regular office set, operated by local gravity batteries LB, and LB_1, is shown connected with the two branch offices A and B through the loop switches LS and LS_1. Intermediate gravity batteries IB and IB_1 are connected in the sending and receiving sides of the circuit, respectively. These batteries must have their poles so connected at the switch LS, that battery IB will be in series with LB, and IB_1 in series with LB_1, otherwise they will be opposing instead of assisting one another. In offices where only dynamos are used, there would be no gravity batteries at LB, LB_1, IB, and IB_1. The resistance of the loop circuits would then be so adjusted that the local-circuit dynamo, such as LB in Fig. 21, would furnish the desired amount of current. Or, two small dynamos of proper voltage used as intermediate batteries, one in place of IB and the other in place of IB_1, could be employed; in this case there would be no batteries at LB and LB_1.

With the switch arm O resting upon the contact button i, the sending leg may be traced from the ground G_3 through $K_3-S_3-IB-LS-LB-$magnet of the pole changer $PC-K-K_1-$switch arm $O-i-LS_1-S_4-K-G_4$ and back through

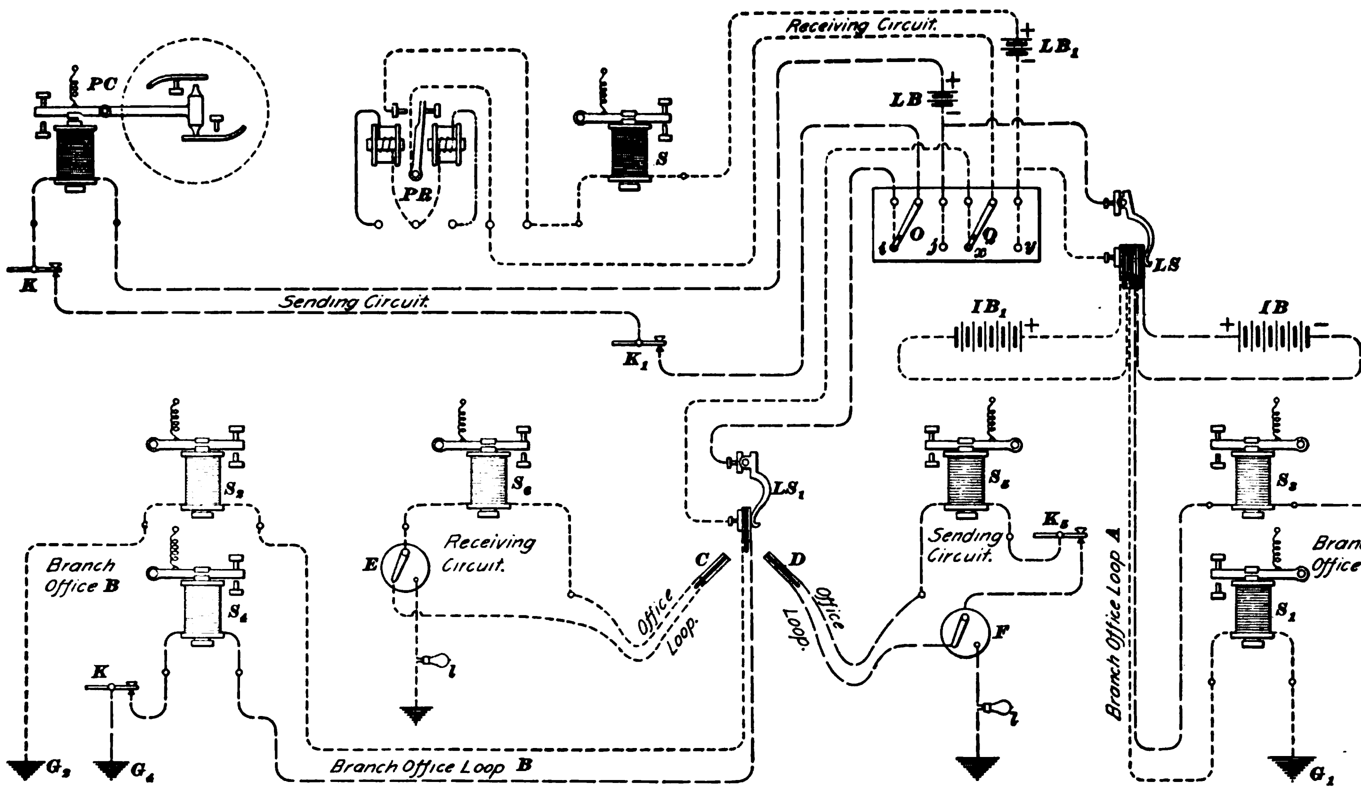

PC
PB
S
Receiving Circuit.
LB
LB₁
O
Q
i
j
x
y
LS
K
Sending Circuit.
K₁
IB₁
IB
S₂
S₆
LS₁
S₅
K₅
S₃
K₃
Branch Office B
S₄
E
Receiving Circuit.
C
Office Loop.
D
Office Loop.
Sending Circuit.
F
Branch Office Loop A
Branch Office A
S₁
K
l
l
G₂
G₄
Branch Office Loop B
G₁
G₃

FIG. 22

the ground to G_2. With the switch arm Q resting on contact x, the receiving leg may be traced from the ground $G_1-S_1-IB_1-LS-LB_1-S$ - contact points of the polar relay PR - switch arm $Q-x-LS_1-S_2-G_2$ - ground back to G_1.

Extra main-office sending and receiving circuits may be easily included by inserting the wedge C in the spring jack LS_1 on the receiving side, and the wedge D on the sending side of the wedge already in the jack; in which case the switches E and F must be turned to the left. By turning either or both of these switches to the right, either or both of the receiving and sending legs extending to the branch office B may be cut off. By turning the switch arm O to contact j and the switch arm Q to contact y, all the loop circuits are cut off, leaving only the sounder S and battery LB_1 in the receiving side and the key K, the magnet of the pole changer PC, and a battery LB in the sending side.

BALANCING THE POLAR DUPLEX SYSTEM

50. In order to explain the method of balancing a polar duplex system, it will be supposed that a line between Scranton and Philadelphia is to be worked on this system, that Scranton, Fig. 19, is the home office and Philadelphia, Fig. 20, is the distant office, and that the home set is to be balanced.

The insulation of a line will vary with the weather, and the lower the insulation, the lower will be the apparent resistance and capacity of the line. Hence, a change in the weather that is sufficient to alter the insulation of the line may require a readjustment, to a greater or less extent, of both the rheostat and the condenser. This is the case even more with a quadruplex than with a duplex circuit, and should not be forgotten when one is at work on such systems. Polar relays on duplex circuits require 25 milliamperes to properly work them.

51. Centering Armature of Polar Relay.—To center the armature of the polar relay Scranton will first request Philadelphia to ground his circuit. Philadelphia will do this by turning the switch arm p to w, thus cutting off all source of current at Philadelphia by inserting the ground coil Gc between the polar relay and the ground in place of the pole changer and the dynamos. Then the Scranton office will ground his set by turning the switch H to r, thus cutting off the battery at the home end. Now, with all source of current cut off, Scranton will adjust the polar-relay armature until it will remain against either stop, or move with equal force from the middle position toward one side or the other. This adjustment, called *centering the armature of the polar relay*, is to make the pull due to the permanent magnetism equal on each side.

52. Obtaining Resistance Balance.—Having centered the armature, the home battery will be turned on, in this case by turning the switch H to p, Fig. 19. If there is now more current in one winding of the differentially wound polar relay than in the other, the armature will be held more firmly against one contact point than against the other, which must be overcome by adjusting the amount of resistance in the artificial line by changing the plugs in the rheostat Rh until the armature will again remain against either contact point, or move with equal force toward one side or the other from the middle position, as before. When this is done the resistance of the line and artificial circuits are equal. This adjustment is called the *resistance balance*. Although this is usually the case, still strictly speaking, it is not necessarily the resistances of the two circuits that are made equal, but, rather, it is the magnetizing effects of the line and the artificial line coils.

If the rheostat is incorrectly adjusted, the signals from the distant office may be too light in one position of the home key and too heavy, or *sticky*, in the reverse position. Hence, it is important to test and, if necessary, to alter the adjustment of the rheostat until the incoming signals are equally good whether the home key is open or closed. Furthermore, the incoming signals should still continue to be good when dots are being rapidly made on the home key. The rapid manipulation of the home key alone may not show that the rheostat was improperly adjusted. This method of obtaining a resistance balance should always be followed especially in wet weather and on poor wires.

53. Obtaining a Static Balance.—If the capacity of the artificial line does not balance that of the line, there will be a kick of the home-relay armature at the instant the home battery is reversed, due to opening or closing the home key. A kick indicates that the line and artificial line have not the same capacities, or that one charges and discharges more quickly than the other. To eliminate this kick, it is necessary to adjust the capacity of the condenser *C*, Fig. 19, or its point of connection with the rheostat *Rh*, by means of the plug *o* until the kick disappears. The best way to do this is to ask the distant office to cut in, that is, to shift the switch arm *p* from contact *w* to contact *v*, and to close his key K_1, Fig. 20. This will close the home (Scranton) polar relay *PR*, Fig. 19. If the kick does not appear when the relay contact is closed, it surely cannot cause trouble at any other time, for that is the actual position of the home-relay armature when the distant office is making a dot or dash and when the home-relay armature must remain closed, that is, in contact with its front stop to which the local battery is connected. Hence, with the distant key closed, adjust the capacity of condenser *C*, Fig. 19, and then, if necessary, adjust the position of the plug *o* in the rheostat so as to retard or hasten the discharge from the condenser, until the kick disappears entirely. This adjustment is called the *static balance*. The nearer the peg *o* is placed to the end of the rheostat that connects with the artificial coil of the relay, that is, the less resistance there is between peg *o* and the relay, the quicker will the condenser charge and discharge.

54. Adjustment of a Battery Pole Changer.—The proper adjustment of the pole changer is very essential to the successful operation of the system in which it is used. The clock-face pole changer, shown in Fig. 15, may be adjusted as follows: Adjust the lever *n* by means of the limit screw *o* and the one below it, which is not shown, so that it will have a play of $\frac{1}{32}$ inch, which is about the same as is ordinarily given to a sounder, care being taken that the armature cannot strike the iron cores. Then, by means of the screw *o*, reduce this play to $\frac{1}{64}$ inch; this will hold the movable contact *e* on the forward end of the lever in its middle position. Now raise the screw *c* until the spring *d* barely touches the contact *e*, being careful not to turn the screw *c* too far. Similarly, lower the screw *b* until the spring *a* barely touches the contact *e*. Finally, raise the screw *o* until the lever has its working play of $\frac{1}{32}$ inch. The contact *e* in moving from one extreme position to the other should momentarily, in about its middle position, touch one spring before parting from the other. If it leaves one before touching the other, the circuit will be momentarily opened. On the other hand, it must not remain in contact with both springs any longer than is absolutely necessary, because the battery is short-circuited from the instant *e* touches one spring until it parts from the other. This period during which the battery is short-circuited can be reduced almost to nothing by carefully adjusting the instrument. No difficulty should be experienced in adjusting the B. & O. pole changer, shown in Fig. 14, if the principle of this pole changer and the adjustment just explained are understood.

55. Peculiarities of Dynamo Pole Changers.—The dynamo walking-beam pole changer is apt to require more attention than any other one instrument in either the polar duplex or quadruplex system. The method of adjusting and caring for it is the same for both systems. The contact points cannot be adjusted as closely as those of the pole changer used with gravity batteries. The battery pole changer uses only one battery of 350 volts but the dynamo pole changer uses two dynamos of, say, 350 volts each, one positive and the other negative; therefore, with the dynamos there is a pressure of 700 volts tending to jump across the air gap between the contact points. As a result, the introduction of dirt or the slightest jar between these two points will aid the electromotive force to establish an arc that acts as a fair conductor for the current, which at once flows through the beam from one dynamo to the other. In the gravity-battery arrangement, the highest pressure that can be short-circuited is 350 volts.

With the pole changer properly adjusted there is a spark at the break, but this legitimate spark is not nearly so harmful as the arc that hangs on when the instrument is so adjusted as to break improperly.

The tension of the spring may be so great that when the magnet releases the armature, the lever will fly to the other contact with such momentum that it rebounds more or less, causing an arc to form at this insecure contact. An arc will also be formed if the lever is not promptly released. This inability to promptly release the lever may be due either to the trunnion being too tight or to the weak tension of the spring necessary when the local battery is too weak. The first may be remedied by properly adjusting the trunnion; the second, by strengthening the battery and increasing the tension of the spring.

56. Adjusting a Dynamo Pole Changer.—A dynamo pole changer may be properly adjusted in the following manner: First, be certain that the current through a 4-ohm pole changer is not less than 250 milliamperes. For fast work, a current of 275 milliamperes is not too strong. Then adjust the contact points so that the signals can scarcely be heard on the pole changer when sent on the key controlling it. Next adjust the tension of the spring so that the down stroke will be just a little heavier than the up stroke, and see that the trunnion is neither loose nor binding. The expert quadruplex attendant adjusts the pole changer almost entirely by sound, because sight adjustment, aside from the preliminaries, is very deceptive. When the pole changer has been adjusted to have minimum play, and gives at the same time low but distinct signals, the tendency to arc is reduced to a minimum.

With the pole changer adjusted to have a minimum play, a sounder is often connected in series with the pole-changer magnet and key in order that the operator may hear his own signals. When there is a sounder in series with the pole changer, it will be necessary to hold down the sounder lever while adjusting the pole changer in order to hear only the signals on the latter.

57. Incorrect Balancing of Polar Duplex.—Mr. Willis H. Jones, in the Telegraph Age, makes the following remarks concerning the way some operators balance the polar duplex:

"Many operators adjust the condenser while the armature of the home relay rests upon the back contact point, and seem to be satisfied when the kick can no longer be heard. They apparently forget that the sound of the kick will disappear with a less amount of static eliminated when the lever rests upon the back stop than when it rests upon the contact point, because in the former position the armature must cross the intervening space before it can produce a signal, while in the latter, it needs but make a start.

"Some operators believe that they are equally successful in centering the polar-relay armature by giving the armature a temporary bias in order to make it more sensitive, but no one will deny that by this plan the magnetic balance is practically destroyed. Of course an endeavor is made to replace the lever in its former position, but such an action is plainly mere guesswork. If there are any that doubt this statement, let them try the plan on a poor wire, and, after having recentered the lever, as they believe, again ground the circuit at each end. It will be found that the experiment may have to be repeated many times before the armature can be found sufficiently well centered to remain where placed without further adjustment.

"To make matters worse, after having destroyed the magnetic equilibrium of the main and artificial line on the displaced armature, frequently attempts are made to mend matters by readjusting the rheostat while the distant office writes.

"When the apparatus is finally considered to be balanced, what are the actual conditions under which the operator is expected to work? Simply this—a practically lopsided relay, and a false line balance. It may work satisfactorily at the start, but the margin is very small, and a slight change in the atmospheric conditions may necessitate another balance."

POSTAL TELEGRAPH-CABLE BATTERY DUPLEX

58. Theoretical Connections of Main Circuit.—The principle of the polar duplex operated by primary batteries as arranged by the Postal Telegraph-Cable Company is shown in Fig. 23. The pole changer *PC* consists of two ordinary relays *r* and *r'*, called *transmitter relays*. The two magnets of the relays are connected in series and are operated simultaneously by the one key *K*. When this key *K* is open, the negative terminal of the main-line battery *B* is connected to the wire *a* lead-

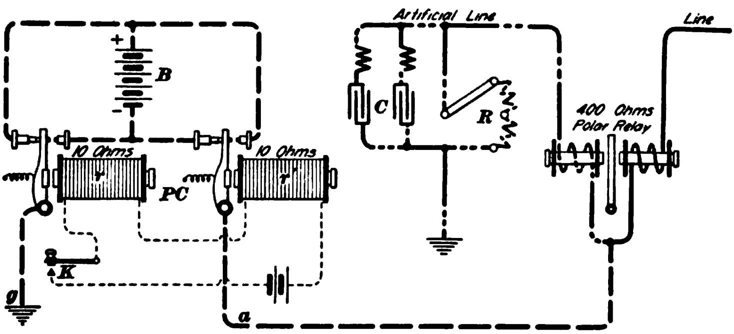


FIG. 23

ing to the middle of the differentially wound polar relay, while the positive terminal is connected to ground *g*. When the key *K* is closed the negative terminal is connected to the ground *g*, and the positive terminal of battery *B* is connected to the wire *a*. The rheostat *R* and condensers *C* constitute the artificial line. The local connections of the polar relay, which are not shown, are made in the usual manner.

59. Actual Connections of Main-Line Circuit.—The actual connections of the main-line circuits of the Postal Telegraph-Cable battery polar duplex are shown in Fig. 24. When turned to the right, as shown, the ground switch is in the operating position; it then connects the middle point *c* of the polar relay to the pole changer. When the ground switch is turned to the left, the center point *c* of the polar relay is connected to the ground for balancing the polar relay. Binding posts similarly lettered are connected together.

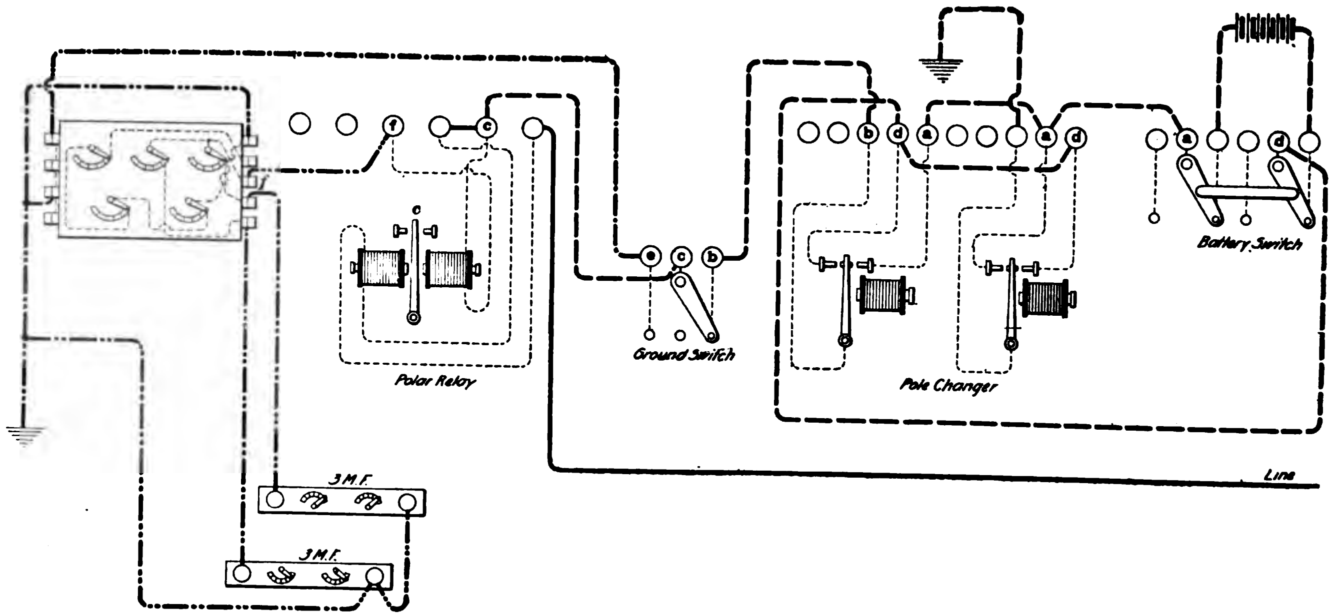

f
c
e
c
b
b
d
a
a
d
a
d
Polar Relay
Ground Switch
Pole Changer
Battery Switch
Line
3 M.F.
3 M.F.

Fig 24

HIGH-POTENTIAL, OR DYNAMO-LEAK, DUPLEX

60. Theoretical Connections.—The principle of the **high-potential** or **dynamo-leak, polar duplex** devised by Minor M. Davis for the Postal Telegraph-Cable Company is shown in Fig. 25.

In this circuit, there are two dynamos of about 385 volts each with their terminals of opposite polarity grounded. In series with each dynamo there is always at least one coil of 600 ohms

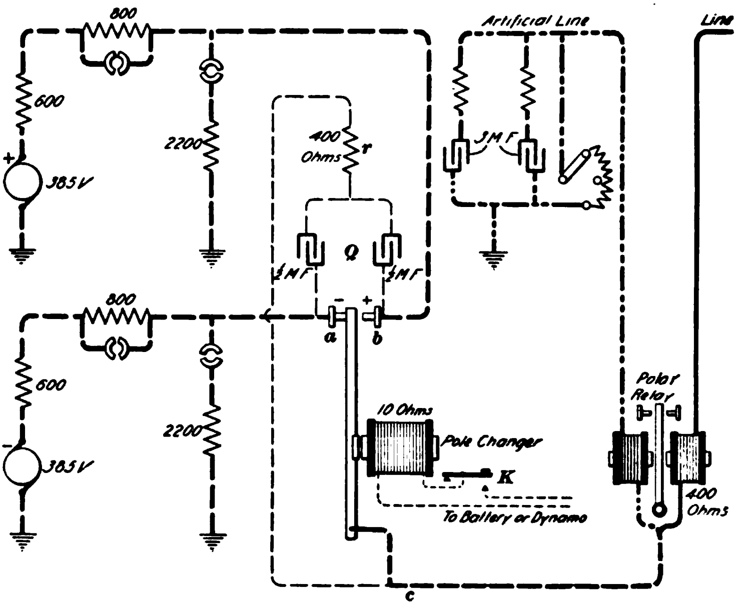
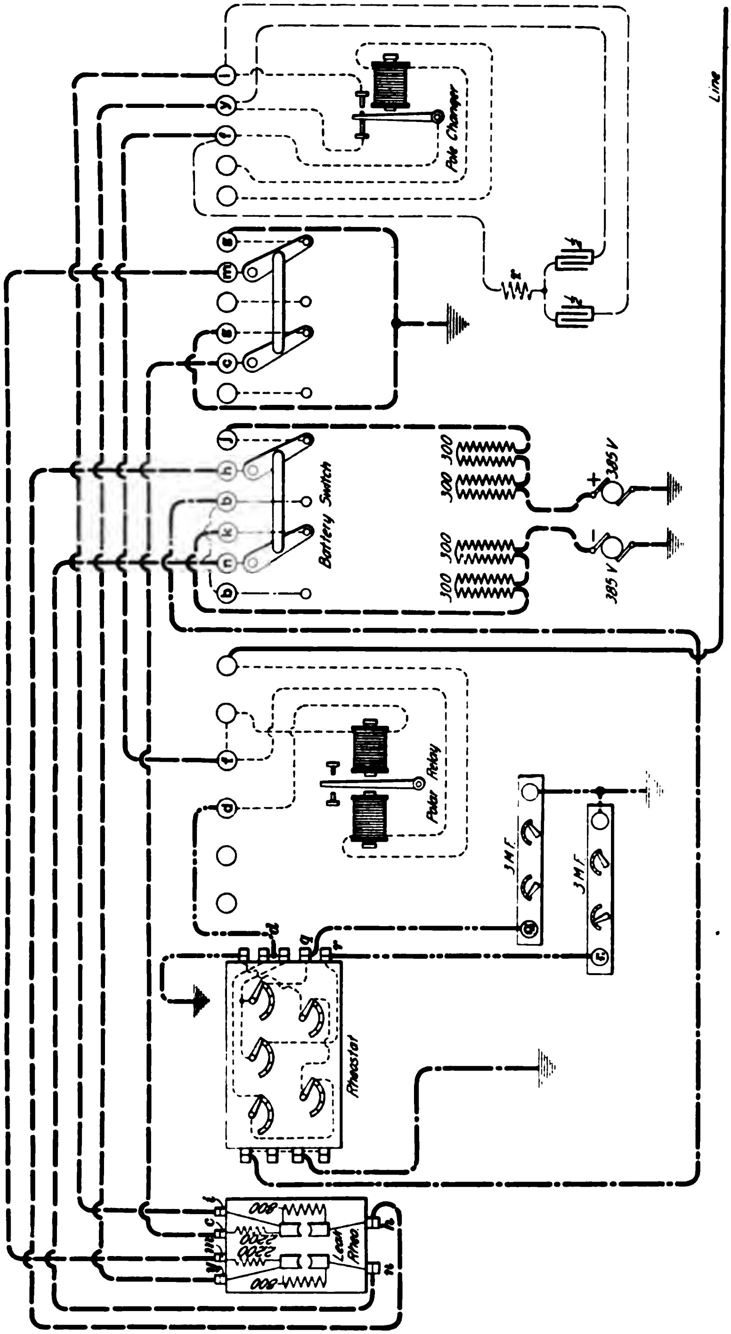


Fig. 25

to protect it from damage due to a possible short circuit. In series with each dynamo there is also a resistance of 800 ohms, which may be short circuited by a plug if a higher electromotive force is required. From each circuit a so-called leak resistance of 2,200 ohms is then connected to ground. This diverts some of the current to the ground and by increasing the fall of potential through the 600-ohm and 800-ohm coils, reduces the potential available at the pole-changer contacts.



Pole Changer
Line
Battery Switch
300
385 V
Polar Relay
3 M.F.
Rheostat
Lead Rheo.
800
2200

Fig. 26

This arrangement enables both long and short lines to be worked duplex in offices where it is not economical to instal special low voltage dynamos for the short lines, but where the high-potential dynamos installed for the regular quadruplex sets may also be used for this duplex system. If it is desirable to increase the potential, or if a lower voltage dynamo is available, the 2,200-ohm leak resistance may be cut out by opening its circuit; also the 800-ohm coil may be cut out by short-circuiting it.

61. The total resistance between the dynamo and ground is 600+800+2,200=3,600 ohms. The current through this ground circuit, neglecting the amount diverted through the line and artificial line, will be $\frac{385}{3600}$ and the fall of potential through the 2,200-ohm coil will be $\frac{385}{3600}\times 2{,}200=235$ volts. Hence, the voltage applied to points *a* and *b* is very nearly 235 volts when the 3,600 ohms is in the ground circuit. The voltage applied to points *a* and *b*, when the 800-ohm coil is short-circuited, is $\frac{385}{2800}\times 2{,}200 = 302$ volts.

At contact *a* there is always a negative potential of the same voltage as the positive potential at contact *b*. Normally, contact *a* is closed and a negative potential is applied to the wire *c* leading to the differentially wound polar relay. When the key *K* is closed an equal positive potential is applied to wire *c*.

A condenser *Q* is connected from each contact of the pole changer through a 400-ohm resistance *r* to the pivot end of the armature of the pole changer to reduce the sparking at the pole-changer contacts. The local circuit of the polar relay is connected in the usual manner.

62. Actual Connections of Main Circuit.—The actual connections of the main circuits of the dynamo-leak polar duplex is shown in Fig. 26. By means of the battery switch each dynamo and its 600-ohm resistance may be connected to or disconnected from the circuit. Binding posts similarly lettered are connected together.

POSTAL RULES FOR BALANCING POLAR DUPLEX

63. The Postal Telegraph-Cable Company give the following rules for balancing their polar duplex systems:

1. Ask the distant station to ground.

2. Throw the ground switch (see Fig. 24), at home station to the left.

3. Set the armature of the polar relay in the center, adjusting the magnets until the armature will remain on either contact or until it vibrates freely in response to the induced currents from the line. The magnets should not be too far from, nor too close to, the armature to give the best results. The correct distance varies according to the resistance of the circuit. The contact screws should be so adjusted that the armature is in a vertical position. The relay will not work well if the armature is not so arranged.

4. Throw the home station ground switch back to the right, thus placing the current on the line. Take a balance; that is, adjust the line resistance in the rheostat until the polar relay again acts as it did when the line was connected to the ground at both ends. This balance should be tried first with the home key open and then with it closed. If there is any variation in the resistance required to effect a balance, an average should be used.

5. Take a static balance in the following manner: Move back $\frac{1}{4}$ to $\frac{3}{8}$ inch the magnet of the polar relay which is on the opposite side of the local contact point, or, in other words, the magnet on the side upon which the armature rests when the sounder is open. Make dashes upon the key, which will show up the static kick. Adjust the condensers until this kick is removed. A variation in the adjustable resistances in the condenser circuits will sometimes aid in accomplishing this result, though it is usually found that when this resistance has been determined for any circuit that it will remain constant. After removing the kick replace the magnet in its former position.

If a table galvanometer is used, take the line balance by adjusting the rheostat (see paragraph 4) until the galvanometer needle points to zero with either open or closed key at the home station. If there is any effect from earth currents, adjust the rheostat so that the amount of deflection from zero on both open or closed key is the same.

To obtain a balance when the distant station has battery to line, wait until he stops signaling temporarily; then adjust the rheostat until it gives the same deflection with home key open or closed.

To obtain a balance with distant station signaling: Keep the home key closed or open and note if the distant station's open and closed key cause the same amount of deflection on either side of zero on the galvanometer. If the amount of deflection from open and closed key varies, adjust the rheostat until the deflections are equal on both sides of the zero.

SUPERIMPOSED POLAR DUPLEX

64. To avoid interruption to service between large cities not too far separated from one another, as between New York and Philadelphia or even New York and Boston, underground cables for the entire distance are coming into use. To avoid disturbing other circuits in the same cable, it is necessary to use complete metallic circuits, that is a pair of evenly balanced cable wires for each circuit.

When a large number of wires are required on main routes, the capital cost of underground construction per mile of conductor is approximately the same as for overhead work, and when the greater freedom from interruption of the underground conductors, as compared with that of open wires and also the probable longer life of the underground work is considered, there is much to encourage the rapid extension of the main underground network of telegraph wires.

To protect one pair of wires from induction from other pairs each pair of wires in some telegraph cables are wrapped with a very thin sheet of metal, preferably iron. To make better use of such pairs, the English post-office telegraph department superimposes an ordinary hand operated polar duplex on a pair of wires that is also used for a quadruplex or a Wheatstone or Hughes duplex by the arrangement shown in Fig. 27. There is bridged across the line wires from *h* to *i* a Wheatstone duplex or a quadruplex set *f* with its artificial line *g*. At *a* is the regular polar duplex with its artificial line *c*. Bridged across the line wires are also two non-inductive resistances *j* and *k* and two condensers *d* and *e*. The two line wires and resistances are connected in parallel from the point *b* and act as one conductor for the less rapidly fluctuating polar duplex current, which does not seem to cause sufficient disturbance to

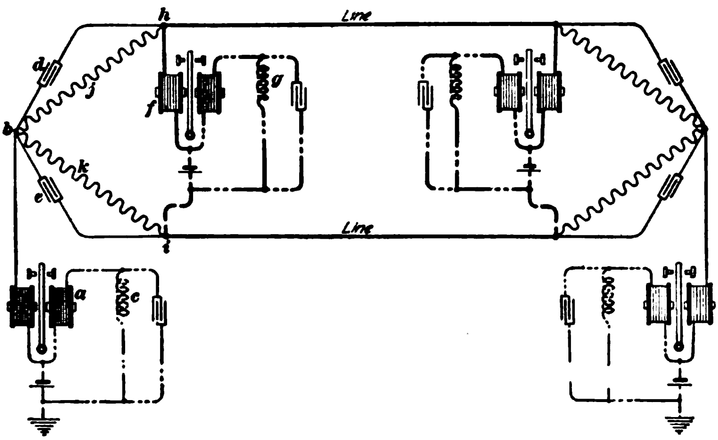


FIG. 27

prevent its use on all pairs in the same cable. The ground forms the return path for the regular polar-duplex current.

For lines under 149 miles (240 kilometers) in length, the resistances *j* and *k* each contain 3,000 ohms; for lines over 149 miles each resistance consists of 5,000 ohms. These resistances *j* and *k* are each shunted by condensers *d* and *e*, thereby increasing considerably the range of working of the polar duplex sets. The capacity of the condensers *d* and *e* is 10 microfarads each for circuits over 149 miles in length, while for lines of less than 99 miles (160 kilometers) no such condensers are required.

DUPLEX AND QUADRUPLEX TELEGRAPHY

(PART 2)

BRIDGE DUPLEX SYSTEM

GENERAL DESCRIPTION

1. The **bridge duplex system,** shown in Fig. 1, has four resistance arms with a relay at each end bridged across from the line to the artificial line. The four arms of the bridge are *a c*, *a d*, $d\ G_1$, and from *c* through the line and apparatus at the distant station to the ground G' and G_2. Included in these arms are four adjustable resistances M, M', N, and N' and the line and artificial lines. The relays R and R' are connected across the adjustable resistances. The *artificial lines* consist of the resistance boxes Rh and Rh' and the condensers C and C' which are connected to the grounds G_1 and G_2. The resistance of the artificial line at each end must be equal to the resistance of the line wire plus the resistance from the distant end of the line to the ground through the apparatus at the distant station. Usually the resistance of one arm *a c* is equal to that of the other *a d*. In any case, the following proportion must be satisfied: Resistance of *a c* : resistance of *a d* = line resistance + resistance from c' through all paths at right-hand station to grounds G' and G_2 : resistance of the artificial line $d\,G_1$. When this is the case, there is no difference of potential between the points *d* and *c*. A rheostat S is so arranged that, as the lever is turned upwards, resistance is taken out of one arm *a c* of the bridge and is added to the other arm *a d*, and vice versa if the lever is moved in the other direction.

When the key of a continuity-preserving transmitter *K* is pressed down, the lever *o* lifts the lever *v* off the contact point *p*, momentarily short-circuiting the battery in order to avoid

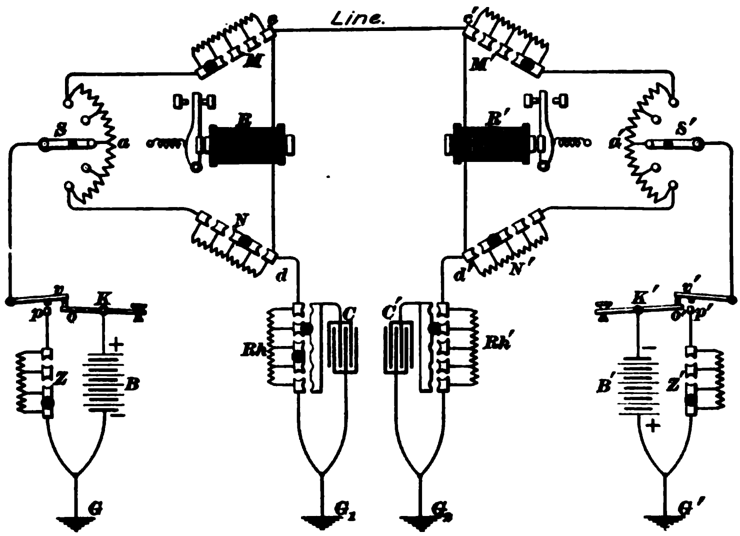


FIG. 1

opening the circuit between the ground *G* and the line. The resistance *Z* is adjusted to equal the internal resistance of the battery *B*. This resistance *Z*, the key *K*, and the battery *B* are arranged and used in the same manner as in the differential duplex. The apparatus and connections at the two stations are similar.

2. If one arm *a c* of the bridge bears the same relation to another arm *a d* that the circuit from *c* through the line and apparatus at the distant station to ground bears to the arm *d* G_1, the relay *R*, which is bridged across the points *c* and *d*, will not be affected by the outgoing current from the battery *B*, for the reason that there is no tendency for any current to flow in either direction between these points between which there is no difference of potential. If the key K' at the distant station is pressed down and the home key K is open, some current will pass along the line and ground and at the point c will divide, a part of it passing through and operating the home relay R because for this incoming current the points c and d are not at the same potential. The position of the home key K will in no wise affect the operation of the home relay R, because the position of the key K does not alter the resistance of the circuit between the point a and the ground G. Thus the relay at one station will be operated only by the key at the distant station.

3. Adjustment of Resistances.—Adjustment of resistances is made in arms $a\ c$ and $a\ d$, first by means of the resistance boxes M and N, and, finally, by the rheostat S. If the resistance from c through the line and apparatus at the distant station to the ground is 4,000 ohms, then a resistance of 1,000 ohms in the arm $a\ c$, 2,000 in the resistance box Rh, and 500 in the arm $a\ d$ will properly balance the bridge. The connection between the condenser C and the resistance box Rh should be adjusted until the artificial line charges and discharges in the same manner as the line, so that no momentary kick would be made by the relay.

4. Comparison Between Bridge and Differential Duplex.—The bridge duplex is superior to the differential duplex in that it requires less condenser capacity in the artificial line, and the resistances and condensers can be more readily adjusted to suit the varying conditions of the line. However, the bridge duplex is inferior to the differential duplex in that it requires more battery power to produce the same strength of current in the relay. This inferiority of the bridge duplex has excluded it from use on long land circuits. On short lines of low resistance, where an excessively high electromotive force will not be required and when batteries of low resistance can be used, it is preferable to the differential duplex, but it has not been generally considered preferable to the polar duplex. The bridge principle is used wherever submarine cables are duplexed; but, while the principle is the same, the apparatus used is quite different from that shown in Fig. 1. The bridge duplex, as applied to submarine cables, will be explained in connection with submarine telegraphy.

POLAR BRIDGE DUPLEX

5. Description.—In Fig. 2 is shown a bridge duplex system used by the American Telephone and Telegraph Company. This company terms it a **polar bridge duplex** because a polar relay is bridged between the line and artificial line. It should be remembered that practically all duplex, quadruplex, and repeater sets employed by this company must be suitable for use in connection with complete metallic telephone toll circuits. Consequently, their operation must produce no clicks or other disturbing noises in the telephones that may be connected across each end of the two wires forming a complete metallic circuit.

The line wire shown is one of two wires that form a complete metallic telephone toll-line circuit. The other telephone line wire may also be used for another duplex set. The apparatus shown may be applied to a single wire, or to a simplexed or composited line circuit. The terms simplex and composite, as used by telephone companies, are explained elsewhere. When there is to be transmission in one direction at a time only, this apparatus will operate over a circuit or combination of circuits that could not be used for full duplex service nor operated satisfactorily by single-line apparatus. When this duplex set operates in connection with both a single line and a duplexed section of a telegraph circuit, this company terms it a *duplex half repeater*. Each duplex set has a cam-lever switch P which enables the set to be used either as a duplex half repeater or for full duplex service. When the main lever of the pole changer rests against its back stop the extra spring levers touch neither the front stop nor the main lever, hence the spring levers are on open circuit.

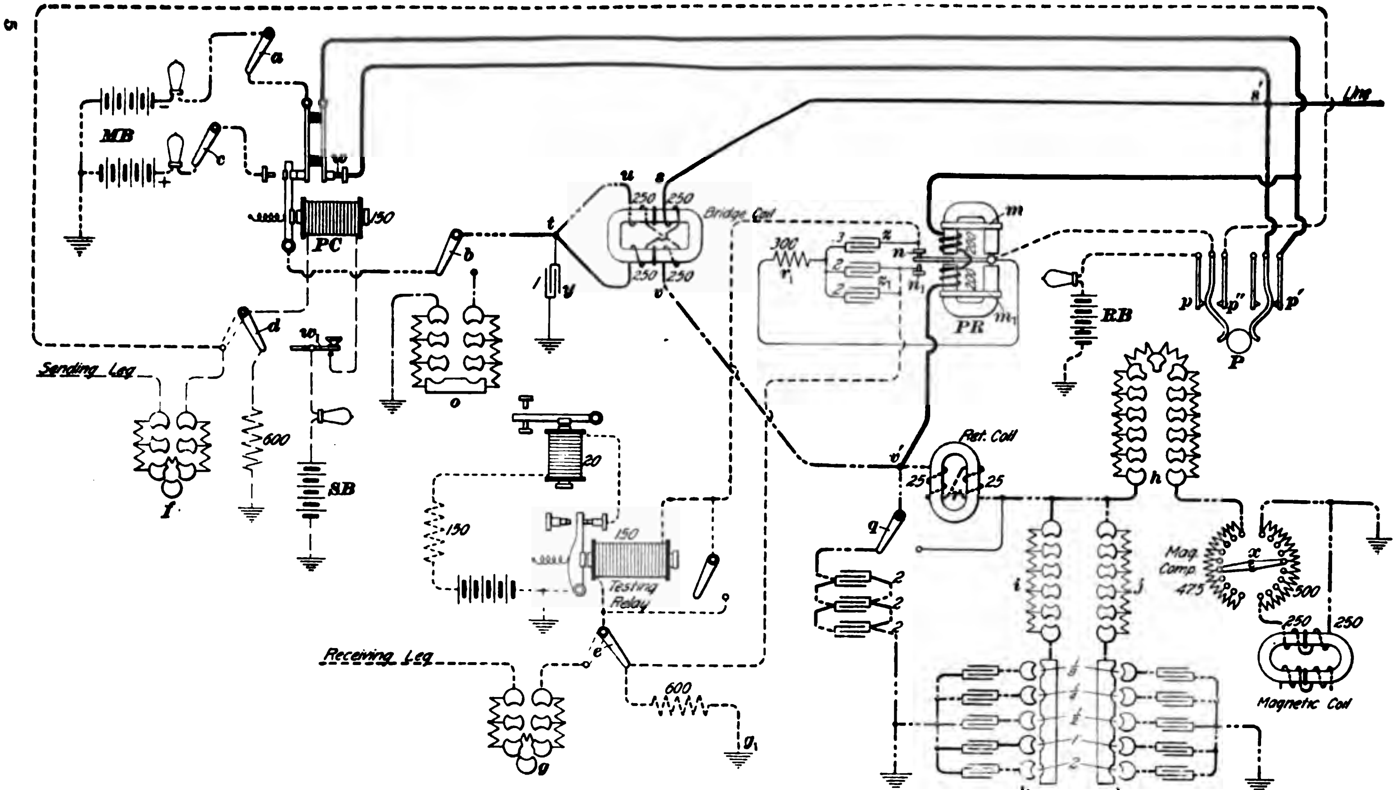

MB
a
c
d
PC
150
w
w₁
600
SB
Sending Leg
f
b
t
y
o
u
s
v
250
Bridge Coil
300
r₁
3
2
z
z₁
n
n₁
m
m₁
PR
RB
p
p''
p'
P
Line
s'
v'
Ret. Coil
25
q
h
i
j
k
l
Mag. Comp.
475
500
x
Magnetic Coil
20
Testing Relay
Receiving Leg
e
g
g₁

FIG. 2

6. Operation.—The polar bridge duplex system operates in very much the same manner as the bridge duplex just explained. The important differences consist in the use of a polar relay *PR* across the bridge in place of a neutral relay, a pole changer *PC* in place of a transmitter, an inductive non-adjustable bridge coil in place of non-inductive adjustable bridge coils, and inductive resistances in the artificial line in addition to the usual non-inductive resistances. A pole-changer *PC*, controlled by the key w_1 connects the point *t* to the negative terminal of one battery for sending dots and dashes and to the positive terminal of a similar battery for terminating the dots and dashes, and therefore for starting the spaces. This polarity should be retained on all sets for the sake of uniformity. Whatever current passes from the home main-line batteries *MB* to the point *t*, there divides equally through the line and artificial line and produces no difference of potential between the points s' and v' to affect the polar relay. An incoming current of either polarity passes from the line through the contact p' on the switch *P* (or when the set is used as a half repeater through contacts *w* on the pole changer *PC*), then through the polar-relay winding to point v', where it divides and passes to ground through the path of least resistance.

7. Rheostat and Switches.—The numbers placed opposite coils and condensers in Fig. 2 represent the resistances of the coils in ohms and the capacities of the condensers in microfarads. The resistances *f*, *g*, *o*, *h*, *i*, *j*, which are adjustable by pegs, are all located in one box, called a **combination quad rheostat.** They are shown separately to avoid a complicated-looking drawing, but the general shape of each set is retained so that there will be no difficulty in locating each one when it is assembled in the one box.

The switches *a*, *b*, and *c* are located on one slate base in the order named and the levers of *a* and *c* are fastened together so that one handle serves to turn both of them to the right or left. The middle lever *b* may be turned, however, to the right or left independently of the other levers *a* and *c*. All three arms are turned to the left while the set is in use either for full duplex or half-repeater service. When the arm *b* is turned to the right an adjustable resistance *o* is substituted for the main-battery circuit.

The switches *d* and *e* are mounted on one slate base and each lever may be turned independently of the other. However, both are turned to the left for half-repeater service and to the right or left for full duplex work.

The switch *q*, which is also mounted on a slate base, is turned to the left when this set is used on a composited wire. It then puts into the artificial line a non-inductively connected retardation coil *r* of 50 ohms and a capacity shunt to ground of 6 microfarads. This switch is turned to the right when the set is used on a single, or simplexed, line and then it cuts out of the artificial line both the condensers and the coil.

8. Bridge Coil.—To prevent an appreciable loss of the rapidly fluctuating telephone current flowing over the line wire, it is necessary to have no path of low inductance between this line wire and the ground side of the duplex set. Therefore, both the bridge coil and polar relay must possess considerable inductance. The polar-relay coils possess considerable inductance and a total resistance of 400 ohms. The bridge coil, which has a very high inductance and a total resistance of 1,000 ohms, has its coils so connected that all four are in series inductively from *s* through $t-u-v$. As these coils may be sent out incorrectly connected, each bridge coil should be tested when installed and the connections so made as to give a maximum inductance between *s* and *t*, between *u* and *v*, and finally from *s* through $t-u-v$. The successful operation of this duplex depends much on this coil being properly connected.

9. Magnetic Coil.—The magnetic coil in the artificial line should have the two windings on the same side connected in series so as to give maximum impedance. These windings, and those of other devices when connected together, may be tested for maximum or minimum impedance in the following manner, but the method applies particularly to this coil.

Connect a telegraph relay in series with a ringing or other generator producing an alternating current having a frequency of at least 20 cycles per second. The relay should be adjusted so that it will respond when the test circuit includes one winding of the magnetic coil. If both windings connected in series for maximum impedance are included in the test circuit, the relay will respond feebly or not at all, but if the windings are connected for minimum impedance, the relay will respond quickly.

10. Resistance in Artificial Line.—The resistance *h*, Fig. 2, in the artificial line may be varied in 10-ohm steps from 0 to 32,000 ohms. In the artificial line there are also the two windings of the magnetic coil; each winding has a resistance of 250 ohms and the two are connected in series in such a way as to give their maximum impedance. This impedance, which is connected at the ground end of the artificial line, compensates for such inductive effects as may reach the home polar relay from the 500-ohm inductive winding in the line side of the bridge coil at the distant set. Since that bridge winding is shunted to some extent by the polar relay in the same distant set, it is essential to use a shunt to the 500-ohm windings of the magnetic coil at this home station. A portion of the non-inductive resistance in the right-hand part of the magnetic compensator *x* is used for this purpose. As the arm *x* is turned counter-clockwise, the resistance in series with the magnetic coil is increased and the resistance in parallel is decreased.

11. In damp weather, the lower insulation resistance of the line requires less resistance in the artificial line rheostat *h* in order to balance this bridge duplex set. This causes more current to flow from each end into the line, nevertheless the effective current at each end is altered less by the opening and closing of the distant pole changer than in dry weather. Consequently there is less inductive disturbance on the home apparatus on account of the inductance of the distant bridge coil and polar relay. This smaller inductive disturbance is balanced by using a smaller non-inductive shunt in the magnetic compensator secured by turning the arm x counter-clockwise. Furthermore, after once securing a resistance balance by adjusting the artificial-line rheostat h, it is undesirable to again alter it when adjusting for inductance effects. Hence, the ten non-inductive resistances in each arm of the magnetic compensator (50 ohms per step in the right-hand side and mostly 5 ohms per step in the left-hand side), are so proportioned and arranged in connection with the 500 ohms in the magnetic coil, that moving the arm x does not appreciably affect the resistance from h to the ground.

By placing the arm x in a vertical position, the artificial line is opened. When in this position, a waste of current when the duplex is not in use and the line batteries have not been disconnected, is prevented; also the operator is able to determine whether this set is actually connected to a line wire.

12. Reducing Sparking.—The 1-microfarad condenser y, Fig. 2, reduces the sparking that would otherwise be troublesome at the main-line contact points of the pole changer PC. In emergencies, this condenser may be replaced by a 2-microfarad one without greatly affecting the operation of this duplex set. The receiving circuit may be traced from ground g_1 through the 600-ohm coil (or from the receiving leg through the adjustable resistance g) – switch e – 150-ohm testing relay – front contact n of the polar relay PR – contacts p of switch P – safety-resistance lamp – receiving battery RB to ground. When this circuit opens, the .3-microfarad condenser z and the 300-ohm resistance r_1 form a circuit across the gap produced at n, causing the condenser to receive a charge instead of producing a bad spark across the gap at n.

13. Adjustment of Pole Changer.—The directions for adjusting the pole changer state that it should have a medium air gap between armature and iron core, and a moderate to light retracting spring. The play of the armature should be only enough to prevent sticking at the contact points. When the set is used for duplex working, the switch P is put in the position shown, in which case the right-hand contacts are together, thereby permanently closing the circuit between the line and the polar relay and throwing out of use the supplementary contacts *w* by short-circuiting them at *p'*.

The supplementary contacts *w* should have very little play. With the switch *P* in the opposite position to that shown, the set is used as a duplex half repeater, and the supplementary contacts *w* open the main-line circuit of the polar relay whenever the pole changer of the same set is open.

14. Adjustment of Polar Relay.—The polar relay should have its armature set midway between the magnet poles with an air gap of about $\frac{1}{32}$ inch on each side. The movement of the armature between the stops should be no larger than is necessary for it to make clear breaks in its local circuit. When the set is used as a half repeater, the smaller the movement of the polar-relay armature, the less exact need be the adjustment of the pole changer; but the polar relay must have enough tendency to move to the front, or closed, side of its center position to insure the lever staying against its front stop *n*, Fig. 2, when the polar-relay coils are cut out of the main-line circuit by the opening of the supplementary contacts *w* on the pole changer. This bias is secured by moving the keeper m_1 on the right-hand permanent magnet toward its coil and allowing the keeper *m* on the left-hand permanent magnet to remain at the most distant point from its coil. In actual use the polar relay is provided with a switch on the base that allows either contact to be used as the closed contact in case the batteries at the distant station should be reversed. Such a switch will be is shown in Fig. 3.

15. Light or Heavy Signals.—If the received signals are too heavy either on account of the sending of the operator or on account of too low an adjustment of the distant pole changer, they can be made lighter by increasing the resistance in the balancing rheostat *h*. The signals are made heavier by decreasing this resistance. When using the set for full duplex work, the character of the signals may be varied by altering the bias of the polar relay.

BALANCING POLAR BRIDGE DUPLEX

16. Approximate Adjustment of Artificial Line. The following directions were issued for balancing the polar bridge duplex system by the A. T. & T. Company:

(1) Set the cam-lever switch *P* in position, as shown in Fig. 2, for full duplex operation.

(2) Make the resistance of the balancing rheostat *h* equal to the estimated resistance of the real line, plus 250 ohms, which is the approximate resistance* of the apparatus in the distant duplex set, less the resistance of the magnetic compensator at the home end, for this already forms part of the home artificial line, but is included in the 250 ohms allowed for the distant set.

(3) Estimate the line capacity at 1 microfarad for each 100 miles of open-wire circuit, or each 10 miles of cable circuit. The total capacity so estimated should be divided about equally between the two adjustable groups *k* and *l* of condensers in the artificial line, connecting about 200 ohms in series with one group and 1,000 ohms in series with the other.

17. Calling Distant Station.—Turn the three switch levers *a*, *b*, and *c* to the left and call the distant station. If the line insulation is very low, the estimated balance may be so far out that the distant end cannot break. Under such conditions it is well to ground between calls by turning the switch lever *b* to the right, thus removing the home batteries from the line and leaving the polar relay free to respond to signals from the distant end.

The resistance in the rheostat *o* should be equal to the resistance from the switch *b* to ground through either main-line batteries *MB*, which should be alike. The use of this resistance *o* prevents unbalancing the circuit for the distant station.

18. Resistance Balance.—Having secured communication with the distant operator, have him make signals. Cut

* This estimate of the resistance of the distant duplex set is good enough for the purpose. Its exact calculation is not of sufficient importance to devote any space to it.

in the home main-line batteries and vary the resistance balance until the signals are just the same, whether the key w_1 is held open or closed.

19. Adjustment of Magnetic Compensator.—Set the magnetic compensator to suit weather conditions. If the insulation resistance of the line is low, cut out nearly all the magnetic coil by setting the lever x near the open (vertical) position; but if the line insulation is good or contains composite apparatus at an intermediate station, set it to include nearly its maximum resistance in the artificial line.

20. Static Balance.—Have the key at the distant end closed and move the keeper m on the closed contact side of the polar relay PR up to the coil. Make dots rapidly, trying different amounts of capacity in the adjustable condensers, until the dotting does not affect the polar relay. Then have the key at the distant end opened and repeat the last test, but with the positions of the keepers m, m_1 reversed. Finally, with both keepers close to the spools, have the distant end write and note if, by dotting rapidly at the home station, the incoming signals are broken up; if so, slight changes in the resistance in series with the condensers, in the magnetic compensator, or in capacity, will remove the disturbance. Sometimes one, two, or all three of these adjustments must be varied to get the best results. After obtaining a balance, return both keepers to the outer ends of the relay. Particular attention is called to the necessity for fast dotting when taking a static or magnetic balance. A balance that appears to be perfect under slow dotting will often be found unsatisfactory when the telegraph subscriber starts fast work.

21. Balancing for Half-Repeater Service.—When the set is to be used for half-repeater service, the cam-lever switch P should be placed in its position (inner contacts closed) for that service and the polar relay biased as described under Adjustment of Polar Relay. In this service the polar relay is only in circuit when the sender's key at the same station is closed, hence, it is only necessary in making a static balance to see that the home relay does not respond to the closing of the home key. Therefore, there is a wider margin for the operation of the set as a half repeater than as a full duplex.

22. Balancing to Distant Ground.—The heretofore customary method of taking a resistance balance with the distant end grounded should not be used. That method was quite satisfactory before the use of trolley systems which cause wide variation in earth potentials, but under present conditions it cannot be relied upon as fully as the method given.

23. Morse Disturbance on Telephone Circuit.—Owing to the high impedance of the terminal apparatus, this duplex worked with 120 volts will cause only about the same Morse disturbance in the telephone of a composited circuit as 60 volts with single Morse. To avoid interference between telegraph signals and telephone ringing currents, the special, high-frequency, telephone, ringing set designed for use on composite circuits should be used for telephone signaling. It is not of sufficient importance to describe here the rather complicated composite telephone-ringing circuit.

24. Operation as a Half Repeater.—When the polar bridge duplex is used as a half repeater, the switch P is placed in the position opposite to that shown, switches d and e, Fig. 2, are turned to the left, and the supplementary contacts w should have very little play. Supposing all circuits to be in normal conditions and that a space signal arrives over the duplex line, and that the receiving leg is extended through a line and the desired office to ground. The polar-relay armature will part from n, and the condenser z and resistance r_1 will then prevent bad sparking at n. The receiving leg will be opened at n, thereby opening the relay at the distant station on the receiving leg, also opening the testing relay and its reading sounder. As the lever parts from the front stop n, the condensers z_1 of 4 microfarads capacity and the 300-ohm resistance r_1 are connected in the circuit: $SB-w_1-PC-d-p''-$polar-relay lever$-r_1-z_1-$600-ohm resistance$-g_1$, thereby causing a charge to pass through the pole changer into the condensers which tides the pole changer over the break and prevents the release of its armature. When the polar-relay lever touches the back stop n_1, the pole-changer circuit is closed through the 600-ohm resistance to ground g_1, thereby preventing the opening of the polar-relay circuit, although the receiving leg has been opened at n. Furthermore, when the polar-relay lever touches contact n_1, the condensers z_1 and resistance r_1 are short-circuited. The resistance r_1 should never be less than 300 nor more than 500 ohms. When a signaling current arrives over the duplex line, all circuits are restored to their former condition, thereby sending a current out over the receiving leg; and as the polar-relay lever moves from n_1 to n, the condensers z_1 are again connected in the battery circuit and the charging of these condensers again tides the pole changer over the no-current period.

When the operator on the receiving leg sends he opens and closes the circuit through the receiving leg $- e -$ testing relay $- n$ $-$ polar-relay lever $- p'' - d - PC - w_1 - SB$, thereby controlling the pole changer which repeats his signals into the duplex line. The supplementary contact w opens the circuit of the polar relay whenever the pole changer opens, thereby preventing the repetition of the signals back to the sending operator, which would cause confusion.

25. When used as a half repeater, the smaller the movement of the polar-relay armature between stops, the less exact need be the adjustment of the pole changer. In this class of service the polar relay must be given enough bias to insure the retention of the lever against its front, or closed, stop when the polar relay is cut out by the opening of the supplementary contacts w of the pole changer or repeating sounder where one is used.

When balancing for half-repeater service, the cam-lever switch P should be placed in its correct position (inner contact p'' closed) for such service and the polar relay biased in the same manner as when balancing this set for full duplex work. In half-repeater service, the polar relay is only in circuit when the sender's key w_1 is closed, hence it is only necessary, when securing a static balance, to see that the home relay does not respond to the closing of the home key. Therefore, there is a wider margin for its operation as a half repeater than there is in full duplex service. In other respects the balancing of this set for half-repeater service is the same as for full duplex work.

26. Single-Line and Half Repeaters.—The **Athearn single-line repeater** may be used with a duplex set for repeating messages arriving over the single line through this single-line repeater and the duplex apparatus into the duplex line, or for repeating messages from the duplex line into the single line. By such an arrangement, the duplex is reduced to a simplex system because it is only possible to send messages in one direction at a time through both the duplex and single-line repeater. It is not as simple an arrangement as a half-duplex repeater, but it is claimed that it permits the use of the duplex set without biasing the polar relay, which is especially convenient in cases of extremely low margin on a duplexed circuit where the polar relay would not operate if given a bias. It is also claimed that this arrangement will withstand a greater amount of inductive disturbance from single-phase alternating-current railroad circuits than a full duplex repeater. Single-line and half repeaters are combined by connecting to the sending leg of the duplex, through an ordinary key, relay, plug, and spring jack, the wire that would otherwise pass from the single-line repeater to one single line, say the west line; and by connecting to the receiving leg of the same duplex set, through a plug and spring jack, the wire that would otherwise pass from the single-line west relay to the battery. In the receiving and sending legs there are adjustable resistances by means of which the desired current may be secured.

27. Cutting Out Extra Test Relay.—When two or more testing relays come into the same circuit by any combination of duplex half repeaters, or of single-line repeaters, or combinations of the two, the magnets of all the testing, or control, relays but one should be cut out of the circuit by means of the short-circuiting switches provided on the base of each relay.

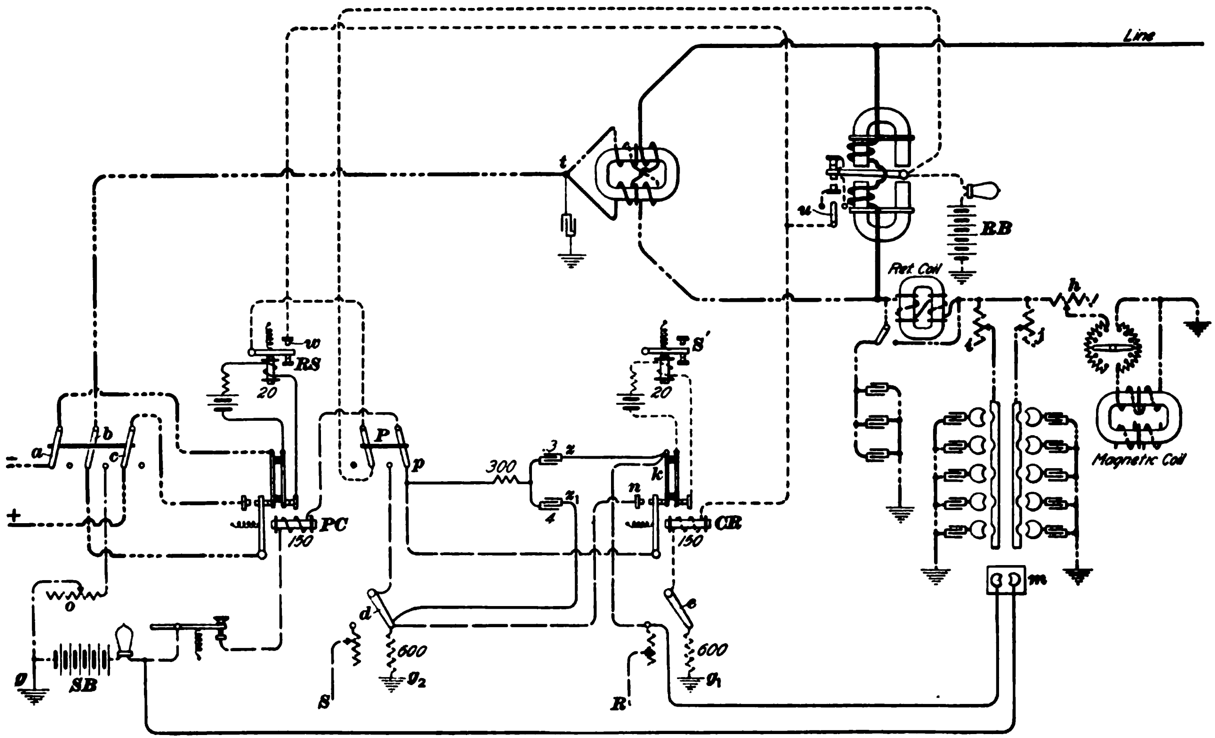

Line
RB
Flat Coil
Magnetic Coil
t
u
h
i
j
m
w
RS
20
S'
a
b
c
P
p
300
3
z
z_1
4
k
n
PC
150
CB
o
d
e
600
g_2
g_1
g
SB
S
R'
-
+

Fig. 3

This quickens the action of the circuit as a whole and increases the margin of adjustment on the pole changer. When two sets are used as half repeaters in each direction, the key of the eastern set should be used when writing for a station west and vice versa. On single-line repeaters use the key on the side next to the station making the request.

MODIFIED POLAR BRIDGE DUPLEX

28. In Fig. 3 is shown a later modification of the polar bridge duplex; it is called the **modified polar duplex** by the American Telephone and Telegraph Company, which uses it. The only change from the system just described is in the local circuits. In the modified arrangement, an additional relay CR, called a *control relay*, is used to control the receiving sounder S' and the circuits containing the .3-microfarad condenser z and the 4-microfarad condenser z_1. When the lever of the control relay rests against its back stop n, the condenser z_1 is practically short-circuited through the 300-ohm resistance and the lever and back stop n of the control relay. When the lever leaves this stop n, the condenser is charged by the battery SB through the coils of the pole changer PC - 300-ohm resistance - condenser z_1 - 600-ohm resistance - ground g_2, thereby holding the pole changer PC closed while the control-relay lever moves from its back to its front stop. The pole changer also controls a repeating sounder RS, which operates the supplementary contacts w. When the main levers of the pole changer and control relay rest against their back stops the extra spring-levers touch neither the front stops nor the main levers, and hence the spring-levers are on open circuit.

The switch P performs practically the same functions as the cam-lever switch P shown in Fig. 2. When the switches P, d, and e, Fig. 3, are turned to the left, the apparatus is connected for full duplex service. The sending and receiving legs S and R are connected through adjustable resistances to the sending-leg and receiving-leg jacks on the Morse board; from this they may be extended to any operator or telegraph subscriber's office.

The center lever *b* of the main-circuit switch operates independently of the levers *a* and *c*, which are controlled by one handle. When lever *b* is turned to the right, the point of the bridge is grounded through a resistance *o* that is adjusted to be equal to the resistance of the sending battery circuits.

29. Duplex Half Repeater.—When switches *P*, *d*, and *e*, Fig. 3, are turned to the right, the apparatus is arranged as a duplex half repeater. A short line that is worked single is connected through suitable jacks and plugs to the receiving leg *R*. If the single line is long, it first passes through a single-line repeater.

The repeating sounder *RS* simply shunts the local points of the polar relay when the pole changer *PC* is open. It thereby eliminates any kick of the polar relay due to the pole changer that might be produced when the line is open in case the set is a little out of balance or biased a little for some special reason. The repeating sounder also quickens the break by allowing the first sign of an open circuit on the single line that is connected to the receiving leg *R* to let the pole changer *PC* open. The opening of the pole changer *PC* opens the repeating sounder *RS* and thereby closes the shunt circuit around the polar-relay points. Closing this circuit holds the control relay *CR* closed and allows the pole changer to open firmly.

30. Operation of Duplex Half Repeater.—When no signal is arriving over the duplex line, the lever of the control relay *CR*, Fig. 3, rests against its back stop *n*. The single line coming to *R* is then open at *k* and the pole changer *PC* is in the closed circuit *g* – *SB* – *PC* – contact *p* – control-relay lever – back stop *n* – 600-ohm resistance – g_2. When a signal arrives over the duplex line, the control relay lever moves to its front stop, thereby closing the circuit *g* – *SB* – *PC* – *p* – lever of control relay – back spring *k* – receiving leg *R* to the single line. Thus the single line has a current sent through it and the pole changer is also held closed. The 4-microfarad condenser z_1, by having the short circuit (from *p* through the lever of the control relay and contact *n* to *d*) around it opened at *n* receives a charge and so prevents the pole changer from opening while the control-relay lever moves from the front to the back stop *n*. When the lever touches *k* the .3-microfarad condenser *z* is simply short-circuited. Thus, the pole changer *PC* remains closed for any position of the control relay *CR*, thereby preventing the signals arriving over the duplex line from being repeated back over the same line. In this manner messages arriving over the duplex line are repeated into the single line.

31. The polar-relay lever normally rests against the stop that keeps the circuit g_1 – 600-ohm resistance – switch *e* – *CR* – switch *u* – polar-relay contact and lever – receiving battery *RB* to ground closed. If the distant battery should be reversed, thereby holding the polar-relay lever against the other contact, it is merely necessary to shift the switch-lever *u* to the other contact. The control relay *CR*, and hence also the pole changer, are consequently both normally closed.

When the operator on the single-line *R* desires to send, he first opens his key, thereby opening the circuit *g* – *SB* – *PC* – *p* – lever of control relay – spring *k* – receiving leg *R* – single line – distant office – ground. This connects the point *t* of the bridge to the positive instead of to the negative battery and hence causes the distant polar relay to open its local control-relay circuit and therefore also opens the circuit of the distant local reading sounder, corresponding to *S'*. When the single-line operator closes his key, the circuit just traced is closed and therefore the pole changer *PC* is closed and the distant polar relay closes its local control-relay and reading-sounder circuits. The half-repeater arrangement really reduces the set to a simplex system, but it gives better service than the Athearn single-line repeater and can be used when it would not work satisfactorily as a full duplex.

COMBINATIONS OF HALF REPEATERS, SINGLE-LINE REPEATERS, AND MORSE SETS

32. Full and Half-Repeater Sets Repeating Into Similar Sets.—If it is desired to make one duplex set repeat into another duplex set, the receiving leg of one set is connected to the sending leg of the other set and the sending leg of the first is connected to the receiving leg of the second set. With such connections messages may be repeated in both directions at the same time. If it is desired to use two sets as half repeaters for repeating from the first set into the second or vice versa, but not both ways at the same time, the two receiving legs are connected together. Messages received on the first set control the pole changer of the second set and vice versa at different times but not simultaneously.

33. Peg Switch.—When two sets are working together as half repeaters, with or without a single-line repeater between, the peg switch is useful. For example, imagine that two duplex half-repeater sets and an Athearn single-line repeater at Scranton connected together as follows: The receiving leg of one half-repeater set is connected to the single-repeater line wire that would otherwise go east and this same circuit after passing through the east relay of the single-line repeater (instead of going to battery and ground) is connected to the receiving leg of the second half-repeater set. The remaining single-repeater line is extended to Harrisburg; one duplex line goes to New York and the other to Buffalo. Then, messages arriving over one half-repeater set will be repeated into the single line by the single-line repeater and through the other half-repeater set into its line, and vice versa; furthermore, the operator at Harrisburg can send and have his messages repeated through the single-line repeater and both half-repeater sets to New York and Buffalo. The battery taps must be connected to opposite terminals of the sending batteries of the two half sets. If the duplexed line running to Buffalo fails, the repeater operator immediately throws the double switch *P*, Fig. 3, on the Buffalo set to the left and inserts a peg in the peg switch *m*. This peg allows current from the battery in the sending tap of the Buffalo set to hold closed the local circuit from the New York set through the single set to Harrisburg and Harrisburg may work with New York while the Buffalo line is being independently patched. This arrangement, of course, compels the sending battery in the Buffalo set to supply current for its own pole changer and also through the receiving leg and the pole changer of the New York set to the opposite terminal of the New York sending battery. The lamp in the Buffalo sending-battery circuit must be low enough in resistance to prevent any interference between the two parallel circuits. If too much current flows normally through the sending leg due to this small lamp resistance, it is regulated by special resistances provided for this purpose in the regular artificial-line-rheostat box. Thus, by means of the peg switch, any leg of a circuit going in several directions through half-repeater sets may be cut off without opening the local circuit into which they all repeat, while the defective leg is being tested out and properly connected or the line wire patched. Duplex half repeaters are being used in practically all the American Telephone and Telegraph Company's leased single lines on account of the great gain in efficiency over the single-line Athearn repeater.

34. Combinations of Half Repeaters and Morse Sets. An arrangement giving excellent service and considerably used by the American Telephone and Telegraph Company consists in looping an intermediate telegraph subscriber having a single Morse set directly in the line between two duplex half repeaters. For example, a wire duplexed direct from Pittsburg to Chicago with half repeaters at each end may have a telegraph subscriber at Columbus connected in series with the duplexed line. At one end of the main line the main batteries are reversed and at the opposite end the local contacts of the polar relay are reversed. When both pole changers are closed, the main line is connected to negative battery at one end and positive battery at the other end, which closes the intermediate relay and both polar relays. If the pole changer at either end is opened, batteries of like polarity are connected to each end of the line; the intermediate relay then opens because practically no current is present in the line and both polar relays open because they have been properly biased to do so. Should the intermediate subscriber open his key while all relays are closed, he opens the line and an open line unbalances each half-duplex set so that the duplex relays are both opened.

35. Another arrangement where it is desired to use a duplexed line to a small office which is not supplied with duplex apparatus consists in equipping one end with a duplex half-repeater and the small-office end with a single Morse set. The two main batteries at the half repeater and the single-line battery at the other end are arranged so that when the pole-changer key is closed, opposite battery polarities are connected at the two end stations. The polar relay is unbalanced and opened when the Morse set key is opened, and the opening of the pole-changer key puts battery terminals of like polarity to both ends of the line, and hence opens both the Morse set and the polar relays. While this does not give quite as good service as a wire equipped with duplex apparatus at both ends, it is much better than a single-line equipment, as it requires less adjustment of the Morse set in bad weather, as the duplex batteries can be adjusted to just neutralize the single-set battery, thereby enabling a low-adjusted Morse relay to be distinctly opened.

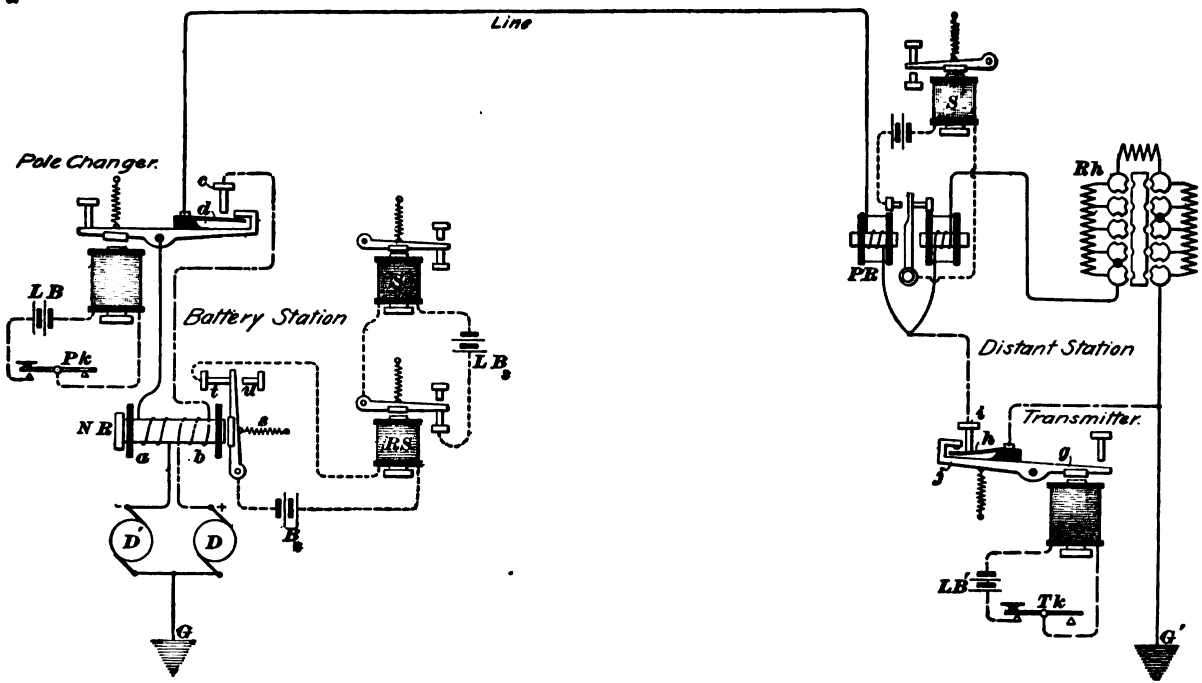

Line
Pole Changer.
d
LB
Pk
Battery Station
NB
a
b
t
u
s
S
RS
LB_2
B_2
D'
D
G
S'
PR
Rh
Distant Station
Transmitter.
i
h
j
g
LB'
Tk
G'

FIG. 4

SINGLE-BATTERY DUPLEX SYSTEMS

MORRIS SINGLE-BATTERY DUPLEX

36. The **Morris single-battery duplex,** invented by Mr. R. H. Morris, of the Western Union Telegraph Company, requires a main-line battery only at one end. It is a great improvement over a somewhat similar system, called the Edison-Smith duplex, and has proved to be one of the most useful and economical systems for short lines; it is considerably used, especially in New York city and the immediate vicinity.

The general arrangement of the apparatus is shown in Fig. 4. The instruments are the same as those used in the duplex and quadruplex systems. An ordinary continuity-preserving transmitter is used at the battery station as a pole changer, in preference to one of the walking-beam pattern, in order that the benefits of a continuity-preserving device may be obtained. Where a low electromotive force is used, a transmitter connected as a pole changer may be beneficially substituted for the ordinary dynamo walking-beam pattern, as the tendency to spark will be small.

37. Distinctive Feature of Morris Duplex.—One distinctive feature of the Morris duplex lies in the use of a differential relay, called a **neutral relay.** However, this relay is not used differentially, and is practically a single relay because the current never flows differentially through the two coils. Thus, one current does not neutralize the effect of the other. Moreover, the direction in which the cores are magnetized is never reversed. The coils are so wound and connected that when current from the negative dynamo D', Fig. 4, circulates through the coil a, the iron is magnetized in the same direction as when current from the positive dynamo D circulates through the coil *b*. When the pole changer shifts the line from one coil of the neutral relay to the other coil, there is a moment when the two dynamos are in series and no current flows over the line. At this time there is quite a strong current through both coils of the neutral relay, but the current is in such a direction through the two coils as to preserve the existing direction of the magnetization of the relay. Hence, the magnetization of the neutral relay does not even fall to zero, much less does it reverse when the pole changer is in operation. Consequently, the magnetization produced at reversal tides the relay over the period of reversal and thus avoids the kick that is so objectionable.

38. This duplex system contains an adjustable resistance *Rh*. When the transmitter at the distant station is closed, this resistance and the one coil of the polar relay *PR* are short-circuited and the line is connected through one coil of the polar relay and through the transmitter to the ground *G'*. When the transmitter is open, both coils on the polar relay and the resistance *Rh* are connected in series between the line wire and the ground *G'*. The resistance *Rh* is so high that when it is in the circuit, the current is reduced to one-fourth the strength that it possesses when the transmitter is closed. But both coils of the polar relay are in series when the transmitter is open and the current flows through the two coils in such a direction that they help each other, and the magnetization produced is still sufficient to operate the polar relay when the current is reversed by the pole changer at the battery station.

The spring of the neutral relay is so adjusted that when the transmitter at the distant station is closed, the current is strong enough to overcome it and attract the armature. But when the distant transmitter is opened the resistance *Rh* is included in the circuit, consequently the current is reduced to about one-fourth its previous strength, and the magnetism produced in the neutral relay is not sufficient to overcome the spring, and hence the armature is released. Therefore, the neutral relay can be closed only by increasing the strength of the current to four times its smaller value and its operation is entirely independent of the direction of the current. On the other hand, the polar relay is operated by reversing the direction of the current and is independent of the strength of the current used.

39. Arrangement of Sounders.—At the battery station, a repeating sounder *R S*, Fig. 4, has its circuit closed when the relay armature is against its front stop, and the ordinary, or reading, sounder *S* has its circuit closed when the armature of the repeating sounder is against its front stop. The arrangement of these two sounders at the battery station is such as to avoid any danger of a false signal when the pole changer short-circuits the two dynamos through both coils. When the distant transmitter is closed, causing the neutral-relay armature to rest against the front stop *t*, the increase in the magnetization of the neutral relay, due to the short-circuiting of the dynamos, can do no harm. Furthermore, experience with this duplex has shown that, even when the distant transmitter is open, the increment of current in the neutral relay, when the two dynamos are short-circuited, does not produce a false signal. This may be due to the fact that the duration of the short-circuiting is much less than the time required for the second coil of the neutral relay, which is empty, to build up from zero. Moreover, it would be necessary, before a false signal could be produced on the sounder *S*, for the armature of the neutral relay to move from the back stop *u* to the front stop *t* and for the armature of the repeating sounder to also move from its back to its front stop. This movement requires time. Whatever may be the true explanation, the short-circuiting at the pole changer is so brief that no false signals are produced. It is a disputed point as to whether a repeating sounder is necessary. However, the apparatus was originally set up that way and it has never been changed.

OPERATION OF MORRIS SINGLE-BATTERY DUPLEX

40. Both Keys Open.—Let both keys *Tk* and *Pk*, Fig. 4, be open, then the armature of both relays *NR* and *PR* will be resting against their back stops and the sounders *S* and *S'* will be open. The negative dynamo *D'* will be sending current through coil *a* - pole changer - line - both coils of the polar relay *PR* - resistance *Rh* - ground *G'* and back through the ground to the negative dynamo *D'*. The direction of this current is such that the polar relay is held open, and because the resistance *Rh* is in the circuit, the strength of the current is not sufficient to overcome the retractile spring *s* of the neutral relay; hence, the neutral relay is also open.

41. Key *Pk* Closed.—Closing key *Pk*, Fig. 4, closes the pole changer and thus shifts the line from the negative dynamo *D'* to the positive dynamo *D* and reverses the direction of the current throughout the circuit. The neutral relay will not be affected, because the strength of the current is the same as before, but the polar relay will be closed. Hence, by closing the key *Pk* at the battery office, a signal is produced at the distant office only.

42. Both Keys Closed.—If, while the key *Pk*, Fig. 4, is closed the key *Tk* is also closed, the transmitter will close and short-circuit the resistance *Rh* and one coil of the polar relay, while the current will increase to four times its former strength. Although there is now only one coil of the polar relay in the circuit, still the current has been sufficiently increased in strength to more than make up for the fewer number of turns in the coils of the polar relay; moreover, closing the key *Tk* does not reverse the direction of the current. Hence, the polar relay is not affected and remains closed as long as the battery-station key *Pk* remains closed. But increasing the current to four times its former value closes the neutral relay *NR* at the battery station. Hence, both relays are closed when the two keys are closed.

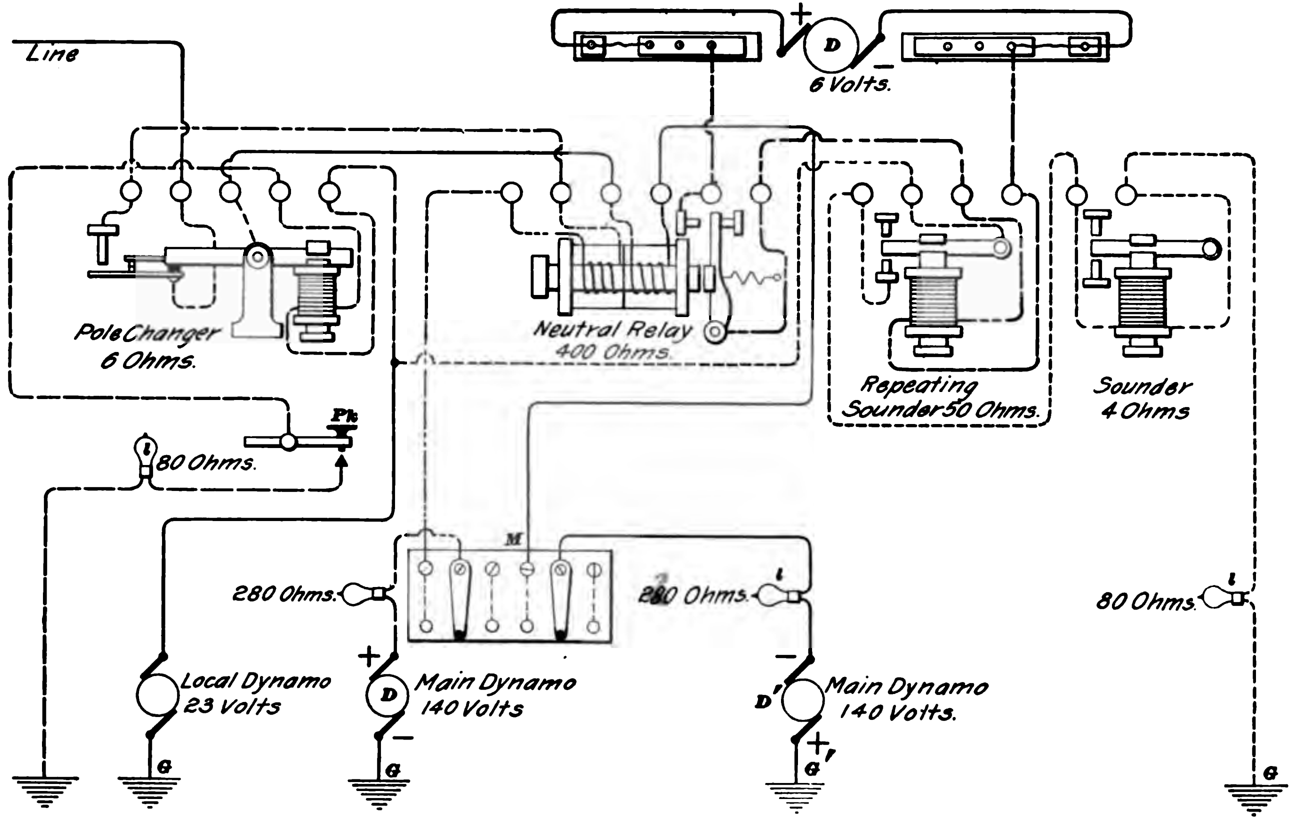

Line
+
D
−
6 Volts.
Pole Changer
6 Ohms.
Neutral Relay
400 Ohms.
Repeating
Sounder 50 Ohms.
Sounder
4 Ohms
Pk
l
80 Ohms.
M
280 Ohms.
280 Ohms.
l
80 Ohms.
l
Local Dynamo
23 Volts
G
+
D
−
Main Dynamo
140 Volts
G
−
D'
Main Dynamo
140 Volts.
+'
G'
G

FIG. 5

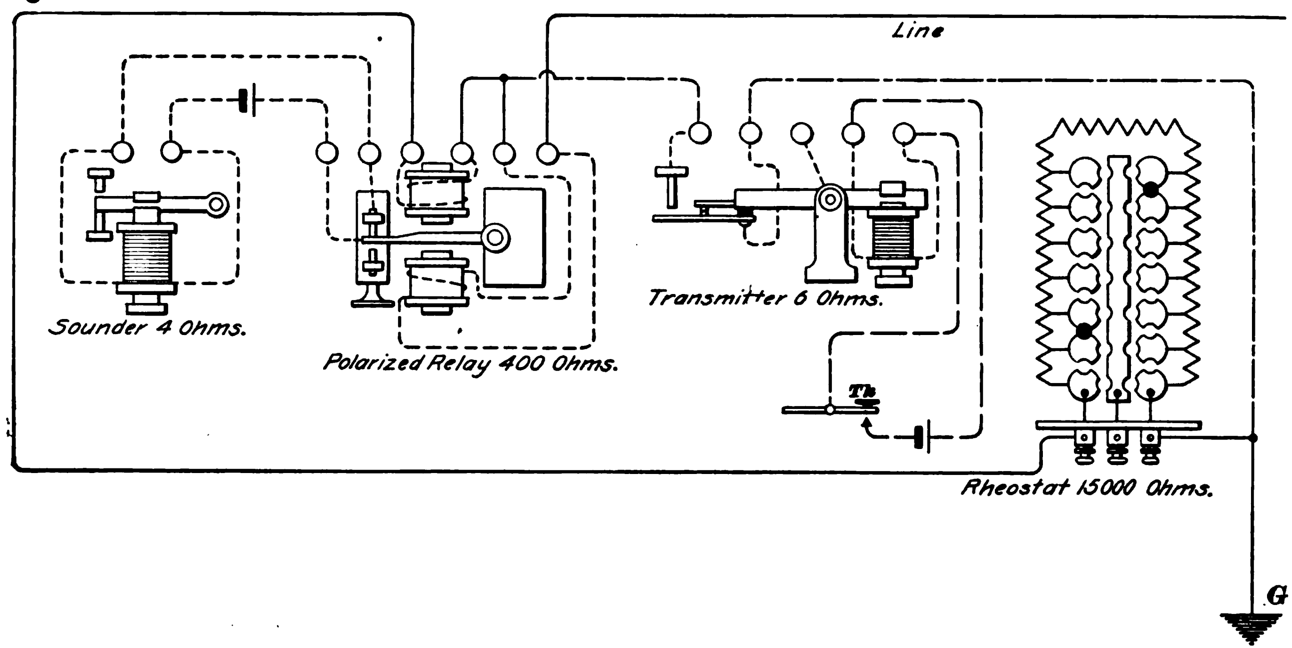

Line
Sounder 4 Ohms.
Polarized Relay 400 Ohms.
Transmitter 6 Ohms.
Tk
Rheostat 15000 Ohms.
G

FIG. 6

43. Key *Tk* Closed.—If now the key *Pk*, Fig. 4, is opened, *Tk* remaining closed, the line will be shifted from the positive to the negative dynamo. This will reverse the direction of the current through the circuit, without causing any change in its strength, and, hence, only the polar relay will be opened. Therefore, the key at one station controls only the relay at the other station, and the operation of a key at one station does not interfere with the signals that are being received by the relay at the same station.

44. Balancing Morris Duplex.—The Morris single-battery duplex is balanced at the battery station by simply adjusting the retractile spring of the neutral relay so that the armature will properly respond to the signals from the distant station, at the same time that the battery-station key is being operated. The polar relay at the distant station requires no adjustment after its armature has been properly centered. The resistance *Rh* is so adjusted as to make the maximum current four times as great as the minimum.

45. Connections of Morris Duplex.—The actual connections of the apparatus at the two offices are shown in Figs. 5 and 6. The two arms of the switch *M*, Fig. 5, are turned to the left when the apparatus is in use. The 50-ohm repeating sounder is supplied with current from a 6-volt dynamo and the other local circuits are supplied, as usual in Western Union offices, from a 23-volt dynamo. Lamps having the proper resistance are connected in the various circuits to help regulate the strength of the current. No primary batteries are used at the battery station, and at the distant office only enough gravity cells to operate the transmitter and the sounder are required.

LARISH SINGLE-BATTERY DUPLEX

46. The single-battery duplex systems are especially useful between main offices and branch or district offices because the operators at the branch or district offices usually have had no experience with any apparatus more complicated than the ordinary relay, key, sounder, and battery; hence, they are unable to adjust and care for systems having polar relays and transmitters, which is the objection to the Morris single-battery duplex. The **Larish single-battery duplex, or city-line duplex,** as it is called by the Postal Telegraph-Cable Company, eliminates this objection as only a transmitting, or pony, relay, a relay looking like an ordinary 150-ohm relay, and an unadjustable resistance, are necessary in addition to an ordinary sounder, key, and local battery.

In Fig. 7 is shown a simplified diagram of the Larish single-battery duplex system, omitting the local sounders, which are

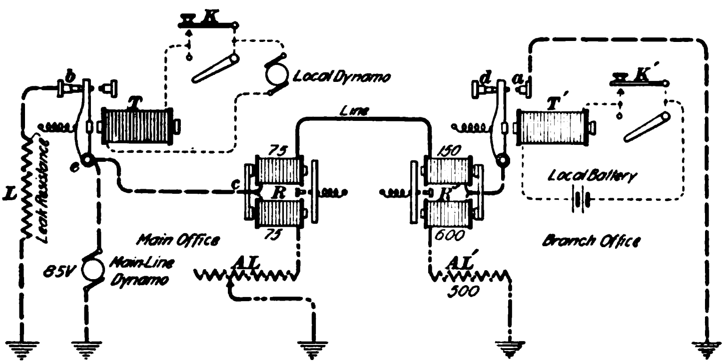


FIG. 7

controlled in the usual manner by the relays R and R'. The branch office contains a relay R', which, to all appearances is an ordinary 150-ohm relay; a pony relay T', which is also called a *transmitting relay;* and a 500-ohm resistance AL', which serves as an artificial line. This resistance is placed out of sight in the base of the relay R'. One coil of this relay is wound to a resistance of 150 ohms, the other coil to a resistance of 600 ohms. The contact a is grounded.

The main office contains an ordinary differentially wound relay R, which has two windings of 75 ohms each; an adjustable artificial-line resistance AL; a transmitting relay T; a leak resistance L connected to contact b; and a suitable main-line dynamo for supplying current for the line relays R and R'.

47. Operation of Larish Duplex.—When the main-office key K is closed, the lever of the transmitter T is against its front stop; therefore, the full voltage of the 85-volt dynamo is applied to the point *c* where the relay *R* is connected to the circuit. When the key *K* is open, the lever of transmitter *T* is against its back stop *b*; sufficient current then passes from the 85-volt dynamo through the leak resistance *L* to reduce the electric pressure at *c* to 40 volts. When the branch-office key *K'* is open and the armature of the transmitting relay *T'* rests against contact *d*, the artificial-line resistance *A L* at the main, or dynamo, office is adjusted until the current divides equally at *c* whether the voltage is 40 or 85; hence, the operation of the main-office key *K* has no effect upon the main-office relay *R*.

But the closing of the main-office key *K* will operate the branch-office relay *R'*. For, if the branch-office key *K'* is open, sufficient ampere-turns will be produced in both windings of the relay *R'* to make the relay *R'* attract its armature; and if the branch-office key *K'* is closed, the 500 ohms in the artificial line and the 600 ohms in one winding of the relay *R'* will be short-circuited, thereby allowing the current in the 150-ohm coil of the relay *R'* to increase sufficiently to give enough ampere-turns to cause the relay *R'* to attract its armature. Thus, the branch-office relay *R'* will attract its armature only when the main-office key *K* is closed and it will attract its armature whether the branch-office key *K'* and transmitting relay *T'* are open or closed. The resistance and number of turns on the relay *R'* are so proportioned as to give this desired result.

48. Closing the branch-office key *K'*, thereby cutting 1,100 ohms resistance out of the line circuit, will increase the current through the line coil of the main-office relay *R*, due to either 85 or 40 volts at *c*, enough to unbalance the relay *R* so that it will attract its armature. The closing of the branch-office key *K'* and transmitting relay *T'* does not affect the branch-office relay *R'*, because when the main-office key *K* is open, the 40 volts at *c* will not produce sufficient current in the 150-ohm winding to cause the branch-office relay *R'* to attract its armature. When the main-office key *K* is closed

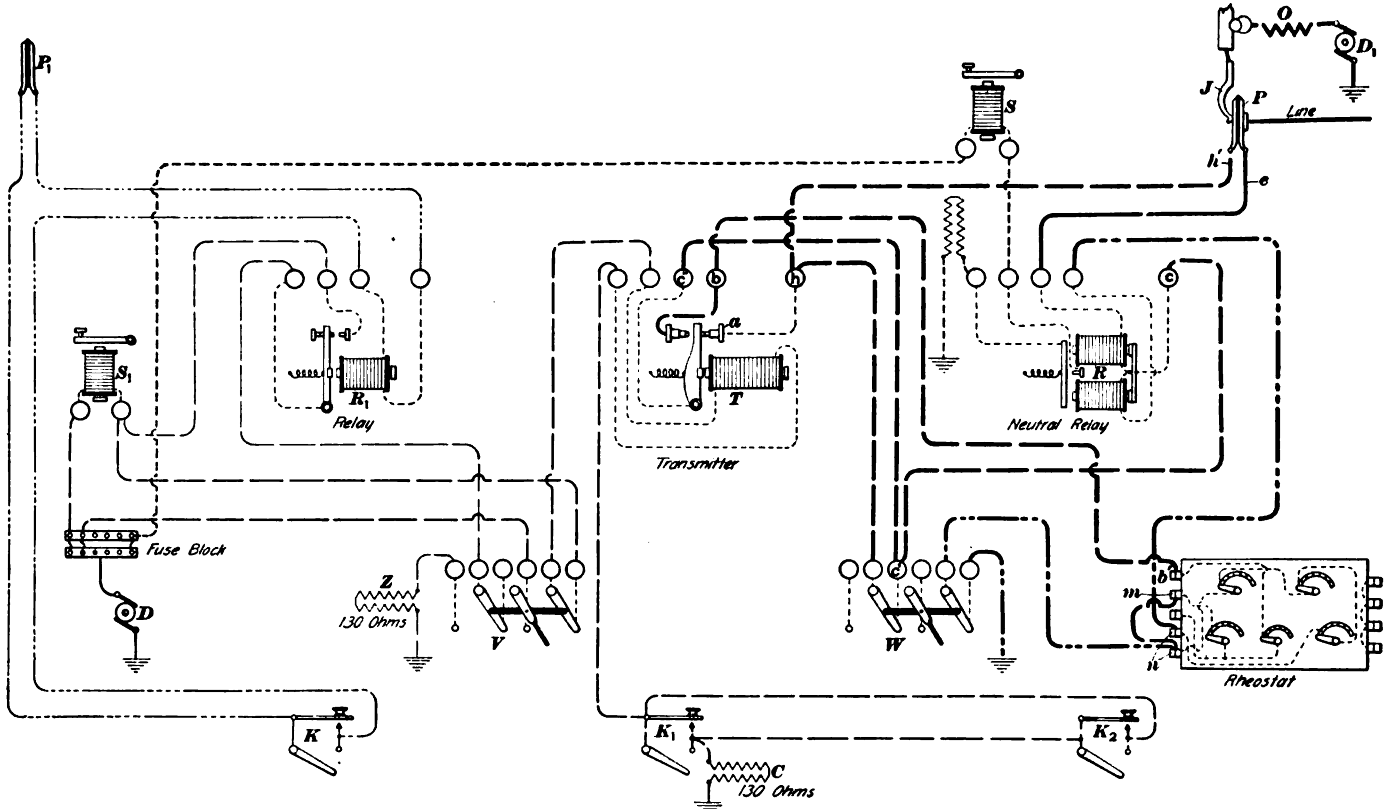

P₁
S₁
Fuse Block
D
Relay
R₁
Z
130 Ohms
V
K
Transmitter
T
a
c
b
h
S
Neutral Relay
R
c
W
K₁
C
130 Ohms
K₂
Rheostat
b
m
n
O
D₁
J
P
Line
h'
e

FIG. 8

and 85 volts is applied at c, the cutting out of 1,100 ohms, still allows enough ampere-turns to hold the branch-office relay R' closed.

49. Practical Diagrams.—In Fig. 8 the connections and apparatus used in the main office are shown. With the wedge P inserted in the jack J and the switches V and W turned to the right, the apparatus is properly connected to operate as a Larish single-battery duplex. The sounder S is controlled by the differentially wound neutral relay R. The sounder S_1 is in circuit with the magnet of the sending relay or transmitter T, the key K_1 on the sending operator's end of the table, the key K_2 on the receiving operator's end of the table, the 130-ohm resistance C, and the local dynamo D. The key K_2 enables the receiving operator to *break*, that is, open the line circuit, if he does not understand what is being sent him. The sounder S_1 enables the sending operator to read his own signals. The leak resistance is included between the terminals b' and m in the rheostat; the artificial line is connected to terminals n in the same rheostat. The plug P_1 and key K are not in use while the line is duplexed.

50. With the wedge P inserted in a jack as shown, the wedge P_1 inserted in a line jack, and the switches V and W turned to the left, two single line sets are formed. The key K then controls the ordinary relay R_1 and the line in which it is connected; this relay R_1 then controls the sounder S_1, the 130-ohm coil Z and dynamo D being included in this sounder circuit. The other line circuit may be traced through e – one winding of the relay R–c – c' – c''–back stop a – h – h'–wedge P– jack J – switchboard–resistance O – main-line dynamo D_1 – ground. The relay R controls the sounder S. There is no key in this line circuit, but either key K_1 or K_2, which are connected in parallel, may be used to control the transmitter T and hence also to send signals through this line. While receiving on the sounder S one or both keys K_1 and K_2 must be closed and while sending with either of these keys K_1 or K_2, the one not in use must be open.

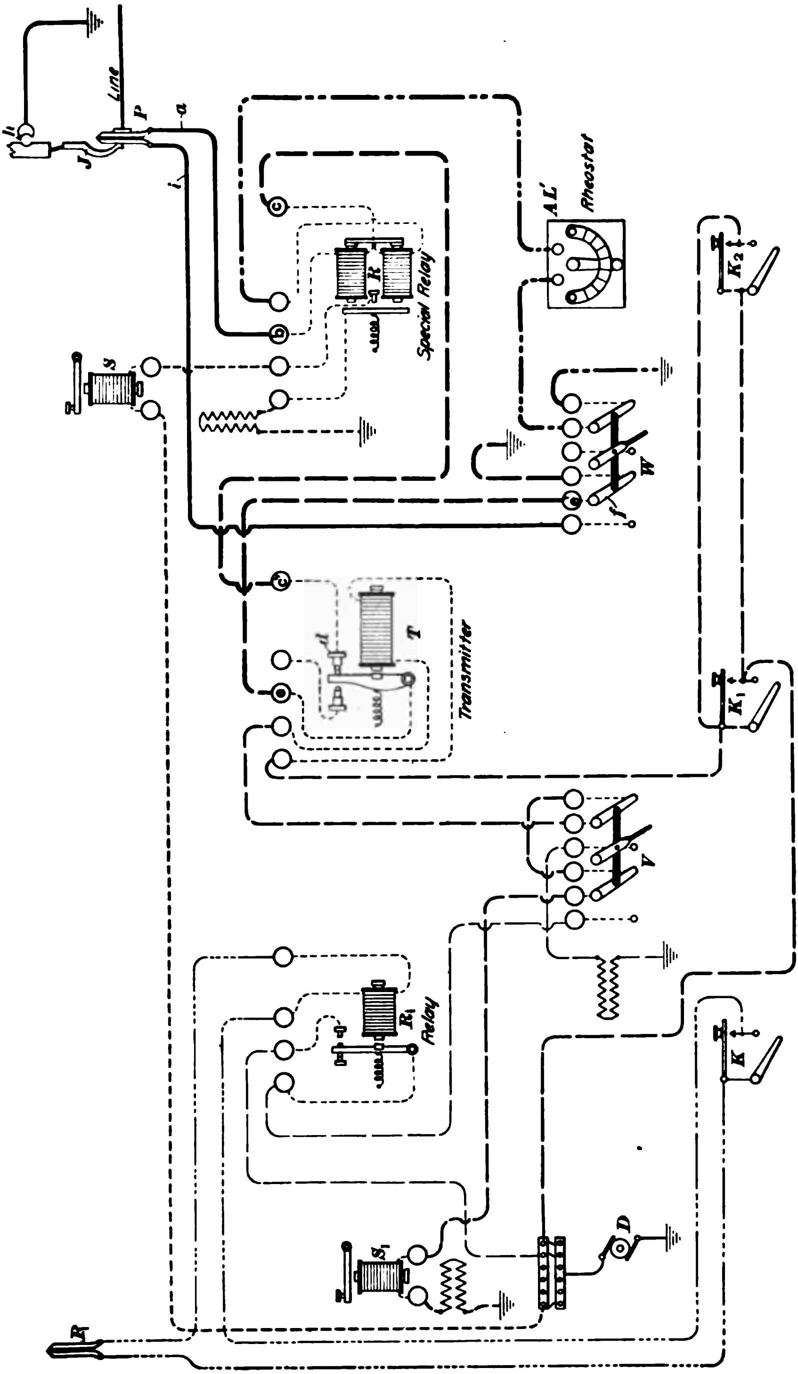

Line
P
a
i
J
h
C
K
Special Relay
S
AL'
Rheostat
K2
W
f
C'
d
T
Transmitter
K1
V
R1
Relay
K
S1
D
R

FIG. 9

51. In Fig. 9 is shown the arrangement of apparatus for the branch office. With the wedge *P* in the jacket *J* and the switches *V* and *W* turned to the right, the apparatus is properly connected to operate as a Larish duplex system. The relay *R* controls the sounder *S* and either key K_1 or K_2 may be used, provided the other is open, to control the transmitter relay *T* and hence to send signals through the line to the main office. The sounder S_1, which is in series with the local dynamo *D* and the winding of the transmitter relay *T*, enables the sending operator to hear his own signals. Although not theoretically necessary, an adjustable resistance AL' is included in the line-relay circuit to assist in regulating the line current; this rheostat may also contain the 500 ohms required in series with one winding of the relay *R*.

With the wedge *P* in line jack *J*, a plug in hole *h*, the wedge P' in a similar line jack with one side grounded, and the switches *V* and *W* turned to the left, two single line sets are formed. The key *K* then controls the ordinary relay R_1 and the line in which it is connected, and this relay R_1 controls the sounder S_1. The other line circuit, which is controlled by means of the transmitter *T* and either key K_1 or K_2, provided one of these two keys is open, may be traced through $a-b-$one winding of relay $R-c-c''-$contact $d-$armature of transmitter $T-e-e'-$switch lever $f-$wire $i-$wedge $P-$jack $J-$plug at *h* to ground. The sounder *S* is controlled by the relay *R*.

DIPLEX TELEGRAPHY

52. The **diplex** is a system of telegraphy by which two messages may be simultaneously transmitted in the same direction over one wire. The form described here should be thoroughly understood, for it is an essential feature of the quadruplex systems.

The principle of the diplex system may be readily understood by the help of Fig. 10, in which *PR* is a polarized relay; *NR*, a neutral relay, so called because its operation depends on an increase in the strength of the current and not on the direction of the current; *PC*, a pole changer; and *T* a transmitter. The transmitter is so connected that when the key is open, only one cell B' is connected between the wires *d* and *e*. When the key is depressed, the lever *a* first touches the lever *b*, thereby short-circuiting, momentarily, the battery *B*, which consists of three cells, before it lifts the moving contact *b* off the fixed contact *c*. When the lever *a* has lifted *b* off *c*, the two batteries *B* and B' are connected in series, making one battery of four cells across the two wires *d* and *e*. Hence, the number of cells in the circuit has been increased

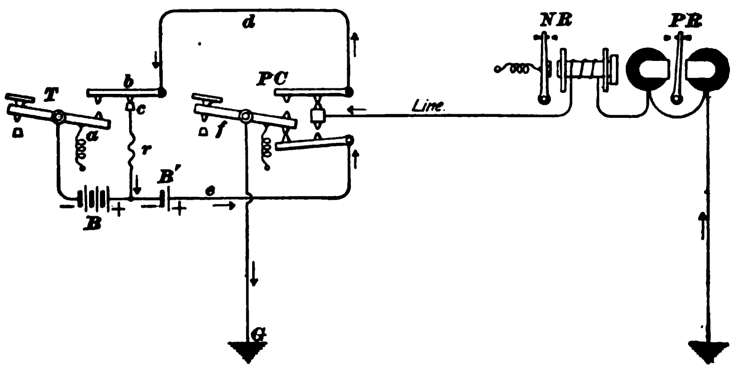


FIG. 10

from one to four; consequently, with the same resistance in the circuit, the strength of the current will be four times as great as before. If the weaker current has a strength of 1 unit, then the stronger current will have a strength of 4 units. That is, the ratio of the two currents is 1 to 4. In order to keep the resistance of the circuit the same whether the battery *B* is cut in or out, it is necessary to insert the resistance *r*, which is equal to the internal resistance of the battery *B* in the circuit when the battery *B* is cut out.

53. Operation of Diplex System.—When the key *f* of the pole changer *PC* is open, that is, up, the line is connected to the wire *d*, and the ground *G* to the wire *e*. When the key is depressed, these connections are reversed. Hence, the pole changer, when operated, reverses the polarity of whatever battery happens to be connected by the transmitter *T* across the two wires *d* and *e*. The operation of the transmitter varies the current from 1 to 4 units, or vice versa, and the pole changer merely reverses the direction of this current through the line whether it is 1 or 4 units. Thus the transmitter and the pole changer do their work independently of one another.

The action of these two instruments when they are combined in this manner should be clearly understood. There are four possible positions of these two keys. If it is not understood that the operation of the pole changer does not affect the strength of the current, and that the operation of the transmitter does not affect the direction of the current in the line, the three other possible positions of the two keys should be drawn on separate pieces of paper and the strength and direction of the current in the line noted in each case. The tongue, or armature, of the polarized relay will move whenever the direction of the current is reversed, no matter whether the strength of the current is 1 unit or 4 units. The reversal of the 4-unit current will perhaps make the polarized relay operate more vigorously than will the reversal of the 1-unit current, but the 1-unit current will operate it and the intensity of the click of the sounder that is controlled by the polar relay will be the same in either case.

54. The neutral relay, however, will tend to attract its armature no matter in which direction the current flows through it, and if the current is only strong enough to overcome the retractile spring, the relay will close its local circuit. The spring is adjusted so that the magnetism produced by the 1-unit current will not be strong enough to overcome it, but the magnetism produced by the 4-unit current will readily overcome the spring and close the local circuit. Hence the message sent by the operator at the transmitter *T*, Fig. 10, is received by the operator at the neutral relay *NR*, and the message sent by the operator at the pole changer *PC* is received by the operator at the polarized relay *PR*. Furthermore, these two messages do not interfere with each other when the apparatus is properly adjusted.

55. Elimination of False Signals.—If the pole changer reverses the direction of the current while the 4-unit current is flowing, in which case the neutral relay is closed, the neutral relay tends to release its armature at the instant of reversal, because when the whole battery is reversed, and, consequently, the direction of the current through the neutral relay is reversed, the magnetism of the neutral relay must fall to zero before it can increase to its normal strength in the opposite direction. If the interval of no current in the neutral relay, which lasts while the battery is momentarily short-circuited, is sufficiently prolonged, a mutilation of the signal, or a **false signal,** as it is called, will be produced that will seriously interfere with the successful operation of the system. However, by adjusting the pole changer so that the interval of no current in the line and relay is as short as possible, and, furthermore, by using a repeating sounder that is closed on the back stop of the neutral relay, and an ordinary sounder that is closed, in turn, on the back stop of the repeating sounder, the tendency to produce false signals can be overcome. When the local circuit is connected to the back stop instead of to the front stop of the neutral-relay armature, a reduction in the magnetizing force of the relay that will allow the armature to momentarily break away from the front stop will not produce a false signal by closing the ordinary sounder circuit, unless the time interval is sufficient for the relay armature to cross the gap between the front and rear stops, and to make contact with the rear stop. Furthermore, both the repeating sounder and the ordinary sounder require some time before their magnetism can build up from zero to a strength sufficient to start the movement of their armatures. Hence, if the relay armature does momentarily close the repeating-sounder circuit, the duration of contact may be too short to allow the repeating sounder, in turn, to close the circuit of the ordinary sounder. Even if this should happen it may last so short a time that the ordinary sounder cannot build up and make a signal.

56. Reading Sounder.—Whenever a repeating sounder is connected to the back stop of a relay and the signals are to be read by sound, a second sounder must be used. The second sounder must be connected to the back stop of the repeating sounder, otherwise, the signals will be reversed; that is, dots and dashes will be transformed into spaces, and vice versa. This second sounder is frequently called the **reading sounder.**

DUPLEX AND QUADRUPLEX TELEGRAPHY
(PART 3)

QUADRUPLEX SYSTEMS

PRINCIPLES OF QUADRUPLEX SYSTEMS

INTRODUCTION

1. The principle of all **quadruplex systems** in which two messages are sent in each direction simultaneously over one line wire is about the same. In the Stearns, or differential, duplex system, the differential relay responds only to signals sent from the distant office; the connection and disconnection of the home battery does not affect the home relay because it is differentially wound. In the polar duplex, the polar relay at the home office responds to the reversals of the distant battery but not to the reversals of the home battery, because the polar relay is also differentially wound. In the diplex system one message is transmitted by increasing and decreasing the strength of the current, independent of its direction, while another message is being sent by reversing the direction of the current, independent of its strength. If in the diplex both the neutral and polar relays are differentially wound and connected at the home station, as shown in Fig. 1, the operation of the home transmitter and pole changer will not affect these relays. This is evidently a combination of the principles involved in the differential duplex, the polar duplex, and the diplex. Each of these systems must be thoroughly understood before it is possible clearly to comprehend the principles of the complete quadruplex systems that will follow.

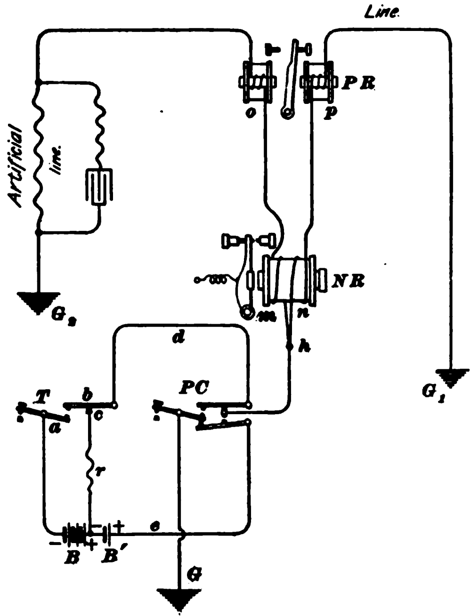


Fig. 1

2. Operation of Quadruplex Systems.—As in the duplex systems, the artificial line is made equal in resistance and capacity to the line wire. In Fig. 1, whatever current finds its way from the battery, through the transmitter and the pole changer, will divide equally at the point *h*. One half will flow through the coil *n* on the neutral relay – the coil *p* on the polarized relay – the line – the ground plate G_1 – the ground – ground plate *G* back to the battery. The other half will flow through coil *m* – coil *o* – artificial line – ground plate G_2 – the ground plate *G* back to the battery. The coils *n* and *p* are called the *line coils*, and the coils *m* and *o*, the *artificial-line coils*. The two relays are differentially wound and so connected that current flowing from the home battery, and dividing at *h*, equally through the line and artificial-line coils, will not magnetize or affect either relay, no matter what may be the strength or direction of this current. The coil *m* neutralizes the effect of the coil *n*, and *o* neutralizes *p* when the current for all the coils comes from the home battery and divides equally at *h*.

3. In the next step, which is illustrated by Fig. 2, a neutral relay NR_1 and a polar relay PR_1 are connected at the distant station in series with the line. The resistance and capacity of the artificial line are adjusted until the current from the battery at the west station divides into two equal parts at the point *h* and passes in opposite directions through the two coils of *NR* and *PR*. Therefore, the operation of the pole changer and transmitter at the west station will not operate the neutral relay *NR*

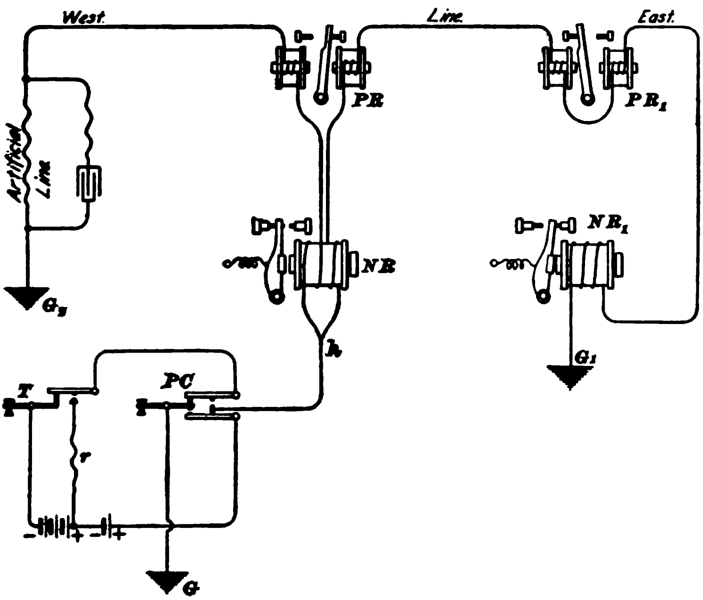


FIG. 2

nor the polar relay *PR* at that station. The current that finds its way over the line and through the neutral and polar relays NR_1 and PR_1 at the eastern station is free to operate those relays, provided it has the proper strength and direction. If the line current is strong enough, it will close the neutral relay NR_1, no matter what its direction may be; and the same current will close the polar relay PR_1, if it flows in the proper direction, no matter what its strength may be. The operation of the pole changer *PC* will not affect the polar relay *PR*, because the latter is differentially wound, nor will it affect the neutral relay NR or NR_1, because merely a change in the direction of the current will not operate a neutral relay. Hence the only relay affected by the operation of the pole changer PC is the polar relay PR_1 at the distant station. The operation of the transmitter T will not affect the neutral relay NR because the latter is differentially wound, nor will it affect either polar relay PR or PR_1, because merely an increase or decrease in the current will not change the polarity of a polar relay. Hence the only relay affected by the operation of the transmitter T is the neutral relay NR_1 at the distant station. Therefore, one operator at T and another at PC may send messages simultaneously, the message sent at T being received by an operator at NR_1 and the message sent at PC by an operator at PR_1.

4. The next step consists in arranging the apparatus in exactly the same manner at both ends, so that two messages may be sent simultaneously in each direction without interfering with each other. This arrangement is shown in Fig. 3. The four relays are differentially wound. In order to have a clear diagram, the apparatus has been reduced to as simple a form as possible, and all local-sounder connections have been omitted. Diagrams showing the practical form and arrangements of the instruments will be given later. The artificial line AL is so adjusted that the resistance from h through AL and G_1 to G equals the resistance from h through the line coils o and l and the line to the ground at the east station. The artificial line AL_1 at the east station is similarly adjusted, so that the resistance in the circuit from h_1 through AL_1 and G_3 to G_2 equals the resistance from h_1 through the line coils o_1 and l_1 and the line to the ground at the west station.

The resistance of the ground return should, strictly speaking, be included in these circuits, but it can usually be neglected without appreciable error. The battery B has twice the electromotive force of battery B_1, as is indicated, by giving the first battery B twice as many cells as the latter B_1. Hence, if battery B_1 has an electromotive force of 100 volts, battery B will have an electromotive force of 200 volts. When battery B_1

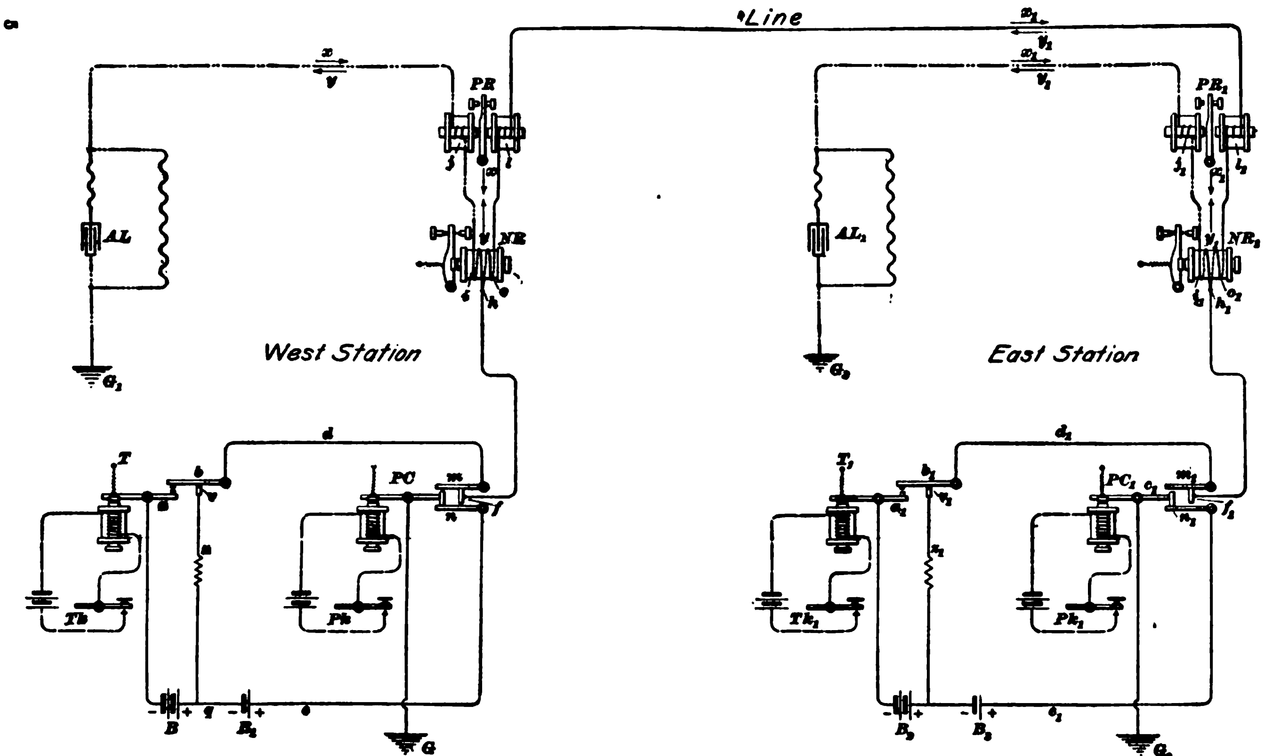

Line
West Station
East Station
PR
NR
AL
PC
T
Tk
Pk
B
G
d
PR1
NR1
AL1
PC1
T1
Tk1
Pk1
d1

Fig. 8

alone is connected between the wires d and e, the electromotive force will be 100 volts; when both batteries B and B_1 are connected in series between lines d and e, the electromotive force will be 300 volts. Hence, if the strength of the current in the first case is represented as 1 unit, the current in the second case will be 3 units.

5. Quadruplex Used as a Duplex.—Either side of a quadruplex can be used as a duplex; the polar side as a polar duplex, or the neutral side as a differential duplex. Duplex sets were excluded from the main office of the Postal Telegraph Company in Philadelphia, which was completed in September, 1900, and only single and quadruplex sets were installed. By this arrangement a second side is always available, when required on a circuit that is at the time being worked duplex.

KEY COMBINATIONS

6. Sixteen combinations may be formed with the four keys, thus giving sixteen current combinations; these combinations are tabulated in Table I. The letter R in the table refers to the resistance from the point h through the line to the ground G_2 and G_3 at the east station, or from h_1 through the line to the ground G and G_1 at the west station. It is also equal to the resistance from the point h through the artificial-line side at the west station to the ground G_1, or from h_1 through the artificial-line side at the east station to the ground G_3. The resistance of the earth return is in each case neglected.

The letters in parentheses, in columns Effective Current, refer to the direction of the current and to the branch carrying the largest current. Thus $\frac{100}{R}$ $(x_1\ AL_1)$ means that an effective or excess current of $\frac{100}{R}$ amperes is flowing through the artificial-line coils of the relays at the east station (AL_1) in the direction of the arrow x_1.

Closing the key Tk closes the transmitter T, and closing the key Pk closes the pole changer PC. The positive pole of the

POSSIBLE KEY COMBINATIONS

No.	Keys				Pressure at Point		Current in			Effective Current		Relays Operated			
	West		East		h West	h_1 East	West	Line	East	West	East	West		East	
	Pk	Tk	Pk_1	Tk_1			AL	L	AL_1	Relays NR and PR	Relays NR_1 and PR_1	PR	NR	PR_1	NR_1
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	Open	Open	Open	Open	−100	−100	$\frac{100}{R}(x)$	0	$\frac{100}{R}(x_1)$	$\frac{100}{R}(x\,AL)$	$\frac{100}{R}(x_1\,AL_1)$	Open	Open	Open	Open
2	Closed	Open	Open	Open	+100	−100	$\frac{100}{R}(y)$	$\frac{200}{R}(y\,x_1)$	$\frac{100}{R}(x_1)$	$\frac{100}{R}(y\,L)$	$\frac{100}{R}(x_1\,L)$	Open	Open	Closed	Open
3	Open	Closed	Open	Open	−300	−100	$\frac{300}{R}(x)$	$\frac{200}{R}(x\,y_1)$	$\frac{100}{R}(x_1)$	$\frac{100}{R}(x\,AL)$	$\frac{300}{R}(y_1\,L)$	Open	Open	Open	Closed
4	Closed	Closed	Open	Open	+300	−100	$\frac{300}{R}(y)$	$\frac{400}{R}(y\,x_1)$	$\frac{100}{R}(x_1)$	$\frac{100}{R}(y\,L)$	$\frac{300}{R}(x_1\,L)$	Open	Open	Closed	Closed
5	Open	Open	Closed	Open	−100	+100	$\frac{100}{R}(x)$	$\frac{200}{R}(x\,y_1)$	$\frac{100}{R}(y_1)$	$\frac{100}{R}(x\,L)$	$\frac{100}{R}(y_1\,L)$	Closed	Open	Open	Open
6	Closed	Open	Closed	Open	+100	+100	$\frac{100}{R}(y)$	0	$\frac{100}{R}(y_1)$	$\frac{100}{R}(y\,AL)$	$\frac{100}{R}(y_1\,AL_1)$	Closed	Open	Closed	Open
7	Open	Closed	Closed	Open	−300	+100	$\frac{300}{R}(x)$	$\frac{400}{R}(x\,y_1)$	$\frac{100}{R}(y_1)$	$\frac{100}{R}(x\,L)$	$\frac{300}{R}(y_1\,L)$	Closed	Open	Open	Closed
8	Closed	Closed	Closed	Open	+300	+100	$\frac{300}{R}(y)$	$\frac{200}{R}(y\,x_1)$	$\frac{100}{R}(y_1)$	$\frac{100}{R}(y\,AL)$	$\frac{300}{R}(x_1\,L)$	Closed	Open	Closed	Closed
9	Open	Open	Open	Closed											
10	Closed	Open	Open	Closed	+100	−300	$\frac{100}{R}(y)$	$\frac{400}{R}(y\,x_1)$	$\frac{300}{R}(x_1)$	$\frac{300}{R}(y\,L)$	$\frac{100}{R}(x_1\,L)$	Open	Closed	Closed	Open
11	Open	Closed	Open	Closed	−300	−300	$\frac{300}{R}(x)$	0	$\frac{300}{R}(x_1)$	$\frac{300}{R}(x\,AL)$	$\frac{300}{R}(x_1\,AL_1)$	Open	Closed	Open	Closed
12	Closed	Closed	Open	Closed	+300	−300	$\frac{300}{R}(y)$	$\frac{600}{R}(y\,x_1)$	$\frac{300}{R}(x_1)$	$\frac{300}{R}(y\,L)$	$\frac{300}{R}(x_1\,L)$	Open	Closed	Closed	Closed
13	Open	Open	Closed	Closed	−100	+300	$\frac{100}{R}(x)$	$\frac{400}{R}(x\,y_1)$	$\frac{300}{R}(y_1)$	$\frac{300}{R}(x\,L)$	$\frac{100}{R}(y_1\,L)$	Closed	Closed	Open	Open
14	Closed	Open	Closed	Closed	+100	+300	$\frac{100}{R}(y)$	$\frac{200}{R}(x\,y_1)$	$\frac{300}{R}(y_1)$	$\frac{300}{R}(x\,L)$	$\frac{100}{R}(y_1\,AL_1)$	Closed	Closed	Closed	Open
15	Open	Closed	Closed	Closed	−300	+300	$\frac{300}{R}(x)$	$\frac{600}{R}(x\,y_1)$	$\frac{300}{R}(y_1)$	$\frac{300}{R}(x\,L)$	$\frac{300}{R}(y_1\,L)$	Closed	Closed	Open	Closed
16	Closed	Closed	Closed	Closed	+300	+300	$\frac{300}{R}(y)$	0	$\frac{300}{R}(y_1)$	$\frac{300}{R}(y\,AL)$	$\frac{300}{R}(y_1\,AL_1)$	Closed	Closed	Closed	Closed

battery is then connected to the line, and the negative pole to the ground G. Reversing the battery in this way, so that the point f is shifted from the negative to the positive pole of the battery, will close the distant polar relay.

7. An effective current of the strength $\frac{100}{R}$, which may be called 1 unit, is not strong enough to close the neutral relays when their springs are properly adjusted. The polar relays are so connected that a current flowing through their artificial-line coils j and j_1 in the direction of the arrows x and x_1, respectively, or through their line coils l and l_1 in the direction of the arrows y and y_1, respectively, will hold the polar relays open. That is, the polar-relay coils are so connected when the apparatus is first set up that this will be the case. Hence, any current through either or both windings of the polar relay that will magnetize the relay in the same direction as these currents will hold the polar relay open, and any current that will reverse the direction of this magnetization will close the polar relay. It is important that this fact should be remembered.

In order to close the neutral relay, the intensity of the resultant magnetization produced by the current in the two coils must be equivalent to that produced by $\frac{300}{R}$ amperes through one coil only. The direction of the current in the various coils is indicated in Table I by the letters x, y, x_1, and y_1, which are found on the various arrows in Fig. 3. Arrow x_1 coincides in direction with the arrow y, and y_1 with x. The arrows x_1 and y_1 are not absolutely necessary, but, by using them, the explanations are made clearer.

8. Some of the current flowing over the line from the east to the west station may go to ground G_1 through the coils i and j and the artificial line, instead of through the pole changer PC and transmitter T circuit to the ground G. This, however, is not a very serious disadvantage, because the direction of this current through the artificial-line coils is always in the proper direction to assist the incoming current through the line coils. Sometimes, when dynamos or batteries of the same electromotive force must be used on both short and long lines, a resistance box is placed in the circuit between the dividing point *h* and the point *f*. By this means, too large a current in the relays on the short lines can be prevented by increasing the resistance in the box.

This resistance forces a larger proportion of the incoming line current through the artificial-line coils of the home relays; but, on account of the charge and discharge of the line and condensers when the distant pole changer is operated, a low resistance to earth is desirable to avoid trouble with the static balance.

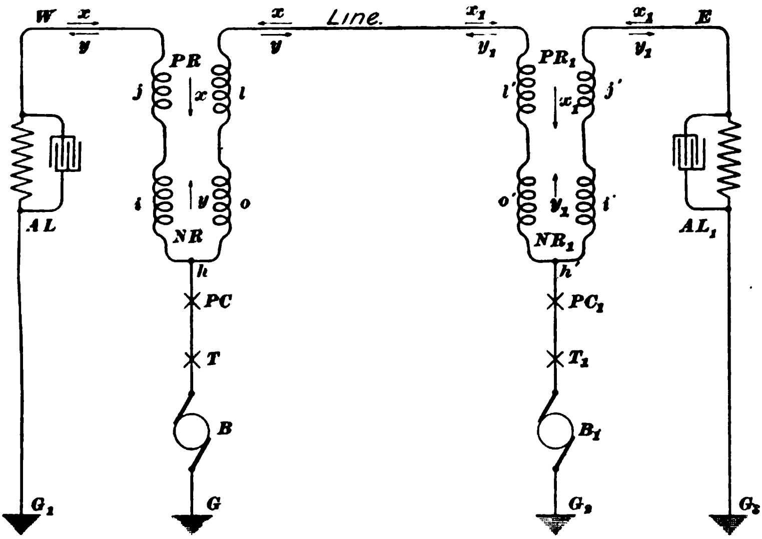


FIG. 4

9. Fig. 4 is merely a simplified diagram of the quadruplex system. The entire group of batteries, or generators, at each end of the line are represented at B and B_1, respectively. The polarized relays at each end of the line are represented by PR and PR_1, and the neutral relays by NR and NR_1. The crosses at PC and PC_1 represent the pole changers that govern the direction of the current sent to the line; and the crosses at T and T_1, the transmitters that govern the strength of the current. Practically the same notation is used as in Fig. 3, so that in the following explanations either figure may be referred to.

Fig. 4 is shown in order that a complete analysis of all the currents in the line and the ground branches of the relays for each of the sixteen possible key combinations may be the more easily made.

10. First Combination.—In the first key combination, No. 1 in Table I, all four keys are open and, consequently, the negatives poles of the short-end batteries, having an electromotive force of 100 volts, are connected to the points h and h_1; this gives -100 in columns 6 and 7. As these two electromotive forces oppose each other, there will be no current in the line L or in the line coils o, l, o_1, and l_1 of the four relays; hence, there is 0 (zero) in column 9. There is, however, a current having an intensity of $\frac{100}{R}$, in the direction of the arrows x and x_1 in the artificial-line coils of all relays. The intensity of this current is not great enough to close the neutral relays, and its direction is such as to hold the polar relays open. Hence, $\frac{100}{R}$ (x) is placed in column 8 and $\frac{100}{R}$ (x_1) in column 10. As there is no current in the line coils of the four relays, as indicated by 0 in column 9, it is evident that the effective current has a strength of $\frac{100}{R}$ and flows in the direction of the arrow x in the artificial-line circuit AL at the west end, and in the direction of the arrow x_1 in the artificial-line circuit AL_1 at the east end. This is indicated by $\frac{100}{R}$ $(x\ AL)$ and $\frac{100}{R}$ $(x_1\ AL_1)$ in columns 11 and 12, respectively. All the relays will be open, as indicated, in columns 13, 14, 15, and 16.

11. Second Combination.—Only key Pk is closed in the second combination. Closing this key Pk reverses the short-end battery B_1 in Fig. 3, causing the potential at h to be $+100$. Consequently, batteries B_1 and B_3 are now in series, giving a current of $\frac{200}{R}$ (y) in the line coils o and l, and one of $\frac{100}{R}$ (y) in the artificial-line coils *i* and *j*. The current $\frac{200}{R}$ (y) in coil *o* and the current $\frac{100}{R}$ (y) in coil *i* is equivalent to an effective current of $\frac{100}{R}$ (y) in coil *o* because the current flows from the point *h* through the two coils *o* and *i* in opposite directions around the iron core; hence, the current $\frac{200}{R}$ (y) in coil *o* neutralizes current $\frac{100}{R}$ (y) in coil *i* and still has left a current of $\frac{100}{R}$ (y) with which to magnetize the neutral relay *NR*. This current is too weak, however, to close this relay. Hence, closing the pole-changer key *Pk* does not affect the neutral relay *NR*.

12. As in the case of the neutral relay *NR*, the current $\frac{200}{R}$ (y) in coil *l* and the current $\frac{100}{R}$ (y) in coil *j* flow in opposite directions around the cores of the polar relay, giving an effective current equivalent to $\frac{100}{R}$ (y) in coil *l* alone, which will, on account of the direction in which it flows, continue to hold the polar relay *PR* open. Or, the current of $\frac{100}{R}$ (y) flowing in the coil *j* may be considered as tending to close the polar relay, but that the current $\frac{200}{R}$ (y) in the coil *l* tends to keep it open, and as $\frac{200}{R}$ is twice $\frac{100}{R}$, the resultant magnetism, which is due to a current of $\frac{100}{R}$ (y) in the coil *l*, will hold the polar relay *PR* open. Hence, closing the key *Pk* does not affect either of the home relays *NR* or *PR*.

There is a current of $\frac{200}{R}$ (x_1) in coil l_1, and a current of $\frac{100}{R}$ (x_1) in coil j_1. The current in coil j_1 is the same in strength and direction as before and tends to hold the polar relay open, but the current $\frac{200}{R}(x_1)$ in coil l_1 tends to close the relay, hence the resultant magnetism which is due to the current $\frac{100}{R}(x_1)$ in coil l_1 will close the polar relay PR_1, as stated in column 15. The resultant of a current of $\frac{200}{R}(x_1)$ in coil o_1 and a current of $\frac{100}{R}(x_1)$ in coil i_1, is a current of $\frac{100}{R}(x_1)$ in coil o_1. This is not sufficient current to close the neutral relay NR_1, hence it remains open. Therefore, when *Pk* alone is closed, the only relay that responds is the polar relay PR_1 at the distant end.

13. Third Combination.—The only key closed in the third combination is *Tk*. Closing this key *Tk* connects the long end of the battery, that is, both batteries *B* and B_1 in series, to the point *h* at the west station; hence, there is -300 volts at *h* and -100 at h_1. The current in the line circuit will be $\frac{200}{R}(xy_1)$. The current in coils *i* and *j* will be $\frac{300}{R}(x)$; hence, the effective current that is due to $\frac{200}{R}(x)$ in coil *l* and $\frac{300}{R}(x)$ in coil *j* will be $\frac{100}{R}(x)$ in coil *j*. The resultant magnetization will hold the polar relay *PR* open.

The resultant magnetization of the neutral relay *NR* is due to a current of $\frac{200}{R}(x)$ in coil *o* and a current of $\frac{300}{R}(x)$ in coil *i*; this is equivalent, as in the polar relay *PR*, to the magnetization produced by a current of $\frac{100}{R}(x)$ in the coil *i*. This current is not strong enough to close the neutral relay *NR*, hence it remains open.

Because the full battery, 300 volts, at the west station opposes the short-end battery of 100 volts at the east station, the effective electromotive force in the line circuit, that is, the difference of potential between the points h and h_1, will be 200 volts in the direction of the arrows x and y_1. Hence, the current in the line coils l_1 and o_1 will be $\frac{200}{R}$ (y_1). The difference of potential between the point h_1 and the ground G_2 is 100 volts, due to the short-end battery B_3. This difference of potential tends to send a current of $\frac{100}{R}$ amperes through the artificial-line circuit AL_1 in the direction of the arrow x_1. Hence, the current in the artificial-line coils j_1 and i_1 is $\frac{100}{R}$ (x_1). Now the currents in the line and artificial-line coils of the east relays circulate around the iron cores in such a direction that they help each other in magnetizing the relays; hence, the resultant magnetization due to a current of $\frac{200}{R}$ (y_1) in the line coils and a current of $\frac{100}{R}$ (x_1) in the artificial-line coils is equivalent to that produced by a current of $\frac{300}{R}$ (x_1) in the artificial-line coils j_1 and i_1. The direction of this current in the coil j_1 is such that the polar relay PR_1 remains open, but the current $\frac{300}{R}$ in coil i_1, is strong enough to close the neutral relay NR_1. Hence, when the key Tk that controls the number of cells connected to the circuit at the west station is closed, the only relay closed is the neutral relay NR_1 at the distant east station.

14. Fourth Combination.—In the fourth combination, the two keys Tk and Pk are closed. Hence, the positive pole of the whole battery at the west station is connected to the point h, giving that point a potential of $+300$ volts, point h_1 remaining at -100, as in the preceding combinations. The current in the line and in the coils o, l, l_1, and o_1 will be $\frac{400}{R}$ $(y\,x_1)$, and the current in the artificial line and in the coils i and j will be $\frac{300}{R}$ (y). Hence, the effective current, due to the difference between a current of $\frac{400}{R}$ (y) in the line and a current of $\frac{300}{R}$ (y) in the artificial line, will be a current of $\frac{100}{R}$ (y) in the line coils o and l. Now, a current of $\frac{100}{R}$ (y) in the coil l is equivalent in its magnetizing effect, both in direction and intensity, to a current of $\frac{100}{R}$ (x) in the artificial-line coil j, but a current in the artificial-line coil j in the direction of the arrow x will hold the polar relay open. Therefore, the polar relay PR is held open by the effective current $\frac{100}{R}$ (y L). Furthermore, this effective current $\frac{100}{R}$ (y L) through the coil o is not strong enough to close the neutral relay NR. The current in the coils l_1 and o_1 is $\frac{400}{R}$ (x_1) and in coils j_1 and i_1 the current is $\frac{100}{R}$ (x_1). Hence, the resultant current $\frac{300}{R}$ (x_1) is not only strong enough to close NR_1, but it is also in the right direction to close the polar relay PR_1. Hence, the closing of the two western keys closes only the two eastern relays.

15. Similarly, the currents in the line and artificial-line circuits and the relays affected by the other various positions of the four keys may be worked out. Table I is complete except for the ninth combination, which is left blank in order that the student may fill in these spaces and thereby acquire a better knowledge of the system.

QUADRUPLEX TERMS

16. The meaning of the terms most commonly used in quadruplex telegraphy should be throughly understood. The battery B_1, Fig. 3, is called the **short end**; the other battery B, is usually called the **long end**, though sometimes this term is used for both batteries B and B_1. The point q is termed the **tap** and the branch $q\,v$, the **tap wire.** The phrase **excess current** means that there is an excess of current in one winding of a relay over the current in the other winding of the same relay.

That portion of the quadruplex that is operated by opening and closing the transmitter key is called the **neutral, common,** or **No. 2 side;** and that portion that is operated by the pole-changer key is called the **polar** or **No. 1 side** of the system. These terms are also applied to the relay. That is, the relay that is operated by the increase and decrease in the strength of the current is called the **neutral, common,** or **No. 2 relay;** and the relay that is operated by a change in the direction of the current through it is called the **polar** or **No. 1 relay.**

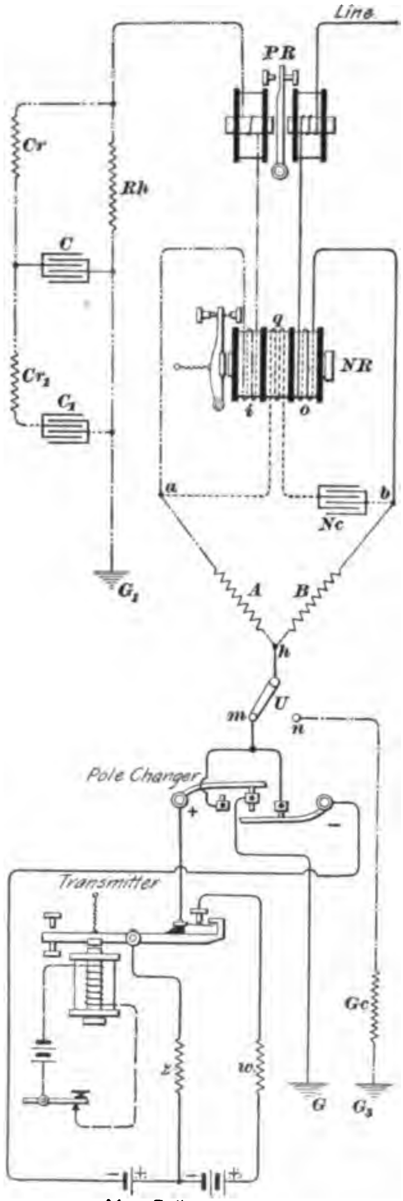


FIG. 5

17. Coils.—The coil, lettered *Gc* in Fig. 5 and in most of the other diagrams, that is included in the circuit in place of the transmitting apparatus and source of current at one end when the system is being balanced, is called the **ground coil.** It is used to replace whatever resistance there may be in the transmitting apparatus when the latter is cut out of the circuit. By this means the resistance from the line through the office apparatus to the ground is kept the same whether the transmitting apparatus is cut in or out.

The coils *Cr* and Cr_1, Fig. 5, which are in series with the condensers in the artificial line, are often called the **retarding** or **retardation coils,** because they retard the charge and discharge of the condensers.

18. Margin.—The pull that can be allowed on the armature of either relay without interfering with the proper working of the system is called the **margin.** Sometimes the margin is defined as the pull or number of turns (either up or down) that may be given to the retractile spring of the neutral relay without interfering with the incoming signals on that instrument. A preferable definition of the margin on the neutral relay is, that it is the difference in pull on the armature of the neutral relay due to the difference between the strength of the current produced respectively by the short end and long end of the distant battery. Hence the margin, or difference in pull produced on the open and closed positions of the distant transmitter, may be increased by increasing the ratio of the strength of the current in these two positions of the transmitter. This ratio may be increased by increasing the electromotive force of the long end of the battery, or by decreasing the electromotive force of the short end of the battery; or by properly altering, in some quadruplex systems, certain resistances included in the circuit. The margin on the polar relay is the pull due to the short end of the battery, for the reversal of the short end gives the smallest force that must move the armature. Hence, to increase the margin on the polar relay, the electromotive force of the short end of the battery must be increased or the resistance of the circuit must be decreased.

ELIMINATION OF FALSE SIGNALS

USE OF REPEATING SOUNDER

19. One of the difficulties to be overcome in quadruplex systems is to prevent the armature of the home neutral relay from being released when the distant pole changer passes through its middle position and reverses the direction of the current. As the change in the direction of the current reverses the magnetism of the neutral relay, there is an interval, although very small, during which the neutral relay, in passing from one direction of magnetization to the other, possesses no magnetism.

To diminish the evil effect due to the reversal of the distant pole changer when the distant transmitter is closed, Edison inserted a repeating sounder between the relay and the reading sounder, connecting the circuit of the magnet of the repeating sounder to the back stop of the neutral relay and the circuit of the reading sounder to the back stop of the repeating sounder. This arrangement has been explained in connection with the diplex telegraph system.

If the reversal in the magnetism of the neutral relay should occur while the relay is closed, although it might be of sufficient duration to break the front contact, no click will ordinarily be heard on the receiving sounder, because the lever does not have sufficient time to cross the gap and touch the back stop, and thereby close the circuit containing the repeating sounder. Therefore, the relay points should not be placed too near each other, nor should the fact be overlooked that there is such a thing as a proper adjustment of those points.

SMITH EXTRA COIL AND CONDENSER DEVICE

20. General Arrangement.—To still further reduce the evil effect due to the interval of no magnetism in the neutral relay when it should remain closed, the arrangement, shown in Fig. 5, is used. It was introduced by Mr. Gerritt Smith in 1884 and is known as the **Gerritt Smith device,** or simply as the **Smith device.** It will be noticed that the neutral relay *NR* has three distinct windings on each core, only one core is shown, however. In addition to the usual line and artificial-line coils *o* and *i*, respectively, there is an extra coil *q* between the other two coils. This coil *q* is connected in series with a condenser *Nc*, and across the line and artificial-line circuits, from points *a* to *b*, as shown. The two coils *A* and *B*, of 300 ohms resistance each, together with the condenser *Nc*, and the extra coil *q*, tend to tide the neutral relay over the period of reversal. This coil *q* is wound and connected in such a direction that it tends to help the other coils close the relay.

When the distant pole changer short-circuits its battery while the home neutral relay is closed on account of the distant transmitter being closed, the condenser discharges through this coil *q* in such a direction as to hasten the period of no magnetism in the relay. The current that charges back through the coil *q* when the distant pole changer again restores the line current, circulates around the relay coils in a direction opposite to that of the line current that has just ceased, and tends to hasten the magnetization of the cores in the opposite direction before the reverse current coming over the line from the distant end reaches its full strength. This reverse current charges the condenser in an opposite direction, causing the charging current to flow in the same direction through the extra coil as did the preceding discharging current. These charging and discharging currents are at a maximum when the line current passes through zero, and as both the discharging and charging currents passing through the extra coil are in the same direction and tend to magnetize the relay in the same direction as the reversed line current, the period of no magnetism is considerably reduced.

21. If there was no resistance *A* and *B* in the circuit $a-h-b$, the terminals *a* and *b* of the condenser and extra coil would never have any difference of potential; hence, there would be no charging or discharging current to flow through the extra coil. The difference of potential between *a* and *b* will depend on the products of the currents and the resistances in the circuits $a-h$ and $b-h$. In order not to destroy the balance between the line and artificial-line circuits coils *A* and *B* must be equal in resistance.

It is necessary to so arrange the connections of the coil *q* that the charging currents from the line and condenser will circulate around the ordinary and extra coils of the relay in the same direction. Long theoretical explanations could be given to show that this coil *q* and the condenser will always tend to tide the relay over the period of the reversal when the neutral relay is closed. However, the fact that practical experience has shown this to be the case is sufficient reason for this arrangement.

22. Three-Coil Neutral Relay.—In Fig. 6 is shown the three-coil neutral relay, in which the iron cores are extremely short, and no more iron is used in the relay than is really necessary; the moving parts are made as light as possible, so that both the magnetic and the mechanical inertia are reduced to a minimum. As a result of this construction the relay is very quick-acting. The cores in the neutral relay used by the Western Union Company have a diameter of $\frac{1}{2}$ inch and a length of $1\frac{3}{16}$ inches. The armature lever is $2\frac{3}{4}$ inches long, while the coils are $1\frac{1}{16}$ inches in length and $1\frac{1}{2}$ inches in diameter.

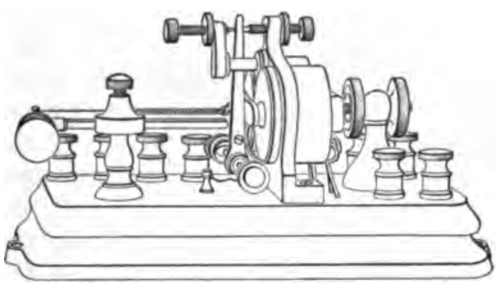


FIG. 6

23. The way in which the coils are wound is shown in Fig. 7. In all quadruplex relays it is very necessary that the coils forming the two halves of the differential winding shall have the same number of turns and the same resistance. Therefore, the first coil that is wound on the core *a* is connected in series with the second coil on the core *b*; these two coils then form one-half of the differential winding. The other half of the differential winding consists of the first coil that is wound on *b* and connected in series with the second coil on *a*. The third coil that is wound on *a* is connected in series with a third coil wound on *b*, the two together forming the extra coil.

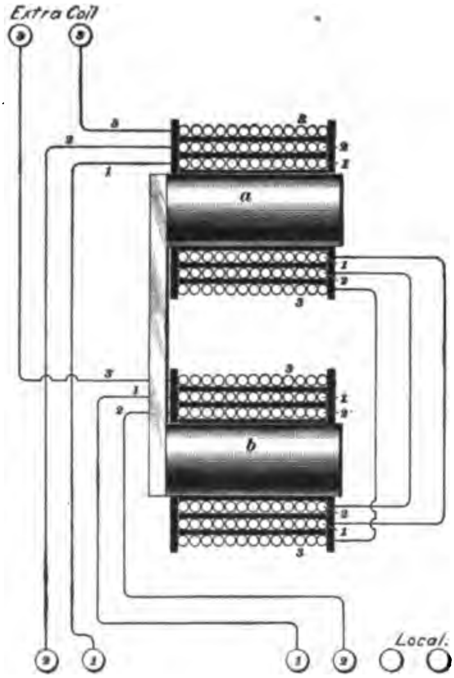


Fig. 7

Each coil on each core contains 1,800 turns of about No. 36 B. W. G. silk-covered wire. Each half of the differential winding has a resistance of about 225 ohms, while the extra coil has a resistance of from 400 to 450 ohms. The third coil has a higher resistance than the other two because it is wound on the outside, and, hence, requires more wire for the same number of turns. For long-line circuits, the line and artificial-line coils are sometimes wound to have a resistance of 400 ohms each.

The binding posts marked *3* form the terminals of the extra coil; the binding posts marked *2*, the terminals of the artificial-line coil; and the binding posts marked *1*, the terminals of the line coils.

24. The manner in which resistances and condensers are connected together to form the artificial line in the Western Union quadruplex system is shown in Fig. 5. Here *Rh* is the main resistance that is adjusted to equal the resistance in the line circuit to the ground at the distant station. The condenser *C* is so connected around this resistance that its charging and discharging current must flow through the resistance *Cr*. The condenser C_1 is so connected that its charging and discharging current must flow through both resistances Cr and Cr_1. The resistances Rh, Cr, and Cr_1, and the condensers C and C_1 are all adjustable, so that the resistance and capacity of the artificial line can readily be adjusted to equal that of the line circuit.

25. Ground Coil.—In Fig. 5, U is a switch that ordinarily rests on contact button m when the system is in operation, but the arm is turned to n when it is necessary to balance the set. Turning the arm of the switch U to n cuts out the main battery, transmitter, and pole changer, and grounds the receiving apparatus directly through the so-called **ground coil** Gc. The resistance of Gc is made equal to the resistance of the circuit from h through the main battery to the ground at G.

26. Working Quadruplex as a Polar Duplex.—It frequently happens when the weather is very stormy and wet that it is impractical to obtain the margin necessary for the successful working of the neutral side of the quadruplex. In such a case it is better to close the neutral side and not attempt to use it, but to work the set as a polar duplex simply. When this is done, it is frequently necessary, in order not to have an excessive current, to include a resistance w, Fig. 5, in series with the whole battery. The increase in the strength of the current from the battery is due to leakage from the line through wet trees, insulators, and posts. Moreover, when only the polar side is in operation, less current is required than would be given by the whole quadruplex battery, but preferably more than would be given by the short-end battery alone. When the weather clears and the system can be again worked as a quadruplex, this resistance w is cut out.

27. Modified Form of Smith Device.—The electrical action of the modified Smith device is exactly the same as the action of the old Smith device, but much better results are secured owing to the ease of adjustment and increased line margin that it gives. In the Gerritt-Smith device a non-inductive resistance is inserted in the line and also in the artificial-line side of the circuit so that there shall be a difference of potential across the third coil and the rather large condenser in series with it. Owing, moreover, to the third coil being wound on the same cores as the differential winding of the neutral relay, it was necessary to have these added resistances adjustable.

The later Smith device, which is arranged as shown in Fig. 8 (*a*), eliminates these added resistances, thereby securing a greater change in current strength in the circuit; and by using an entirely separate adjustable-core magnet for the third winding, a good adjustment may be secured. The arrangement, as adapted to a skirrow neutral relay, is shown in Fig. 8 (*b*). Each half of each differential coil is wound to 150 ohms and the

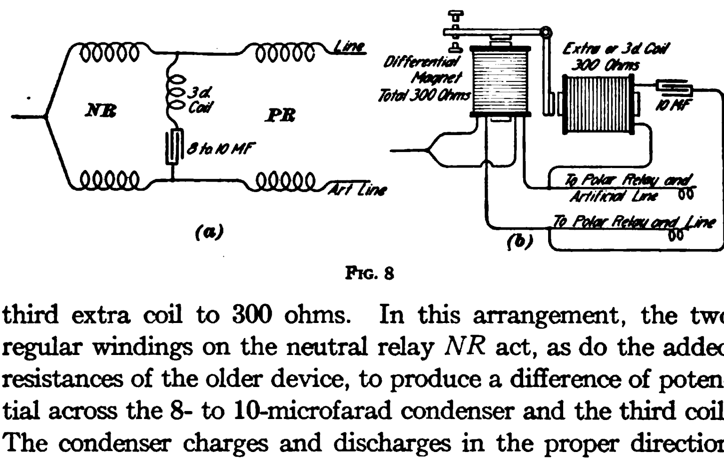


FIG. 8

third extra coil to 300 ohms. In this arrangement, the two regular windings on the neutral relay *NR* act, as do the added resistances of the older device, to produce a difference of potential across the 8- to 10-microfarad condenser and the third coil. The condenser charges and discharges in the proper direction though the extra coil as the potential across it reverses. The use of this arrangement will be shown in connection with the main-line circuits of the dynamo quadruplex used by the Postal Telegraph-Cable Company.

FERNANDEZ ARRANGEMENT

28. Mr. J. M. Fernandez has devised the arrangements shown in Fig. 9 to overcome the breaking up of incoming signals received by the neutral relay when caused by the operation of the distant pole changer. He states that it meets all requirements and is very simple. The contacts and armature of the neutral relay are indicated at *c*, *d*, and *i*, respectively; *s* is a polarized sounder, neutrally adjusted, so that its lever will remain against either stop. Such sounders are used in England and a polar relay controlling an ordinary sounder could doubtless be used in its place. In the arrangement shown in view (*a*), the current flowing from the battery *h* in the direction of the arrow *j*, holds the sounder *s* in its normal position, when the neutral relay attracts its armature. A signal is made by reversing the current through *s*, as indicated by arrow *k*. This signal will not be disturbed by an ordinary reversal of the distant battery, because to move the sounder armature the relay lever must move across the gap and make contact with *c*, since to affect the sounder it is necessary not only to stop the current, but to reverse its direction through the sounder *s*.

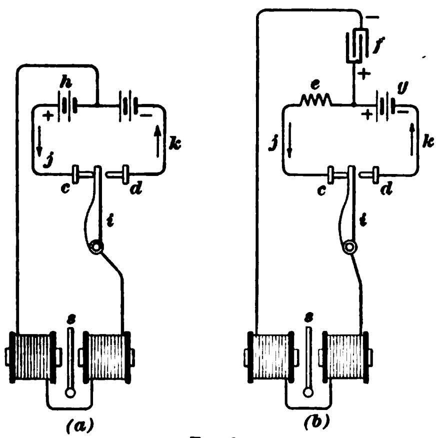


Fig. 9

29. In view (*b*) the same result is accomplished without having current flowing through the sounder *s* in its normal position. When the neutral relay armature is attracted, the condenser *f* is charged as indicated by the positive and negative signs, and this charging by current flowing in direction *k*, from the battery *g*, is sufficient to reverse the magnetism of the sounder, thereby moving its armature against the signal stop. The sounder is not then affected unless the relay armature *i* crosses the gap and touches stop *c*, in which case the condenser discharges through resistance *e* in the direction of arrow *j*, thereby reversing the magnetism of the sounder *s* and producing the space signal.

Mr. Fernandez states that both arrangements will work in any line where the ordinary quadruplex can be worked and give firmer signals, expecially appropriate for repeating, as every dot or dash is longer in the sounder, since it lasts not only while the relay lever is against the marking or signal contact but also during the time it takes to cross the gap. When the *CR* product of the line is very high, it is necessary to delay further the release of the sounder lever, which can be done by inserting an inductance coil in the circuit going to contact *c*.

GHEGAN'S BUG-TRAP DEVICE

30. Mr. J. J. Ghegan has devised a method, termed a **bug trap,** that he claims is superior to Edison's repeating-sounder arrangement for eliminating false signals due to the reversal of the distant quadruplex pole changer while the distant transmitter is closed. The method was described in the Telegraph Age, from which the following abstract was made. One of his arrangements, shown in Fig. 10, may be used with

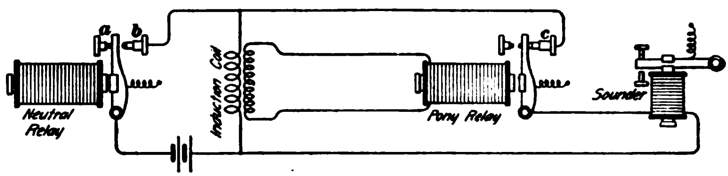


Fig. 10

quadruplex apparatus by transposing in the binding posts of the distant transmitter the wires that come from the terminals of the long- and short-end batteries, respectively. That is, these wires should be connected so that the short-end current, and not the long-end, goes to line when the transmitter is closed. When the arrangement shown in Fig. 10 is used at both ends, the long-end and short-end wires at each end must be reversed.

31. Operation.—When the distant transmitter is open, the neutral relay will hold its armature against the front stop *a*, and the sounder circuit will be open at *b*. When the distant pole changer reverses the electromotive-force polarity, even if the neutral-relay armature should be released enough to touch stop *b* an increasing current followed by a decreasing current as the armature is quickly drawn away from stop *b*, will flow through the primary winding of the induction coil. In each case, this current will induce a current in the secondary that will cause the pony relay to open the sounder circuit at *c* and so prevent the production of a signal by the sounder. Furthermore, when a dot is being made by the neutral relay, there is said to be no appreciable shortening of the dot, as might be expected, due to the current induced in the pony-relay circuit, as the circuit is first closed and then opened at *b*.

32. Another arrangement, which is claimed to be successful, is shown in Fig. 11. In this, the front contacts on both the neutral and the pony relays are used instead of the back stops. The contacts of the neutral and pony relays are connected in parallel. Therefore, when the armature of the neutral relay is momentarily separated from its local contact by a

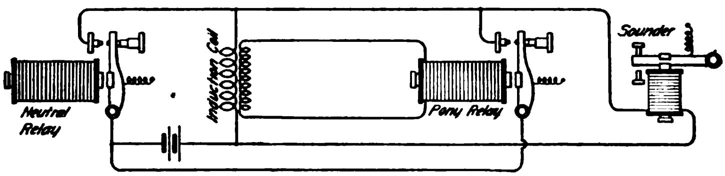
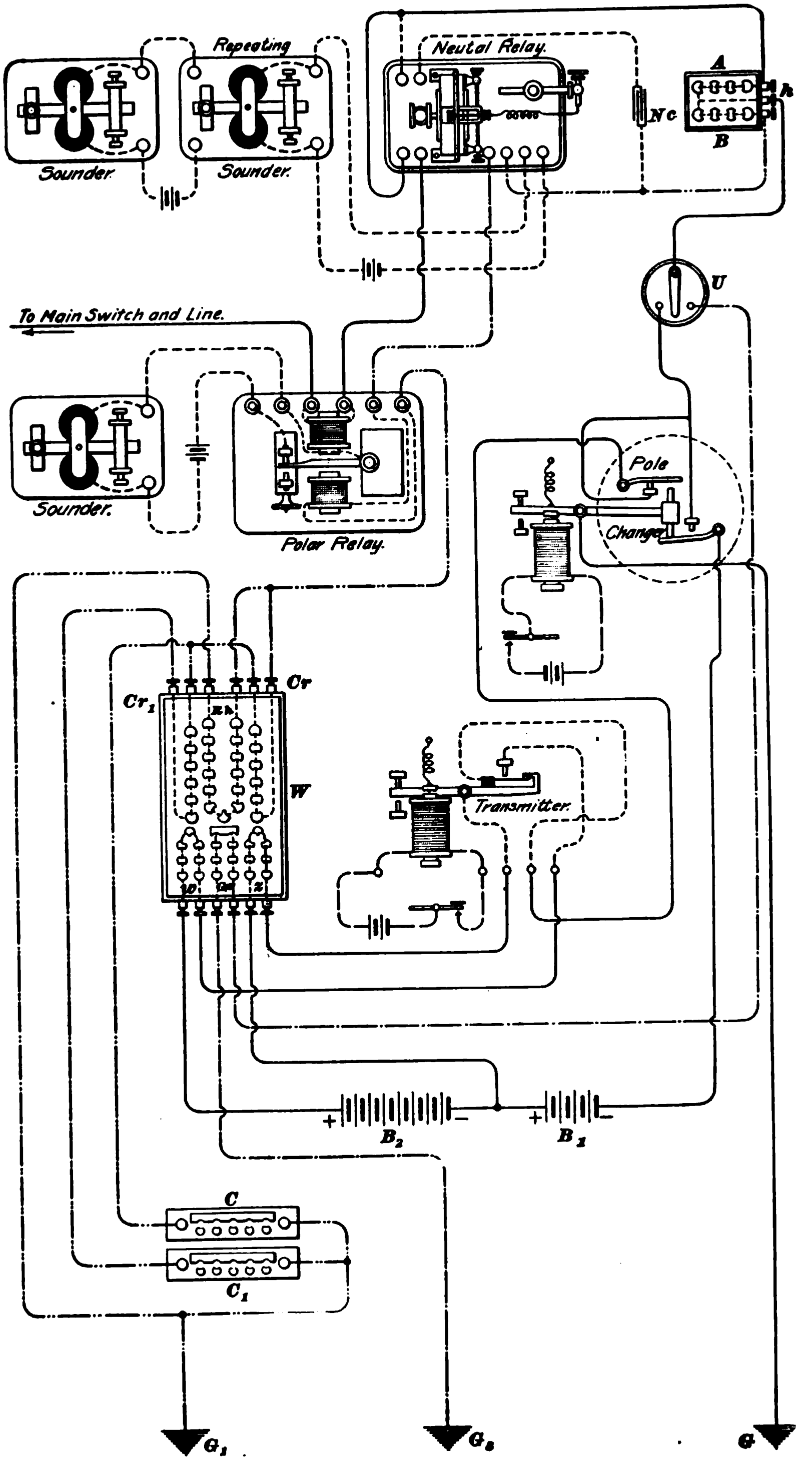


FIG. 11

reversal or other kick of short duration, the sounder is not affected, because the impulse from the induction coil causes the pony relay to close its contacts for an instant and thus keep the local-sounder circuit closed. This arrangement has the effect of slightly lengthening all dots and dashes, which is a decided advantage on long lines where the dots come in rather light on the neutral relay. When using this arrangement, the connections of the distant transmitter are not changed, as in the other Ghegan arrangement, but the connections to the local contact points of the home neutral relay are transposed so as to operate the sounder from the front stop as shown. When this arrangement is used at both ends, the neutral-relay contacts are reversed at both ends. The only special apparatus required for either Ghegan arrangement is an induction coil and pony relay. Both of these are made to go in one case, the induction coil being placed in the base. The pony relay



Repeating
Neutal Relay.
Sounder
Sounder.
A
B
h
Nc
U
To Main Switch and Line.
Sounder.
Polar Relay.
Pole
Changer
Cr
Cr1
W
Transmitter
B2
B1
C
C1
G1
G2
G

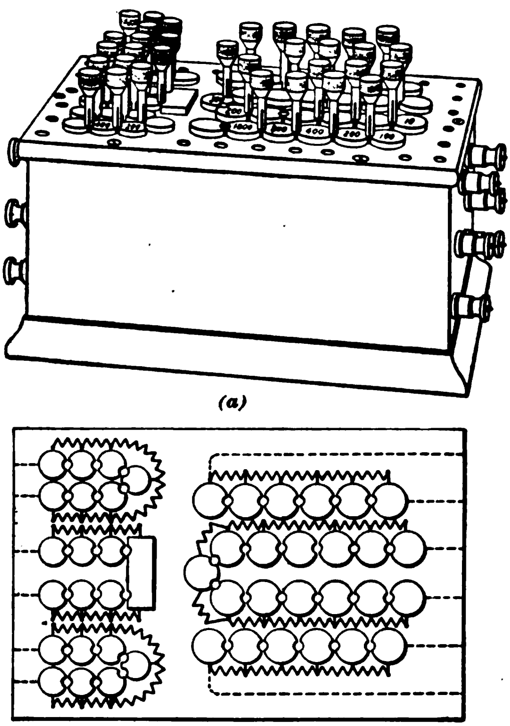
Fig. 12

has a cover to protect it on all sides from dust and injury. The pony-relay contact points should be adjusted so that its armature will respond to both make and break impulses, while the local battery should be sufficiently strong to work the pony relay with a snap.

BATTERY QUADRUPLEX SYSTEMS

WESTERN UNION BATTERY QUADRUPLEX

33. In Fig. 12 is shown the practical arrangement of the Western Union quadruplex system, in which gravity batteries are used for both main and local circuits. The various condensers and instruments are lettered exactly as in Fig. 5. In connection with the neutral relay a repeating sounder, controlling an ordinary sounder, is used to eliminate false signals. The pole changer is of the clock-face type and the transmitter is one of the ordinary continuity-preserving kind. The box *W* contains all the various resistance coils except the two *A* and *B* that are used in connection with the



(a)

(b)

FIG. 13

extra coil on the neutral relay. The resistance *Gc* is made equal to the resistance of the battery circuit; that is, to the internal resistance of the whole battery B_2 and B_1. Thus, when the switch *U* is turned to the right, the point *h* to which the neutral and polar relays are connected is joined to the ground G_3 through the resistance *Gc*, so that the resistance offered to the incoming current is the same as in the working condition of the apparatus.

34. In Fig. 13 (*a*) is shown the general appearance of the box *W*, which contains six separate adjustable resistances; the resistance of these coils is adjusted by means of numerous pegs. There are six binding posts on each end of the box; in (*b*) is shown, more clearly, these six resistances. The wave lines represent the resistances, usually non-inductively wound coils of German-silver wire, that are contained in the box and connected to the insulated brass pieces on the top of the box as indicated.

POSTAL TELEGRAPH-CABLE BATTERY QUADRUPLEX

35. Theoretical Circuit.—In Fig. 14 is shown the battery quadruplex as arranged by the Postal Telegraph-Cable Company. The transmitter *T* controls the number of cells connected across the point *h* and ground *G*. A tap resistance *z* is included between the front stop *f* of this transmitter *T* and the intermediate connection to the battery at *b*. This tap resistance *z* has a resistance of 2½ ohms for each cell in the long end *b c* of the battery. For instance, if the long end *b c* contains 100 cells, *z* will have a resistance of 250 ohms. The entire battery *a c* is connected between the back stop *e* of this transmitter *T* and the back stop *d* of the pole-changer magnet *r*, and the front stop of the pole-changer magnet *r'*. The short end *a b* of the battery is connected from the back stop *f* of the transmitter *T* to the same contacts of the pole-changer magnets as the long-end terminal. The pole changer *PC* controls the polarities connected to the point *h* and the ground *G*. The pole changer *PC* consists of two transmitters *r* and *r'*, the magnets of which are connected in series and controlled by one key *K*. The positions in the circuit of the neutral and polar relays are shown at *NR* and *PR*, respectively.

The only way to short-circuit the battery is by such an unusual adjustment of any transmitter as will cause both stops of the same transmitter to touch the armature lever at the same time. This will seldom or never happen and yet the adjustment can be so close as to require very little time for either a reversal of polarity or a change in the number of cells connected between the circuit and ground. When a lightning arrester is required to protect the quadruplex appa-

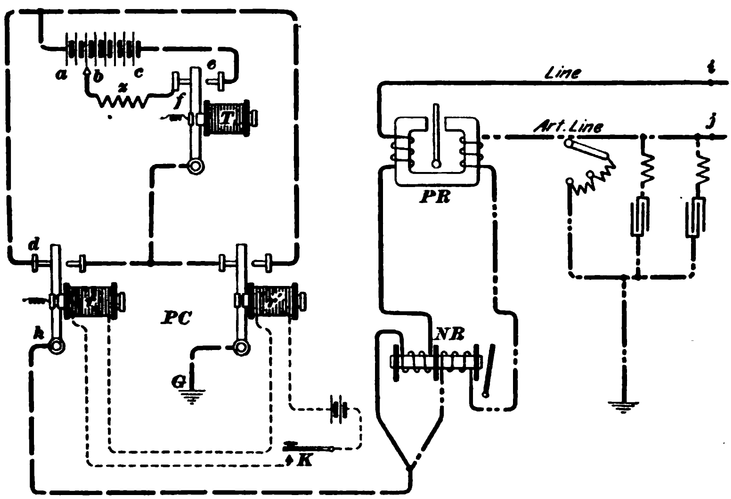
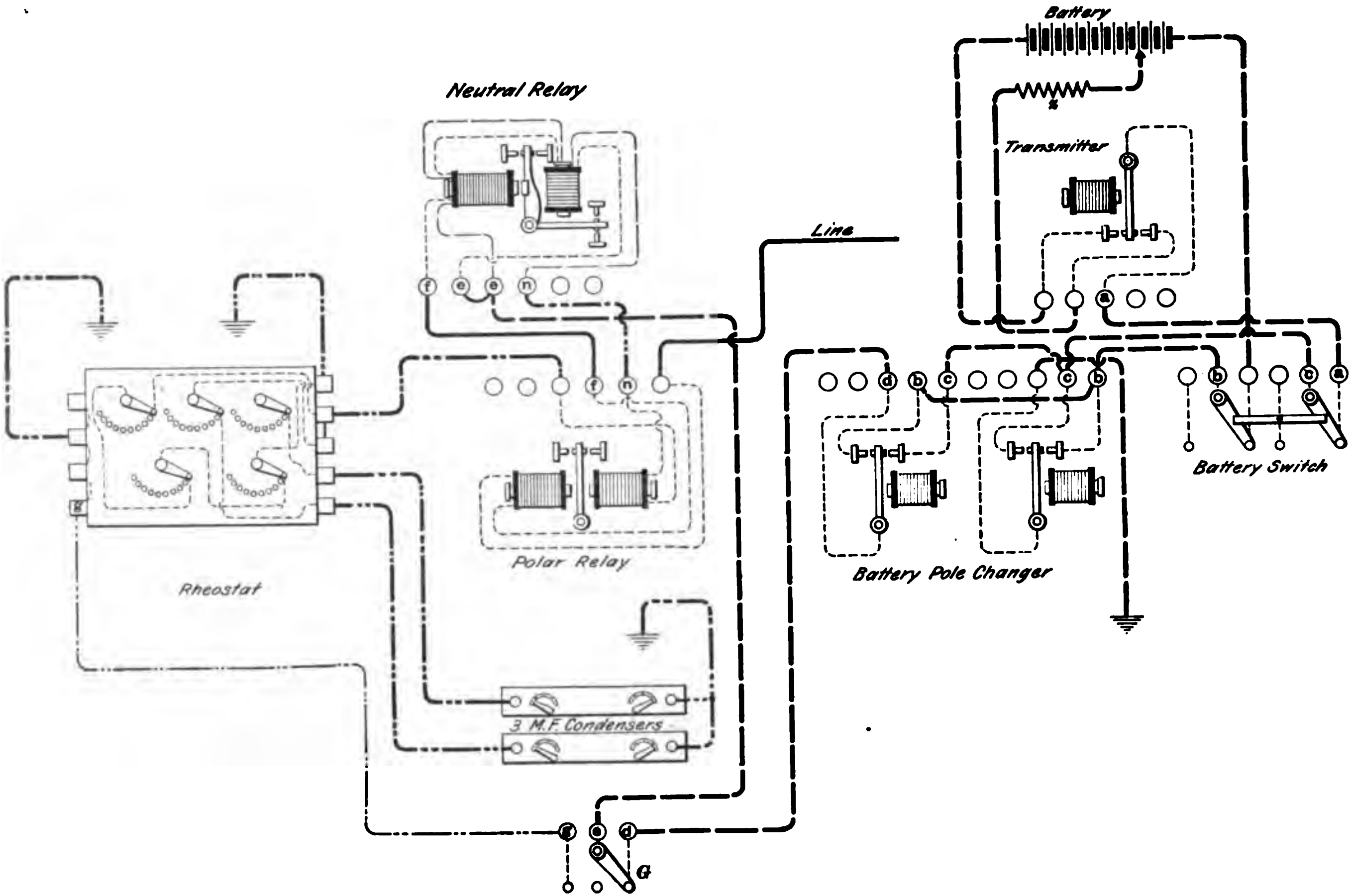


FIG. 14

ratus, one carbon is connected to *i*, another to *j*, and the middle one to *ground*.

36. Actual Connections.—The actual connections of the Postal Telegraph-Cable Company's battery quadruplex are shown in Fig. 15. The battery and transmitter are connected or disconnected from the rest of the circuit by means of the battery switch, and the receiving apparatus may be connected to ground for balancing purposes by means of the ground switch *G*. Skirrow neutral and polar relays, which will be described later, are used. In the ground coil, used for balancing purposes only, there is a resistance of 2½ ohms for each cell in the battery, while the tap resistance *z* contains 2½ ohms for



Battery
Transmitter
Neutral Relay
Line
Battery Switch
Battery Pole Changer
Polar Relay
Rheostat
3 M.F. Condensers
G

Fig 15

each cell in the long end of the battery to compensate for the internal resistance of this portion of the battery when it is cut out by the transmitter. The ground coil is located in the rheostat.

The neutral relay used in this system is sometimes called the **Skirrow neutral relay.** It has two sets of short cores and coils, the four coils, one on each core, being in series. There are, of course, really eight coils since the relay is differentially wound. The reason for this construction is to allow the use of large wire so as to reduce the heating and yet get sufficient pull on the armature. Both this neutral and the polar relay are provided with a rack-and-pinion control, as applied to them by J. F. Skirrow; for this reason, they are sometimes called **Skirrow relays.**

DYNAMO QUADRUPLEX SYSTEMS

INTRODUCTION

37. A different arrangement from that which has already been explained is necessary when dynamos are used in the quadruplex systems in the place of primary batteries. For the sake of economy, one dynamo supplies current for all circuits requiring about the same voltage; therefore, it is impossible to reverse the line and earth connections of the dynamo without also reversing the polarity for all other line circuits that are supplied by that dynamo. Hence, in duplex and quadruplex systems, one dynamo is generally used to supply negative current, and another to supply positive current. The machines themselves are seldom reversed; the line connection is merely shifted from one machine to the other. Furthermore, it is sometimes desirable to make one dynamo supply both the long-end and short-end currents of one polarity, and another dynamo to supply both the long-end and short-end currents of the opposite polarity. The current in a circuit can be increased and decreased by changing the resistance in series with a dynamo that generates a constant electromotive force.

WESTERN UNION DYNAMO QUADRUPLEX

38. Pole-Changer and Transmitter Circuits.—When dynamos replaced primary cells for the operation of quadruplex systems, about the only alterations required were in the pole-changer and transmitter connections. In Fig. 16 is shown the theoretical arrangement of instruments when dynamos are

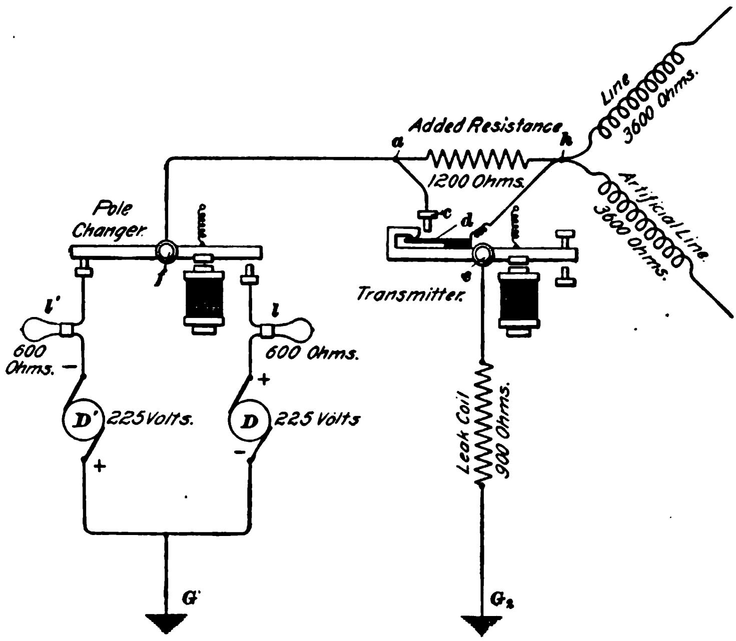


FIG. 16

used to supply the current for the Western Union quadruplex system.

The pole changer and the dynamos D and D' are arranged in the same manner as in the polar duplex, and the continuity-preserving transmitter is the same as the one used in several systems that have been described. It is necessary in a quadruplex system, not only to be able to reverse the current and to vary the strength of the current in the ratio of 1 to 3 or 1 to 4, but it is also necessary to keep the resistance of the circuit at each terminal station as constant as possible. It would not do to directly insert or remove a resistance in such a manner as to appreciably alter the resistance of the whole system.

39. Added-Resistance and Leak-Coil Method.—The arrangement of resistances shown in Fig. 16 was devised by Mr. S. D. Field. Two resistance coils, one of 1,200 ohms and another of 900 ohms, called the **added-resistance** and **leak coil,** respectively, are so arranged in connection with the pole changer and the transmitter that the resistance of the circuit remains practically constant in all possible positions of these two instruments. The lever *f* of the pole changer is connected to a point *a* where the circuit divides, one branch being directly connected to the stop *c* on the transmitter while the other branch is connected, through the added resistance of 1,200 ohms, to the point *h*. The line and artificial-line circuits come together at this point *h*, which is also connected directly to the tongue *d* of the transmitter; this tongue is insulated from the lever *e* in the closed, or attracted, position of the lever, being held down by the stop *c*. The 900-ohm leak coil is connected between the lever *e* of the transmitter and the ground G_2.

40. Resistance of Circuit.—Let it be supposed that the line circuit, which includes the line coils of the neutral and polar relays and the apparatus in the line circuit at the distant station, has a resistance of 3,600 ohms, then the artificial-line circuit will have the same resistance. In series with each dynamo is a lamp of 600 ohms, which is necessary to protect the dynamos from the injury done to an accidental short circuit.

The resistance of the circuit from the point *h* to the ground, through the transmitter and pole changer at the home office, to incoming currents is constant whether the transmitter is open or closed. With the transmitter open, the added resistance, 1,200 ohms, is in series with the 600-ohm lamp *l* or *l'*, making 1,800 ohms in this path. This 1,800 ohms, however, is in parallel with the 900-ohm leak coil, and, hence, the combined resistance of these two paths from *h* to the ground is

$$\frac{900 \times 1{,}800}{900 + 1{,}800} = 600 \text{ ohms}$$

When the transmitter is closed, the added resistance is short-circuited, because the tongue *d* of the transmitter touches the contact stop *c*; the line current then passes through $h-d-c-a$ to the pole changer. At the same time, the leak coil is on open circuit, because the tongue *d* no longer touches the hook of the lever *e*. Hence, the only resistance between the point *h* and the ground through the transmitter and pole changer is the 600-ohm lamp in the dynamo circuit. Therefore, the resistance from the point *h* to the ground through the transmitter and pole changer is the same, 600 ohms, in both positions of the transmitter.

41. The resistance is also the same in the two positions of the pole changer, because there is a similar 600-ohm lamp in series with each dynamo. Moreover, the resistance of the artificial line remains the same, namely, 3,600 ohms; hence, the combined resistance to incoming currents of all possible paths from *h* to the ground at the home station is always

$$\frac{3{,}600 \times 600}{3{,}600+600} = 514 \text{ ohms}$$

Therefore, the incoming line current has a path of the same resistance from the point *h* to the ground in the open and closed positions of both the transmitter and pole changer. The same is also true at the distant end; hence, the resistance of the circuit is the same for all sixteen combinations of the four keys, as long as the resistance of the line circuit remains constant.

42. Furthermore, it can be shown that the total current supplied by either dynamo to one quadruplex circuit arranged in this manner is the same in both open and closed positions of the transmitter. This fact, however, is not strictly true of the intermediate positions of the two pole changers (one at each end). In the intermediate position of the pole changer, both dynamos, with their 600-ohm lamps, are on open circuit, but the time during which this is the case is extremely short when the pole changer is properly adjusted. This open circuit probably has some effect on the distant neutral relay, due to the fact that the line retards the arrival of the reversed current; and the neutral relay, although exceedingly quick in magnetizing and demagnetizing, has some magnetic inertia, though the amount may be very small, that must be overcome; hence, some time is required to reverse its magnetism. The momentary absence of the current does not cause any trouble in the polar relay, because the tongue of the polar relay will remain on whichever side it happens to be at the instant when the current ceases.

When the transmitter is open, the resistance from the ground G through either dynamo circuit to the point h is 1,800 ohms. From the point h to the ground through both the line and the artificial-line circuits the resistance is 1,800 ohms, because the line and artificial-line circuits are in parallel with each other. This 1,800 ohms is in parallel with the 900-ohm leak coil; hence, the total resistance from h to the ground through the line, artificial line, and leak coil is

$$\frac{1{,}800 \times 900}{1{,}800 + 900} = 600 \text{ ohms}$$

This resistance is in series with the 1,800 ohms in the dynamo circuit, 1,200 in the added resistance, and 600 in the lamp; hence, the total resistance of the circuit to which the dynamo supplies current, in the open position of the transmitter, is $1{,}800 + 600 = 2{,}400$ ohms.

43. When the transmitter is closed, the added resistance is short-circuited and the leak coil is on open circuit. Then the resistance from the ground G through either dynamo to the point h is 600 ohms, and the path from h to the ground consists only of the line and the artificial-line circuits, which have a combined resistance of 1,800 ohms. Thus the total resistance of the circuit to which the dynamo supplies current in the closed position of the transmitter is $600 + 1{,}800 = 2{,}400$ ohms, the same as in the open position of the transmitter. Therefore, as the resistance remains the same, the current supplied by the dynamo will remain the same. The amount of current that will flow into the line in the two positions of the home transmitter may be calculated as follows.

44. Resistance With Transmitter Open.—It has just been shown that the total resistance of the circuit to which either dynamo supplies current when the transmitter is open is 2,400 ohms; hence, if the dynamo generates an electromotive force of 300 volts, there will be flowing between the ground G and the point h a current of $300 \div 2,400 = .125$ ampere, or 125 milliamperes. This current divides at the point h and flows through three paths. The same quantity evidently flows through the artificial-line circuit as flows through the line circuit, because the two circuits are exactly equal in resistance; hence, by calculating the total current that flows through these two circuits, the strength of the current that flows in the line circuit may be found by dividing the result found by 2. The joint resistance of the line and the artificial-line circuit, which are in parallel, will evidently be one-half of 3,600 ohms, or 1,800 ohms. This 1,800 ohms is in parallel with the leak coil of 900 ohms. The total current will divide inversely in proportion to the resistance in these two circuits; that is, the sum of the currents in the line and artificial-line circuits will be to the total current supplied by the dynamo as the joint resistance of the three paths, 600 ohms $\left(=\frac{1,800 \times 900}{1,800+900}\right)$, is to the joint resistance of the line and artificial-line circuits, 1,800 ohms. Consequently, the sum of the two currents that will flow in the line and in the artificial-line circuits will be $125 \times 600 \div 1,800 = 41.6$ milliamperes, and the current in the line will be one-half of 41.6, or 20.8 milliamperes.

45. Resistance With Transmitter Closed.—When the transmitter is closed, the 1,200-ohm added resistance is short-circuited through the contact stop c and the tongue d of the transmitter, Fig. 16, and the 900-ohm leak coil is cut out of the circuit. With the transmitter in this position, the total resistance of the circuit will be 600 ohms + 1,800 ohms = 2,400, as before, and the total current is also the same. The total current will be 125 milliamperes, and one-half of this, or 62.5 milliamperes, will flow through the line.

46. Ratio of the Two Currents.—When the transmitter was open, the current in the line was 20.8 milliamperes; when closed, the current was 62.5 milliamperes. From this fact, it is evident that closing the transmitter increases the current in the line from 20.8 milliamperes to 62.5 milliamperes; that is, in the ratio of about 1 to 3. Nevertheless, the resistance of the home circuit to incoming currents and the total current remains the same in both positions of the transmitter.

It is frequently desirable to have the ratio of the current increase 1 to 4 instead of 1 to 3. In order to accomplish this, it is only necessary to increase the 1,200 ohms in the added resistance to 1,800 ohms, and to decrease the 900 ohms in the leak coil to 800 ohms. It can be shown in the same manner as before that the ratio of the strength of the current in the two positions of the transmitter will now be as 1 to 4.

47. The ratio of the line currents for the open and closed positions of the transmitter for any values of the dynamo, leak coil, added, and line resistances may be calculated from the general formula,

$$n=\frac{(d+a)(l+k)+l\,k}{l(d+k)} \qquad (1)$$

in which n = ratio between currents;
d = dynamo, or lamp, resistance;
a = added resistance;
l = leak coil;
k = joint resistance of line and artificial-line circuits.

The *dynamo resistance* is the resistance from the ground through either dynamo and its protective resistance to the pole-charger contact. In the case shown in Fig. 16, this resistance d is practically the resistance of the lamp l or l', which in this case is 600 ohms.

EXAMPLE.—If the joint resistance of a line and artificial-line circuit is 1,500 ohms, the dynamo resistance is 600 ohms, the added resistance is 1,200 ohms, and the leak coil is 900 ohms, what is the ratio of line currents for the open and closed positions of the transmitter?

SOLUTION.—Substituting in formula 1 gives

$$n=\frac{(600+1{,}200)\times(900+1{,}500)+900\times 1{,}500}{900\times(600+1{,}500)}=3. \quad \text{Ans.}$$

The ratio between the line currents when the transmitter is open and when it is closed may also be calculated by the formula

$$n=\frac{d+a+l}{l} \qquad (2)$$

According to this formula, the ratio between the currents for the values given in Fig. 16 is 1 to 3, for $\frac{600+1,200+900}{900}=3$.

For a ratio of 1 to 2, the resistance of the leak coil l must be equal to the dynamo resistance d plus the added resistance; or

$$l=d+a \qquad (3)$$

For a ratio of 1 to 3, the resistance of the leak coil must be

$$l=\frac{d+a}{2} \qquad (4)$$

For a ratio of 1 to 4, the resistance of the leak coil must be

$$l=\frac{d+a}{3} \qquad (5)$$

48. Solving formula 2 just given for the resistance of the leak coil gives

$$l=\frac{d+a}{n-1} \qquad (1)$$

In order that the artificial line will remain balanced, in both the open and the closed position of the transmitter, the resistance of the terminals must remain unchanged; that is, d must equal $\frac{(a+d)\,l}{a+d+l}$. If, under this condition, n is a ratio desired and d the resistance of the dynamo, or battery, circuit, then the resistance of the leak coil is also

$$l=\frac{d\times n}{n-1} \qquad (2)$$

EXAMPLE 1.—If a ratio of 1 to 4 is desired with a resistance of 600 ohms in the dynamo circuit, what should be the resistance of the leak coil?

SOLUTION.—Substituting in formula 2 gives

$$l=\frac{600\times 4}{4-1}=800 \text{ ohms.} \quad \text{Ans.}$$

EXAMPLE 2.—If a ratio of 1 to 3 is desired with a resistance of 600 ohms in the dynamo circuit, what should be the resistance of the leak coil and added resistance?

SOLUTION.—Substituting in formula 2, the resistance of the leak coil l is

$$\frac{600\times 3}{3-1}=900 \text{ ohms. Ans.}$$

Solving formula 1 for the added resistance a gives

$$a=l\,(n-1)-d=900\times(3-1)-600=1{,}200 \text{ ohms. Ans.}$$

49. Resistances in Field-Key Systems.—Should it be desired to obtain a different ratio between maximum and minimum line currents without disturbing the balance of the system, the ratio must be secured without changing the joint resistance of the terminal apparatus in either the open or the closed position of the transmitter. Fulfilling these conditions, Mr. F. F. Fowle gave in the Telegraph and Telephone Age, the following simple formulas and the values given in Table II. If the joint resistances $\left(d+k \text{ and } d+a+\frac{l\,k}{l+k}\right)$ of the terminal and line are not altered and hence if the artificial lines are not thrown out of balance, the ratio between the currents is equal to the sum of the lamp, or dynamo, resistance and the added resistance divided by the dynamo resistance; or

$$n=\frac{d+a}{d} \qquad (1)$$

in which n = ratio between line currents;
d = lamp, or dynamo, resistance;
a = added resistance.

For a given lamp resistance d and a desired ratio n, the necessary added resistance is obtained by solving formula 1 for a, which gives

$$a=d\,(n-1) \qquad (2)$$

That is, the added resistance a is equal to the lamp resistance d multiplied by the ratio n less one, that is, by $(n-1)$.

EXAMPLE.—What should be the added resistance when the dynamo resistance is 500 ohms and a ratio of 5 to 1 is desired?

SOLUTION.—Substituting in formula 2, the added resistance is

$$600\times 4=2{,}400 \text{ ohms. Ans.}$$

50. Value of Added and Leak Resistances.—As the values of the added and leak resistances depend on the resistance of the lamp in the generator tap and the desired ratio of currents, and not on the line resistance, any values of the added and leak resistances that give a desired ratio will be good for lines of any length, provided the lamp resistance *d* is not changed. The lamps used, however, do not have a perfectly constant resistance. The resistance of carbon-filament lamps decreases as the current increases, and hence their resistance should be measured with values of current equal to what they carry in actual service. This can readily be done with a voltmeter and ammeter.

TABLE II

ADDED AND LEAK RESISTANCES

Lamp Resistance *d* Ohms	Value of Ratio *n*					
	3		3.5		4	
	a Ohms	*l* Ohms	*a* Ohms	*l* Ohms	*a* Ohms	*l* Ohms
100	200	150	250	140	300	133
200	400	300	500	280	600	267
300	600	450	750	420	900	400
400	800	600	1,000	560	1,200	533
500	1,000	750	1,250	700	1,500	667
600	1,200	900	1,500	840	1,800	800
700	1,400	1,050	1,750	980	2,100	933
800	1,600	1,200	2,000	1,120	2,400	1,067
900	1,800	1,350	2,250	1,260	2,700	1,200
1,000	2,000	1,500	2,500	1,400	3,000	1,333

The use of Table II will save the labor of computation. The choice of lamp resistance is an important matter as it affects the efficiency of the line in bad weather. The working margin on a line that has a large amount of leakage will be made greatest by keeping the lamp resistance as small as possible. Of course, there is a limit to the lowest practical resistance that the lamp may have; this is determined by the appearance of sparking at the transmitter contacts. The lamp resistances should correspond with the voltages across them, but, although important, often no attention is given to this matter.

51. Added Resistance and Leak Box.—In order to readily accomplish the change in the added resistance and leak coil necessary to obtain the desired ratio between the line currents, the **resistance box** shown in Fig. 17 is used. Between the binding posts *a* and *b* two coils are joined in series, one of which has a resistance of 600 ohms and the other a resistance of 1,200 ohms; and between the binding posts *c* and *d*, two coils are joined in series, one of which has a resistance of 100 ohms and the other a resistance of 800 ohms. The resistance between the binding posts *a* and *b* will be 1,800 ohms when there is no plug in the hole *e*. When, however, a plug is put in the hole *e*, the resistance between the binding posts *a* and *b* is only 1,200 ohms, because the 600-ohm coil is short-circuited. When there is no plug in the hole *f*, the resistance between the binding posts *c* and *d* is 900 ohms, and when there is a plug in the hole *f*, the resistance between the bind-posts *c* and *d* is only 800 ohms. Hence, it is evident, that with one plug in the hole *e* there is an added resistance of 1,200 ohms and a leak coil of 900 ohms. By shifting this plug from one hole *e* to the other *f*, the added resistance is 1,800 ohms and the leak coil 800 ohms; hence, it is a very simple matter to change the ratio of the current from 1 to 3 to 1 to 4.

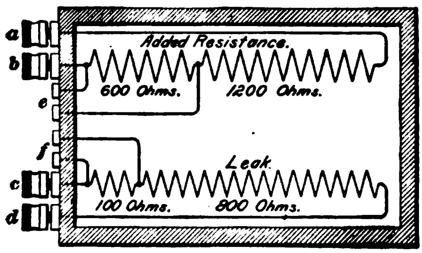
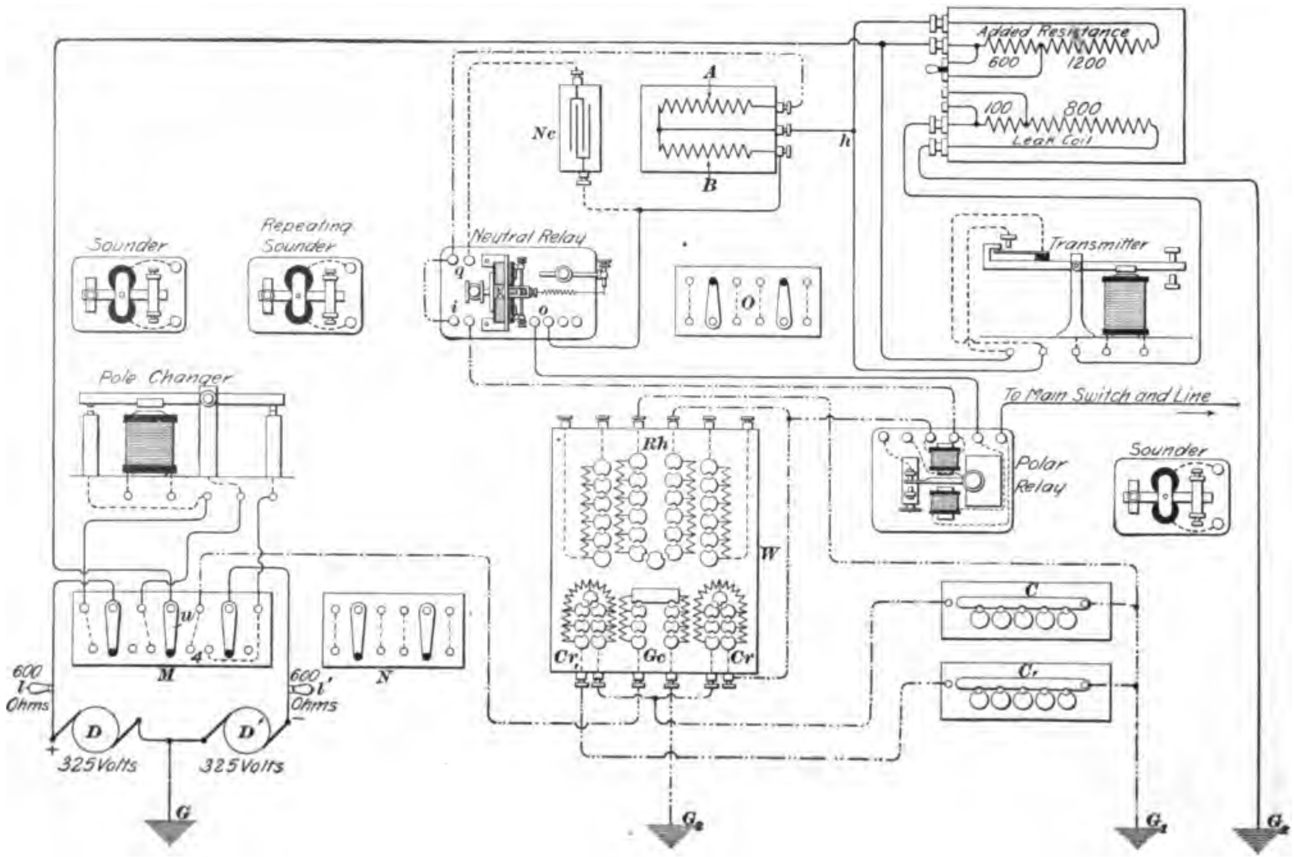


Fig. 17

52. Complete Main- and Artificial-Line Circuits. Fig. 18 is a diagram of the Western Union quadruplex, showing the connections of the main-line and artificial-line circuits when dynamos are employed. The local circuits for the sounders, transmitter, and pole changer will be shown in Figs. 23 and 24.



Added Resistance
600
1200
100
800
Leak Coil
A
B
h
Nc
Transmitter
Sounder
Repeating Sounder
Neutral Relay
q
i
o
O
Pole Changer
To Main Switch and Line
Rh
W
Polar Relay
Sounder
C
C_1
Cr
Gc
Cr
w
4
M
N
600 l Ohms
600 l' Ohms
D
D'
325 Volts
325 Volts
+
−
G
G_2
G_1
G_3

Fig. 18

The apparatus and connections in Fig. 18 are lettered, as nearly as possible, as in the preceding figures. The three arms of the switch *M* are all turned to the left when the system is in working order. The arm *u* of the switch *M* is turned so as to rest on the right-hand button *4* when the set is being balanced. This disconnects the two dynamos *D* and *D'* and the pole changer entirely from the circuit, and connects the neutral and polar relay through the center arm *u* of the switch and through the ground coil *Gc* to the ground G_3. In series with each dynamo is a lamp *l* or *l'*, having a resistance of 600 ohms. The various resistances are placed in boxes and means are provided for readily adjusting both them and the condensers. The latter are usually placed under the table. The box *W* contains all the resistance coils for the artificial line; that is, the resistances *Rh*, *Cr*, and Cr_1, and, also, the ground coil *Gc*. The condenser and resistances, respectively, that are used in connection with the extra, or third, coil of the neutral relay are represented at *Nc* and *A B*, respectively.

FREIR SELF-POLARIZING RELAY

53. In quadruplex telegraphy, where two messages are simultaneously sent in the same direction, one by reversals and the other by changes in current strength, the period of no current through the neutral relay at the moment of current reversal interferes with the accurate reception of the signals due to changes in current strength. The armature of the neutral relay when attracted by the stronger current will be momentarily released when the current is reversed and will make a movement toward the back or working contact, which, if completed, would cause a false signal. The *Freir self-polarizing relay* was designed to produce a neutral relay that would be very sensitive to changes in the strength of the current but which would avert, as far as possible, the false movement of the relay armature during the cessation of current at the moment of reversal.

The Freir relay, although called a self-polarizing relay, is, in reality, not a polarized relay. It does not respond to a change in the direction of the current, and, therefore, cannot be used except as a neutral device. Like all "common-side" relays, it is operated only by alterations in the strength of the current. It derives its name from the fact that its armature becomes alternately positive and negative by reversals of the current.

54. The **Freir self-polarizing relay,** shown in Fig. 19, has three parallel coils *A*, *B*, and *C* wound on soft-iron cores. To each end of each core is fastened a soft-iron extension that forms a pole piece; three of these *a*, *b*, and *c* are shown. in the figure. There are also two soft-iron armatures; one *D* rests in the pole piece *b* and the other in a similar pole piece at the other end of the coil *B*. These armatures are fastened to an aluminum frame. The magnets and armatures are enclosed in a brass case with a rubber top. The retractile spring *e* tends to hold the armature *D* against the stop *p*.

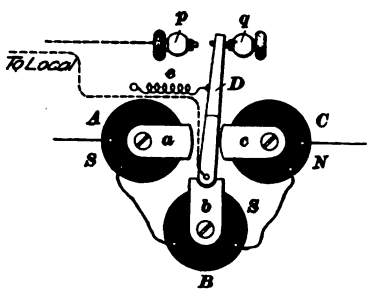


FIG. 19

The three electromagnets are connected in series, their coils, however, being so wound and connected that a current passing through them in one direction produces a south pole at *a* and *b* and a north pole at *c*. At the same time, the south pole at *b* produces, by induction or by actual contact, a south pole in that portion of the armature that is between the pole pieces *a* and *c*. Thus, with this direction of current, the south pole at *a* tends to repel and the north pole at *c* to attract the armature. If this current is strong enough, the armature *D* will be moved from *p* against *q* and will remain there until the strength of the current is sufficiently diminished to allow the spring *e* to pull it against the stop *p*. Whenever the current is reversed by the operation of the distant pole changer, there will be a momentary cessation of current through the coils *A*, *B*, and *C*, but with a relay constructed in this manner, the momentary absence of current is not of sufficient duration to permit the armature to be sufficiently released to allow it to return to the back stop *p*. When the current is reversed, a north pole is produced in pole pieces *a*, *b*, and in that portion of the armature that lies between pole pieces *c* and *a*, while a south pole is produced in pole piece *c*. Hence this pole piece continues to attract the armature and the pole piece *a* to repel it. Thus, although the magnetism of the several pole pieces is reversed, their respective attractions and repulsions remain unchanged.

55. Advantages of Freir Self-Polarizing Relay. Aside from the self-polarizing principle, the absence of yokes, the small amount of iron in the cores, and the excellent disposition of the cores, pole pieces, and armature, and the light weight and consequent small inertia of the moving parts, make this relay work very quickly and efficiently. Moreover, it requires no condensers or devices, as in some quadruplex systems, to tide the neutral relay over the interval of no magnetism while the current is reversing. Some say this relay is very satisfactory, others say it is not good on circuits exceeding 200 miles and that even for lines less than 200 miles long it is inferior to the Smith device.

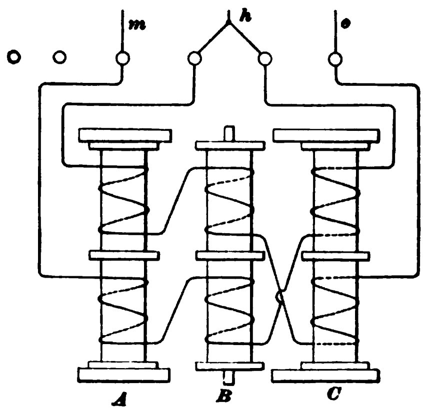


Fig. 20

56. Winding of Freir Relay.—Each coil of the Freir self-polarizing relay consists of two separate windings, so that the relay can be connected differentially in the circuit the same as any differentially wound relay. Each half of the winding on each core contains about 1,900 turns of No. 36 B. & S. wire; it then has a resistance of 93 to 100 ohms. This makes a resistance of about 300 ohms in the main-line and 300 ohms in artificial-line circuits. The method of winding this relay is shown in Fig. 20, which is a view of the relay as it appears when looked at from above, all the details that might tend to complicate the figure being omitted. The binding posts are shown along the top of the figure. When the current flowing into the relay divides equally at h, half flowing out at m and half out at o, the direction of the current in each coil around the iron core is such that the two coils on each core neutralize each other; hence, the relay is not magnetized. If, however, the current does not divide equally at h, the relay is energized and the armature will close the local circuit if the difference in the strength of the current in the two halves is sufficient to overcome the opposing spring.

57. Adjustment of Freir Relay.—In order that the contact points of the Freir relay will not remain permanently closed, there is attached to the armature a retractile spring that has a tension strong enough to keep the relay open when it is magnetized only by the smaller current employed in the quadruplex system. The adjustment of the spring is identical with that of the ordinary neutral relay.

The proper position of the armature lever D between the pole pieces is shown in Fig. 19. The space between the armature D and the pole piece a should, under ordinary conditions, be at least twice as great as that between armature D and pole piece c. Ordinarily, the pole piece c should be placed $\frac{1}{32}$ inch from the armature and the pole piece a about three times that distance, or $\frac{3}{32}$ inch, from the armature. As the magnet A repels the armature D and the magnet C attracts it, it is natural to suppose that the magnet A should be nearer the armature so as to help the magnet C move the armature D, but that is not the case. Under normal conditions the repelling magnet A should not help the magnet C do its work, for which reason it is placed farther away from the armature, as stated. If the repelling magnet A is placed too close to the armature D, the lines of force from the attracting magnet C will cut through and weaken the polarity of the armature D and so reduce the attraction of the latter for the magnet C.

The third coil B may seem to be superfluous, and easily dispensed with. This is not the case, however, because it has, in practice, proved to be beneficial to bring the repelling coil *A* closer to the armature *D*, when the effective current on a long circuit is weakened by the leakage due to wet weather and when the force of the repelling magnet *A* is actually needed in order to help a feeble incoming current move the armature *D*. This adjustment enables the repelling lines of force to cross the intervening gaps in their endeavor to reach the opposite polarity, and their transit being in the same direction as those of the attracting magnet, the movement of the armature is accelerated by their combined strength.

A relay very similar to the Freir self-polarizing relay, but without the third coil, has been used in England. A strong point in favor of the third coil is found in the fact that the three-coil arrangement has given satisfaction where the English two-coil relay has failed.

STANDARD WESTERN UNION QUADRUPLEX

58. Fig. 21 gives the diagram of connections of a later standard quadruplex of the Western Union Telegraph Company, in which later apparatus and dynamos are used. In order to keep the diagram as clear as possible, all sounders and local circuits have been omitted; they will be shown in Figs. 23 and 24. The apparatus to which it is desirable to call particular attention is the Freir self-polarizing relay, which is used in place of the ordinary three-coil neutral relay; the newer form of polar relay; and the resistance boxes *Rh* and *V*, which are slightly different in form from any previously shown. The use of the Freir relay has improved the working of the system and does away with the condenser *Nc* and the coils *A* and *B* shown in Fig. 5, as they are not needed to bridge this relay over the interval of no magnetism due to the reversal of the distant pole changer. The Freir relay merely replaces the older form of neutral relay and does not change the principle of this quadruplex system in any way.

The resistance box *Rh*, Fig. 21, contains the resistance for the artificial line corresponding to *Rh* in Fig. 5. In Fig. 21, both the top *w* and the front *p* of the box containing the resistance *Rh* are shown. This rheostat contains ten coils, which

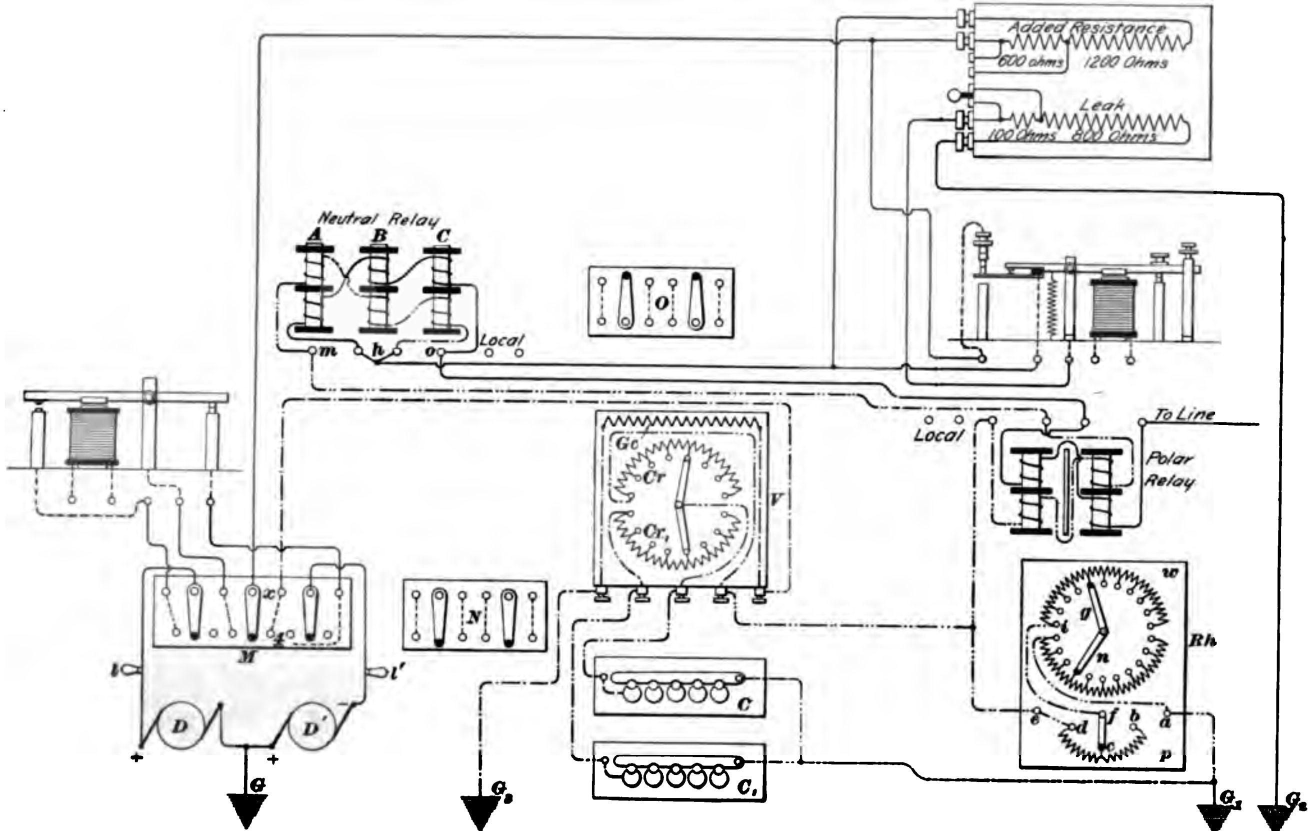

Added Resistance
600 ohms
1200 Ohms
Leak
100 Ohms
800 Ohms
Neutral Relay
A
B
C
m
h
o
Local
O
To Line
Local
Polar
Relay
Gc
Cr
Cr,
V
w
g
i
n
Rh
e
d
f
b
a
c
p
N
M
x
l
l′
D
D′
+
+
G
G₃
C
C,
G₁
G₂

Fig. 21

have a resistance of 400 ohms each, in its upper part and ten coils having a resistance of 40 ohms each in its lower part. On the front *p* of the box is a switch arm *f* that connects the contact button *i* with any one of the contact buttons *b*, *c*, or *d*. Between these contact buttons are two coils, each of which has a resistance of 3,000 ohms. When the arm *f* rests on contact *b*, both of these coils are connected in series in the artificial-line circuit; when the arm *f* rests on contact *c*, one of these coils is cut out; and when it rests on contact *d*, both coils are cut out. The arm *g* on the top of the box makes a contact with any one of eleven buttons; the arm *n* may similarly be placed in contact with any one of eleven other buttons. The amount of resistance in the circuit between points *a* and *e* depends on the positions of the arms *g*, *n*, and *f*.

59. The box *V*, Fig. 21, contains a coil *Gc*, corresponding to the ground coil *Gc*, in Fig. 5. This coil is included in the circuit for the purpose of balancing the system; it need not be adjustable and has a resistance of 600 ohms, which is equivalent to the resistance of the lamp in each dynamo circuit. The coils *Cr* and Cr_1 are adjusted by means of two radial arms; they correspond to the coils *Cr* and Cr_1, respectively, in Fig. 5. The condensers *C* and C_1 correspond to the condensers *C* and C_1, respectively, in Fig. 5. The total resistance in the upper, or *Cr*, portion of the box *V* is 525 ohms, and the total resistance in the lower, or Cr_1, portion of the box amounts to 1,000 ohms. Thus the resistance *Cr* may be adjusted from 0 to 525 ohms, and the resistance Cr_1 from 0 to 1,000 ohms. Usually, the condenser *C* should have about twice the capacity of C_1, for it equalizes the charge on the near end of the line, which is greater than the charge toward the center of the line. The charge beyond the near end of the line is to a large extent equalized by condenser C_1. These radial-arm resistance boxes are reliable as the arms make as good, if not better, contact than boxes having plugs. They are more easily and quickly adjusted and they have no plugs to be lost or become dirty.

60. Barclay Rheostat.—The quadruplex combination rheostat devised about 1904 by Mr. J. C. Barclay for the artificial line in the Western Union dynamo quadruplex is shown in Fig 22. Revolving arms are used for adjusting the retarding resistances in series with the condensers as well as for adjusting

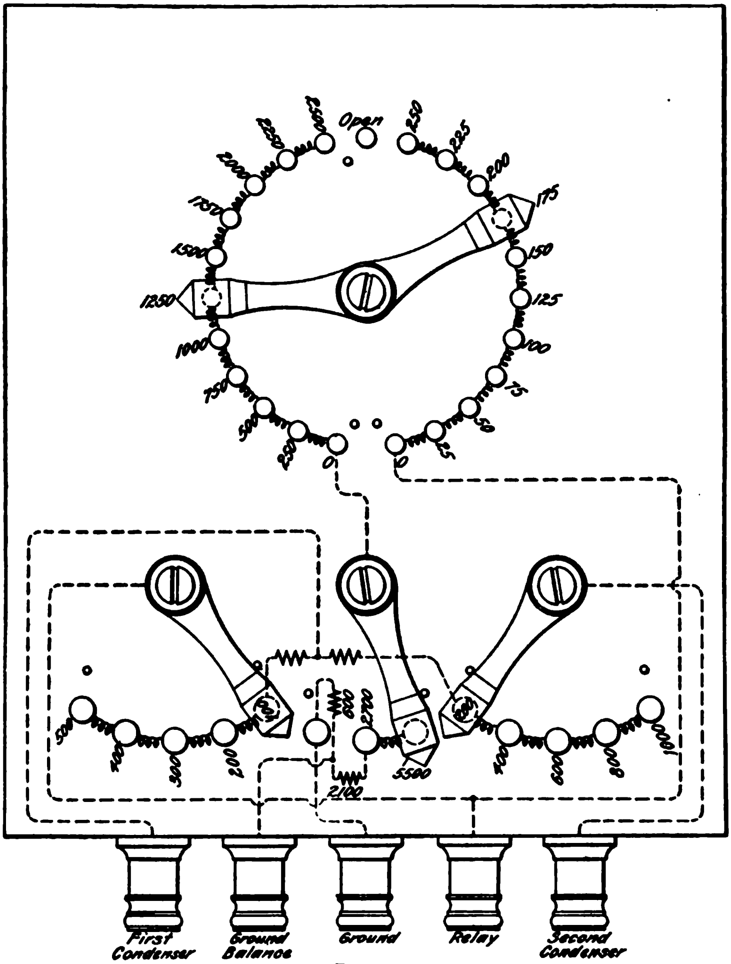


Fig. 22

the main resistance in the artificial line. The values of the resistances are such as to enable a close adjustment of the artificial line without including more resistance than is apt to be required. This box combines all the resistance included in boxes *V* and *Rh* in Fig. 21.

61. The switch *M*, Fig. 21, has already been shown in connection with quadruplex and duplex systems. When the three arms of the switch rest on the left-hand contact buttons, the apparatus is properly connected for use. In order to balance the quadruplex, the switch arm *x* should be turned to the right until it rests on the contact button *4*. This cuts off both dynamos, the transmitter, and the pole changer, and connects the receiving apparatus directly to the ground through the ground coil *Gc*.

62. Local Connections.—Figs. 23 and 24 show the connections for the local circuits of the Western Union quadruplex system when dynamos are used. Fig. 23 represents the neutral, common, or No. 2, side of a complete set; Fig. 24 represents the polar, or No. 1, side. In this figure, in order that the apparatus and connections on the neutral side may appear as they would to a person facing that side of the table instead of the polar side, it is only necessary to turn the figure upside down. In both of these figures the apparatus is arranged and lettered the same as it is in Fig. 18. The local circuits for Fig. 21 would be connected in the manner shown in these two figures. The repeating sounder that is controlled by the neutral relay is operated by the 7-volt dynamo D_1, which was used for operating all repeating and ordinary 100-ohm sounders in the main office of this company. All 4-ohm sounders, pole changers, and transmitters are supplied with current from the same 23-volt dynamo *D*.

The local circuits are so arranged that they may be extended through the loop switchboard to a branch office. On the neutral side, shown in Fig. 23, the receiving circuit is controlled by the repeating sounder, which, in turn, is controlled by the neutral relay. On the polar side, shown in Fig. 24, the receiving circuit is controlled by the polar relay. Both receiving circuits are shown by dotted lines; the sending circuits, one of which includes the pole changer and the other the transmitter, are shown by dash lines. Two keys are placed in each of the sending

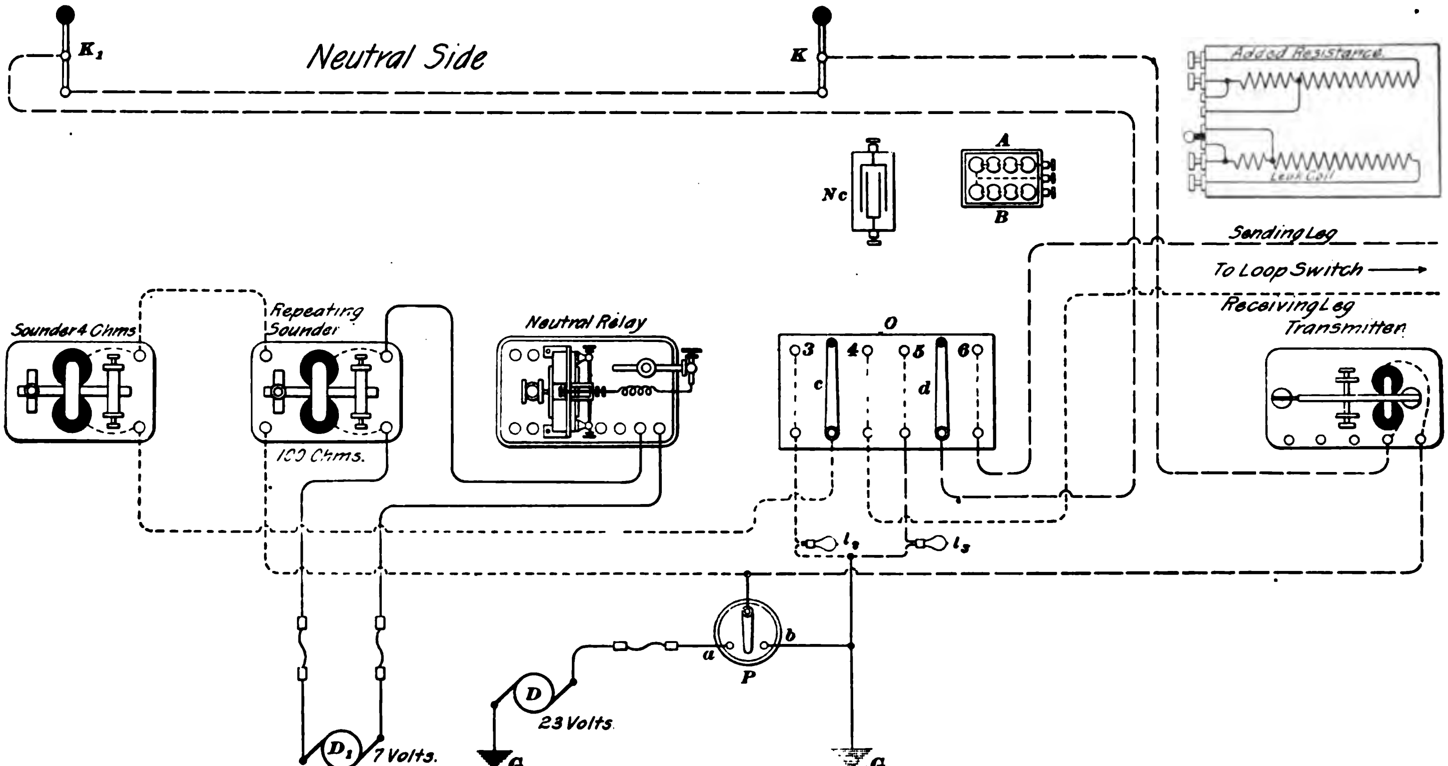

Neutral Side
K₁
K
Added Resistance
Leak Coil
Nc
A
B
Sending Leg
To Loop Switch
Receiving Leg
Transmitter
Sounder 4 Ohms
Repeating Sounder
100 Ohms.
Neutral Relay
O
3
4
5
6
c
d
l₂
l₃
a
b
P
D
23 Volts.
G
G₁
D₁
7 Volts.

FIG. 23

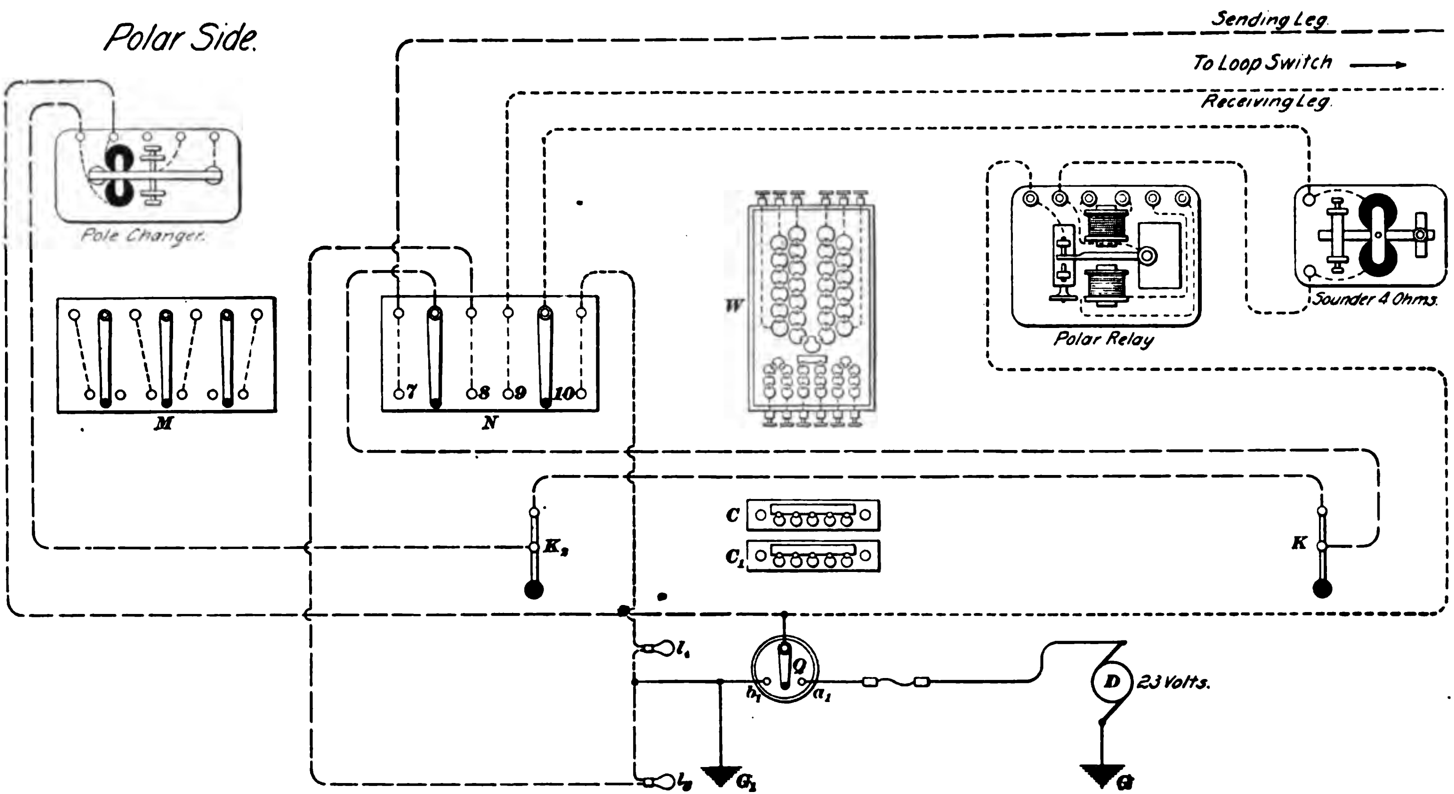

Polar Side.
Sending Leg.
To Loop Switch →
Receiving Leg.
Pole Changer.
M
7
8
9
10
N
W
Polar Relay
Sounder 4 Ohms.
C
C_1
K_2
K
l_1
l_2
Q
b_1
a_1
D
23 Volts.
G_1
G

FIG. 24

circuits; the second key in each circuit is to enable the receiving operator to break and communicate with the distant end without having to leave his position. Of course, it is only allowable for him to break when the sending operator on that side is not using his key.

63. The switches *O* and *P*, Fig. 23, and *N* and *Q*, Fig. 24, are used in the same manner as are those that were described in connection with the polar duplex. When the system is in operation and the local circuits are not to be extended to any branch office, the arms of the switch *N* should rest on the contact buttons *8* and *10*; the arms *c* and *d* on the contact buttons *3* and *5*; and the switches *P* and *Q* on the contact buttons *a* and a_1, respectively. With the switches in this position, the receiving circuit on the neutral side, Fig. 23, may be traced from the ground *G* through the 23-volt dynamo *D* – contact button *a* – arm of switch *P* – contact points of repeating sounder – the magnet of reading sounder – the switch arm *c* – contact button *3* – lamp l_2 to the ground G_1. The transmitter circuit may be traced from the ground *G* – through the 23-volt dynamo *D* – contact button *a* – arm of switch *P* – the magnet of transmitter – keys *K* and K_1 – switch arm *d* – contact button *5* – lamp l_3 to ground *G*. The two circuits on the polar side may be traced in the same manner, and the reader should be able to do this for himself.

64. When the receiving and sending circuits are to be extended to branch offices, the sending and receiving legs on one side are ordinarily connected to one branch office, and the sending and receiving legs on the other side to another branch office. It is not necessary that both sending and receiving circuits should be extended to the same branch office. The branch offices are able to receive the messages that are entering through the neutral and polar relays, and to send out messages by controlling the transmitter and pole changer. In order to extend these receiving and sending circuits to branch offices, the arms of the switch *N*, Fig. 24, are turned to the left until they rest on contact buttons *7* and *9*, and the arms of the switch *O*, Fig. 23, are turned to the right until they rest on contact buttons *4* and

6. The arms of the switches *P* and *Q* remain on buttons *a* and a_1 as before.

65. The receiving circuit on the neutral side, shown in Fig. 23, may be traced from the ground *G* – through the 23-volt dynamo *D* – switch *P* – contact points of repeating sounder – magnet of reading sounder – switch arm *c* – contact button *4* – receiving leg to loop switchboard – main switchboard – line wire and finally through a sounder to the ground at the branch office. The sending circuit on the same side may be traced from the same ground *G* – through the 23-volt dynamo *D* – switch *P* – magnet of transmitter – keys *K* and K_1 – switch arm *d* – contact button *6* – sending leg to the loop switchboard – main switchboard – line and finally, through a sounder, key and ground at the branch office.

The connections through the loop switchboard and the branch office are exactly the same as those shown in connection with branch-office circuits in the polar duplex system. It will be noticed that the lamps l_2, l_3, l_4, and l_5 are not in the circuit when the arms of the switches *N* and *O* are turned so as to extend the circuits to the loop switchboard and branch offices. Each of these lamps has a resistance equal to the resistance in one leg of the branch-office loop, so that the current through the sending and receiving sides is the same in both positions of the arms of the switches *N* and *O*. When the sets are not in use, all connections with the 23-volt dynamo are broken by turning the switches *P* and *Q* to the contact buttons *b* and b_1, respectively.

66. The quadruplex apparatus shown in Figs. 23 and 24 is arranged on a large table that is divided into four parts, one quarter being for each operator. Two operators sit side by side; one of these is sending through the pole changer while the other is receiving through the polar relay. Facing these two operators are the other two, one of whom is sending through the transmitter while the other is receiving through the neutral relay.

DUPLEX AND QUADRUPLEX TELEGRAPHY

(PART 4)

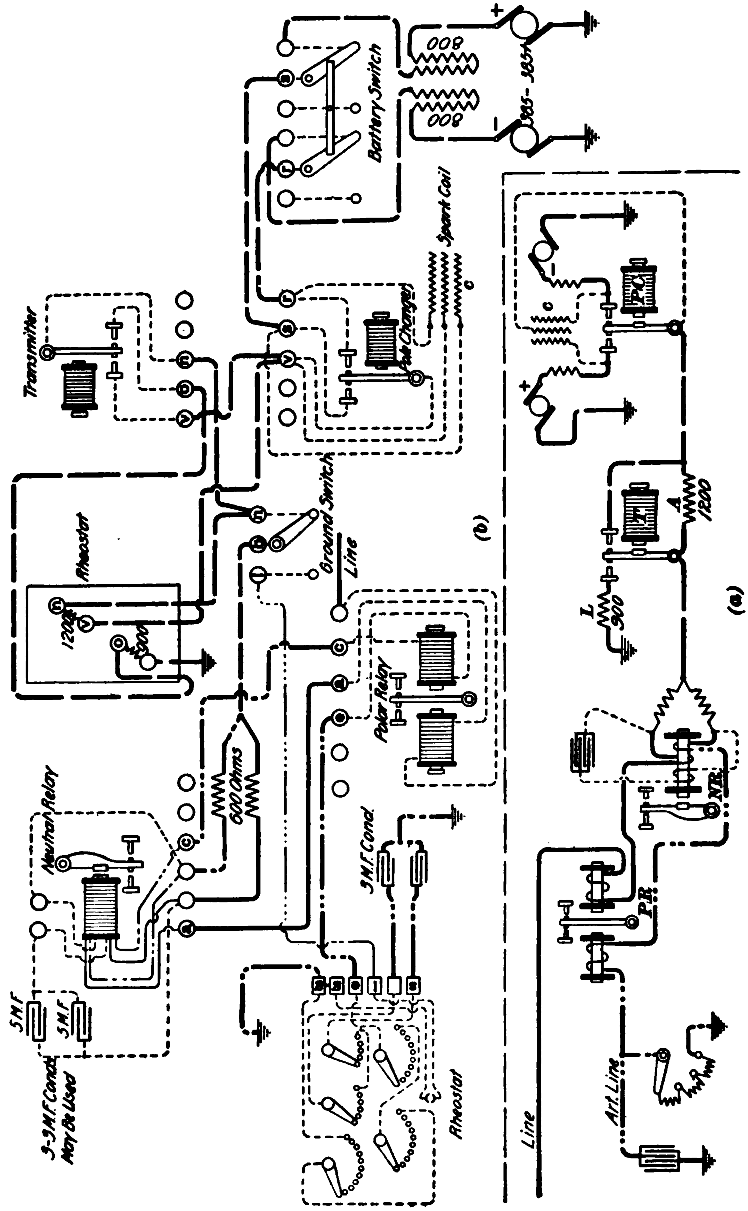
QUADRUPLEX TELEGRAPHY

DYNAMO QUADRUPLEX SYSTEMS

POSTAL DYNAMO QUADRUPLEX

1. Diagram of Main Circuits.—In Fig. 1 (*a*) is shown the theoretical diagram and in (*b*) the actual wiring of the main- and artificial-line circuits of the added-resistance-and-leak-coil, dynamo, quadruplex system, with the Smith neutral-relay device, as used by the Postal Telegraph-Cable Company. This system is practically the same in principle as similar systems already explained. The added resistance *A* is 1,200 ohms and the leak coil *L* has a resistance of 900 ohms for a current ratio of 1 to 3, while for a ratio of 1 to 4, *A* has a resistance of 1,800 ohms and *L* 800 ohms.

The pole changer and transmitter are merely transmitting relays, which are now extensively used by this company. It seems practicable to put the contacts close enough together, to avoid breaking the circuit long enough to cause trouble at the distant neutral relay and yet without causing injurious sparking at the pole changer. Binding posts similarly lettered are connected together, a practice customary with this and other companies. This quadruplex equipped with the Smith device is said to be giving very satisfactory results.



Transmitter
Rheostat
Ground Switch
Line
Pole Changer
Spark Coil
Battery Switch
800
800
385-385V
(b)
Neutral Relay
600 Ohms
Polar Relay
3 M.F. Cond.
5 M.F.
5 M.F.
3-3 M.F. Conds. May Be Used
Rheostat
Line
Art. Line
P.R.
N.R.
L 900
A 1200
P.C.
(a)

FIG. 1

2. The action of the Smith device, including an extra coil on the neutral relay and two resistances, in this case 600 ohms each, in tiding the neutral relay over the period of reversing magnetism has been fully explained. The ground switch is shown in its normal position; when turned to the left the receiving apparatus is directly grounded for balancing the quadruplex set. The line coils of the neutral relay are wound to 150 ohms and the extra coil to 400 ohms. The regular Postal bug-trap local circuits are used in connection with the relays.

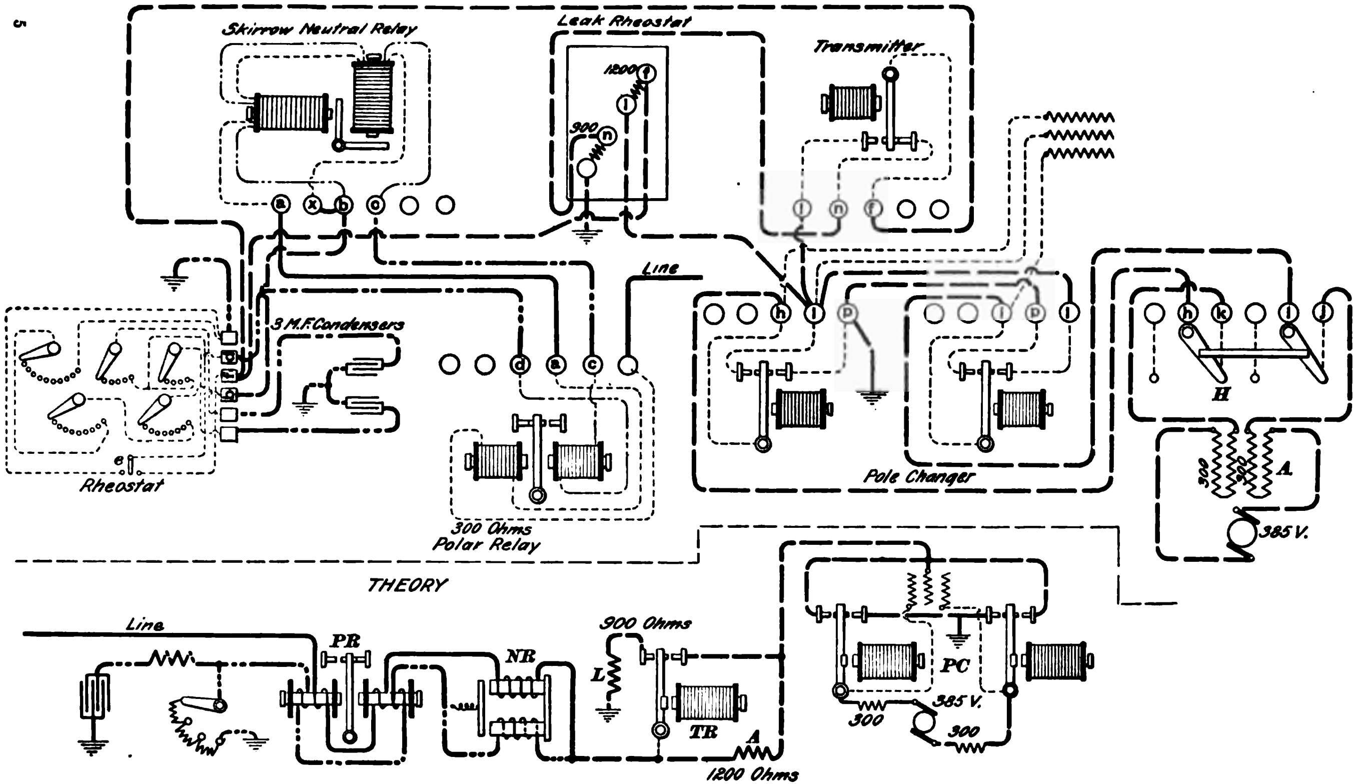
3. Johnson Coil.—The so-called Johnson coil, used by the Postal Telegraph-Cable Company in many of its circuits to minimize the spark at the pole-changer contacts, is shown at *c*. This coil was devised by Mr. C. A. Johnson, at the time he was manager at Meadville, Pennsylvania. It amounts to the same thing as two condensers in series with a resistance in each of the three wires running from them to the contact points and lever of the pole changer. The idea is to so time the discharge from the condenser by passing it through a suitable resistance as to best neutralize the tendency of the dynamos to produce a spark across the contact points as they separate. Hence the arrangement is sometimes termed a *perfectly timed condenser*. Each winding, which is open at one end, is constructed to have not only the desired resistance but also the desired electrostatic capacity between windings. The resistance retards the discharge, hence the condenser is not so rapidly discharged and its discharge persists as long as there is any tendency for the production of a spark across the pole-changer contacts.

4. Resistance Coils.—The 800-ohm resistances in the dynamo circuits are either Ward-Leonard or Wirt coils. The **Ward-Leonard coils** consist of a single winding of special wire wound upon porcelain tubes, covered with enamel and baked hard. The **Wirt coils** are similarly made, but the wire is embedded in a compound known as dielite, the composition of which is perhaps known only to the makers, and then covered with enamel and baked hard. Formerly these resistances were wound on tin tubes, many of which are still in use.

5. Quadruplex With Skirrow Neutral Relay.—The Skirrow neutral relay, which is shown in connection with Fig. 2, may replace the neutral relay and Smith arrangement shown in Fig. 1. In that case, the binding posts *a* and *c* on the polar relay and the binding post *b* on the ground switch, in Fig. 1, must be connected to the binding posts *a*, *c*, and *b*, respectively, on the Skirrow neutral relay in Fig. 2. Also posts *b* and *x* on the Skirrow neutral relay must be connected together, as shown in Fig. 2. The two 600-ohm resistances and the two 5-microfarad condensers forming part of the Smith arrangement in Fig. 1 will be entirely removed from the circuit.

6. Postal Single-Dynamo Quadruplex.—It is often desirable to use dynamo current when the service will not warrant a regular standard dynamo equipment to be set up. In such cases, where but a single quadruplex is required and especially if it is used only a part of the time, a simple, efficient, and economical plan is to use a single dynamo worked on the plan shown in Fig. 2. But this dynamo cannot, at the same time, be used for any other purpose. This plan contains no principles that have not been explained in connection with other quadruplex systems, except the use of only one dynamo. The added-resistance and leak-coil method of varying the strength of the line current, and the Postal double-magnet type of pole changer are employed.

The dynamo has one terminal connected through the switch *H* to one pole-changer lever, and the other terminal through the switch *H* to the other pole-changer lever; neither dynamo terminal is grounded except through the pole changer. In one position of the pole-changer levers, one terminal of the dynamo is connected to line and the other terminal is grounded; in the other position of the pole-changer levers, the polarity of the dynamo between line and ground is reversed. The pole changer must be adjusted so that the levers will open and close simultaneously, the contacts being so adjusted as to leave the main circuits open as short a time as possible without producing a short circuit across the dynamo. In case of a momentary short circuit, the 600-ohms resistance *A* in series with the



Skirrow Neutral Relay
Leak Rheostat
Transmitter
1200
900
Line
3 M.F. Condensers
Rheostat
300 Ohms
Polar Relay
Pole Changer
H
300
A
385 V.
THEORY
Line
PR
NR
900 Ohms
L
TR
A
1200 Ohms
PC
385 V.
300
300

FIG. 2

dynamo will protect the latter. To reduce the sparking at the pole-changer contacts a Johnson spark coil is connected as shown.

APPARATUS FOR QUADRUPLEX SYSTEMS

7. Skirrow Neutral Relay.—In Fig. 3 is shown the arrangement of the parts and circuits of the **Skirrow neutral relay** used by the Postal Telegraph-Cable Company. The general appearance of the instrument is shown in Fig. 4. The magnets of this relay are very short and almost as large in

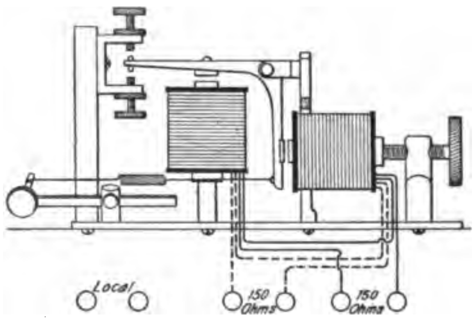


FIG. 3

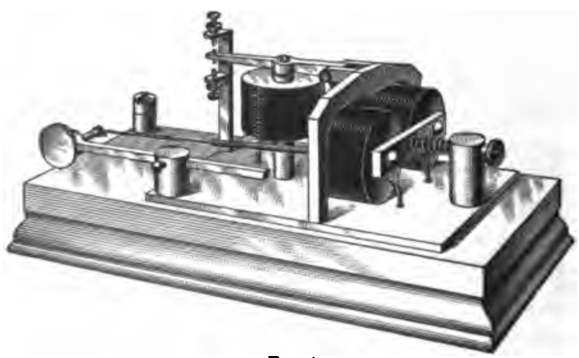


FIG. 4

diameter as they are long. To reduce the eddy currents, the cores are slotted their entire length; while to give a low magnetic reluctance, the magnetic circuit is broad and large in cross-section. The horizontal magnets may be easily adjusted by means of the supporting screw; the vertical magnets, however, cannot be adjusted except by means of the contact screws. Each armature is fastened to the aluminum armature lever by a single screw. Projecting rubber plugs are fitted to the ends of the cores to prevent the magnets being placed too close to the armature. The general appearance of the relay is massive.

8. It is claimed that the careful design of the magnetic circuit makes the Skirrow neutral relay very quick acting and at the same time more powerful with weak currents than the Freir relay. It works very well on short circuits, where there is plenty of margin, but its low resistance winding makes it less satisfactory than the Freir relay on long circuits. Its low winding, which is only 300 ohms, makes necessary an extremely careful adjustment of both the relay and the distant pole changer to tide the relay over the interval of no magnetism while the current is being reversed. But when rewound, and used in connection with the new Smith arrangement, the Skirrow neutral relay is said, by some, to give better satisfaction than anything on the market.

9. **Skirrow Polar Relay.**—In Fig. 5 is shown a skeleton view of the important features and winding of the Skirrow polar relay, as used by the Postal Telegraph-Cable Company, while Fig. 6 shows the general appearance of the instrument. Two sets of laminated permanent magnets *a* and *b*, are placed with like poles opposite each other. At the juncture of these poles, the soft-iron armature *c d* is pivoted, the upper ends playing between the cores of two sets of soft-iron magnets. These magnets are adjusted back and forth from the iron armatures by thumbscrews in about the same manner as the magnets of an ordinary relay. An iron armature *c d* is stamped from one piece of soft iron, but is equivalent to two armatures fastened together. The contact by means of which the local circuit is closed is shown at *e*. There are four cores with two coils on each core. The line circuit passes through the coils *m*, *n*, *o*, and *p*, while the artificial-line circuit *AL* passes through the coils *q*, *r*, *s*, and *t*.

That is, the line current circulates around a coil *m* on the rear of one core, around the coil *n* on the front of the opposite core, around the coil *o* on the rear of the core facing the core with the

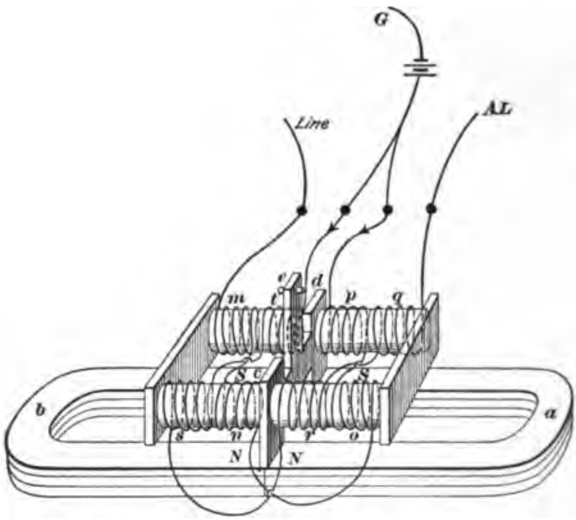


FIG. 5

coil *n* on its front end and around the coil *p* on the front end of the core facing the core with the coil *m* on the rear of the core. The artificial-line circuit *AL* passes through a set of similarly

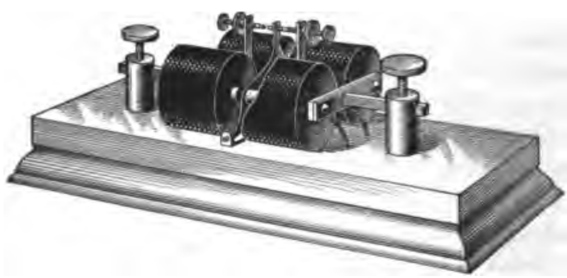


FIG. 6

located coils. Thus, the current in the line and in the artificial line will have, as nearly as possible, equal effects upon each iron armature, and hence the coils constitute an almost perfect differential winding.

10. Quadruplex Rheostat.—The rheostat used in duplex and quadruplex sets by the Postal Telegraph-Cable Company is shown in Fig. 7. It contains five movable arms for varying the amount of resistance in each group. The groups controlled by the arms *a*, *b*, and *c* are connected in series between the artificial line and ground binding posts on the right side of the box and constitute what is usually called the *rheostat in the artificial line*. Between the artificial line and binding post *p* is connected the group of resistances controlled by arm *d*, while the group controlled by arm *e* is connected between the

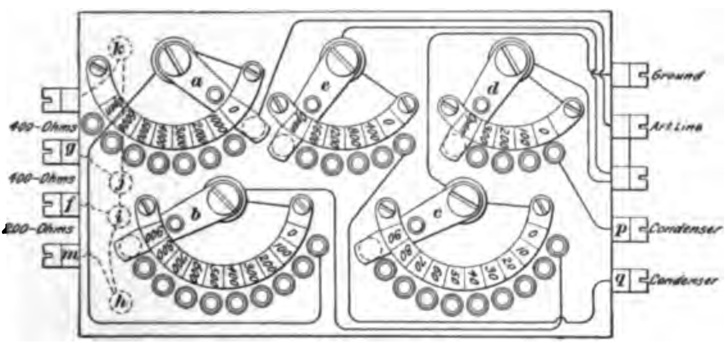


FIG. 7

artificial line and binding post *q*. To binding posts *p* and *q* are connected the ungrounded terminals of two condensers. The resistances *d* and *e* retard the discharge of the condensers.

Four binding posts on the left are connected to points *h*, *i*, *j*, and *k*, where suitable, but unadjustable, resistances may be inserted. Either post *f* or *g* is usually grounded. These resistances may be used for any desirable purpose; for instance, in the battery quadruplex the post *g* is connected to the ground while between posts *m* and *g* enough resistance may be inserted for balancing purposes. This is usually 2½ ohms for each gravity cell in the main battery.

BALANCING THE QUADRUPLEX

INTRODUCTION

11. Theoretically, a quadruplex balanced in identically the same manner as is the polar duplex should suffice for both the first and second sides; and, in fact, too great a proportion of those detailed to look after the apparatus consider their work finished when such a balance has been obtained. In practice, however, such a balance is not sufficient to obtain the maximum efficiency. Even the careful adjustment of the No. 2 relay afterwards, although helpful, must necessarily be experimental and cannot be depended on. These remarks, this method for balancing the quadruplex, and the suggestions on locating and remedying quadruplex disturbances, were largely given in various numbers of The Telegraph Age by Mr. Willis H. Jones.

The evenness of the incoming signals produced by the distant battery is interfered with by an excess of magnetism in one coil of the neutral relay over and above that in the other as well as by the period of no magnetism in the relay. If all relays were perfect, both in proper ohmic resistance and magnetic density, there would be little trouble, but, unfortunately, they are not. When new they pass a regulation test and give satisfactory results, but, like all devices, they are liable to deteriorate more or less. A stroke of lightning or an accidental excess of heat may burn the silk insulation around the copper winding and cause a few of the convolutions to be cut out in one coil. Though the damage may be very small, it will cause a proportionate inequality in the density of the magnetic lines of force set up in the iron core by the two currents from the home battery, although flowing with equal strength in both the main-line and artificial-line coils. In other words, if an ammeter shows that the strength of the current flowing in each coil of the relay has identically the same value, the magnetism in the relay, produced by the current in the slightly defective coil, will be somewhat less than that in its side partner, because there will be a smaller number of convolutions of wire. Hence, the excess of magnetic energy in the stronger coil will antagonize the incoming signals, which antagonism must not occur. When the statement is made that the current should flow equally through each coil, it really means that the magnetic energy in the two coils must be of identical value.

12. If a quadruplex possessing, say, a slightly defective polar relay and a perfect neutral relay is balanced in the manner stated, the result will be that in order to magnetically equate for the polar relay, more current must traverse the weaker coil than passes through the other. This inequality of current strength can only be obtained by a corresponding difference in ohmic resistance of the main and artificial lines. Hence, if the current is adjusted until this polar relay is unaffected by the operation of the home pole changer, the balance so obtained will necessarily be false. If false, the evenly wound neutral relay will receive more current through one coil than through the other, as its coils are in the same path as the polar-relay coils, and are fed by the same currents. As the same rule applies equally to both relays, the excess of current strength in one coil of an imperfect relay will interfere with the incoming signals in the perfect relay.

It must not be supposed, however, that the defective polar relay described is to be met with very frequently, but there are so many combinations continually arising on the various circuits, that a practically similar state of affairs actually exists to a certain degree. But whether such conditions arise or not, the neutral relay is the weaker instrument, and attention should be devoted largely to it, even at the expense of the polar side, if necessary, as the latter instrument can dispense with considerable of its working margin without material injury. To attain the highest degree of efficiency, therefore, the following plan for balancing a quadruplex is given.

THE JONES METHOD

13. Centering Armature of Polar Relay.—To center the armature of the polar relay, ask the distant office to ground. This is done by having the distant ground switch turned to the position that connects the receiving apparatus, usually the polar and neutral relays, through a simple resistance to the ground. This cuts out all the transmitting apparatus, which usually consists of the transmitter, pole changer, and dynamos or batteries, and in their place substitutes the simple equivalent resistance. Then after grounding the home-station receiving apparatus in a similar manner, the armature of the polar relay may be centered in the same way as explained in connection with the polar duplex.

14. Resistance Balance by Polar Relay.—To obtain a resistance balance by means of the polar relay, cut in the home main-line batteries, or dynamos, by turning the ground switch to the position that puts the transmitting apparatus in circuit. Then close the transmitter and adjust the artificial-line rheostat in the open and closed positions of the pole changer until the armature of the polar relay will remain on either side.

15. Resistance Balance by Neutral Relay.—To obtain a resistance balance by means of the neutral relay, turn the ground switches to the position that puts the transmitting apparatus and dynamos, or batteries, in circuit. Then close the key on the second, or neutral, side and tell the distant office to cut in and dot on his second, or neutral, side only. Pay no attention to the polar side, but consider the No. 2 relay and the pole changer an ordinary Stearns duplex set and proceed to balance as if that apparatus were being handled. In other words, while the distant office is dotting on the neutral side only, turn the retractile spring of the neutral relay down; that is, weaken the spring so as to make it as sensitive to interference from the home battery as possible, and yet respond to the dots made at the distant station. Then proceed to adjust the rheostat until the key controlling the home pole changer can be closed and opened without having the slightest influence on incoming signals.

16. Static Balance.—To eliminate the kick due to the electrostatic capacity of the line, commonly termed the "static" ask the distant office to close his key on the polar side only, keeping his neutral, or No. 2, side open, the home key on the neutral side being closed. This places the local contact points on each home relay in their most sensitive position. Then, as before, turn down the retractile spring until the tension is very slight, and devoting attention to the neutral relay alone, adjust the condensers and retarding coils until the home reversals fail to produce a kick. As most of the static discharge is usually from that portion of the line nearest the home office, the condenser that discharges through one resistance should have about twice the capacity of the other. Adjust the condenser until one plug gives too great a discharge and the next one too little, and then adjust the resistances in the retarding coils until the desired static balance is obtained.

17. Adjusting the Neutral Relay.—Ask the distant office to write on his neutral, or No. 2, side while he dots on the other; then adjust the retractile spring of the neutral relay to the signals as would be done if it were an ordinary relay. While adjusting, the home transmitter key should be closed and the neutral relay should be adjusted until the distant signals are clear. When the home pole changer is reversed, reverse it slowly at first, in order to make sure that the signals come equally clear under each reversal, then reverse it rapidly by dotting rapidly. As dots often come clearly when words will not, it is better to test the incoming signals from the writing rather than from the dots made by the distant operator.

18. Adjusting Instruments in Distant Office.—The Jones method of balancing a quadruplex system, in addition, of course, to the proper adjustment of the pole changer, has been followed by quadruplex experts for years and the superiority of such a balance has been shown by its success. But, because the kicks, when obtaining the static balance, invariably disappear from the polar relay first, the polar relay must not be depended on to show when a perfect balance has been obtained. After having followed the instructions up to this point, attention should be paid to the apparatus at the other end of the wire, because it is the duty of the home office to determine and to notify the distant office when his transmitting apparatus is not properly adjusted and when his battery is out of order.

ADJUSTMENT OF THE DYNAMO POLE CHANGER

19. The proper way to adjust a dynamo pole changer was explained in connection with the polar duplex. That explanation should be thoroughly understood before considering this one, which applies to the further adjustment and testing of the pole changer when it is used on a quadruplex system. When the pole changer has been adjusted so as to have a minimum play, and at the same time gives low but distinct signals, the tendency to arc is reduced to a minimum. The receiving operator on the neutral side of the quadruplex at the distant office will then find that his relay is getting the maximum increase in current for a working margin. If the contact points of the walking-beam pole changer are too far apart, the duration of "no current to the line" will be so great that the neutral relay of the quadruplex set at the distant office will have time to partially demagnetize. As a result, its armature lever will be pulled from the contact point by the spring at the very time, perhaps, that it is making a signal, thus mutilating it.

20. Should an operator at the home station believe that the distant pole changer is not properly adjusted, he should request the distant operator to close the key on the transmitter side of the desk, thus placing the home neutral-relay armature in position for making a dash. He should then ask the distant operator to dot on the key controlling the distant pole changer, the transmitter at the home station being kept closed. As soon as the home operator hears the dots on the polar side, he should turn his main-battery switch to the ground, in order to cut off all current except that from the distant station. Now, if the distant pole changer is improperly adjusted, there will be a kick on the home neutral relay every time that the key on the polar side at the distant office is manipulated, in spite of the fact that the signals may be received in good order on the polar side of the home station. If such is the case, the home operator should say to the distant operator: "Your reversals break up the second side." The home operator will pronounce the adjustment of the distant pole changer all right when the home neutral relay, or second side, is no longer improperly interfered with.

21. There is probably no part of a quadruplex set so liable to be out of order as the walking-beam pole changer, although it is not so troublesome, when properly adjusted, as many seem to think. The normal adjustment of a pole changer requires very close contact points and a free movement of the lever in the sockets or trunnions. The less play the lever can be given without causing the joints to spark, the less will be the tendency for it to *break over*, as the resulting interference with signals on the other side is usually termed. No quadruplex will yield its full efficiency with too much play between the lever and contact points of the pole changer. When the potential of the battery is too great to permit of a close adjustment, condensers should be connected around the contact points for the purpose of eliminating excessive sparking.

As a close adjustment of a pole changer causes the latter to give out a very feeble sound, sending operators sometimes find it difficult to hear their signals and, in ignorance of the consequences, give the pole-changer lever more play. This either kills the other side of the quadruplex entirely or greatly reduces its efficiency. To avoid this possibility, it is customary to insert an ordinary sounder in series with the pole-changer magnet. This reading sounder may then be adjusted to suit the fancy of the sending operator while the pole-changer adjustment may be forced to the limit.

ADJUSTING THE TRANSMITTER

22. Many quadruplex attendants apparently believe that a transmitter is adjusted when each platinum contact point breaks clear and free. As a rule such an adjustment is sufficient, but when the tongue, although apparently making contact, is not drawn sufficiently firm against the platinum contact point, owing to a weak tension or bent spring, a great deal of trouble is not only created but an inexperienced quadruplex chief may be sorely perplexed in locating the source of the resulting disturbance. Under such conditions the added-resistance-and-leak-coil box will not cause the proper strength of current in the line. The lower potential applied to the line, when there is poor contact between the tongue and the lever-contact point, is not as low as it should be because the drop in the leak coil, due to the smaller current flowing, is less than it should be. Consequently the potential and current for the short end are entirely too great and thus reduce the working margin of the current for the long end.

Transmitter tongues should be examined carefully and often, as a bent or untempered tongue spring in connection with a feeble retractile-spring tension will cause no end of trouble for the man at the distant end of a quadruplex circuit.

ADJUSTING REPEATING SOUNDER OR RELAY

23. When a repeating sounder or relay is used in connection with a neutral relay on a quadruplex circuit, the contact points of both the neutral relay and repeating sounder or relay should be sufficiently far apart to give the levers considerable play. The effectiveness of the repeating devices depends, in this case, on the space between the contact points of both the relay and repeating sounder being too great for a feeble discharge current from the line to force the levers entirely across. This is a point too frequently overlooked by those having charge of quadruplex apparatus. On the other hand, when a repeating sounder or relay is used merely to shunt a local circuit, as in some single-line repeaters, the points should be closer together and the springs stronger.

THE HANCOCK METHOD

24. A method of balancing a quadruplex system described by Mr. B. P. Hancock in The Telegraph Age may be called the **Hancock method.** This method also is based on a neutral-relay balance. Not infrequently, after an apparently perfect balance has been obtained by the usual method, the polar relay having been used as a medium, it is found that when the distant office is cut in, the neutral side shows unmistakable signs of an imperfect equilibrium. This result may be due to inequalities between the windings of the polar or neutral relay, or it may be that inductive currents are so much in evidence, and keep up such a rattle on the instruments under attention, that it is impossible to tell when a perfect balance has been reached. Whatever the cause may be, some reliable method is needed to secure a practically true balance of the neutral side—the one object of marked solicitude at all times. The following method has given satisfactory results to Mr. Hancock and his associates for some time.

25. Centering Armature of Polar Relay.—While the Hancock system makes use only of the neutral relay as the medium for obtaining the balance, it is best to begin by grounding the circuit at both ends and adjusting the polar relay until the armature rests indifferently on either stop or vibrates properly between them.

26. Resistance Balance.—In making a resistance balance, cut in the home battery and adjust the rheostat until a line balance is secured. Then have the distant office cut in by opening his neutral side and closing his polar side. Now take the home battery off the line by placing the arm of the ground switch on the grounded contact button and turn the spring of the neutral relay down to the very lowest tension necessary to hold the armature in an open position, making certain that the magnets are sufficiently far from the armature to make only a slight tension necessary to produce that result. When this has been done, it will be found, when the home battery is restored to the line and the key on the neutral side is closed, that if the balance is at all defective, the neutral relay will respond to the movement of the pole changer—closing when the pole changer is opened and opening on the reversal, or vice versa.

27. To obtain a balance, place the pole changer in such a position that the neutral relay remains closed; gradually alter the resistance of the rheostat until, with the least change in resistance, the neutral-relay armature opens. The quickest way to reach this result is to remove the plug that will insert 1,000 ohms into the artificial-line circuit and note the effect on the neutral-relay armature. If it opens, replace this plug and unplug, say, 400 ohms. If the relay does not open, add say, 100 ohms to the circuit and continue adding resistance until a grinding movement appears in the neutral relay; then unplug about 10 ohms more, and the desired result will have been obtained. Should the neutral relay fail to open when plugs are removed from the rheostat, proceed in the same manner, but insert the plugs instead of removing them. If the home battery does not manifest itself under these conditions it is not likely to do so at all.

28. Static Balance.—To find the static balance, turn the neutral-relay spring just high enough to keep the armature quiet when the home keys are at rest; then adjust the condensers and retardation coils so that the neutral relay is not affected by your reversals. A perfect static balance is of the utmost importance if satisfactory results are to be obtained.

POSTAL RULES FOR BALANCING QUADRUPLEX

29. Following are the rules given for balancing the Postal Telegraph-Cable Company's quadruplex systems:

1. Ask the distant station to ground.

2. Throw the ground switch at the home station to the left.

3. Set the armature of the polar relay in the center by adjusting the magnets until the armature will remain on either contact, or until it vibrates freely in response to the induced currents from the line. The magnets should not be too far from, nor too close to, the armature to give the best results. The correct distance varies according to the resistance of the circuit. The contact screws should be so adjusted that the armature is in a vertical position. The relay will not work well if the armature is not so arranged.

4. Throw the home-station ground switch back to the right, thus placing the current on the line. Take a *line balance;* that is, adjust the artificial-line resistance in the rheostat until the polar relay again acts as it did when the line was on

ground at both ends. This line balance should be tried with the home key first open and then closed. If there is any variation in the resistance required to effect a balance an average should be made.

Following this, ask the distant station to cut in and dot or write on the neutral or common side. With the home keys quiet, the neutral relay-spring tension should be adjusted as low as it will go and still clearly produce the signals from the distant station. The home battery should then be reversed and if this makes the signals from the distant station heavier or lighter the rheostat should be adjusted until the reversal of the home battery does not affect them.

To obtain a static balance: Ask the distant station to open his key on the common side, thus placing his short end to the line. Close the common-side key at the home station. With the distant keys quiet, the neutral-relay spring tension should be adjusted very low and the condensers adjusted until reversals of the home battery, no matter how rapid, do not affect the neutral relay.

BALANCING WITHOUT HELP FROM DISTANT OFFICE

30. It frequently happens that duplex and quadruplex sets are located in some out-of-the-way place in the office where the operator cannot get at the apparatus without leaving his desk and sometimes the assistance of the quadruplex chiefs at both ends cannot be secured simultaneously for a long time. Furthermore, repeaters are also frequently inserted in such lines, causing a longer delay in securing attention. For such cases and wherever the ground switch is not available to the operator, who may even be a competent quadruplex man, Mr. E. L. Bugbee gave in The Telegraph Age the following method for balancing duplex and quadruplex sets without grounding the sets at either end. On a polar duplex it is merely necessary to "break," thereby stopping the other end from sending for a moment; on a quadruplex, it is necessary to stop the sending from the other end on both sides and to close the key on the second side to get the full force of the home battery. Then proceed as follows:

Place a finger of the left hand on the armature of the polar relay, resting the hand or arm against something to steady it. If the key at the other end is open, press forwards on the armature; if the key at the other end is closed, press backwards on the armature until the magnetic force of the coils is nearly overcome by the pressure of the finger. Then with the right hand, open and close the key, working the pole changer slowly, making very long dashes. If the relay armature under the pressure of the finger follows the movement of the key, that is, if the receiving sounder closes when the key closes, the balance is too short and needs *lengthening;* in other words, the artificial line needs more resistance. On the contrary, if the armature goes backwards when the key closes, the balance is too long and needs *shortening;* that is, the artificial line needs less resistance.

Having properly adjusted the resistance of the artificial line, proceed to adjust its capacity. If the armature jumps when the key closes, more capacity is needed in the artificial line; on the contrary, if the armature jumps when the key opens, less capacity is required.

31. If the armature of the polar relay is out of center, it may be moved either way required, which can be fairly accurately judged by the eye and more so by the finger. The balance may then need further adjustment. When the armature is on the center and the artificial line balances the line, there will be no movement or jump of the armature under the most delicate pressure of the finger; and the finger can be trained to possess a very delicate touch. The first efforts to balance in this manner may be awkward and inaccurate, as they are by other methods, but practice makes perfect. Mr. Bugbee says that this method of balancing is especially valuable at the terminals of a duplex or quadruplex circuit containing a repeater and that no time should ever be lost, because of being out of balance, at the terminal of a polar duplex by waiting for the repeater attendant to ground for a balance, nor on a quadruplex under ordinary conditions.

REDUCING SENSITIVENESS OF RELAY TO INDUCTIVE DISTURBANCES

32. At the present time the tendency of American practice is to use lower electromotive forces at the terminals of telegraph circuits and lower resistances in relays for multiplex systems. Very satisfactory results have recently been obtained on quadruplex circuits by using electromotive forces as low as 200 volts on well-insulated lines of comparatively low resistance (2 ohms per mile), and with polar relays wound to 100 ohms and neutral relays wound to 50 ohms. The length of the cores of these relays has been somewhat increased. The 600-ohms resistances usually inserted next to the current generators have, in such cases, been reduced to 300 ohms and the added resistance in the Field systems has been reduced from 1,200 to 600 ohms and the leak coils from 900 to 450 ohms. The object is to reduce the inductive effects upon parallel circuits and to render the relay less sensitive to inductive disturbances from any source.

33. Relay Windings.—The use of neutral relays wound with enamel-covered wire is very desirable, because the neutral side is the least reliable and every improvement in the margin is valuable. An 800-ohm polar relay, like the Skirrow, has 14,200 turns of No. 35 B. & S. black enameled wire, while the 800-ohm Freir neutral relay has 14,100 turns of No. 35 B. & S., single, silk-covered wire. It is better, however, to wind the neutral, rather than the polar, relay with the enameled wire.

A certain quadruplex circuit of No. 9 B. & S. copper, including 8 miles of cable, was 500 miles long. The voltages at one end were 290 and 85, giving a ratio of 1 to 3.4. The voltages at the other end were 255 and 80, giving a ratio of 1 to 3.2, or an average ratio of 1 to 3.3. The polar relays were wound to a total of 180 ohms, or 90 ohms per side, and the neutral relays to 150 ohms per side. The Field key system was used, but the lamp resistance was only 200 instead of the usual 600 ohms, the resistance of the artificial line for a balance in fair weather was 2,990 ohms; in bad weather the lowest balance at which all four sides would operate was about 1,800 ohms. The least value of magnetizing current to which the neutral relay would respond in commercial operation was .054 ampere; any increase in leakage would require a lower balance than 1,800 ohms, which made the neutral side inoperative. The insulation was .78 megohm per mile. The neutral side failed quite a number of times per year, with every occurrence of fairly heavy weather over the line as a whole. The diminished lamp resistance increased the margin and the reduction in polar-relay resistance produced the same result without jeopardizing the proper operation of the polar side. The operation could have been improved by the use of Freir relays and a greater electromotive force. A standard quadruplex neutral relay wound with 5,600 turns of No. 33 B. & S. enameled wire would operate on a change in the line current of .005 ampere, the lowest commercial operating line current being .04 ampere.

LOCATING AND REMEDYING QUADRUPLEX DISTURBANCES

INTRODUCTION

34. One of the most perplexing problems that chief operators and those detailed to oversee and care for quadruplex apparatus, with which they are not familiar by previous experience, have to meet is the determination and location of a fault directly it is reported. The ability to do this quickly and with any degree of certainty necessitates not only a thorough knowledge of both the mechanical construction and the theory of the apparatus, but a careful and persistent observation of each accompanying symptom as the various disturbances appear from time to time.

Nevertheless one must not be discouraged should the task of locating the disturbance by the observance of one or more of the numerous signs prove to be at fault. The most experienced experts are frequently compelled to make several tests before arriving at a definite conclusion, on account of the similarity of certain features accompanying faults of a widely different character. But as a rule, the most frequently occurring disturbances can be readily determined with a reasonable degree of certainty, after a comparatively short experience, if one will but take the trouble to learn the significance of the ever-present guides, of which the following are the most trustworthy.

WIRE FAULTS

35. Open Line.—It is a sure sign that the line wire is open if the polar relay promptly and distinctly records the signals made on the key on the No. 1 side of the desk at the same station (even though the *back stroke* is obtained; that is, even if the armature returns to the back stop when the key is released) and the removal or insertion of plugs in the rheostat has no disturbing effect on the signals.

36. Bad Wires.—To determine whether a wire has failed, the following method is successfully used by experienced operators: When a duplex or quadruplex apparatus becomes badly out of balance, it is frequently hard to determine whether the wire has failed or not, especially in stormy weather. In such a case the best, and probably the only, way for the terminal stations to find each other is for each in turn to ground his set temporarily after first giving a few calls. If the wire itself is all right, the station with the grounded set can hear the call from the other end, no matter how badly the apparatus is out of balance. This method should always be followed when a new wire is placed in circuit or the wire in use gives trouble.

37. Crossed or Grounded Lines.—Should the signals be broken up, or otherwise interfered with when the operator is testing for bad wires, it will denote that the line wire is closed, but that it probably is crossed or grounded at some unknown point. If it is simply grounded, the armature of the polar relay may be centered when the home switch is turned to the earth, exactly as would be the case were this ground the legitimate compensating ground coil in the quadruplex apparatus at the distant office.

38. Finding Faulty Wire.—To determine on which side of a repeating station the wire has failed, it is only necessary to listen to the signals produced on the relay by manipulating the key. If the fault is beyond the repeating station, the signals will be recorded on the relay and sounder a fraction of a second after the key makes contact. In other words, the signals will apparently lag just behind the motion of the wrist.

39. Foreign Current.—Should the lever, under the foregoing conditions, persist in clinging strongly to one pole of the magnet, there is present a current of electricity, which is probably from some foreign circuit with which the wire is crossed. Of course, it is possible that the current may be legitimate, and that the distant station, through defective or improper adjustment of the apparatus, may be unable to make himself heard; but where the office at the other end of the circuit is completely lost, it is quite safe to attribute the current to a cross.

When a wire is free from foreign currents, that is, when an ammeter gives no indication of a current of electricity while both the home and distant stations are connected to the ground as for balancing, the current readings produced by the home battery may be obtained with the regular quadruplex circuit grounded at the distant station as for balancing. But when a foreign current enters the line, it is useless to attempt to measure the current due to either the home or distant battery while the faulty line wire is in circuit, as the readings will necessarily be very inaccurate, owing to one pole of the battery being assisted by the foreign potential and the other pole opposed by it to a like degree.

40. Escaping Current.—A current escaping from the line should not be mistaken for a foreign current entering the line. An escaping current, such as frequently occurs on wet days, will not cause one terminal of the home battery to give more or less current than the other terminal, and it is frequently possible to adjust over it. But a leak into the line from some other circuit or a difference of potential between the earth at the two stations, which will give any reading on the ammeter when both quadruplex sets are grounded, as for balancing, is a dangerous condition that often decides the working efficiency of a quadruplex circuit and is a factor too commonly ignored by wire chiefs. The first test made should always be to ascertain whether current is leaking into the line.

41. Disturbances Due to Aurora Borealis.—When electrical disturbances, that usually accompany the aurora borealis displays, appear, the quadruplex circuits are first rendered useless, then the duplex circuits. When the duplex refuses to work on the usual line wire, it may be retained if there is a wire between the same stations that can be used, by the following procedure. Use the higher resistance line as the regular duplex line and the lower resistance line in place of the ground, breaking all connections with the ground at both ends and transferring them to the wire used as a return. The duplex set must be rebalanced and the addition of another condenser may be necessary.

When the aurora begins, the next station should be frequently asked to answer on the duplex line, and when the reply is light one time and a few minutes later heavy, trouble is not far off. Another test is to ask the distant office to ground; if the aurora is causing trouble the distant grounding cannot be felt at all, or, if it is maintained for a few minutes, the current may reverse and the polar armature will go to the other side. Under such conditions it is not advisable to attempt to work by rebalancing, because the balance so obtained will not hold for any length of time and when the aurora, which may not last 15 minutes, has gone, the set will be all out of balance, and will have to be balanced all over again.

42. As the aurora becomes worse, work the line single. As the current may reverse every few minutes, it is best to use a battery at one end only, or with no battery, grounding the line directly at the end or ends where no battery is used. When the disturbance gets very bad it may be necessary to watch the polar relays closely to prevent their overheating by removing them from the line. In fact one of the first indications on long duplex lines of an aurora disturbance is that the polar relay gets hot. It may, however, get quite hot and still work through the disturbance.

When the disturbance is so bad that wires cannot be even worked single, two wires, where available, may be worked as a metallic circuit; that is, the extra wire may be used as a return circuit in place of the earth.

43. Inductive Disturbances.—When a quadruplex circuit is affected by induction from a neighboring parallel cable or aerial lines, the short-end current should not fall below 12 or 15 milliamperes, 18 being about normal. Less than 12 milliamperes is unsatisfactory except on very short circuits free from inductive or other outside sources of disturbance. The long-end current should, of course, be three or four times the short-end current, according to the proportion used.

DEFECTIVE APPARATUS

44. It sometimes happens that while the wire "quads" O. K. at this end (to use familiar language), the distant office fails to get four corners out of his apparatus. It is in such cases that the skill of a chief operator is most severely tested, and when an opportunity is presented for him to help out of a difficulty an inexperienced quadruplex attendant at a small repeating station. It will be assumed for the purpose of demonstration, that the wire and the apparatus at the other end of the circuit are O. K., but still the distant operator is unable to read the home signals clearly on one or perhaps either of his relays. It will also be assumed that the apparatus is arranged for dynamos and that the trouble is in the home set.

The distant office should be asked to state the nature of the fault, in order that the search may be made in the right direction. If he says that the signals are distinct on his common side only when the home, or chief operator's, polar side is quiet, it is more than likely that the home, or chief operator's, pole changer is improperly adjusted. After the contact points of the home pole changer have been cleaned and adjusted as closely as is possible, without giving them a tendency to spark, the distant office should be asked to ground and to listen to his own neutral relay while the home, or chief operator's, pole changer is worked with the full home battery connected in the line, that is, with the chief operator's transmitter closed. If under these conditions the distant operator hears no click on his neutral relay, the fault will have been eliminated.

45. It frequently occurs that the distant operator cannot hear on his neutral relay the signals made at the near, or home, end. When notified of this fact, the home office should immediately examine the tongue of its transmitter, as well as the wire attached to the leak box in the added-resistance-and-leak-coil quadruplex. In nearly every case, the trouble will be found at one of these points. Perhaps the adjustment of the contact points is such as to prevent the tongue from being pulled away from the upper post when the transmitter is opened, thereby making no connection with the leak coil. Under these conditions, the full home battery will continue to go to the line by way of the upper post of the transmitter, regardless of its position, and the neutral relay at the other end of the wire will, therefore, remain closed.

For a similar reason, the distant neutral relay will remain open, irrespective of the position of the home transmitter, should the tongue of the latter always cling to the lower contact point. In the latter disarrangement of the device, the 900-ohm leak coil in the added-resistance-and-leak-coil quadruplex will always be connected, and, consequently, the electromotive force will be reduced to a strength equal to that of a short-end battery.

46. Defect in Leak-Coil Circuit.—Should the wire attached to the leak coil in the added-resistance-and-leak-coil quadruplex become broken or disconnected, the neutral relay at the distant station will remain closed, regardless of the position of the home transmitter, because the short route that reduces the home electromotive force is now unavailable.

A short-end current of 20 or even 25 milliamperes on a very low resistance line, and a proportionately increased value for the long end, merely indicates that the distant station is supplying more current than is actually required, but it is doing no harm. But a short-end current exceeding 25 or 30 milliamperes, without a corresponding increase for the long end, indicates a faulty transmitter or leak box.

47. Defect in Ground-Coil Circuit.—Suppose that a station informs the home office that, notwithstanding the fact that his balance is apparently all right, on attempting to work the apparatus, he finds that both of his relays are more or less interfered with by his own battery. One pole of his battery may cause the incoming signals to be either light or heavy, as the case may be, while the other pole may have the opposite effect—possibly shutting out altogether the incoming signals. The home office should immediately suspect its own ground coil of being the cause of the trouble. It is quite evident that the apparatus at the other end of the wire is out of balance, and it therefore follows that the abnormal resistance to which the rheostat had been adjusted, while the home end was grounded, disappeared the moment that the home ground switch was turned to the battery again.

The reason for this fact is that an open ground coil will compel the incoming current to find a ground through the home-office rheostat or the leak coil, either of which contains a much greater resistance than does the proper compensating ground coil. The balance at the distant station will, therefore, be false, because, after the home office has cut in, the actual resistance of the circuit will be much less than when the artificial line at the distant station was balanced, and hence the artificial-line resistance at the distant station is too high.

A loose connection of the wire that is connected to a ground coil, or an ink-covered disk on the rheostat, may add a resistance of several hundred ohms to the ground coil and thus destroy its usefulness. If the fault cannot be quickly repaired, the distant station should adjust his rheostat to the incoming signals on his neutral relay, while the home office dots or writes for him on its transmitter only, in accordance with the method of balancing that has been given.

48. Defective Ground Wire.—If, after obtaining a correct balance at both the home and distant stations, the maximum current is very much less than it should be, it is probable that the ground wire from the dynamos or battery is loose at one or both ends, or that it is open at one end. If it is open at one end, the incoming current is forced to reach the ground through the artificial line instead of through the ground wire, thus reducing the current to about one-half its strength, because the resistance in the path of the current to the ground is about double its normal value.

BATTERY FAULTS

49. One Pole of Battery Open.—When the distant office, after taking a careful balance, informs the home office that he can hear the home-office signals on his neutral relay only when the home-office key on the polar side is closed (or open, as the case may be), it is possible that one pole of our battery is open, or, at least, that the current is not passing through the pole changer. To quickly verify this fact, place the switch lever in such a position that it is not in contact with the button connected to the transmitter or pole changer, but so close to the grounded button that a lead-pencil point or knife blade will make contact between them. Then by opening and closing the pole-changer key while inserting the pencil point or knife blade between the grounded button and switch lever, a spark will appear the instant contact is made if there is no open circuit in either polarity. The absence of a spark will show that no current reaches that point, while the position of the pole-changer lever will indicate which polarity is missing.

50. Should it be impossible to restore the battery at once, it will be possible to get a duplex out of the quadruplex apparatus by so setting the home-office key on the polar side that the lever of the pole changer will rest on the good pole of the battery. The common or neutral side may then be used as a duplex. Do not attempt, in this case, to transmit on one side of the quadruplex and receive on the other side, because the apparatus will not so work, for both sides cannot be properly balanced under such conditions, and an attempt to work thus will simply destroy both sides.

51. Defective Cell.—Many of the troubles found in connection with quadruplex systems are due to loose connections, broken wires, defective batteries, punctured condensers, and defective resistance boxes, in addition to the bad condition of the various contact points. A defective cell in either the long-end or short-end battery is very often the cause of considerable trouble. If there is a defective cell in the long-end battery at the distant office, the fault will appear only when the distant office has his transmitter key closed. If the cell is so bad as actually to open the battery circuit, the polar relay will not be affected when the distant pole changer is operated, as long as the distant transmitter is closed; and the operation of the distant transmitter will not operate the home neutral relay at all. On the other hand, should there be a defective cell in the short end of the distant battery, the trouble will appear in either position of the distant transmitter, and the current will be too weak to even operate the polar side.

52. Defective Tap Wire.—A break in the tap wire at the distant station will interrupt all current when the short end of the distant battery is connected to the line, as it should be when the transmitter is open. In this case, the polar relay will work all right when the distant pole changer is operated, provided the distant transmitter is closed. When the distant transmitter is open, neither side will work.

There are symptoms that, although pointing strongly in a certain direction, may possibly be due to an entirely different cause from the one suspected. For example, after having taken a careful balance and adjusted the apparatus for the best results, it is frequently found that, in spite of these efforts, the incoming signals on the neutral relay are still more or less interfered with as soon as the distant office begins to send on the polar side; in a majority of cases the trouble is due to an improper adjustment of the distant pole changer. But to be certain that the home apparatus is not defective, it is well to exchange the set, temporarily, with one that is known to be in good condition. Should there still be no improvement and it is known that the wire itself is perfectly clear, it will then be in order to suspect the distant battery.

53. Margin Too Small.—It is possible that the strength of the incoming current, due to the short end of the distant battery, too nearly approaches the strength of the current due to the long end of the distant battery. In such a case, the distant office should be notified that his proportions are incorrect, meaning, of course, that the respective currents from his short-end and long-end batteries are not reaching the home office in the proper ratio of 4 to 1, or 3 to 1, as the case may be.

This discrepancy may arise from a variety of causes, but in nearly every instance (assuming that the wire is perfectly clear and free from escapes) the trouble will be found to be due to a defective or improperly adjusted transmitter, dirty contact points, a defective leak coil, or a loose connection of the wire attached to the leak coil at the distant station. Possibly one contact point of the distant pole changer is black from oxidation, thereby causing a higher resistance in one position of the pole changer than in the other.

54. A dirty or improper contact between the tongue of the transmitter and the lever bar might add a resistance of hundreds of ohms to the route of the current. The effect of such a condition on the current in the added-resistance-and-leak-coil quadruplex is identical to increasing the resistance of the leak coil by just that many additional ohms. Under these conditions, the resistance of the 600-ohm lamp in the dynamo circuit plus the 1,800 ohms in the added resistance coil will be considerably less, in proportion to the resistance through the tongue and the leak coil, than it should be. Hence, a much larger proportion of the total current might be forced through the line to the distant relays than is intended. Therefore, an abnormal condition, due to an unusually high resistance of a part of the circuit, may cause the strength of the current from the short end of the battery to be very nearly equal in value to that from the long end. A loose connection at the binding post of the leak coil will also increase its resistance and so increase the short-end current in the line in the same manner.

In verification of this fact, it is only necessary to call attention to the fact that to increase the short-end current under normal conditions, 100 ohms is added to the leak coil by removing the plug from the right-hand hole of the leak-and-added-resistance box, which contains that amount of surplus resistance for this very purpose. The addition of a resistance in the leak-coil circuit, therefore, increases the strength of the current from the short-end battery, but does not necessarily alter the value of the current from the long-end battery.

55. Improperly Adjusted Transmitter.—Quite frequently the stronger current is greatly reduced in value, notwithstanding that the dynamo or battery may be furnishing full pressure. Under these conditions, the working margin of the neutral relay will appear to be very small. In all probability, the source of this small margin will be found in a double contact between the tongue of the transmitter and both the upper and the lower contact points, owing to an improper adjustment of the transmitter. Should the tongue accidentally touch the lever bar so imperfectly as to cause a high resistance at that point, during the time it should make contact only with the stop, a much smaller proportion of the total current will flow through the line and distant relays than was intended; hence, it may cause the strength of the current due to the long end of the battery to be very nearly as small as that due to the short end.

If, during wet weather, the system has been worked as a duplex only and an extra resistance in the battery circuit was necessary in order not to have an excessive current, this resistance must be cut out when the wet weather clears and the system is to be used again as a quadruplex. If this resistance is not cut out at the distant end, the margin on the home neutral relay will be very small. When it is suspected that the weakening of the incoming current, when the long end of the distant battery is connected to the line, is due to the fact that this resistance is still included in the circuit at the distant end, the distant operator should be requested to see that this resistance is cut out.

56. Defective Condensers.—Sometimes the condensers in the artificial line will be punctured by a lightning discharge during a thunderstorm. When this happens, the artificial line is short-circuited, and no amount of adjustment of the resistances or condensers will balance the line. The defective condenser must be replaced by a good one before a balance can be obtained.

57. Experience Required.—It requires considerable actual experience to be able to nicely adjust the apparatus; but one of the safest guides to follow is to see that the contact points of all transmitting apparatus are as close together as they will work without sparking, and give to the spring a tension that will not cause a jar as the armature rebounds. At the same time, the lever must work freely in the trunnion without destroying the good contact. The down stroke of all armatures should be slightly stronger than the up stroke. Above all things, the spring on the pole changer must not cause the lever to tremble, or vibrate, when released by the local magnet, and the closer together the pole-changer points are placed, the better will the man at the distant station get the home-office signals on his neutral relay.

MEASURING INCOMING CURRENT

58. The most important thing to bear in mind when making tests of the incoming current is that no matter what value the ammeter, or current indicator, gives for the strength of the current from the long-end battery, the strength of the current due to the short end of the distant battery should be approximately just one-third or one-fourth that due to the long end, according to whether the distant station is giving you a proportion of 3 to 1 or 4 to 1. When an improper ratio between the incoming line currents in the open and closed positions of the distant transmitter is suspected, the manner in which the strength of the current from the distant battery may be measured, assuming, of course, that the wire itself is clear and free from abnormal escapes, is as follows:

59. Western Union Method.—If the current is to be measured at the desk of a Western Union quadruplex set:

1. Ask the distant office to close both keys.
2. Turn the home switch to the ground button.
3. Remove the main-line wire from the binding post of the polar relay (usually the binding post at the extreme right), and with the fingers of one hand only firmly hold the wedge of the ammeter between the line wire and the binding post; or insert the ammeter in the main line at the switchboard.
4. Note the deflection of the needle of the ammeter, and record the reading as the value of the current from the distant long-end battery, that is, with the distant transmitter key closed.
5. Cut in the battery and say to the distant office: "Open the key on the polar side only." Then ground the wire again and proceed as before. The reading now shown by the needle of the ammeter will represent the strength of the current from the long-end battery, but due to the other pole of the battery, and should be practically the same as that due to the other polarity. Neutral quadruplex relays require from 45 to 60 milliamperes; hence, the strength of the current from the distant long-end batteries should give a value within these limits.
6. Cut in again and say: "Open the keys on both sides of the table." Then ground and measure as before. The needle will denote the value of the current from one pole of the distant short-end battery. The other polarity is measured in a like manner, after first requesting the distant office to close the key on the polar side only. These two measurements of the current from the distant short-end battery should also agree in value. Polar relays on quadruplex circuits require from 15 to 18 milliamperes for the value of the current from the distant short-end battery.

60. Current Ratio.—A convenient method of determining the current ratio produced by the home battery is to ground the line wedge of the quadruplex apparatus at the main switchboard through about 3,000 or 4,000 ohms, and a milliammeter; then note the readings of the milliammeter with the pole changer and transmitter, both open and both closed. The current values thus obtained will not indicate the current that actually goes to the line when the apparatus is working on a regular line circuit, but from them may be obtained the true current ratio that the apparatus is capable of producing when the line to which it is assigned is free from foreign influences. With this method, it is immaterial whether the reading for the short-end current is 10 or 40 milliamperes, provided both the positive and negative terminals of the battery give identical readings, and the long-end current is 3 or 4 times, as the case may be, that of the short-end current. Abnormal currents observed with this arrangement are caused by the resistance temporarily inserted in the line being greater or less than the normal resistance of the circuit with which the apparatus is regularly used.

61. Postal Telegraph-Cable Method.—In order to measure the ratio between the strength of the incoming current in the open and closed positions of the distant transmitter in the Postal Telegraph arrangement of connections, insert the wedge, to which the milliammeter is connected, between the lever of the ground switch and the ground button. The current flowing through the milliammeter, when in this position, will be somewhat smaller than the current actually flowing in the line coils of the relays. Nevertheless, the milliammeter reading will be proportional to the strength of the current in the line coils, and, consequently, if the reading of the milliammeter is reduced one-third when the distant transmitter is opened, the current in the line coils is also reduced to one-third its previous strength.

To test the home battery, have the distant office ground his end, and insert the home-office milliammeter wedge between the lever of the ground switch and the battery button. Then, by opening and closing the transmitter key, the ammeter will indicate the difference between the current from the long-end and short-end batteries.

If the ratio between the electromotive forces, or the ratio between the added and the leak resistances in the dynamo quadruplex at the distant station are correct, the value of the long-end measurements (irrespective of battery polarity) should be represented by a figure practically either three or four times as great (depending on the ratio employed) as that obtained by the short-end measurement.

62. Determining Condition of Circuit with Galvanometer.—When the Kansas City office of the Postal Telegraph-Cable Company was equipped, a galvanometer was included in the multiplex circuits in order that the condition of each multiplex circuit between the home office and the other terminal, or repeater, stations could be told at a glance, thus avoiding the necessity of trying a balance, and, consequently, saving much time. If one coil of a differentially wound galvanometer is permanently connected in the line circuit and the other coil in the artificial-line circuit, it can easily and quickly be determined if the current from the home station divides equally between the two circuits mentioned and, also, if the ratio between the minimum and maximum current is the one desired. When the line and artificial line are equal in resistance and the distant keys are not being operated, the differential galvanometer will be deflected a certain amount, which should remain the same for either the open or closed position of the home pole changer.

DISTURBANCES DUE TO TROLLEY CURRENTS

63. In some localities where trolley or electric-light plants are located, the potential of the earth frequently becomes so high, through leakage or otherwise, that if one end of a telegraph wire is buried in the earth at that point and grounded at a distant station, a current will flow through the conductor from the point of the highest potential to the normal ground at the other end of the circuit. Should such a condition exist, the office at the station possessing the normal ground will apparently find his apparatus out of balance. If the foreign electromotive force from the distant ground is 10 volts positive, it will add that many volts pressure to the positive pole of the battery located at that point; it will, equally, oppose 10 volts to the negative pole, and thus actually cause a difference of 20 volts between the two polarities. The neutral relay at the station possessing the normal ground will therefore be more strongly magnetized by the incoming current from one pole of the battery than from the other. This will render impossible the adjustment of the retractile spring on the home neutral relay to suit the strength of both currents.

In order to ascertain whether the inequality thus found in the two currents is due to the presence of an auxiliary electromotive force, ground the wire at each end of the circuit, thereby cutting off both batteries, and then measure the current with an ammeter. Should the ammeter show an undue deflection (still assuming the wire to be clear), the source of the disturbance may be properly attributed to the leakage of current from a trolley or electric-light plant, which gives the earth at that point a certain electrical potential.

64. Remedy.—When the disturbance in potential between two stations is constant and permanent, the remedy is to insert a few cells of battery in the common ground wire running to the dynamo; or, in the case of the gravity battery quadruplex, between the ground and the pole changer. The value of the electromotive force of the inserted cells must be identical with that producing the earth current. The direction, of course, should be in opposition to the disturbing element; that is, if a foreign current from the ground is being forced into the wire with a pressure of 10 volts positive, 10 volts positive must be inserted against it in order to destroy its detrimental effect.

65. To determine the number of cells to be inserted, ground the wire at both ends of the circuit and note the deflection of the needle of an ammeter connected in the line circuit. Then insert a few cells of battery in the common ground wire and again observe the deflection. If the strength of current, as shown by the ammeter, has been increased in value, it will indicate that the wrong end of the row of cells has been placed toward the line. Reverse their position, and measure as before. Continue inserting or subtracting cells until the needle returns to zero.

It is important that the cells used for this purpose should have little or no appreciable internal resistance, as an appreciable resistance will be equivalent to increasing the resistance of the dynamo or battery circuit, which would be wrong. A gravity battery, therefore, is not desirable, but a storage battery is an ideal one for this purpose. As the value of the earth current must necessarily fluctuate more or less between the periods of wet and dry weather, it is well to have in reserve a few cells that can be switched in or out of circuit as occasion requires.

DUPLEX AND QUADRUPLEX TELEGRAPHY

(PART 5)

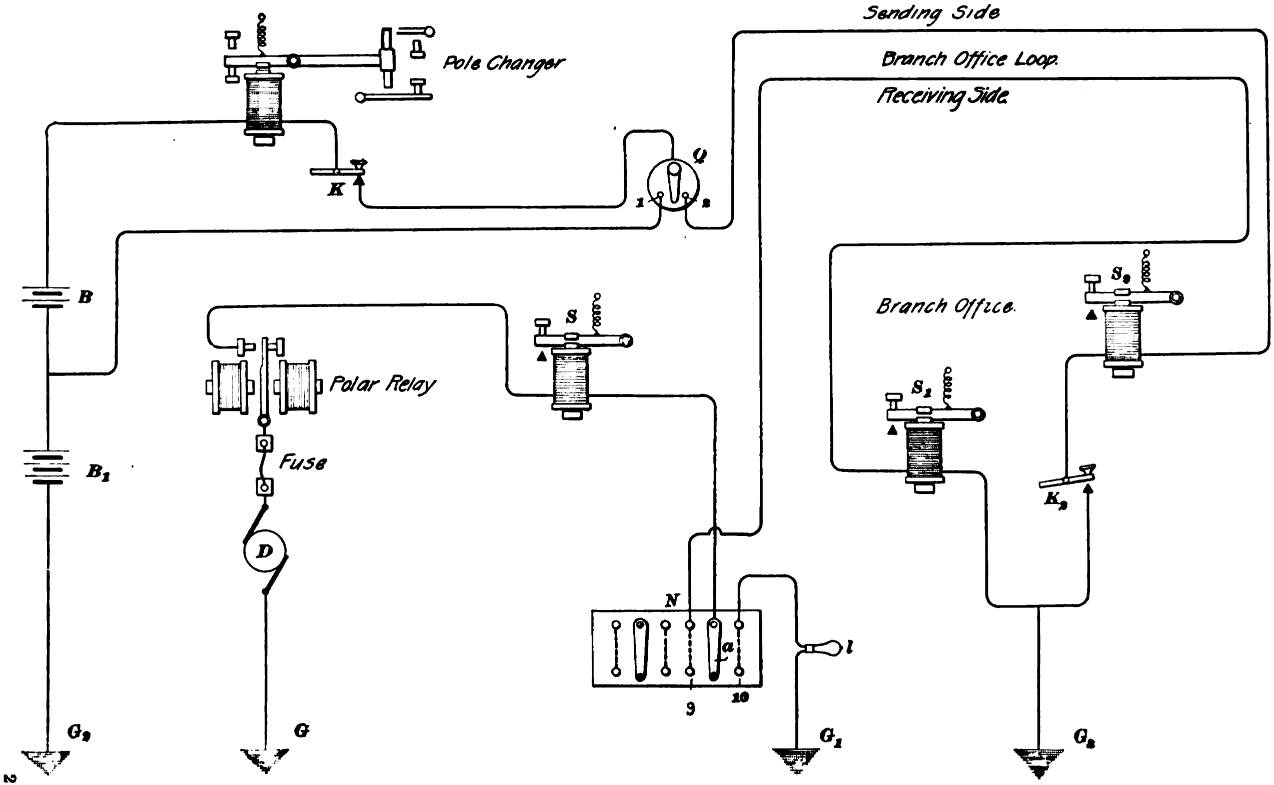
QUADRUPLEX TELEGRAPHY—(Continued)

QUADRUPLEX LOCAL CIRCUITS

BRANCH OFFICES ON MULTIPLEX CIRCUITS

1. It is often desirable to extend the receiving and sending sides of the duplex and quadruplex circuits to a branch office; where dynamos or primary cells are used, the general method of doing this is shown in Fig. 1. Where batteries are used, it is customary, in order to get the same current, to increase the number of cells when the circuit is extended to a branch office; the method of doing this is shown in connection with the pole changer. When the arm of the switch Q rests upon the contact button *1*, the magnet of the pole changer is connected in series with the key K and the battery B. When the arm of the switch Q is placed on contact button *2*, the pole changer is placed in series with both batteries B and B_1, the sending side of the branch-office loop, the sounder S_2, and the key K_2 at the branch office. The circuit in this case is completed through the ground from G_3 to G_2.

2. Where dynamos are used, as shown, in connection with the polar relay, it is not convenient to increase or decrease



Sending Side
Branch Office Loop
Receiving Side
Pole Changer
K
Q
1
2
B
B1
Polar Relay
Fuse
D
S
Branch Office
S2
S1
K2
N
a
9
10
l
G2
G
G1
G2

Fig. 1

the electromotive force of the dynamo; therefore, in order to keep the current the same, a resistance, usually a lamp *l* in Western Union offices, is placed in the circuit when it is not extended to the branch office. The switch *N* is the form generally used in connection with the local circuits of duplex and quadruplex sets where dynamos are employed. Only such connections of this switch are shown as are necessary to explain the figure. When the arm *a* rests on contact button *10*, the dynamo *D*, contact points of the polar relay, the main-office sounder *S*, and the lamp *l* are placed in series; the return circuit is through the ground from G_1 to *G*. When the switch arm *a* rests on contact button *9*, the branch-office receiving side, including the branch-office sounder S_1, is placed in circuit in place of the lamp *l*. The circuit may then be traced from the ground *G* through the dynamo *D*–contact points of the polar relay–main-office sounder *S*–switch arm *a*–contact button *9*–receiving side of branch-office loop–sounder S_1–ground G_3 back to the ground *G*. Obviously, in order to have the same current through the sounder *S* in both positions of the switch arm *a*, the lamp *l* should have a resistance equal to that of the branch-office sounder S_1 and the line wire (receiving side) between the main and branch offices. In offices where dynamos are employed, there would be a main switch at which the line wire would terminate, and usually a loop switch at which the branch-office loop would terminate, but these switches have been omitted here for the sake of simplicity.

POSTAL DUPLEX AND QUADRUPLEX LOCAL CIRCUITS

3. Use of Bug Traps.—The local circuits controlled by the neutral relay, as arranged for use with the various dynamo duplex and quadruplex systems of the Postal Telegraph-Cable Company, are shown in Fig. 2. The repeating sounder, or relay, *BT*, which is called a **bug trap,** because it is used to eliminate false signals, or *bugs* as they are termed, is connected across the contacts of the neutral relay. Normally, the bug trap is short-circuited by the neutral relay; when the latter attracts its armature, this short circuit is opened, the bug trap receives current, attracts its armature, and hence closes the circuit of the receiving sounder.

The receiving sounder has its circuit extended through an ordinary jack *J*–a pin jack *C*–a 130-ohm resistance coil to

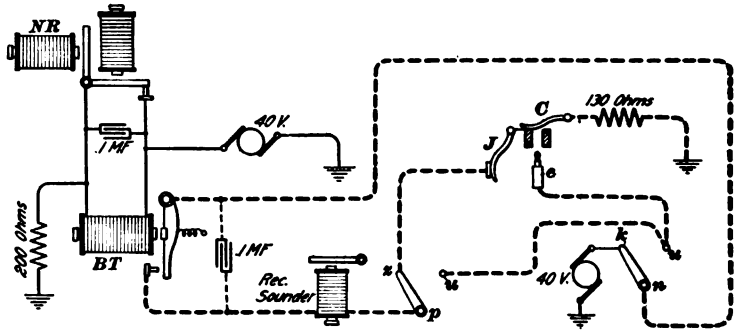


Fig. 2

ground. By inserting suitable wedges in the jack, the circuit may be extended to a branch office or it may be made to repeat into another quadruplex or duplex set. When the plug *e* is inserted in the pin jack, the flexible conductor is placed in contact, through the side of the plug with the jack, while the spring of the pin jack *C* is pushed away from the jack by the insulated tip of the plug and the 130-ohm resistance is cut out of the circuit. Then by turning the lever *p* to contact *u*, the receiving circuit may be extended through plug *e*, jack *J*, and whatever is there connected to the ground. A

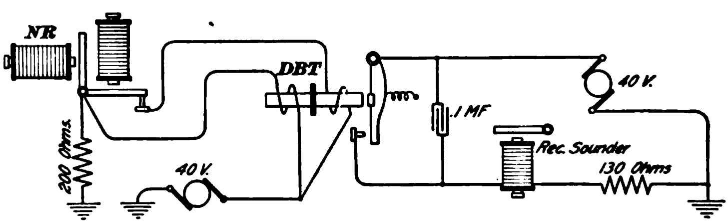


Fig. 3

branch-office circuit may be connected by a wedge to jack *J*. By inserting the plug *e* in the pin jack *C*, turning the lever *n* to *u*, lever *p* to *z*, and with suitable wedges in *J* and similar jacks, this corner of this set will repeat into a corner of another quadruplex set. Condensers of .1 microfarad capacity are connected across the contacts of both the neutral relay and bug trap to reduce the sparking.

4. Where a differentially wound bug trap is used it is connected as shown in Fig. 3, in which the jacks and switches have been omitted to simplify the figure. When the neutral relay is not energized, current flows through both windings of the differential bug trap *DBT* and it is not energized. When the neutral relay *NR* attracts its armature, one winding of the differential bug trap is opened, the other winding then energizes the bug trap and the sounder circuit is closed.

In Fig. 4 is shown the local circuits for the polar-relay corner. On the polar-relay base is a switch *y* that enables either relay

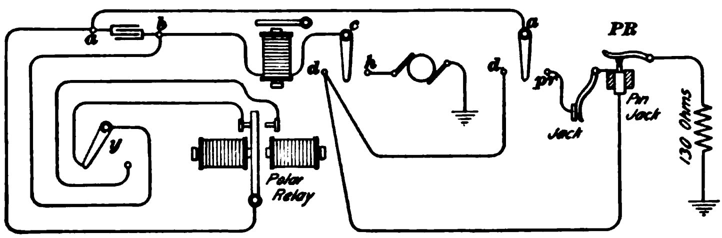
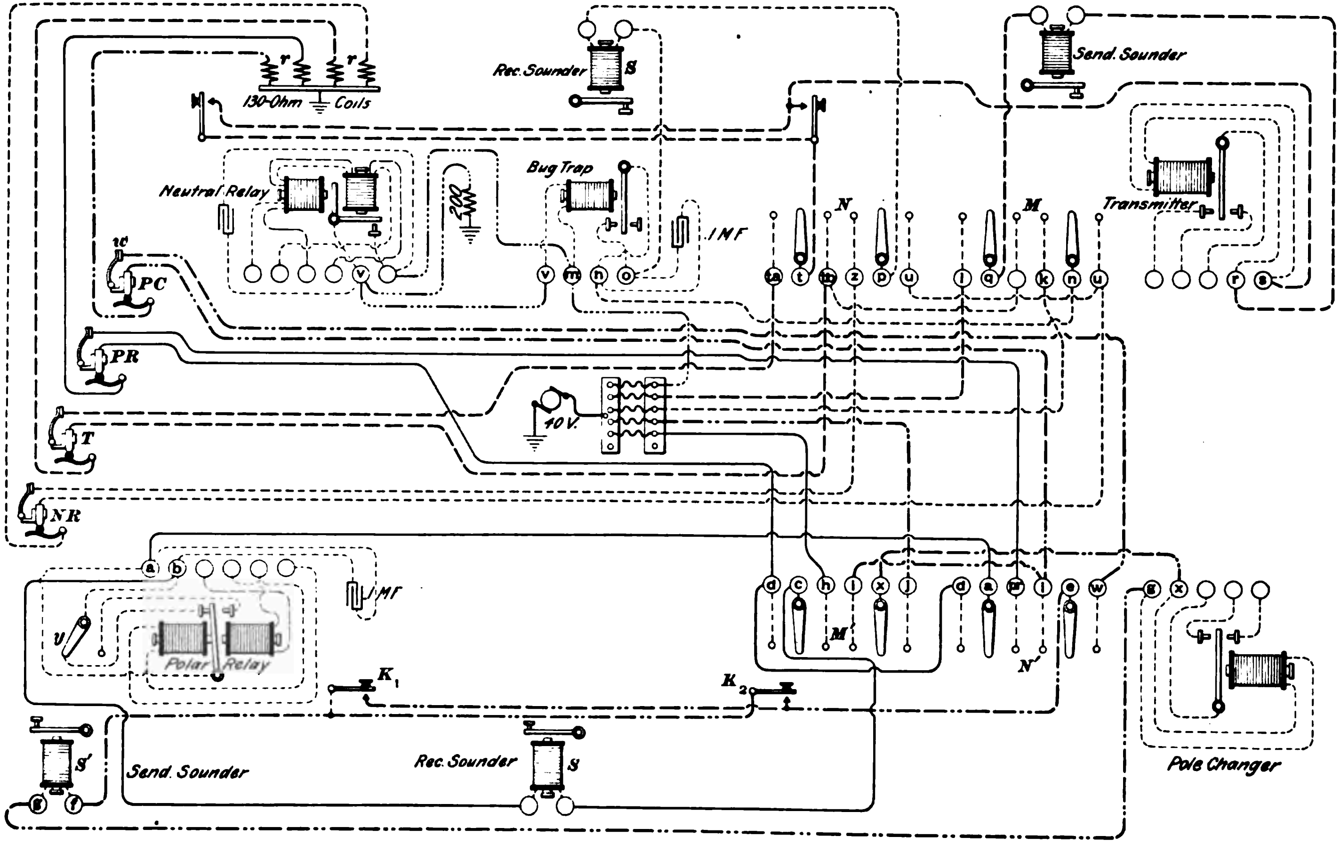


FIG. 4

contact to be used for closing the sounder circuit. This is useful should the polarity of the relay become reversed for any reason, such as the reversal of the main-line dynamos. The same parts in Figs. 2, 4, and 5 are similarly lettered.

5. Complete Diagram.—A complete diagram showing the connection of all local circuits for the dynamo duplex and quadruplex systems of the Postal Telegraph-Cable Company is given in Fig. 5. The four local sending and receiving circuits are connected to jacks and switches in about the same way as shown in Figs. 2 and 4, for which reason the same parts are lettered the same as in Fig. 5. The jacks are lettered *NR*, *T*, *PR*, and *PC* to indicate the local circuit with which each is associated. A spring on each jack is connected through 130 ohms to ground. The spring normally connects the 130-ohm resistance to the jack, but the insertion of a rubber-tipped



130-Ohm Coils
r
r
Rec. Sounder
S
Send. Sounder
Transmitter
Neutral Relay
200
Bug Trap
I.M.F.
N
M
PC
PR
T
NR
10 V.
I.M.F.
Polar Relay
K1
K2
M′
N′
Send. Sounder
S′
Rec. Sounder
S
Pole Changer

Fig. 5

plug pushes the spring away from the jack, thus cutting the 130 ohms and its ground connection out of the circuit. When there are no wedges or plugs in the jacks, each sending and receiving circuit is closed through 130 ohms to ground. If the switches M, M', N, and N' rest on proper buttons, the 40-volt dynamo supplies current to each local circuit. Spring jacks arranged in this manner are called *looping jacks*, a later and slightly different arrangement for accomplishing exactly the same results and called *patching jacks*, are shown in Fig. 6.

6. In Fig. 5, each branch office is so arranged that it has a total resistance of about 130 ohms; hence, the current in the sending and receiving circuits will not be appreciably altered if branch-office circuits are substituted for these 130-ohm resistances r. By the insertion of rubber-pointed plugs in the pin jacks, in this figure, the 130-ohm resistances are cut out and the wedge jacks are connected through the sides of these rubber-tipped plugs to the switches M, M', N, and N', then each sending and receiving circuit can be extended to a branch office in about the same manner as is shown in Fig. 6. The contacts of the neutral, polar, and bug-trap relays are shunted by .1 micro-farad condensers to reduce sparking.

7. When the quadruplex set, wired as in Fig. 5, in a main office is not to be connected with any branch office, nor arranged so that it will repeat into another quadruplex set, there will be no wedges in the spring jacks nor plugs in the pin jacks; also, switches M, M', N, and N' will be turned to the right, when one is facing the side of the table on which each switch is located. (As now looking at Fig. 5, the switches M and N will be turned toward the left and switches M' and N' toward the right.) The sending circuit on the polar side, which is shown as 2-dash and 2-dot lines, may be traced from the 40-volt dynamo through a fuse – binding post j – switch arm – binding posts x – magnet of pole changer – sending sounder S' – keys K_1 and K_2 – binding post e – switch arm – binding post w – jack terminal w – lower, or extra, spring on this jack – (there is supposed to be no pin plug in this jack now) – 130-ohm resistance r to ground. The other circuits may

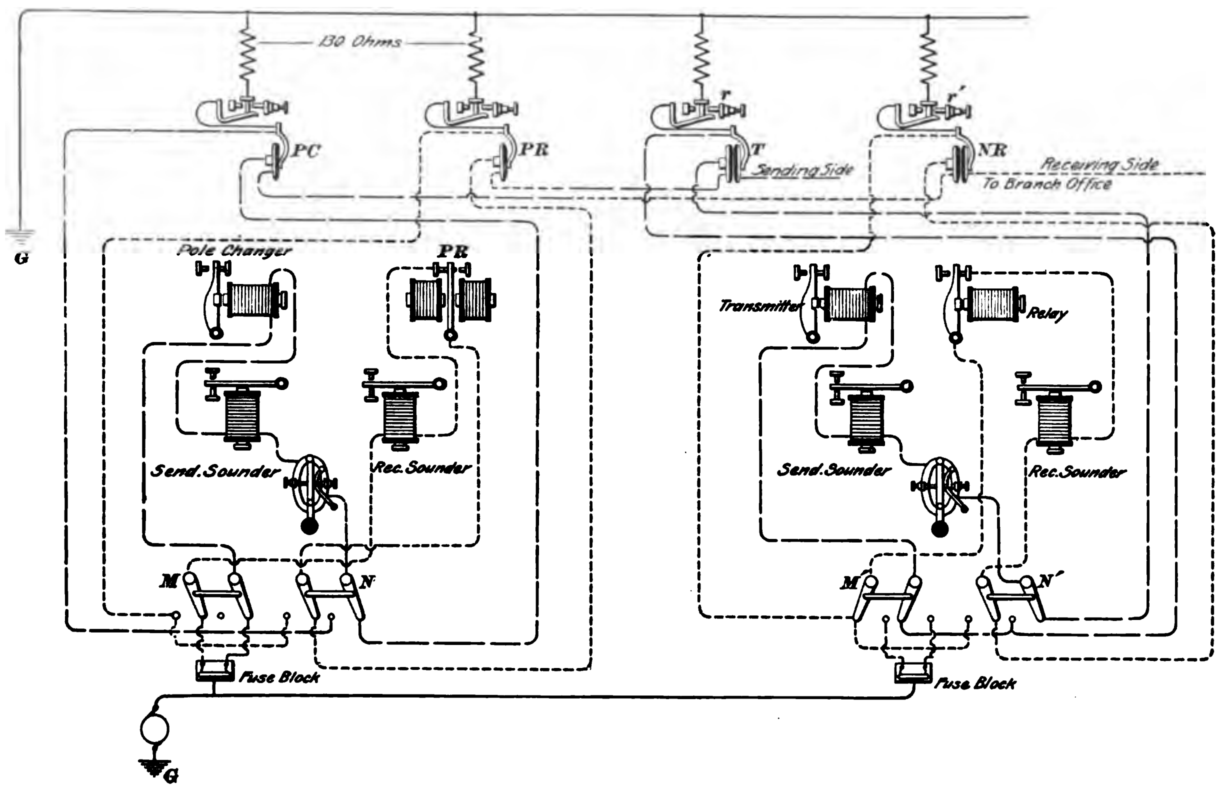
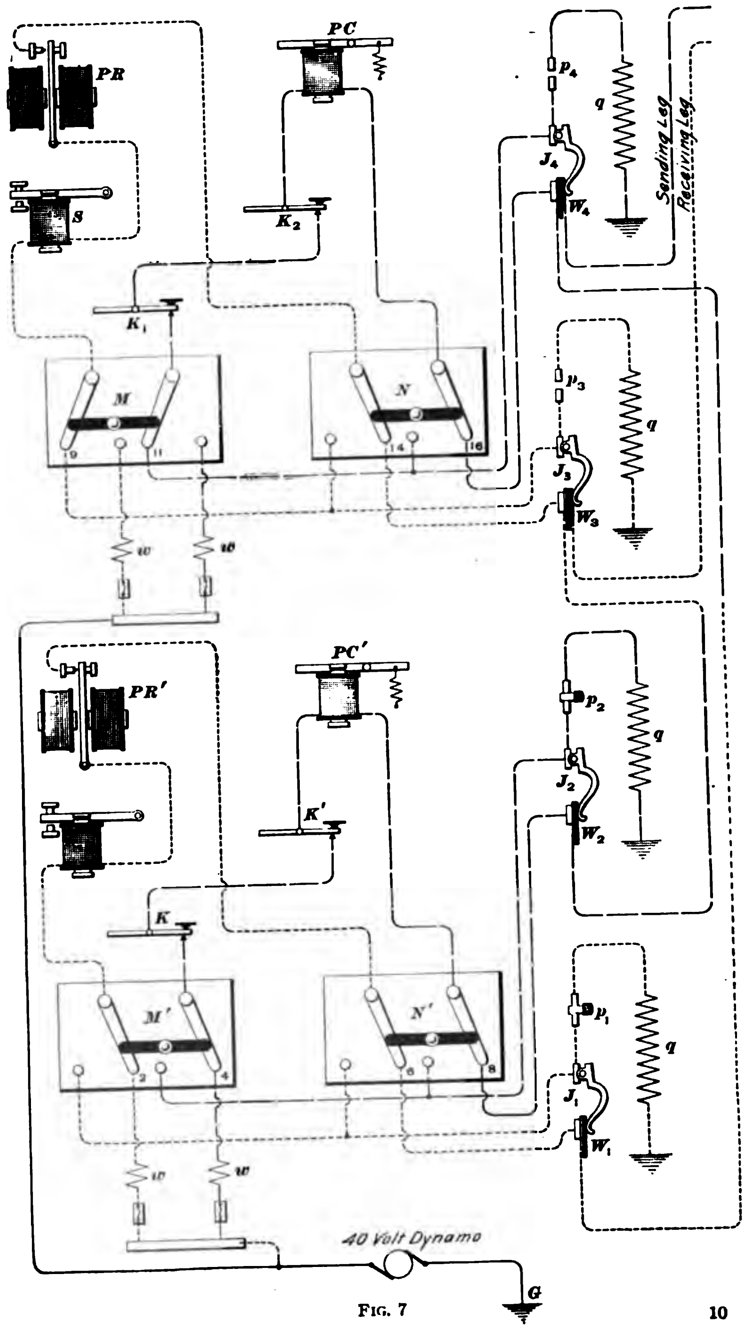

130 Ohms
r
r'
PC
PR
T
NR
Sending Side
Receiving Side
To Branch Office
G
Pole Changer
PR
Transmitter
Relay
Send. Sounder
Rec. Sounder
Send. Sounder
Rec. Sounder
M
N
M'
N'
Fuse Block
Fuse Block
G

FIG. 6

be traced in a similar manner. The local circuits of the polar-duplex sets are connected in the same manner as shown in the lower part of this figure.

8. Quadruplex Repeating Arrangement.—In Fig. 6 is shown the arrangement of switches and jacks for repeating from the polar relay of one duplex, or quadruplex, set into the transmitter of another set and from the bug-trap relay of the second quadruplex set into the pole changer of the first quadruplex, or duplex set. Patching jacks *PC*, *PR*, *T*, and *NR* are shown here in preference to the looping jack, because they eliminate the use of the special rubber-tipped plug; any ordinary kind of plug can be used in this jack and give exactly the same results as the looping jack. The patching jacks associated with each set are connected, as shown, by means of flexible wires, plugs, and wedges, to 130-ohm resistances and to switches *M*, *M′*, *N*, and *N′*. When plugs are inserted in all the pin jacks, each sending and receiving circuit is closed through 130 ohms to ground. If the plugs are withdrawn from the pin jacks, the 130-ohm resistances are cut out of the circuit and the wedge jacks are connected only to the switches *M*, *M′*, *N*, and *N′*, so that each sending and receiving circuit can be extended to a branch office.

9. In order to make each side work independently, it is only necessary to turn the switches *M*, *M′* toward the right and *N*, *N′* toward the left, leaving all plugs and wedges in the jacks. To extend the receiving circuit of the bug-trap relay and the sending circuit of the transmitter to a branch office, turn switch *N′* to the left, switch *M′* to the right and remove the pin plugs *r* and *r′* from their jacks. At the branch office a key, sounder, and enough resistance to make a total of 130 ohms will be included in the sending side and a sounder and enough resistance to make a total of 130 ohms in the receiving side, both sides being finally grounded. The other side of a quadruplex set may be extended from jacks *PC* and *PR* to a branch office by turning switch *N* to the left and switch *M* to the right.



PC
PR
S
K₂
K₁
M
N
p₄
q
J₄
W₄
Sending Leg
Receiving Leg
p₃
J₃
W₃
w
PC′
PR′
K′
K
M′
N′
p₂
J₂
W₂
p₁
J₁
W₁
40 Volt Dynamo
G

FIG. 7

10. Postal Telegraph Loops.—An older form of the Postal Telegraph-Cable Company's loop system is shown in Fig. 7. It also illustrates a method employed for connecting a branch office with the quadruplex set, so that the branch office may receive on one leg and send on another. When the switch M is turned toward the left, the switches N, M', and N' toward the right, the pin plugs being removed from holes p_3 and p_4, and the single wedges W_1 and W_2 inserted in the jacks J_1 and J_2, and two single wedges W_3 and W_4 inserted in jacks J_3 and J_4, respectively, (these connections being shown in this figure) the polar relay PR controls the pole changer PC', and also sends its message through the receiving leg to the branch office, which is not included, however, in this figure. Thus the message that is received on the polar relay PR is sent to the branch office and, by means of the pole changer PC', is repeated into another quadruplex set and is thus sent to another distant main office. This circuit may be traced from the ground G through a 40-volt dynamo – fuse – resistance w – contact button *4* on switch M' – keys K and K' – pole changer PC' – switch N' – contact button *8* – jack J_2 – wedge W_2 – wedge W_1 – jack J_1 – contact button *14* on switch N – contact points of the polar relay PR – sounder S – switch M – contact button *9* – jack J_3 – wedge W_3 – receiving leg of the branch-office loop – through the branch-office sounder (not shown in this figure) to the ground. When the plug p_3 at the jack J_3 is removed, the receiving leg of the branch-office loop circuit replaces the resistance q that is connected between the ground and the upper part of this jack. The other circuit through the polar relay PR', the pole changer PC, and the sending leg of the branch-office loop may be traced in a similar manner. In order to disconnect the branch-office loop, and to make the two circuits work independently of each other, it is only necessary to replace the plugs p_3 and p_4 and to turn the switches M and M' toward the right, and N and N' toward the left.

11. With all the wedges and the pin plugs p_1 and p_2 in place, the three switches N, M, and N' turned toward the right, and M' toward the left, the two circuits will repeat into each other. In this case it is immaterial whether the pin plugs p_3 and p_4 are in or out of place.

With the plugs p_3 and p_4 removed, and the three switches M', N', and N turned toward the right, and M toward the left, the two circuits not only repeat into each other, but the message is sent to the branch office. Furthermore, the branch office, by operating the key in the sending leg, can send a message through the pole changer PC, provided PR' remains closed, to the distant main office that is connected with the contact points of the pole changer PC. By operating a key in the receiving leg, the branch office can send a message through the pole changer PC' to the distant main office that is connected with the contact points of the pole changer PC'. Thus, two messages can be sent simultaneously from the branch office, one to each terminal office; however, the terminal offices cannot send on the same side of a quadruplex, and not at all on a duplex system at the same time; hence, in the latter case the system is only worked single, and not duplex.

12. Resistance Coils.—The Postal Telegraph-Cable Company uses standard 130-ohm coils in the local circuits of quadruplex and duplex sets, duplex repeaters, and direct polar-relay repeaters operated by 40 volts; 180-ohm resistance coils in the local circuits of Weiny-Phillips, Ghegan, and other Morse repeaters and half repeaters; 200-ohm coils in all Morse local and bug-trap relay local circuits, and in all city and main-line wires operated through main or district switchboards by 40 volts; 300-ohm coils in all city and main-line wires operated through a main-line switchboard by about 90 volts; 400-ohm coils in all circuits operated through main-line switchboards by 110 to 130 volts; 600-ohm coils in each long and short end of plus and minus potentials and of quadruplex sets, also for all duplex sets and for all wires operated through main-line switchboards by 130 to 200 volts. These 600-ohm resistances usually consist of two 300-ohm coils in series. The resistance coils are made by winding enameled wire of suitable composition upon a porcelain or hard-clay tube and the whole dipped in enamel and baked hard.

WESTERN UNION BRIDGE QUADRUPLEX

DESCRIPTION OF APPARATUS

13. The quadruplex system introduced, in 1910, by the Western Union Telegraph Company possesses some features that, it is claimed, make four-corner working entirely feasible over long telegraph lines that it was formerly difficult to so work and that also greatly increase the carrying capacity of such circuits as had, in preceding years, been limited to duplex operation. The main-circuit diagram, Fig. 10, shows that this quadruplex is a combination of the polar bridge duplex of the American Telephone and Telegraph Company, the differential added-resistance-and-leak-coil duplex, and special forms of transmitter, pole changer, and differential relay. The information from which the following explanation was prepared was secured from articles in the Telegraph and Telephone Age and in the Journal of the Telegram. The original success of this quadruplex system is said to be largely due to the use of a pole changer and transmitter designed to minimize the interval of no current. It is also partly due to a neutral relay provided with an auxiliary magnet that is said to be very effective in holding the relay armature closed when the distant pole-changer lever is in transit from one to the other of its battery posts, during which period the signaling battery is entirely disconnected from the main line.

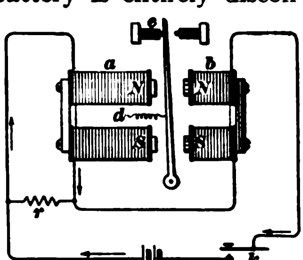


FIG. 8

14. Pole Changer and Transmitter.—The pole changer and transmitter, which are alike, are shown in Fig. 8, in which *a* represents an electromagnet having solid-iron cores enclosed in copper cylinders or jackets and coils having a total resistance of 4 ohms, and *b* represents an electromagnet with laminated iron cores and coils having a total resistance of 4 ohms. In later instruments the cores *b* are not shorter, as shown in this figure, than the cores *a*. All the coils are connected in series. With current flowing in the direction indicated by arrows, the polarities of the core ends are indicated by letters *N* for north and *S* for south. When the electrical circuit is closed, the core ends opposite each other always have the same polarity; hence, they oppose each other, and each electromagnet always tends to attract the armature, which is provided with a light retractile spring *d* that normally holds it against stop *e*.

15. When the local circuit is completed by closing the key *k*, both electromagnets are energized. But because it is laminated and in some instruments shorter, the laminated core attains its maximum magnetic strength and also, when the key is opened, loses its magnetism much more quickly than the unlaminated electromagnet, which has a solid core enclosed in copper, and, in some instruments had shorter cores and a non-inductive resistance *r* in parallel with its coils. This resistance *r* shunts a larger proportion of the current past the magnet coils, the more rapidly the current is changing in strength. Thus, when the current first starts to build up and is consequently increasing in strength at its maximum rate, a larger proportion of the increase takes place in the non-inductive resistance than later when the current has reached its maximum value. This difference in magnetic activity between the two cores results in a rapid movement of the armature in the direction of the laminated core. The reverse of this takes place upon opening the local circuit, for then the laminated core loses its magnetism very quickly and allows the retractile spring, together with the more slowly disappearing, or residual, magnetism of the solid core, to pull the armature quickly in the opposite direction, that is toward stop *e*. The laminated electromagnet has been omitted from some pole changers and transmitters, the claim being that it was not sufficiently beneficial to warrant its extra cost. The non-inductive shunt seems to have been omitted for a similar reason. A vertical view of the pole changer and transmitter and the connections are shown in Fig. 9 (*c*). The solid-core magnet can be adjusted by a screw *a* in the same manner as an ordinary relay.

16. Neutral Relay.—Notwithstanding the rapidity of the movement of the pole-changer armature, the no-current interval is sufficiently pronounced on long circuits to impair the efficiency of the working on the common side. To obviate this, the neutral relay, shown in Fig. 9 (*a*), is provided with a holding coil *h* connected as shown in the main-line circuit diagram given in Fig. 10. In series with this holding coil *h* is a condenser *q*. Suppose that current starts to flow from the right-hand station through the line to the left-hand station. It first flows from the line through the holding coil *h* to the condenser *q* on account of the lower time constant of this path; hence, the holding coil furnishes the first pull on the armature, then the regular relay coils build up and finish the pull as the current through the holding coil dies away.

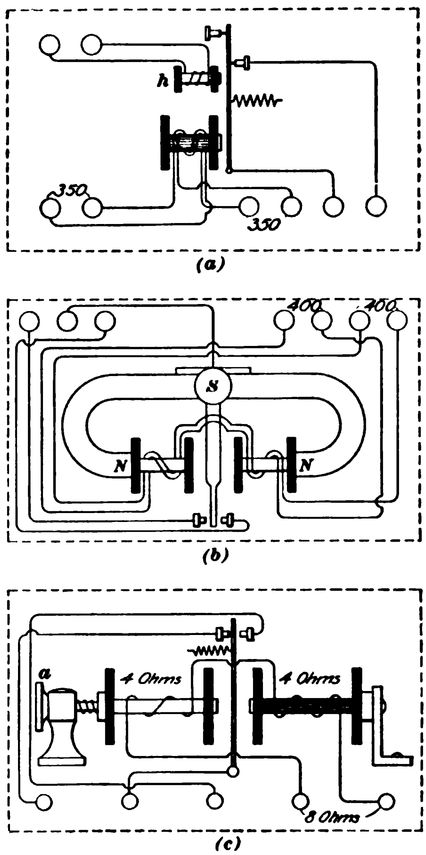


FIG. 9

When contact is broken at the distant pole changer, the magnetism previously existing in the receiving relays suddenly dies away and in doing so generates an electromotive force that tends to keep the current flowing in the same direction through them. Moreover, the condenser *q* also tends to discharge a current through the holding coil *h*, hence the inductance of the receiving relays and the discharge current through the holding coil tend to hold the

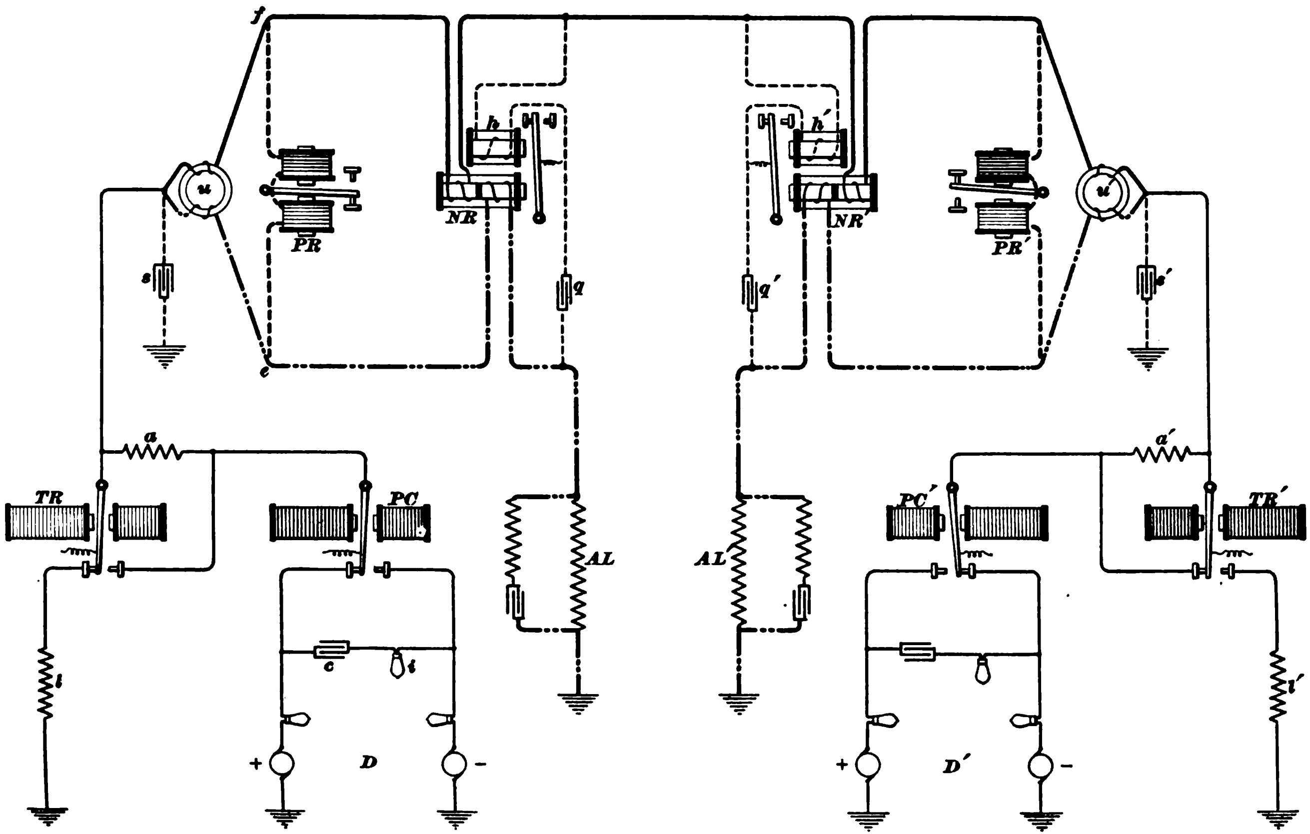


Fig. 10

armature of the neutral relay while the distant pole-changer lever crosses its gap.

The path of this extra current, the strength of which is greatly intensified by the inductance of the impedance coil *u*, also includes the main-line and artificial-line coils of the neutral relay, the armature of which, as a result of a combination of magnetic forces all acting in the same direction, retains its armature firmly on the front contact at a time when it would otherwise tend to fly open.

17. Polar Relay.—The form and connections of the polar relay are shown in Fig. 9 (*b*). Each core is differentially wound. Each winding, which consists of a coil on each core, has a resistance of 400 ohms. This relay operates like any other differentially wound polar relay.

18. Impedance Coil.—The impedance coil *u*, Fig. 10, has a circular core of fine iron wire that forms a very efficient closed magnetic circuit. This inductance coil *u* is particularly beneficial in connection with the holding coil of the neutral relay. The magnetic discharge is not only utilized to energize the holding coil but owing to the gradual manner in which the closed core parts with its magnetism, the discharge current is prolonged, and is thus enabled to act upon the neutral relay armature for a period of time more nearly corresponding with that represented by the interval of no current at the distant pole changer.

19. The impedance coil *u* not only operates to the advantage of the neutral relay, as already explained, but it has also a beneficial effect upon the working of the polar relay. This is due to the fact that the inductive action of the impedance coil at the opening and closing of the distant pole changer, produces a momentary extra current whose circuit is partly completed through the coils of the polar relay. Also, this current is in such a direction as to assist in the prompt operation of that relay. An incidental advantage of the impedance coil is that in combination with the grounded, or so-called *spark*, condenser *s*, the rise and fall of the signaling currents in the line become so gradual as to have little inductive disturbing action upon neighboring line wires.

The absence of inductance in any circuit tends to allow the current therein to attain its maximum and zero values very abruptly at the making and breaking of the battery contact, producing what is shown as a *square-top*, or *sharp-pointed wave*. This wave gives rise to more intense inductive effects in neighboring lines than a gradual, or sine-curve, type of current wave. On the other hand, inductance tends to round off the sharp points, that is, it makes the rise and fall of the current more gradual, and to develop a sine-curve type of current wave.

20. Operation.—It will be noticed from Fig. 10 that both the differential- and bridge-duplex principles are involved. The coils of the neutral relay are differentially wound and connected in the line and artificial-line circuits in the usual way, while the polar-relay is connected in the cross-wire of the bridge, two arms of which are represented by the two windings of the impedance coil *u*. The pole changer *PC* at the left side is represented as sending out a positive, or spacing, current. The strength of this current is cut down to its short-end, or smaller, value by having to pass through the added resistance *a*; it is then divided between the leak resistance *l* and the main and artificial lines. No part of this current will pass through the polar relay, under well-balanced conditions, because it produces no difference of potential between points *e* and *f*. The same is also true with regard to the holding coil *h* and its condenser *q*. The outgoing current divides equally between the windings of the impedance coil *u* and the neutral relay, but the two windings on each device oppose each other and therefore no appreciable magnetization is produced in either.

21. At the receiving end, the pole changer *PC′* is represented as open and the transmitter *TR′* closed, hence the full voltage of the negative dynamo is connected to the line. The incoming line current enters the line coil of the neutral relay, and a momentary impulse traverses the holding coil, but the relay is not appreciably affected because its armature is resting against its back stop and this current is not strong enough to overcome the spring. After leaving the neutral relay, the current divides, a portion going through one winding of the impedance coil *u'* and another portion through the polar relay and the other impedance-coil winding to point *h*, where they reunite and pass through the transmitting apparatus to ground.

The amount of current diverted through the polar relay is comparatively small, but this current is reinforced by the action of the impedance coil, which under favorable weather conditions sometimes permits a multiple arrangement of the relay coils to be used with advantage. When, however, the strength of the current is considerably reduced by loss through leakage, or otherwise, the coils may have to be connected in series.

At the right end, the full strength current of negative polarity is directed toward the line and both receiving relays at the left end will be closed. The tendency to arc across the pole-changer contacts is reduced by the use of a $\frac{1}{2}$-microfarad condenser *c* in series with a 20-ohm or 30-ohm resistance *i* placed across the battery leads.

COMPLETE BRIDGE-QUADRUPLEX CIRCUITS

22. Improved Circuit.—The circuits of the Western Union bridge quadruplex system, as arranged in Fig. 11, were put into use in 1911. This circuit differs in some details, but not in principle, from the one previously shown. The pole changer and transmitter are shown without the extra electromagnets, which have been omitted on some sets. There has been added an arrangement to change the current ratio and the usual table switches for extending the local circuits to branch offices and to make one set repeat into another set. Both the main-line and local circuits are supplied with current from dynamos of suitable voltages. A milliammeter for use in balancing the quadruplex set is connected in series with the coils of the polar relay.

The neutral and polar relays have two coils on each spool, as usual, although only one is shown for simplicity sake. The resistances in the artificial line are contained in the Western

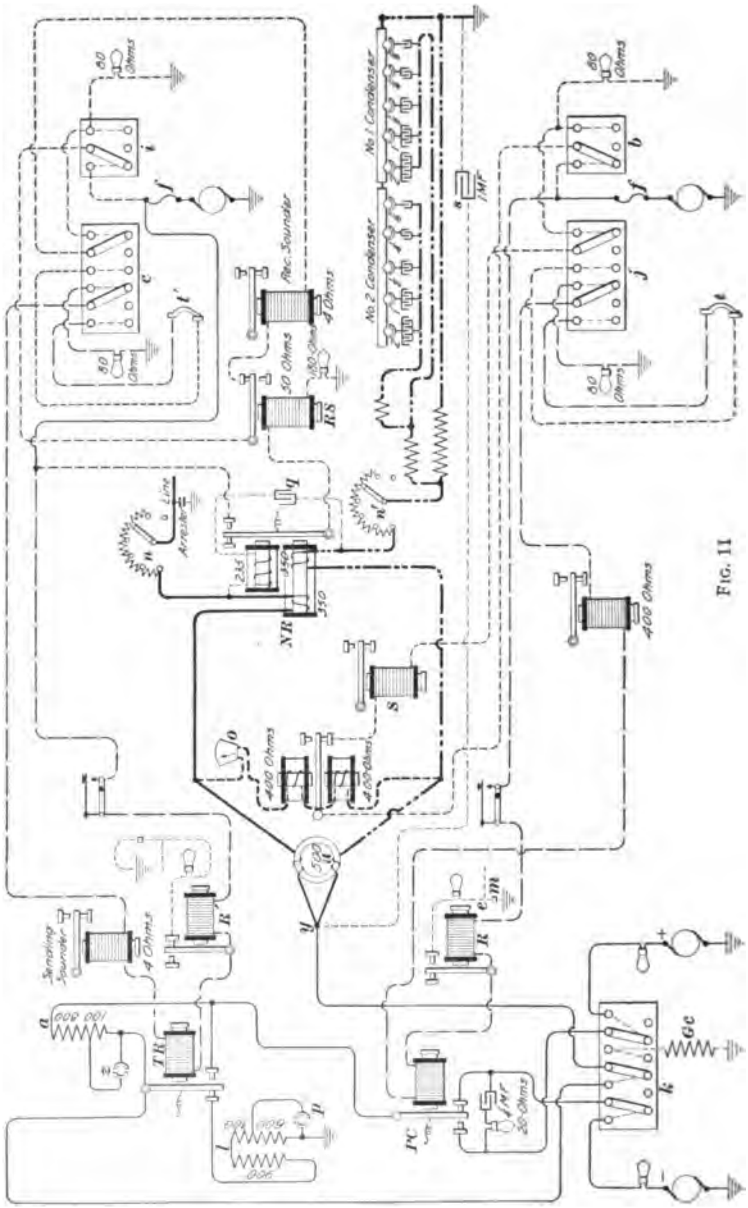

Rec. Sounder
4 Ohms
50 Ohms
RS
No. 1 Condenser
No. 2 Condenser
Line
Arrester
NR
400 Ohms
S
Sending Sounder
4 Ohms
TR
PC
Ge
k
80 Ohms

FIG. 11

Union radial-arm rheostat and the artificial-line condensers and the spark condenser *s* in a box arranged about as shown.

To enable sending operators and repeater attendants to hear the sending signals without depending on the transmitter and pole changer, sending sounders are used. The neutral relay controls a 50-ohm repeating sounder *RS* which in turn controls an ordinary 4-ohm receiving sounder.

23. Repeating Sounder.—The double sounder arrangement of the older quadruplex systems is still retained. The necessity for it though would seem to have disappeared with the advent of more efficient transmitting and receiving appliances, which together with the impedance coils form a combination that has practically eliminated all tendency of the neutral relay to kick during distant-battery reversals. It is, therefore, possible to eliminate the repeating sounder and operate the local sounder direct from the front stop of the neutral relay, as has been done in the case of several long quadruplex circuits. A sufficient number of experiments had not been made up to 1911 to test the feasibility of the front-contact arrangement under all conditions of working; meanwhile all neutral relays were provided with both front and back stops so as to afford facilities for further trials in this direction.

24. Signaling Relays.—For attracting the attention of quadruplex and duplex attendants to the quadruplex circuit, there are low-resistance relays *R* and *R'*, Fig. 11, and a 2-candle-power lamp in series with each transmitter and pole changer. When the sending circuits are extended through loop switches, or one set is repeating into another, these lamps by remaining steadily lighted or out indicate that the sending side is out of order or not in use. Not more than twelve such lamp circuits may be joined together at one point *e* and from that point one wire may pass through a suitable audible signal *m*, such as a bell or buzzer, to the ground. Thus, the sound gives an audible indication of trouble and the lighted lamp will show the set needing attention.

25. Line-Resistance Box.—The line, after proper connection to a lightning arrester, has an adjustable resistance *n*,

Fig. 11, included in its circuit. A similar resistance is also inserted in the artificial line. For this reason, this resistance box has two sets of equal coils and turning one handle moves both levers *n* and *n'*; therefore, one operation inserts or withdraws the same amount of resistance from both the line and the artificial line. Each rheostat contains five coils of 250 ohms each, so that a total resistance of 1,250 ohms is available in each rheostat for increasing the line resistance of short quadruplex or duplex circuits, so that they can be operated from the potentials ordinarily provided for long circuits. This resistance may be used advantageously to reduce the strength of earth currents on lines between whose terminal ground plates there exist potential differences that would detrimentally affect the working, particularly of short-line quadruplex circuits.

This resistance may occasionally be useful on longer circuits under such changeable weather conditions as might detrimentally disturb the line balances. The use of this resistance would then have the same effect as removing the main line from the immediate vicinity of the home apparatus, which will then be less sensitive to changes in magnetism due to variation of the leakage. This resistance can also be used to reduce the current in low-resistance telephone lines to a strength not exceeding 100 milliamperes, which is necessary not to interfere with the telephone signaling current nor to harm the load coils, and to eliminate the production of sounds due to the Morse signals in the telephone receiver. Where resistance is inserted in the line, it should generally be divided equally between the two ends. The distant office should be informed of any change in the line and artificial-line resistances so that a new balance may be made there if necessary.

26. Resistance Ratios.—As shown in Fig. 11, the added resistance *a* contains 900 ohms, and the leak coil *l* 1,200 ohms, giving a ratio of 3 to 1. If the plug at *p* is removed and one is inserted at *z*, the resistances are 800 ohms and 1,800 ohms and the ratio 4 to 1. A current ratio of 3 to 1 is ordinarily employed on the longer quadruplex circuits; 60 milliamperes on the long end and 20 milliamperes on the short end generally afford sufficient margin for all practical conditions of working. The dynamo or battery voltage should be such as to give the desired current.

BALANCING THE BRIDGE QUADRUPLEX

27. The usual practice of connecting the distant end to ground while balancing the home set is regarded as unnecessary. The milliammeter in the polar-relay circuit allows a balance to be made quicker with the distant battery connected to the line and under conditions that eliminate all differences that may happen to exist between the ground-coil resistance and battery resistance. The home apparatus is rendered insensible to the operation of the home keys when there is no difference of potential between the terminals of the polar relay and equal currents flow through the line and artificial-line coils of the neutral relay.

28. Resistance Balance.—A resistance balance is made as follows:

1. At the distant station have both keys closed, causing the home milliammeter to deflect in the marking direction, which will be to the left or downwards, depending on the position of the instrument. If the connections of the milliammeter in the circuit or the polarity of all main-line dynamos are the reverse of that generally used, the deflection will be to the right or upwards. In this explanation reversed conditions of the milliammeter or the potentials will not be further considered unless specifically mentioned.
2. The deflection obtained on the milliammeter is noted after the needle has come to rest, first with the pole-changer key open, and second with it closed.
3. While the pole-changer key is closed, adjust the artificial-line resistance until the milliammeter needle reaches a point midway between the two readings obtained in 2, which point will represent the deflection required to give the resistance balance. It should be remembered that the distant battery is connected to the line; hence, in one position of the home key the two batteries oppose each other and in the other

position they are in series. For example, if one reading is 26 and the other 20, the mean is 23, and the rheostat should be adjusted to give a reading of 23 milliamperes. For duplex working an average current of 12 milliamperes is about right.

It will be found that when the resistance in the artificial line is greater than that of the main line, the needle will swing somewhat deliberately in an upward, or spacing-current, direction upon closing the pole-changer key; and when the resistance in the artificial line is less than that of the main line, the needle will swing in the downward, or marking-current, direction.

29. Static Balance.—An unbalanced static condition will make itself known by producing a sudden momentary throw of the milliammeter needle in one direction as the key is closed and in the opposite direction as the key is released, the needle returning to its normal or steady position after each movement of the key. In order to avoid confusion during these balancing operations, it will be well to disregard the effects produced upon the needle at the opening of the key, taking note only of those produced at the closing thereof.

If upon closing the key, the needle swings in a spacing, or upward, direction, and then rapidly returns to its former steady position, it indicates that the capacity of the artificial line is too small and should, therefore, be increased. If, on the other hand, the throw of the needle is in the downward, or marking, direction on closing the key, the condenser capacity should be diminished.

The amplitude of the swing, or kick, in each case will indicate the amount of the unbalance; the swing depends on the difference between the momentary current charging the line and that charging the artificial line.

30. Retardation Balance.—If the retarding resistances in the circuit of the artificial-line condensers are not accurately adjusted, the time required to charge and discharge the condenser will differ from that required to charge and discharge the main line. If this difference is very pronounced, the milliammeter will give a peculiar *double kick* each time the key is opened and closed. This double kick usually is readily distinguished from that due to the ordinary unbalanced static condition on account of its decidedly more jerky and lively appearance during its brief existence. It may, however, be somewhat difficult to distinguish the two, if the milliammeter is made to vibrate by induction from neighboring wires, as is ordinarily the case; such interference renders it difficult to make accurate readings. Under such conditions, the final adjustments may be made by rapidly dotting on the pole-changer key while adjusting the artificial-line condensers, and particularly the retardation resistances in series with them, until the needle will show the least amount of disturbance.

31. Approximate Balances.—It is only when the operation of the home pole-changer key does not affect the home milliammeter needle that a **perfect balance** is obtained. A perfect balance is difficult to obtain and often requires more time than can be afforded; hence, it is only necessary as a rule to secure a good **working balance,** that is, one in which the clearness of the incoming signals are practically unaffected by the outgoing signals. The operator should be able to restore a set to a good working balance without the delay involved in waiting for a repeater or other chief operator to balance the set.

ADJUSTMENTS OF BRIDGE QUADRUPLEX

32. Neutral-Relay Adjustment.—The armature of the neutral relay should not be brought too close to the main-line magnet cores. A sufficient air space is necessary to prevent the armature from sticking or exhibiting that sluggishness of movement that is frequently caused by residual magnetism in the relay cores. It is far more preferable to minimize any such tendencies by increasing the air gaps and then suitably reducing the retractile-spring tension, than by the reverse method of adjustment. The tension of the spring, however, should always be sufficient to pull the armature smartly against its back stop whenever the magnetism excited by the long-end current is cut down to that excited by the short-end current.

The wider separation between cores and armature will also lessen the amount of disturbance produced by the outgoing currents upon the home relays as a result of imperfect balances. Besides, it tends to counteract the effect of earth currents, voltage inequalities, or other irregularities that make an incoming current of one polarity greater or less than that of opposite polarity.

33. Holding-Coil Adjustment.—After a balance has been secured, the holding coil is brought as close as possible to the relay armature without actually touching it. Then the distant station is requested to close his transmitter key and make dots on his pole-changer key; while this is being done the home office should increase the capacity of the holding condenser *q*, Fig. 11 (usually by inserting pegs) until enough (but no more) capacity has been introduced to keep the neutral-relay armature steady on its front stop. Between 1 and 2 microfarads is generally sufficient for the purpose; too much tends to allow inductive disturbances to act upon the holding coil.

34. Repeating Sounder Adjustment.—The armature of the repeating sounder, as in the case of the neutral relay, ought to be far enough removed from the magnet cores to eliminate the detrimental effect due to their residual magnetism without unduly diminishing the attractive force exerted upon the armature. The retractile force of this armature spring should be adjusted to suit these conditions. In this way the rapidity of action so highly essential in this instrument can be best attained. The local, or repeating, points of the sounder should be closely adjusted.

35. Polar-Relay Adjustment.—The relay coils may be connected either in series or in parallel according to line conditions. The series arrangement has generally given the best results on long or leaky circuits, while the parallel arrangement seems better adapted for short and well-insulated lines.

Whenever it is necessary to center the polar relay, which is advisable in the initial stages of adjustment, first throw the double lever of the line resistance box over to its extreme right-hand position, which will open both the main and the artificial lines. Then set the armature lever midway between the relay cores, leaving an air gap of about $\frac{1}{32}$ inch on each side. Afterwards adjust the limiting stops until the play of the lever between them is just sufficient in amount to prevent sticking and ensure clear breaking of the contact points.

36. Transmitting-Apparatus Adjustments.—The position of the coils of both pole changer and transmitter should normally be such as to leave an air gap of about $\frac{1}{64}$ inch (or not less than four thicknesses of ordinary receiving blanks) between the armature and cores of the right-hand magnet of each instrument in its closed position. This adjustment should be permanently fixed. The other, or solid-core, electromagnet may be moved back and forth like the core of an ordinary relay, but its most effective position will generally be found at a point where (with the local circuit closed) the armature rests indifferently on either of its contact stops when placed there by the finger. When signals are light at the receiving station, the long coil at the transmitting station should be pulled away from its armature; and vice versa it should be moved toward its armature when the writing is heavy.

37. The play of the armature of the pole-changer lever between its battery posts should be as small as possible without producing injurious arcing, which is liable to occur at the breaking of the battery circuit. To reduce such arcing, a $\frac{1}{4}$-microfarad condenser in series with a 20-ohm lamp is connected across the battery contacts, as shown in Fig. 11.

Sparking is liable to occur at the pole-changer points, both at making and breaking of the battery contact. The spark at the make represents the static discharge from the main and artificial lines. To modify the effects of this spark is the purpose of the so-called spark condenser *s*, which temporarily absorbs the discharge instead of forcing it to seek a path across the pole-changer or transmitter contacts as they approach each other. The spark at the break, which is due to the tendency of the high electromotive force of self-induction developed at that instant to prolong the existing current, is the more serious of the two, because it is likely to lengthen out and produce an arc as the pole-changer lever leaves its battery post. The particular function of the small condenser *s* is to absorb the extra current, thus diverting it from the pole-changer contacts.

38. Milliammeter.—The milliammeter *o*, Fig. 11, facilitates balancing the set and it serves as an index of the general condition of the circuit. By their peculiarly distinctive effect upon the milliammeter, escapes in underground cables may be detected due to the different electrolytic action of currents in opposite directions through such faults. A *positive current*, that is a current flowing from the conductor through a fault to earth, tends to seal up the fault while a *negative current* tends to make the fault worse. Hence, the balancing of a set in which such a fault occurs will be more difficult on account of the changeable character of the resistance of the fault under reversing currents.

At each disturbance of the balance, the milliammeter needle will first be suddenly deflected to one side or the other of its previously assumed position, depending on the direction of the current, and then gradually move in that same direction until it reaches some other point where the needle will remain more or less stationary. Symptoms of this character will indicate the particular nature of the trouble, to which the attention of the wire chief should be immediately directed.

The milliammeter being connected in the bridge arm, its deflections do not represent line currents, but if the sets are well balanced and the two terminal potentials are equal, the main-line current will normally be from six to eight times that indicated by the milliammeter. It is better to measure the line current directly however by inserting an ammeter in the main line at the switchboard or elsewhere while the terminal potentials are assisting each other, that is, with the pole changer at one end open and at the other end closed and the transmitters closed.

39. Switches.—The switch *k*, Fig. 11, allows the connecting or disconnecting of the main-line generators and also

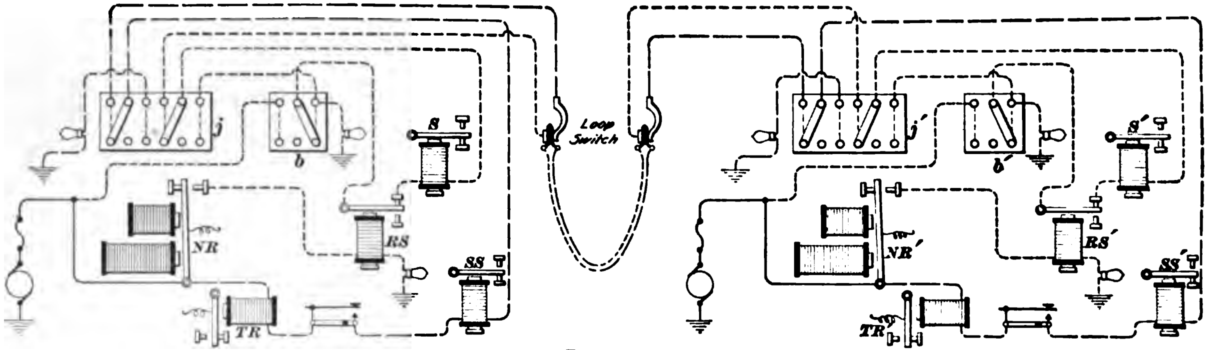
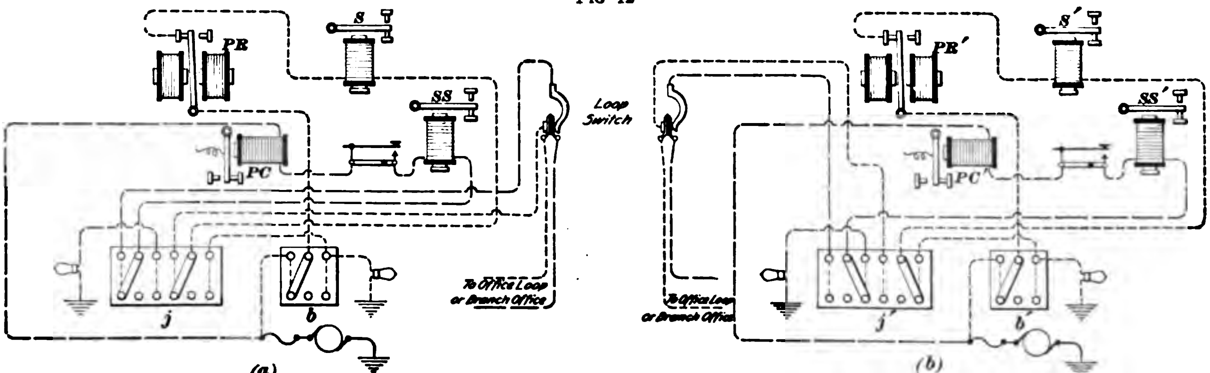


FIG 12



(a) (b)

FIG. 13

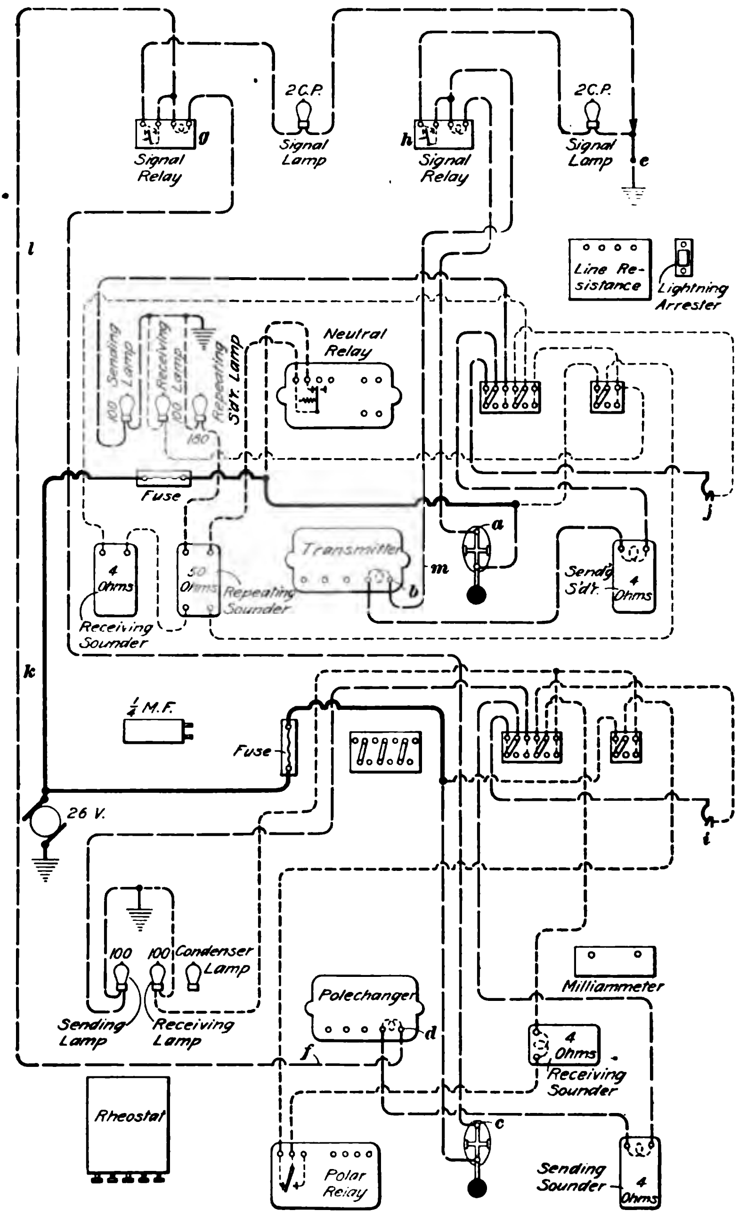

2C.P.
Signal Lamp
Signal Relay
g
h
e
2C.P.
Signal Lamp
Signal Relay
Line Resistance
Lightning Arrester
l
100 Sending Lamp
100 Receiving Lamp
180 Repeating S'd'r. Lamp
Neutral Relay
Fuse
Transmitter
a
m
b
4 Ohms
Receiving Sounder
50 Ohms
Repeating Sounder
Send'g S'd'r.
4 Ohms
j
k
¼ M.F.
Fuse
26 V.
i
100
100
Condenser Lamp
Sending Lamp
Receiving Lamp
Polechanger
d
f
Milliammeter
4 Ohms
Receiving Sounder
Rheostat
c
Polar Relay
Sending Sounder
4 Ohms

FIG. 14

provides for grounding the point *y* through the usual ground coil *Gc*. By means of the switches *b*, *j*, *i*, and *c* and the spring jacks *t* and *t'*, the sending and receiving sides may be extended to the operators' tables or to branch offices and one set may be made to repeat into another in the usual manner.

In Fig. 12, the neutral sides of two sets are arranged to repeat into each other, the switches *j* and *j'* being turned to the left and switches *b* and *b'* to the right. In Fig. 13 (*a*), the switches *j* and *b* are turned to the left, which is the position for extending the receiving and sending circuits to a branch office; in (*b*), the similar switches *j'* and *b'* are turned so as to cut off the branch, or office, loop in order to balance the set. The indirect repetition thus obtained through the local circuits should only be used when bridge duplex repeater sets, which are more efficient, are not available.

40. Quadruplex Local Circuits.—In Fig. 14 is shown the arrangement of instruments on the quadruplex tables and the wiring of the local circuits. The instruments below an imaginary line at *k*, are on the bottom shelf, those between imaginary lines at *k* and *l* are on the next shelf, while signaling relays and signal lamps are on the top shelf. Where no signal relays and lamps are used, the binding post *a* on the key controlling the transmitter is connected to binding post *b* (the wire *m* and all beyond it on the side of the signal relay *h* will not be present) and the binding post *c* on the key controlling the pole changer is connected to binding post *d* (the wire *f* and all beyond it on the signal-relay side will not be present). If, in addition to the visible signals supplied by the signal lamps, an audible signal is also desired, a pilot relay may be inserted at point *e*, which is common to not more than twelve signal lamps. To use this set for repeating purposes, it is merely necessary to place the various switches in the proper positions, as has just been explained, and to connect the loop jacks *i* and *j* through flexible cords to similar jacks of another quadruplex set.

41. Duplex Working.—When the weather conditions are such as to render quadruplex working impracticable, the set may be operated as a polar duplex by closing the second side transmitter at both offices. To avoid the overheating of the devices by the excessive current under such conditions, sufficient resistance should be added to the circuit by means

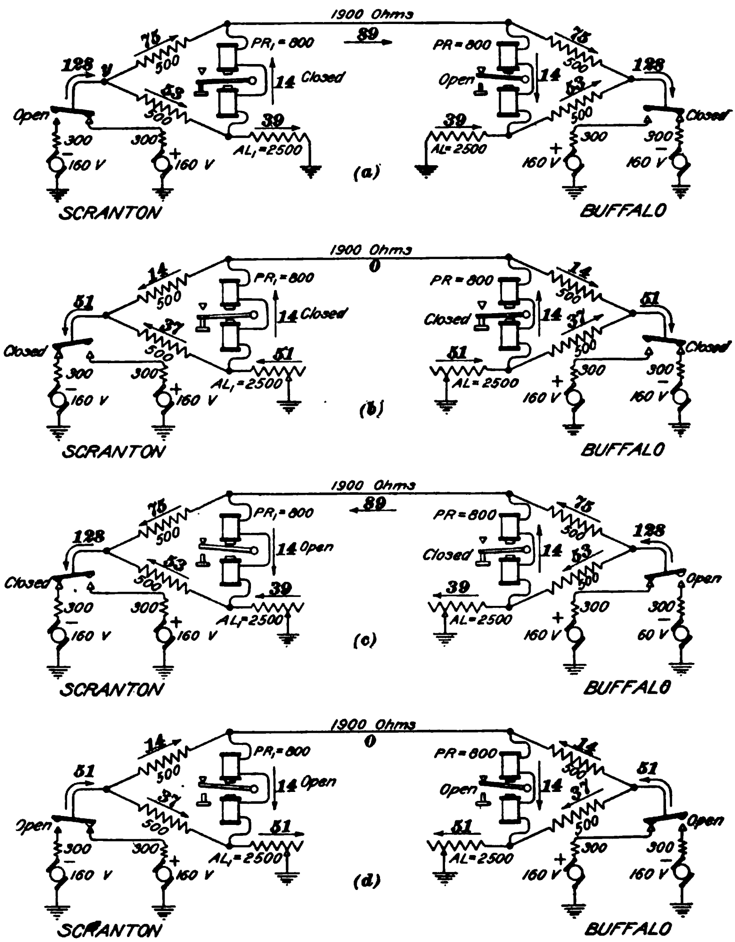


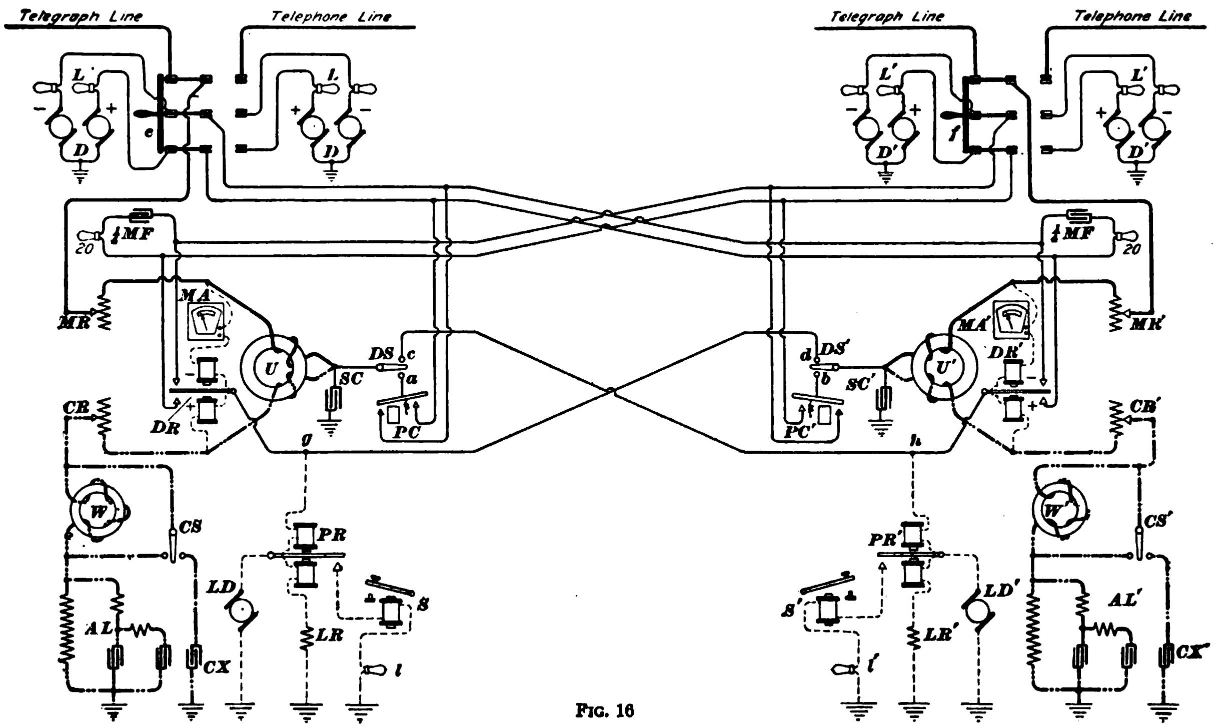
FIG. 15

of the line-resistance box to reduce the incoming current to a value that will produce a reading of not more than 10 on the milliammeter. If the leakage along the line is fairly well distributed, this extra resistance should be divided between the two offices, equal amounts being preferably inserted at each end. But where the insulation is low at one end of the line and about normal at the other end, the larger portion of this resistance should be inserted at the office nearest the place where the low insulation exists.

42. In Fig. 15 (*a*), (*b*), (*c*), and (*d*) is shown the current in the various branches of a polar-bridge duplex circuit for the four possible positions of the two pole changers, one at each end. The keys that would be used to control the pole changers are not shown. The numbers on the arrows represent the current, in milliamperes, in the various parts of the circuit; numbers on devices represent their resistance, in ohms, and numbers opposite dynamos represent the potential difference between their terminals.

The two positions of the key at Scranton, as shown in (*a*) and (*b*), give a current of the same strength and direction through the polar relay at Scranton, but reverse the direction of the current through the polar relay at Buffalo. At any point where circuits join, the sum of all currents flowing toward the point must be equal to the sum of all currents flowing away from the point. Thus at *y*, the current of 128 milliamperes flowing toward it is equal to 75+53 milliamperes flowing away from it.

The two 500-ohm coils in the bridge represent the two windings on the 5-**U** impedance coil used in all these duplex and quadruplex bridge sets. No condensers have been shown, but the capacity of the line must be balanced by an equal capacity in the artificial lines and the sparking at contact points is reduced by condensers associated with them as shown in other figures. The local circuits are connected in exactly the same manner as shown in connection with the pole changer and polar relay in Fig. 14.



Telegraph Line
Telephone Line
Telegraph Line
Telephone Line
L
L'
D
D'
e
f
MF
20
MR
MR'
MA
MA'
U
U'
DR
DR'
DS
DS'
SC
SC'
PC
PC'
a
b
c
d
g
h
CR
CB'
W
W'
CS
CS'
AL
AL'
CX
CX'
PR
PR'
LD
LD'
LR
LR'
S
S'
l
l'

FIG. 16

WESTERN UNION BRIDGE DUPLEX REPEATER

43. In Fig. 16 are shown two **polar bridge duplex sets** arranged to repeat through each other. They can be operated independently for adjustment or for communication with each end from the repeater station. The sets may be used with regular telegraph or telephone line wires and their proper electromotive forces. When both dividing switches *DS* are turned to contacts *a* and *b*, two independent duplex sets are obtained; when they are turned to contacts *c* and *d*, one set repeats into the other on the principle of direct polar-relay repeaters, which have been explained. The three-pole double-throw switches *e* and *f*, when turned to the left, connect the set to ordinary telegraph wires and dynamos supplying as high a voltage as is commonly used with telegraph lines; when these switches are turned to the right, telephone lines and 26- or 52-volt dynamos or storage batteries are used.

44. Leak-Relay Circuit.—To ascertain the character of the signals transmitted to each line by the direct-repeating sets, the two main-line wires are tapped at the tongues of their respective relays (at *g* and *h* in this figure), and a small portion of the outgoing currents from each transmitting relay is diverted through a high-resistance leak circuit, in which is connected a sensitive polar relay *PR*, called a *polar leak relay*, controlling a local sounder *S*.

The regular box form of polar relay with its coils connected in series is used and the leak resistance *LR* is contained in a box whose coils range from 8,000 to 20,000 ohms and is so arranged as never to contain less than 8,000 ohms. The leak resistance should be as high as will allow just sufficient current to pass through to operate the leak relay properly when it is adjusted to work with the smallest possible current. Otherwise, the main line is deprived of more current than is necessary. The leak relay should be kept properly centered, which can be done without interfering with the passing signals, by opening the leak circuit by throwing the proper lever of the leak box over to the stud marked open.

The composite coils W and W' and condensers CX and CX' are cut out by turning the switches CS and CS' to the left. They are cut in by turning these switches to the right, which is done only when composited telephone lines are used, in order to balance the inductance and capacity in the composited set to eliminate the sounds of the Morse signals from the telephone receiver. When used with a simplexed telephone line, the switches CS and CS' should be turned to the left, as the inductance coils W and W' and condensers CX and CX' are not then required to eliminate the Morse signals from the telephone receiver.

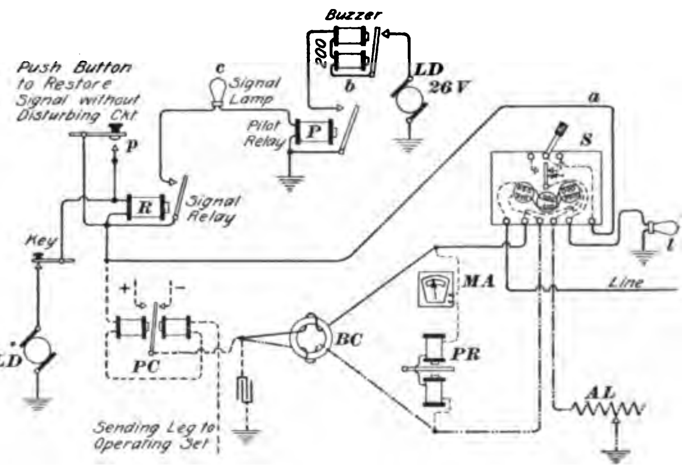


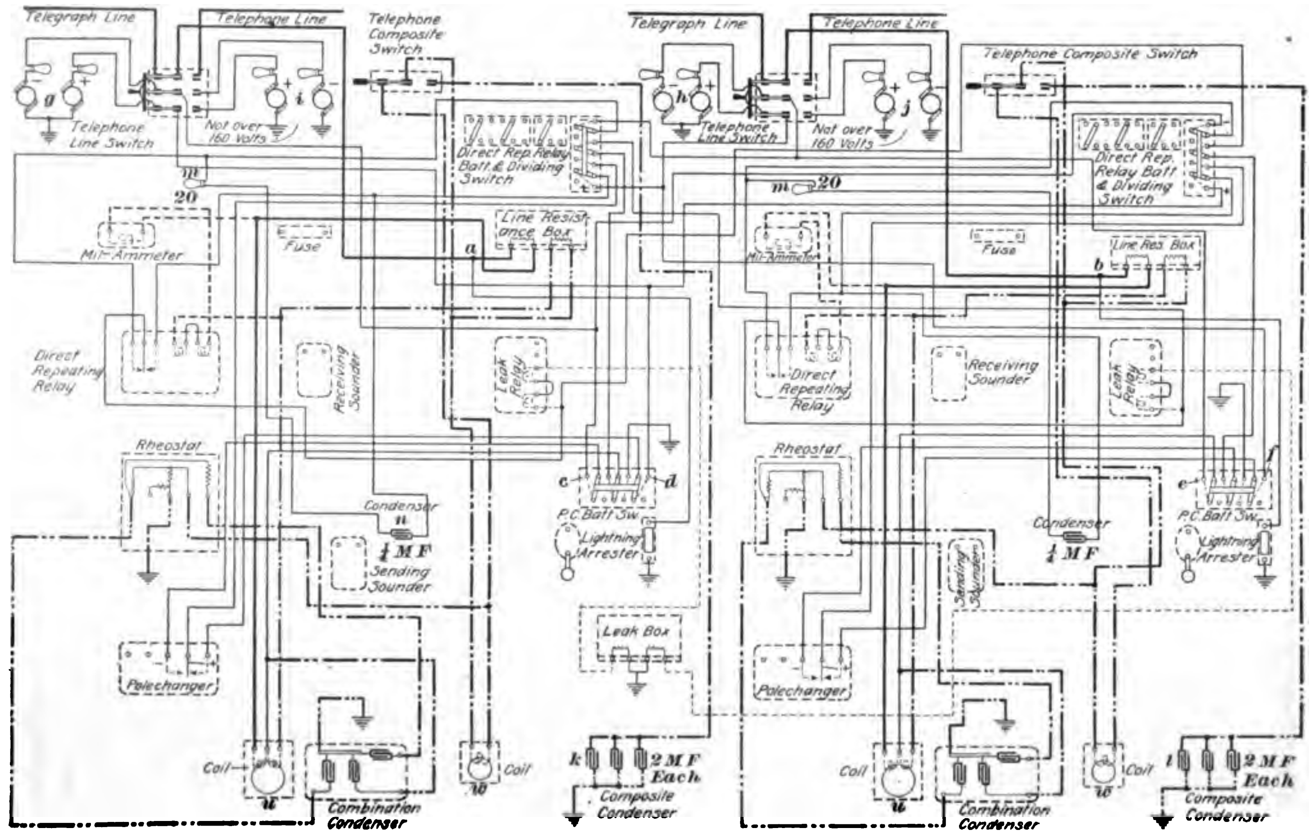
FIG. 17

45. Signaling Circuit.—In Fig. 17 is shown a newer signaling circuit than that shown in Fig. 14. In the line and artificial line circuits are included coils of the so-called ***neutral signal relay*** S, having a single-pole double-pole switch on the base whereby the wire a may be connected to either the front- or back-contact stop of the relay. Equal currents through the coils of this relay will allow the spring to hold the lever against the back stop. If the distant operator opens his line circuit, the current in the home artificial line will operate this signal relay S, sending current through the 60-ohm resistance lamp l and closing the signal relay R, which is locked in its closed position and allows current to illuminate the signal lamp *c*, to close the pilot relay *P*, and to sound the 200-ohm buzzer *b* until the home operator restores all signals by pressing the push button *p*, which causes the relay *R* to release its armature provided the distant operator has closed his line circuit. Thus, the distant operator has to open the circuit only a moment and the repeater attendant can reply as soon as he is free to do so. No other unexplained principles are involved in this signaling arrangement.

BRIDGE DUPLEX REPEATER SETS

46. The complete connections of the main and artificial-line circuits of the **bridge duplex repeater sets** arranged for use with either telegraph or telephone lines is shown in Fig. 18. It is quite common practice, especially in complicated circuit drawings, not to loop one line over another where two wires do not make electrical contact, but to simply draw the lines across one another, care being taken to put a distinctive black dot where wires do make electrical contact, which method is followed in this figure so that such drawings may be fully understood. It enables the drawing to be made much quicker and when it is understood causes no confusion. The two telephone composite switches, correspond to switches *CS* and *CS'* in Fig. 16, and are used to cut coils *w* and condensers *k* and *l* out of the circuit when telegraph lines are used and into the circuit when telephone lines are used.

When such sets are to be used with telegraph lines only, the two triple-pole, double-throw, telephone-line switches, the generators *i* and *j*, the two telephone composite switches and the impedance coils *w* are eliminated and the telegraph line wires are connected directly to points *a* and *b*, the generators *g* are connected to points *c* and *d* on one pole-changer battery switch and the generators *h* to the points *e* and *f* on the other pole-changer battery switch. Otherwise the connections are exactly the same as shown here. The 20-ohm lamp, or resistance, *m* and the ½-microfarad condenser *n* are connected in series across the contacts of the direct repeating relay to reduce



Telegraph Line
Telephone Line
Telephone Line Switch
Not over 160 Volts
Telephone Composite Switch
Direct Rep. Relay Batt. & Dividing Switch
Line Resistance Box
Mil-Ammeter
Fuse
Direct Repeating Relay
Receiving Sounder
Leak Relay
Rheostat
Condenser
¼ M F
Sending Sounder
P.C. Batt. Sw.
Lightning Arrester
Leak Box
Polechanger
Coil
Combination Condenser
2 M F Each
Composite Condenser
Line Res. Box

FIG. 18

sparking. The leak resistances, one in series with each leak relay, are both placed in one leak box.

The pole-changer battery switches are shown in the operating positions; when turned to the right, the generators are disconnected from the pole-changer contacts and the middle points of the two impedance coils *u* are directly grounded for balancing purposes. The direct-repeating relay, battery, and dividing switches are shown in their position for making a repeater out of the two sets. When turned to the right, the contacts of the direct-repeating relays are disconnected from the generators and from the contacts of the opposite pole changers and the center points of the two coils *u* are disconnected from the tongue of the opposite pole changer and connected to the tongue of the pole changer on the same side so that two independent sets are secured and the attendant operator may telegraph to one or both terminal stations. No other new principles are involved, so that no further explanations seem necessary.

POSTAL BRIDGE QUADRUPLEX

47. In Fig. 19 is shown the bridge quadruplex system first described in the Telegraph and Telephone Age in 1912 and

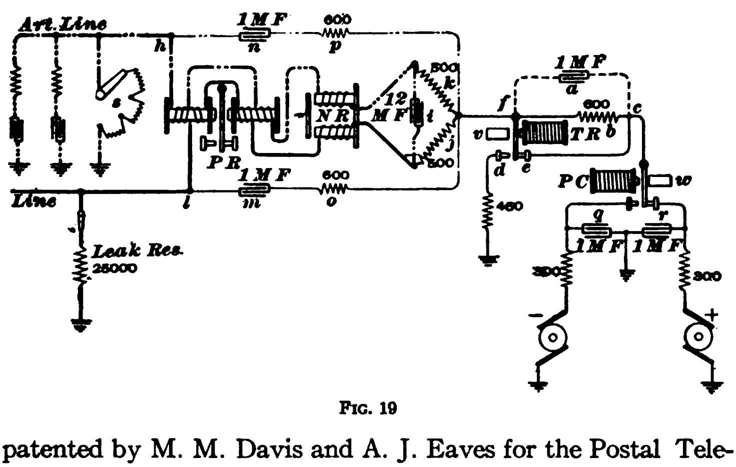


FIG. 19

patented by M. M. Davis and A. J. Eaves for the Postal Telegraph-Cable Company and called their improved quadruplex.

The pole changer *PC* and transmitter *TR* are alike in construction. They are provided with permanent magnets *v* and *w* in place of springs for withdrawing the armatures from the electromagnet cores, thereby, it is claimed, eliminating vibration and producing more uniform contact resistances. The transmitter controls an ordinary added-resistance-and-leak-coil key system. However, the Jones system requiring two equal positive and two equal negative potentials can also be used. For instance, where a three-wire direct-current lighting or power system with a grounded middle, or neutral, wire is available, the positive and negative short-end potentials may be obtained direct from the outside wires of the three-wire system, and the positive and negative long-end potentials by means of boosters, which are motor generators, operated from the three-wire circuits and designed to raise the potential to the desired voltage.

48. The condenser *a* around the 600-ohm added resistance *b* is charged to the potential between the points *c* and *d* when the transmitter *TR* is open. When the transmitter closes, the condenser and added resistance are short-circuited, the added-resistance coil resists the quick stopping of the current through it and if alone short-circuited it tends to delay the rise of potential at *f*, but the condenser discharges through $c-e-f$, thereby hastening the rise of potential at *f*. When the circuit is opened at *e*, the condenser absorbs the excess current due to the removal of the short circuit around it and the consequent rise in potential across its terminals and the coil *b* resists the increase of current through it, thereby hastening the fall of potential at *f*. This condenser also tends to reduce the sparking between the armature and the contact points *d* and *e*. The grounded condensers *q* and *r* reduce the sparking at the pole-changer contacts.

49. A circuit bridged from the line *l* to the artificial line *h* contains the coils of the polar relay *PR* and the neutral relay *NR* and two 500-ohm resistances *j* and *k*. Across the 500-ohm resistances is a 12-microfarad condenser *i*. The bridge resistances tend to steady the balance of the set by reducing the effect upon the apparatus of changes in line resistance and leakage caused by the weather and the condenser across them accelerates, by its discharge, the reversal of the received current. For high-resistance lines, the bridge resistances can be advantageously eliminated, that is, short-circuited.

The 1-microfarad condensers *m* and *n* in series with the 600-ohm resistances *o* and *p*, which shunt the relays and bridge resistances, are said to accelerate the rise and fall of the current sent to the line, thereby counteracting the retarding effect upon the same current of the inductances in the bridge circuit in which the outgoing current rises and falls gradually.

The rapid rise and fall of the current in the line tends to produce the desirable snappy action of the distant relays and the tendency of the home relays to produce false signals is reduced by passing around them the first rush of current produced when the home pole changer reverses the potential. The resistance in series with the condenser slightly retards the rise and fall of the condenser current, so that it will not have spent all its energy before the current by way of the relays reaches its maximum value. The line current, therefore, reaches its maximum value quickly and retains it until reversed.

The condensers *m* and *n*, by furnishing a path around the relays for currents induced in the line, tend to keep these currents from disturbing the relays. Furthermore, these condenser circuits furnish a path through which the relays can discharge when the home potentials are reversed, thereby reducing the sparking at the pole-changer and transmitter points through which such discharges would otherwise have to pass.

50. Relays.—The relay and protective resistances are kept as low as will give sufficient ampere-turns in the relays and safety and freedom from interruption to service by the blowing of fuses in the protective-resistance circuit. The polar relay has 2,800 turns of No. 32, single-silk-covered wire per spool and the relay has a total resistance of only 200 ohms. It is made with a short stubby armature lever of about half its former weight and accurately balanced. As a result the relay operates well on the reversal of a small current. This polar relay has given good signals on a line having a resistance of 35,000 ohms and a capacity of 15 microfarads with a current of 1 milliampere at a speed of 45 words per minute produced by a Wheatstone automatic transmitter. It should therefore work satisfactorily on any manually controlled quadruplex system. The neutral relays have a core $1\frac{7}{8}$ inches long, instead of $1\frac{1}{32}$ inches as heretofore, and are wound with 2,800 turns of No. 31, single-silk-covered wire per spool, making a resistance of approximately 60 ohms per spool.

The contact points secured to the armatures of all relays and transmitters are locked in position with a setscrew and can be quickly removed and replaced. All armatures and contact screws can also be quickly removed and replaced; in fact, all parts, as far as practicable, are removable and interchangeable, so that minor replacements may be made at stations without returning the apparatus to the repair shop. The contact points are made of an alloy that is said to resist wear and to reduce the amount of cleaning required. The magnet adjustments are quick-acting rack-and-pinion type and the bases are slate, free from iron and mounted on brass subbases having soft-rubber feet to minimize vibration caused by typewriters on the same table. Sounders are connected in series with each transmitter and mounted in resonators so that each transmitting operator may readily hear his sending.

51. Balancing Rheostat.—The balancing resistance *s* in the artificial line is arranged with radial arms and is mounted upon slate and iron. The coils are made of enameled wire on porcelain cores. They are fireproof and practically troubleproof.

All the condensers are the rolled type hermetically sealed in metal cases. Each .1 microfarad unit is mounted in a case so that any one can be quickly removed and replaced. A quick-acting rack-and-pinion commutator operated by a single knob, cuts capacity in or out, by tenths of a microfarad, from .1 to 3 microfarads. This enables the attendant to quickly balance the capacity of the line.

52. With the exception of the wooden tops on the adjustable condenser cases, which are used to secure high insulation for the rack-and-pinion commutator, and the wooden bases under the sounders to secure resonance, no wood is employed in the construction of the apparatus which is, therefore, practically fireproof. An explanation of the operation of this quadruplex system seems unnecessary, as no new principles are involved.

PHONOPLEX SYSTEMS

EDISON PHONOPLEX

53. The **Edison phonoplex system** is a well-known method of transforming a single Morse wire into a duplex circuit on which it is possible to send two separate messages from one station, or to send one message and receive another at the same time. It is thus an excellent emergency system, meeting the requirements of special occasions and doubling the number of circuits where wires are scarce. It is especially invaluable to the railroad service, where the number of wires is usually limited, as it provides an extra circuit that is available at all times.

54. Principle of Phonoplex Systems.—In Fig. 20, the two stations are represented as equipped with a Morse and a phonoplex set. The Morse relays and keys are bridged by condensers C_3 and C_4, while coils of wire M and M_1 wound on an iron core so as to have a high inductance, and called the *magnetic coils*, are placed in the circuit, one at each station. Condensers C and C_1 of small capacity are bridged around the magnetic coils M and M_1; these condensers sharpen the impulses sent into the line.

In order to explain the phonoplex principle, an ordinary walking-beam pole changer Pt is here shown. This pole changer is operated by the local battery LB and the key Pk in the usual manner. A resistance coil d of about 10 ohms is connected between the battery Pb, which may be called the phonoplex battery, and the pole-changer contact *p*. This coil *d* produces in the *phone* an effect resembling the up-and-down stroke of an ordinary sounder.

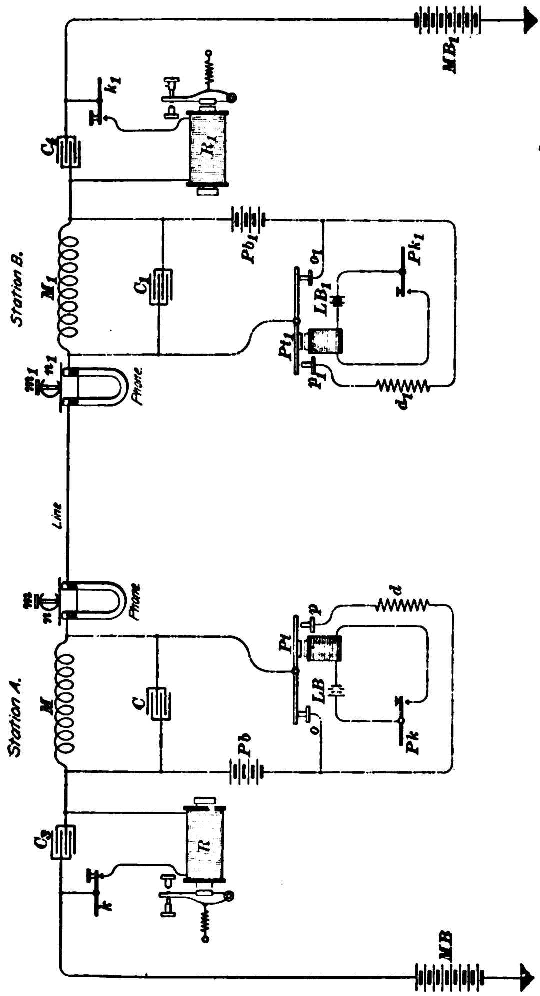


FIG. 20

The receiving instrument, or **phone**, consists of an elongated horseshoe magnet, having a small coil of insulated copper wire wound on each of its terminals; above the poles is a large diaphragm. So far the phone resembles a double-pole telephone receiver. In addition, however, there is a split steel ring *n* resting on the diaphragm, but so arranged that it can move freely up and down on a vertical pin *m*. Each agitation of the diaphragm causes the steel ring to be thrown against the nut, producing an excellent imitation of the tone of a telegraph sounder.

55. Operation of Phonoplex.—To comprehend the working of the apparatus, it will be necessary to bear in mind that the transmitter produces the effect of dots and dashes by opening circuits and not by closing them. Suppose that the key *Pk* is open; then a steady current of considerable strength will be flowing from the phonoplex battery *Pb* through the magnetic coil *M* (which has a resistance of a few ohms only) and the stop *o*.

If the key *Pk* is now closed, this current will be abruptly broken at *o*, causing quite a high counter electromotive force to be developed in the magnetic coil *M*, due to its high self-induction. As the circuit is open at *o* and *p*, there is at this instant no outlet for the electrical impulses except along the line, along which they must therefore travel. The phone at the distant end responds to these impulses, but the impulses are comparatively feeble in comparsion with the Morse current; moreover, they change very rapidly in strength and hence will pass through the condenser C_1, around the magnetic coil M_1, and through the condensers C_3 and C_4 instead of the relays *R* and R_1, and thus will not operate the relays. The sound made by the phone corresponds to the down or front stroke of an ordinary sounder. A moment later the circuit is closed at *p*, and although impulses are doubtless set up again in the magnetic coil, they can now expend themselves in the closed local circuit and do not produce any impulses of appreciable strength in the line circuit. The current flowing is not as strong, on account of the extra resistance *d* which is now included in the circuit with the phonoplex battery, as the current that flowed when the lever touched *o*.

56. When the key is released, this smaller current will be abruptly broken at *p*, and will develop in the magnetic coil a counter electromotive force of somewhat less intensity than when the key was closed. These impulses, for the reason given before, will travel along the main line, but will produce a sound less intense, however, than before, and so will resemble the sound produced by the back stroke of an ordinary sounder.

A moment later the circuit will again be closed at *o*, but the impulses that are developed in the magnetic coil will not flow out over the main line, but will expend themselves in the closed local circuit. Thus the down and up, or front and back, strokes of an ordinary sounder have been closely imitated and the system is ready for the production of another signal.

The key *Pk* is not intended to merely open and close the circuit of the battery *Pb* through the coil *M*, but rather to cause impulses of two different intensities to be sent through the main line. Since the phone is an instrument that produces a sound only when the current passing through it is rapidly changing in strength, the slowly changing Morse current will not operate it. The phone is adjusted by means of the screw *a*, Fig. 21, so that the diaphragm is beyond the influence of the comparatively steady Morse currents, but is still within the influence of a rapidly changing current.

57. Practical Arrangement of Phonoplex.—In Fig. 21 the complete and practical arrangement at an intermediate station is shown. The connection at the terminal station will be practically the same. This figure is lettered as far as possible like the preceding one. The key *Pk* is slightly different from the ordinary key. The contacts *b* and *h* are insulated from the base or framework of the key. The bent lever *l* is permanently connected with the base and, consequently, to the wire *3*, which is also permanently connected to the base of the key. The wire *1* is connected, as usual, to a platinum point that is insulated from the base. When the bent lever *l* is turned to the left, which is called the *closed position*, the phonoplex battery *Pb* is left open at the point *b* and the magnetic coil *M* is short-circuited through the wires *9* – *8* – spring *e* – transmitter lever - wire *3* - base of key - the bent lever *l* - wire *6*. Thus, in this position of the bent lever, the phonoplex transmitting apparatus is practically cut out of the circuit. The phonoplex

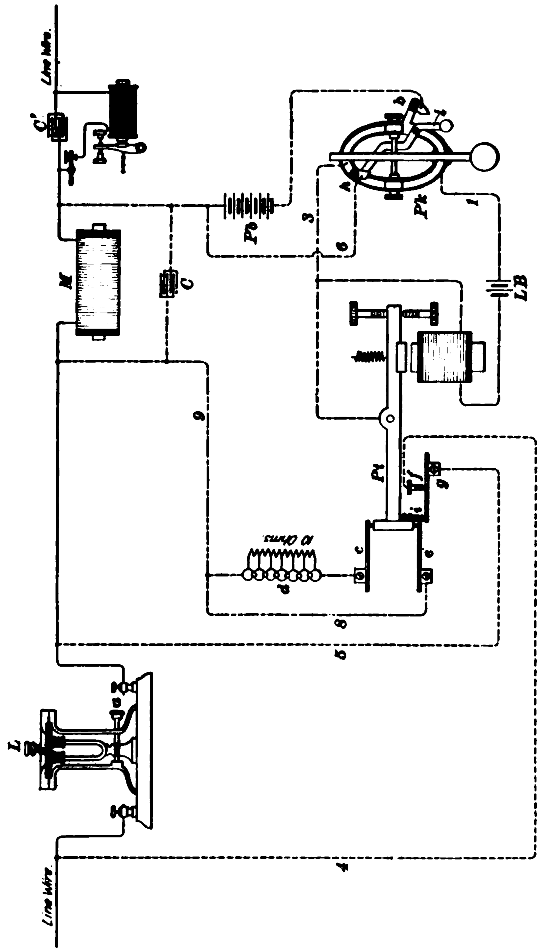


FIG. 21

battery is left open for the reason that it is of low resistance and depreciates rapidly when left on closed circuit. The magnetic coil *M* is short-circuited when not in use, so as to keep its resistance out of the main line.

58. Transmitting Position of Key Lever.—When the key is opened, that is, when the bent lever *l* is pushed to the right so as to come into contact with *b*, the phonoplex battery is connected through *b* - bent lever *l* - base of key - wire *3* - transmitter spring *e* or *c* - magnetic coil *M*. This position of the lever *l* opens the short circuit around the magnetic coil and throws it into the line circuit, and furthermore closes the circuit of the phonoplex battery *Pb* through the magnetic coil and the transmitter springs. This is done when the operator desires to send a message. If the key is now manipulated, the transmitter will make and break the current through the magnetic coil. The key has no ordinary circuit closer; consequently, the circuit through the local battery *LB* and the transmitter magnet is open at all times, except when a dot or dash is being made.

59. Receiving Position of Key Lever.—When the operator wishes to receive, he throws the lever *l* to the left, which act corresponds to closing the ordinary key, but in this system the movement disconnects the local battery *LB* from the transmitter, leaves the phonoplex battery *Pb* on open circuit, and short-circuits the magnetic coil, thus allowing the phone to be more readily affected by the discharge from the distant magnetic coil. The same result could, of course, be obtained with an ordinary key and a pole-changing switch.

When the key *Pk* is depressed while the lever *l* is turned to the right, the local circuit is closed and the armature of the transmitter is attracted, thereby breaking contact at spring *e* and sending an impulse from the magnetic coil into the line. When the key is released, the armature of the transmitter is also released and the circuit is broken at the point *c*, thus sending another but weaker impulse into the line. This time, however, the impulse produces a less intense sound that corresponds to the back stroke of an ordinary sounder, thereby enabling the operator to distinguish the difference between the two and thus avoid getting a back-stroke effect. Wires *4* and *5* connected to the points *f* and *g*, respectively, short-circuit the phone when the circuit containing the transmitter magnet is closed.

60. An insulated piece *i* attached to the lower part of the lever of the transmitter permits the spring *g* to make contact with the screw *f* just before the circuit is broken at *e* as the armature lever of the transmitter is attracted, and then breaking contact at *f* after the circuit has been broken at *c* as the armature is released. The phone at the home office is thus silenced while the home office is working. It is arranged this way because the response of the home phone to local impulses would be very loud if it were permitted to work, and some difficulty would be met with when the receiving operator desired to break. The small condenser *C* not only quickens the impulses and helps the incoming signals, but also prevents excessive sparking at the contact points of the springs *c* and *e*. The Gordon, Edison-Lalande, bichromate of potassium, or other good closed-circuit, low-internal-resistance battery should be used for operating the phonoplex and only 10 or 12 volts are required.

61. Advantages of Phonoplex System.—One advantage of the phonoplex system over the Morse is that it is less likely to be affected by ordinary trouble on the wire. It will work readily across heavy escapes or when the phonoplex wire is grounded or crossed with some other wire. Even bad weather fails to affect the signals to any great extent. All Morse sets in intermediate offices are bridged with condensers and the operation of the relays does not interfere in any manner with the working of the phonoplex. It is adapted for use between intermediate stations or between terminal stations.

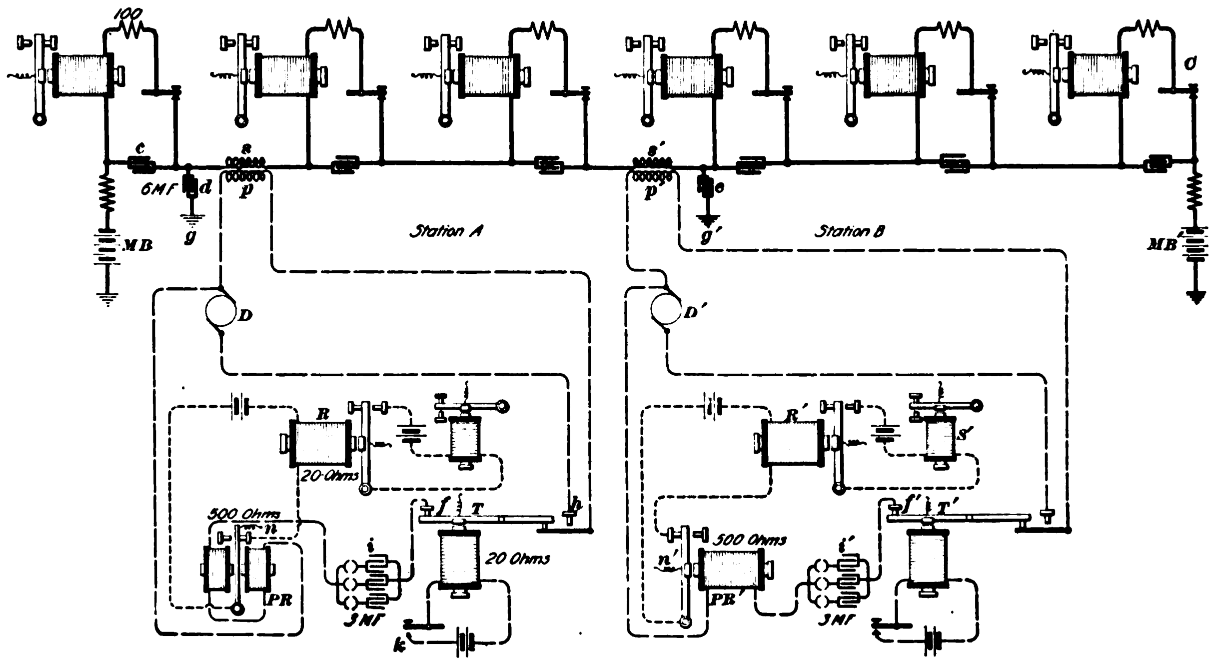
A serious objection to the system is the fact that only one circuit can be worked successfully on the same line of poles carrying a number of wires, such as is usually strung along a railroad. A companion phonoplex on a line of poles on the opposite side of the track is even impracticable, for the reason that the phonoplex impulses are so penetrating that their inductive effects extend far into the space around the wire; hence it is much better to arrange only one phonoplex circuit along a line of wires in any one given direction. The phonoplex system at least duplexes the capacity of the line, as it may be used between any number of intermediate stations, any two of which may carry on telegraphic communications independently of the Morse system. It has been successfully worked on wires already duplexed or quadruplexed. The construction and operation of this system is simple, and the ease with which it can be adjusted places it within control of an ordinary operator.

THE PHANTOPLEX

GENERAL DESCRIPTION

62. The name **phantoplex** has been given to a telegraph system, invented by Mr. F. W. Jones, in which *phantom circuits* are used. A phantom, or extra, telegraph circuit is one produced out of a line already in use as a Morse telegraph circuit without the addition of an extra line wire. As the phantoplex currents have a much higher frequency than the Morse, they will readily act through condensers bridged across the Morse sets; but the inductance of the Morse relays prevents an appreciable part of the phantoplex current from passing through and in any way interfering with the operation of these relays. As the Morse current cannot pass through these condensers, it is confined to the circuit including all the Morse sets. Moreover, the Morse current cannot interfere with the phantoplex current because the rate of change of the Morse current is so slow that it produces no appreciable induction from the secondary to the primary of the phantoplex transformers.

63. Phantoplex Apparatus.—In Fig. 22 is shown an arrangement for operating a phantoplex system between a terminal station *A* and any way station *B* over an ordinary Morse circuit terminating at offices *A* and *C* and having the usual way stations between. The phantoplex apparatus at each office includes an alternating-current dynamo *D* that



100
c
6MF
d
g
MB
s
p
Station A
D
R
20 Ohms
500 Ohms
n
PR
i
3MF
f
T
h
20 Ohms
k
s'
p
e
g'
Station B
D'
R'
S'
f'
T'
500 Ohms
n'
PR'
i'
3MF
o
MB'

FIG. 22

produces an alternating current having a frequency of from 150 to 175 cycles a second at about 100 volts for an ordinary telegraph circuit about 300 miles long, not including way offices. Each Morse relay and key in the battery circuit is bridged by a 6-microfarad condenser *c*, while the line is connected to ground through 6-microfarad condensers *d* and *e* at each phantoplex office toward the terminal end of the line wire. If an intermediate dynamo is in use between the two phantoplex sets, it also should be bridged by a condenser. The action of the relays is improved by inserting a 100-ohm, non-inductive resistance between the Morse relay and key, for this coil will increase the ratio of non-inductive to inductive resistance. Of course, the insertion of this coil will increase the electromotive force required.

64. Operation of Phantoplex.—When the key *k* controlling the transmitter *T* is closed, alternating current flows from the dynamo *D* through the contact *h* into the primary winding *p* of the phantoplex transformer. It there induces, in the secondary winding *s*, an alternating electromotive force of the same frequency as the primary current and of suitable voltage. This electromotive force causes an alternating current to flow through ground *g* – condenser *d* – secondary winding *s* – line and condensers at way stations – secondary winding *s'* – condenser *e* – ground *g'* back to ground *g*.

The current flowing through the secondary winding *s'* produces an alternating current of the same frequency and suitable voltage in the circuit through the transformer primary coil *p'* – contact *f'* of the transmitter *T'* – condenser *i'* – relay *PR'* – back to primary coil *p'*. This current causes the armature of the relay *PR'* to vibrate and keep its local circuit open such a large percentage of the time that the pony relay *R'* releases its armature and thereby closes its local circuit on the rear contact, causing the sounder *S'* to be energized. When the key *k* of the transmitter *T* is released, no current flows through the phanto relay *PR'*, the circuit of the local pony relay *R'* is then closed and the circuit of the local sounder *S'* is opened.

65. Phanto Relays.—The so-called **phanto relay** *PR'* is merely a neutral relay so constructed as to be especially sensitive and suitable for operation by alternating currents. When connected in series, the two coils have a resistance of 500 ohms and the armature is normally held against the local, or back, contact stop by a suitable spring *n'*. Polarized relays, connected as shown at *PR* and having the armature held against one stop by a light spring *n*, were originally used in place of the phanto relay *PR'* and may still be found in the older sets.

SIXTY-CYCLE PHANTOPLEX

66. Where telegraph and telephone wires run parallel with each other, 60 cycles is used for the phantoplex, because this lower frequency does not interfere with the operation of

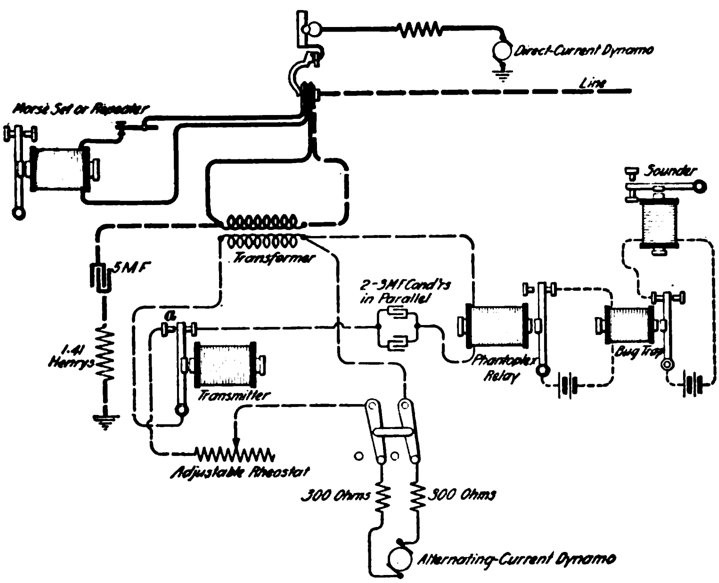


FIG. 23

the telephone as does the 150-cycle, or higher frequency, alternating current. In Fig. 23 is shown the arrangement of apparatus used by the Postal Telegraph-Cable Company at a terminal station for a 60-cycle phantoplex. The heavy dash line indicates the path of the alternating current in the line and one winding of the transformer to ground. The direct-current dynamo supplies current that flows through the Morse set and one winding of the transformer to the line.

When the transformer wedge is inserted in the jack, the end of the transformer to which the 5-microfarad condenser is connected must always be placed next to the Morse set, as shown. The operator's key circuit that controls the transmitter is not shown. When the key in this local transmitter circuit is closed, the local alternating-current circuit is opened at *a*. No alternating current then flows through either winding of the transformer or over the line, and hence the distant phantoplex relay releases its armature, thereby closing the circuit of the distant bug trap, which in turn closes the circuit of the distant reading sounder.

PHANTOPLEX REPEATER

67. In Fig. 24 is shown a phantoplex repeater arranged, in this case, to repeat from one duplex circuit *A* to another duplex circuit *B*. In order to preserve the balance of the duplex sets, transformers *m* and *n* are inserted in the artificial-line side of each set to give the artificial line an inductance equal to that in the line due to the phantoplex transformers; 6-microfarad condensers *a* and *b* connected to ground are also necessary in the line and artificial-line side of each duplex set. When the switches *E* and *F* are turned to the left, phantoplex messages arriving over either line are repeated into the other line. Phantoplex currents arriving at *A* act through the transformer *o* and open the local circuit of the polar relay *PR*, thereby causing the pony relay *R* to release its armature. This closes the circuit containing the reading sounder *S* and the transmitter magnet *T′*, which repeats the signal by means of the alternating-current dynamo *AC′* and phantoplex transformer *p* into the line of the duplex set *B*. The reading sounders, when not in use, may be short-circuited by the switches shown.

With the switches *E* and *F* turned to the right, the phantoplex repeater may be used as two independent sets. To avoid

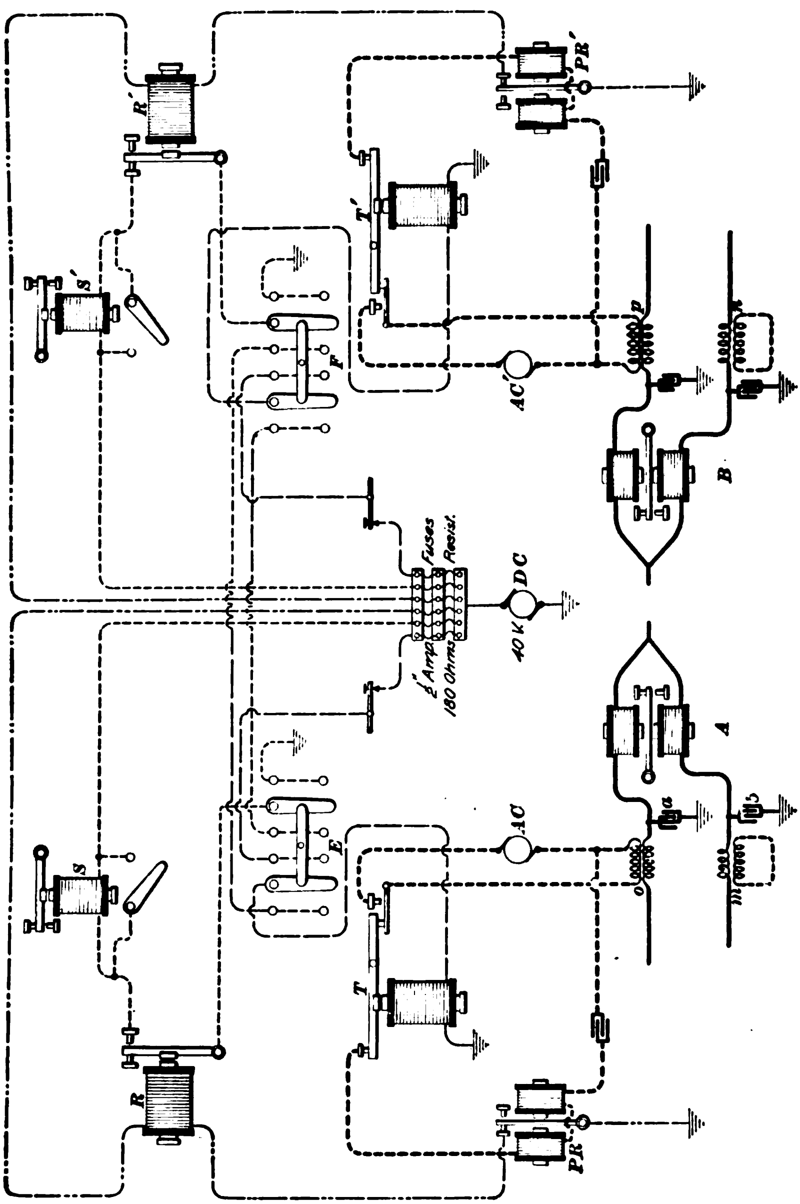

R'
S'
T'
PR'
F
AC'
p
n
B
Fuses
Resist.
DC
40 V
½ Amp
180 Ohms
AC
E
S
R
T
PR
A
a
b
o
m

FIG. 24

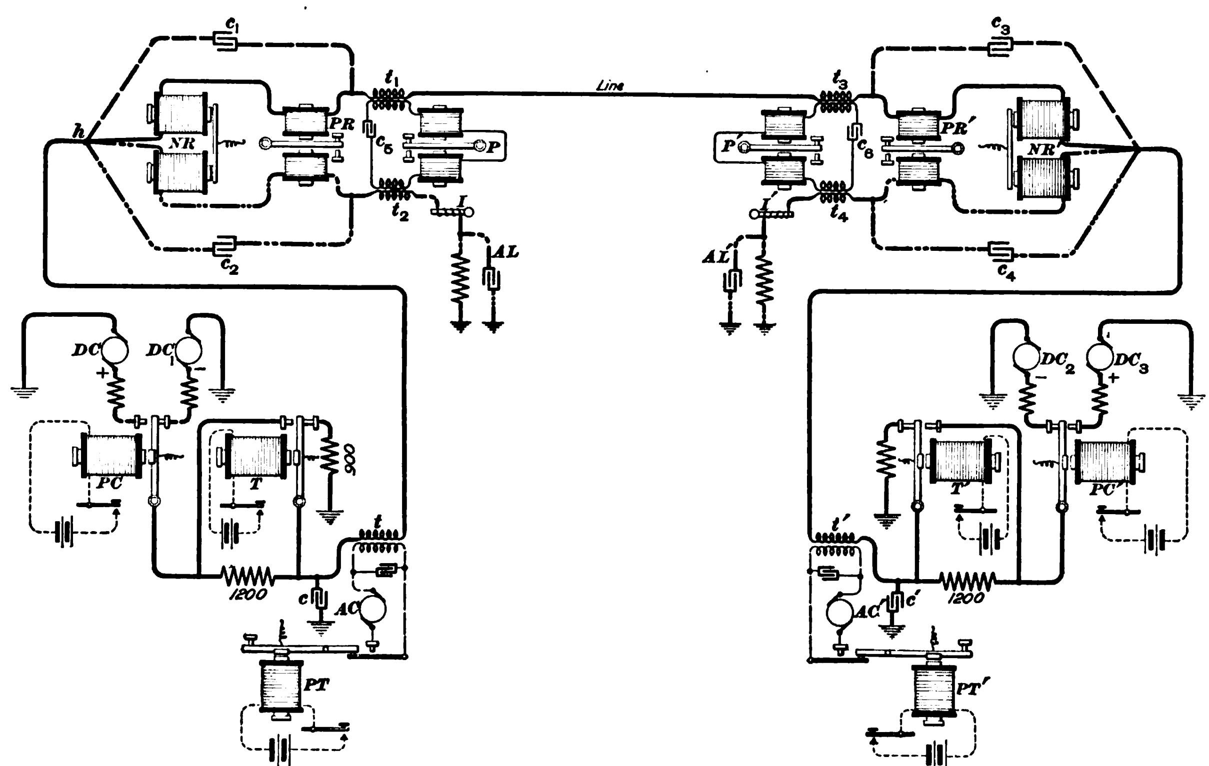

Line
c_1
c_2
c_3
c_4
c_5
c_6
t_1
t_2
t_3
t_4
h
NR
PR
P
I
AL
NR'
PR'
P'
I'
AL'
DC
DC_1
DC_2
DC_3
PC
T
900
1200
t
c
AC
PT
PC'
T'
t'
c'
AC'
PT'

FIG. 25

unnecessary repetition, the transmitting apparatus of the regular direct-current polar duplex sets has been omitted in this figure. By inserting inductance and capacity in the artificial line, as shown in this figure, it is evident that phantoplex can be worked over a duplex or quadruplex line.

THE SEXTUPLEX

68. The **sextuplex,** invented by Mr. S. F. Jones, and shown in Fig. 25, is a combination of the added-resistance-and-leak-coil quadruplex and the phantoplex. It may also be considered as a combination of three duplex systems; namely, the phantoplex, polar, and high-potential, differential duplex systems. The quadruplex apparatus at each end consists of the two direct-current dynamos *DC* and DC_1, of equal voltage but opposite polarity, the pole changer *PC*, the transmitter *T* controlling the connections of a 1,200-ohm added-resistance coil, a 900-ohm leak coil, a neutral relay *NR*, a polarized relay *PR*, and an artificial line *AL*. These are associated with the line in the same manner as in the ordinary quadruplex system and, therefore, require no further explanation.

69. The phantoplex transmitting apparatus consists of the regular phantoplex transmitter *PT*, alternating-current generator *AC* of rather high frequency and giving as near as practicable a smooth sine wave, and a transformer *t*. The phantoplex receiving apparatus consists of a polar relay *P* provided with a retractile spring for giving the armature a slight bias in one direction (consequently acting as a neutral relay), two transformers t_1 and t_2, condensers c, c_1, c_2, and c_5, and an adjustable inductance coil *I* in the artificial line. The condenser c provides a path to the ground for the high-frequency alternating current that is induced in the line coil of the transformer *t*. The condensers c_1 and c_2 provide paths for the same current around the neutral and polar relays *NR* and *PR*, one being in the line side and the other in the artificial-line side of the circuit. The phantoplex polar relay is connected in series with one winding of the transformers t_1 and t_2 and a condenser c_5.

Two transformers t_1 and t_2 are used to preserve the balance of the line and artificial line and also to prevent the alternating current generated at the home station from affecting the home phantoplex relay. These transformers are so wound that alternating currents of equal strengths flowing from *h* through the condenser c_1 and transformer t_1 to line and through the condenser c_2 and transformer t_2 to the artificial line will develop equal but opposing electromotive forces in the local windings of the transformers t_1 and t_2, and hence no current is produced in the circuit containing the local windings of the transformers t_1 and t_2, the relay *P*, and the condenser c_5. If, however, the alternating current in the line winding of one transformer t_1 is enough stronger than that in the artificial-line winding of the other transformer t_2, or vice versa, a current will be produced through the relay *P*, which will cause the armature to leave the stop against which it is held by the retractile spring, thereby opening the circuit of a repeating sounder, which in turn closes the circuit of a reading sounder.

70. After the artificial line has been balanced, as for an ordinary quadruplex set, its inductance is also made equal to that of the line by adjusting the inductance coil *I* until the alternating current produced at the home station when the key *K* is closed does not affect the home relay *P*. Where an alternating current is used in the manner shown here, it is necessary to balance the line inductance as well as its resistance and capacity. Thus, the strong and weak direct currents sent toward the line by the operation of the transmitter *T* and pole changer *PC* will divide at *h* equally through the line and artificial-line circuits and affect none of the relays *NR*, *PR*, or *P*. It does not affect relays *NR* and *PR* because they are differentially wound. It does not affect relay *P* because, even if the change in current strength should induce electromotive forces in the local windings, the transformers t_1 and t_2, they would be in opposition and no current would be produced through relay *P*, which would, therefore, be unaffected. Steady direct currents will induce no currents in the local windings of the transformers t_1 and t_2. Alternating currents from the home station will pass from *h* through the condensers c_1 and c_2 around the relays *NR* and *PR* because the condensers offer less impedance to such high-frequency alternating currents than the relays, which possess considerable inductance. Furthermore, the electromotive forces induced in the transformers t_1 and t_2 are equal and opposite, so that no alternating current is produced through the phantoplex relay *P*. Consequently, outgoing currents whether direct or alternating, produce no effect upon the three home relays.

71. Incoming direct currents will properly operate the relays *NR* and *PR*, but not the relay *P*, because they do not vary in strength at a high enough rate to induce an appreciable current (through the transformer t_1) in the local circuit containing relay *P*. Incoming alternating current will, however, induce enough current through the transformer t_1 to cause the relay *P* to draw its armature away from its back stop. But this current will pass through the condensers c_1 and c to ground, thereby not affecting the neutral and polar relays.

In the parts of the circuit where both direct and alternating currents flow simultaneously, the small but high-frequency alternating current is superimposed upon the direct current, producing probably a direct current that fluctuates in strength very rapidly but by very small amounts. It is said that the phantoplex part of the system will continue to work satisfactorily in stormy weather long after the neutral-relay side fails.

72. Johnson Coil.—To reduce sparking at contact points of quadruplex pole changers, **Johnson coils** may be used. These coils consist of three German-silver wires wound together on a wooden spool having an air core. The wires are insulated with a double-cotton covering saturated with paraffin. At one end one wire is connected to the pole-changer lever, a second wire is connected to the positive stop, and the third wire to the negative stop. One end of each winding is left open. These coils act like condensers in eliminating sparks at the contact stops, and are about 7 inches long and 1 inch in diameter. The resistance of the coils makes the discharge take place gradually and like the discharge from the circuit.

MULTIPLEX TELEGRAPHY
(PART 1)

QUADRUPLEX TELEGRAPHY

HEALY QUADRUPLEX

1. In Fig. 1 is shown the quadruplex system devised by Mr. C. L. Healy and known as the **Healy quadruplex.** It has been used by the New York Quotation Company. The same principle is used as is found in those systems that have already been explained; namely, the reversal of the polarity of the current for working the distant polar relay, and an increase and decrease in the strength of the current for operating the distant neutral relay. The arrangement of the apparatus is somewhat different, however.

2. The transmitter consists, practically, of two ordinary continuity-preserving devices. The two levers are mechanically fastened together but are insulated from each other by the insulating material *b*; thus, one magnet really operates two transmitters of the ordinary form. When the key *Tk* is closed, as shown in the figure, the wire *m* is connected with the end of the lever *d* and, hence, to the coil *C*; the wire *n* is connected with the end of the lever *d'* and, hence, to the coil *C'*. Consequently, when the key is closed, the positive pole of the dynamo *D* is connected through the resistance *C* to the end of the lever *d* and wire *m* to the front stop *o* of the pole changer, and the negative pole of the dynamo *D'* is connected through the resistance *C'* to the end of the lever *d'*, and the wire *n* to the rear stop *p* of the pole changer. Thus, the opposite poles of two similar dynamos are connected through exactly similar resistance coils and through the transmitter to the front and rear stops of the pole changer. When the pole changer is closed, a positive machine will be connected to the point *h*;

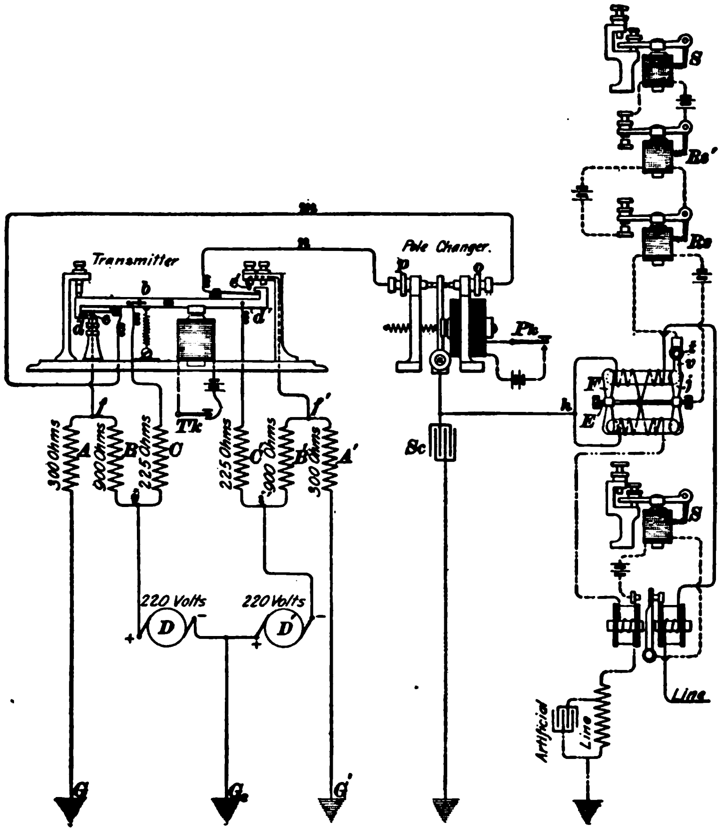


Fig. 1

and when open, a negative machine will be connected to the same point *h*.

3. When the transmitter is open, the positive pole of the dynamo *D* will be connected through the resistance *B* – point *f* – stop *e* and wire *m* to the stop *o* of the pole changer; and the negative pole of the dynamo D' will be connected through the resistance B-stop e' and wire n to the stop p of the pole changer.

In the closed position of the transmitter, the current from the dynamo has two paths, one through the resistance C and the line to the ground at the distant station, and the other through the resistances B and A to the ground G. In the open position of the transmitter, no current can flow through the coil C, because it is open at d. The pole changer, by opening and closing, merely shifts the line and artificial-line circuits that come together at h from a machine of one polarity to that of the opposite; and the transmitter, by varying the arrangement of the resistances between the dynamo and pole changer, alters the strength of the current so as to give the ratio desired.

4. Constant Resistance of Circuit.—The resistance from the point h, through the pole changer, transmitter, resistance coils, and dynamo is the same in all positions of the pole changer and transmitter; evidently the position of the pole changer does not alter the resistance of this circuit in any way. The position of the transmitter itself alters the arrangement of the resistances, but does not alter the total resistance between h and the ground at the home station. The resistance from h through the transmitter to the ground will evidently be 225 ohms when the transmitter is closed, because the resistance from i to G_2 through the dynamo is perfectly negligible.

When the pole changer is closed and the transmitter is open, the point h is connected through the wire m and stop e to the point f, from which point it has two paths, one through the resistance A to the ground G and the other through the resistance B and dynamo D to the ground. The joint resistance of these two coils, as they are in parallel, will be $\frac{300\times900}{300+900}$ $=225$ ohms, which is exactly equal to the resistance of the coil C. Hence, the resistance from h through the transmitter to the ground is 225 ohms in either the open or closed position of the transmitter. As the resistance from the ground through the transmitter to the point *h* is the same in both positions of the transmitter and pole changer, the total resistance of the circuit is the same in all possible combinations of the four transmitting keys, two at each end.

5. Ratio of Current.—The ratio of the current in the line, between the open and closed position of the transmitter, may be calculated in the following manner, assuming that the line (including the resistance of the distant station) and artificial-line circuits each have a resistance of 1,800 ohms: In the closed position of the transmitter, the resistance in the circuit consists of the 225 ohms in the coil *C* the 1,800 ohms in the line, and the 1,800 ohms in the artificial line. The line and artificial-line circuits are in parallel and, hence, their joint resistance is 900 ohms. This resistance added to 225 ohms gives 1,125 ohms; hence, the current in the circuit under consideration, if each dynamo generates 220 volts, will be $220 \div 1{,}125 = .196$ ampere, or 196 milliamperes. One-half of this current, that is, 98 milliamperes, will flow through the line and the same amount through the artificial line.

6. When the transmitter is open, the coil *C* will be on open circuit and the current from the dynamo will divide at the point *f*, part going toward the line and part through the coil *A* to the ground *G*. The resistance of the circuit from the point *f* to the ground now consists of three branches, one branch passing through *A*, one through the line, and one through the artificial line. The joint resistance of the line and artificial line is 900 ohms, as before, and is in parallel with the 300 ohms in the coil *A*; hence, the resistance from *f* to the ground through these three paths will be $\frac{900 \times 300}{900 + 300} = 225$ ohms. This resistance is in series with the coil *B* that contains 900 ohms; hence, the total resistance of the circuit is $225 + 900 = 1{,}125$ ohms. The total current will be $220 \div 1{,}125 = .196$ ampere, or 196 milliamperes. This current will divide at the point *f* inversely as the resistance of the two paths; hence, there is obtained the proportion 900 (joint resistance of the line and artificial line) is to $\frac{900\times300}{900+300}$ (=225) as the total current flowing in both circuits, 196 milliamperes (which is the same as the current in the coil *B*), is to the current flowing toward the line from the point *f*. Hence, the current flowing toward the line from the point *f* equals $\frac{225\times196}{900}=49$ milliamperes. One-half of this current, or 24.5 milliamperes, will flow through the line and the other half through the artificial line.

When the transmitter is closed, the current in the line is 98 milliamperes; when open, the current is 24.5 milliamperes; from which fact it is evident that closing the transmitter increases the current in the line in the ratio of 1 to 4. In order to have the ratio 1 to 3 instead of 1 to 4, the resistances *A* and *A′* should be 400 ohms each; *B* and *B′*, 800 ohms; and *C* and *C′*, 267 ohms.

7. Neutral Relay.—The neutral relay used in the Healy quadruplex system is different from any heretofore considered. The straight cores on which the coils are wound are about 2½ inches long and have a wire space of about 2 inches. They are made from very soft iron wire, as there are no yoke pieces; hence, the magnetism of the relays will reverse very rapidly on account of the low inductance of the electromagnets due to the absence of iron yokes and the small quantity of good soft iron in the cores. Each core has two coils wound upon it, which form the two windings necessary for a differential relay. It is preferable to wind these two coils upon the cores side by side, so that the differential action will be directly between adjacent turns, through which the current from the home generator circulates in opposite directions, rather than between the magnetism produced by such currents in the cores. In Fig. 1, however, for the sake of clearness, the two windings are represented as occupying separate longitudinal sections. Between and parallel with the cores is a brass shaft *E* that is held by centering screws at its ends. On the ends of the shaft *E* are secured two armatures *F* and *j* that move at right angles to the cores. These armatures are made light in weight, especially at the extreme ends, so as to reduce the inertia. The ends of the cores are beveled, and the two armatures, being of like shape, resemble the blades of a propeller. The armatures overlap the beveled ends of the cores and passing on opposite sides of the latter are simultaneously attracted or released by the cores; so that, being rigidly fastened to the brass shaft, they help each other. The armature *j* has an extension *v* working between two contact points and connected with an adjustable retracting spring (that is not shown in the figure because it is at right angles to the paper).

The inventor of this relay claims that, since the wire space extends nearly over the whole length of the non-movable iron parts, there being no yoke over which wire cannot be wound, and these magnets can be wound with larger wires, giving, nevertheless, a greater number of convolutions with the same or a smaller resistance than it was previously possible to obtain. Hence, the electromagnet should be more efficient than the ordinary relay. Furthermore, the core being short and there being no yokes, the reversals of magnetism take place very rapidly, and the time of no magnetism in the core, during the time that the reversals are taking place, is said to be reduced one-half.

8. **Pole Changer.**—The pole changer, although somewhat different in form, is really equivalent to the walking beam type that has been already described. The arrangement of the contact stops, it is claimed, will enable a very close and positive adjustment to be made, so that the interruption of the current while the armature is shifting from one stop to the other lasts for a very small interval of time. A condenser *Sc* is connected between the lever of the pole changer and the ground to reduce the sparking between the lever and the stops *p* and *o*.

9. **Sounders on Neutral Side.**—In order, apparently, to avoid using the Smith arrangement of condenser and resistances, or the Edison system of one repeating sounder and one reading sounder, Mr. Healy devised the arrangement of two repeating sounders *Rs* and *Rs'* and one reading sounder *S*,

which are connected as shown. The repeating sounder *Rs* has its circuit closed when the neutral-relay armature rests against its back stop *t*. The second repeating sounder *Rs'* has its circuit closed when the armature of the first repeating sounder *Rs* rests on its front stop. The reading sounder *S* has its circuit closed when the armature of the second repeating sounder *Rs'* rests against its back stop. By this arrangement it is claimed that the time necessary to cause any mutilation of the received signals is doubled and that, in practice, this arrangement has been found to greatly increase the working margin of the neutral side.

ALTERNATING-CURRENT SYSTEMS

ROBERSON QUADRUPLEX

10. The **Roberson quadruplex** system, the invention of O. R. Roberson and used by the Western Union Telegraph Company, transmits messages by means of alternating currents. When properly handled, this quadruplex is said to work *four-cornered* (that is, four messages may be transmitted simultaneously) better in extremely wet weather and on a smaller wire than will most of the other quadruplex systems. The principal objections to its use are the necessity of expert handling and the reluctance of telegraph companies to adopt a system employing alternating currents. Fearing a troublesome inductive effect on adjacent circuits seems to have made the chief operators very backward in advocating its adoption.

11. Principles of System.—In the Roberson system, one message is transmitted by positive and the other by negative pulses, although there is sent to line at all times a series of weak alternating currents. On short lines, signals may be transmitted by merely sending a series of positive or negative pulses, according to which key is depressed. On longer lines, signals are sent by increasing the strength of one polarity or the other, or of both, of the current normally flowing to line; that is, the positive pulses are strengthened by depressing one key, while the negative pulses are strengthened by depressing the other. Thus with both keys open, only weak alternating pulses at a frequency of about 40 periods per second, are sent to line, while on their depression, strong positive, or strong negative, or strong pulses of both polarities are transmitted as one or the other or both of the keys are depressed. There is employed at each station an alternating-current dynamo provided with suitable collector rings and connections for sending to line positive and negative pulses for the two sets of signals.

12. Representation of Sine Waves.—Fig. 2 (*a*) represents waves of positive pulses that are transmitted for the purpose of closing one relay at the receiving station. View (*b*) represents waves of negative pulses that close the second relay at the receiving station, while (*c*) represents waves of both positive and negative pulses for simultaneously closing both relays at the receiving station.

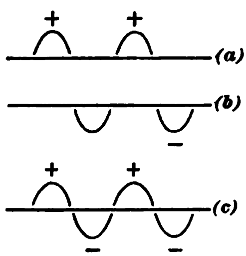
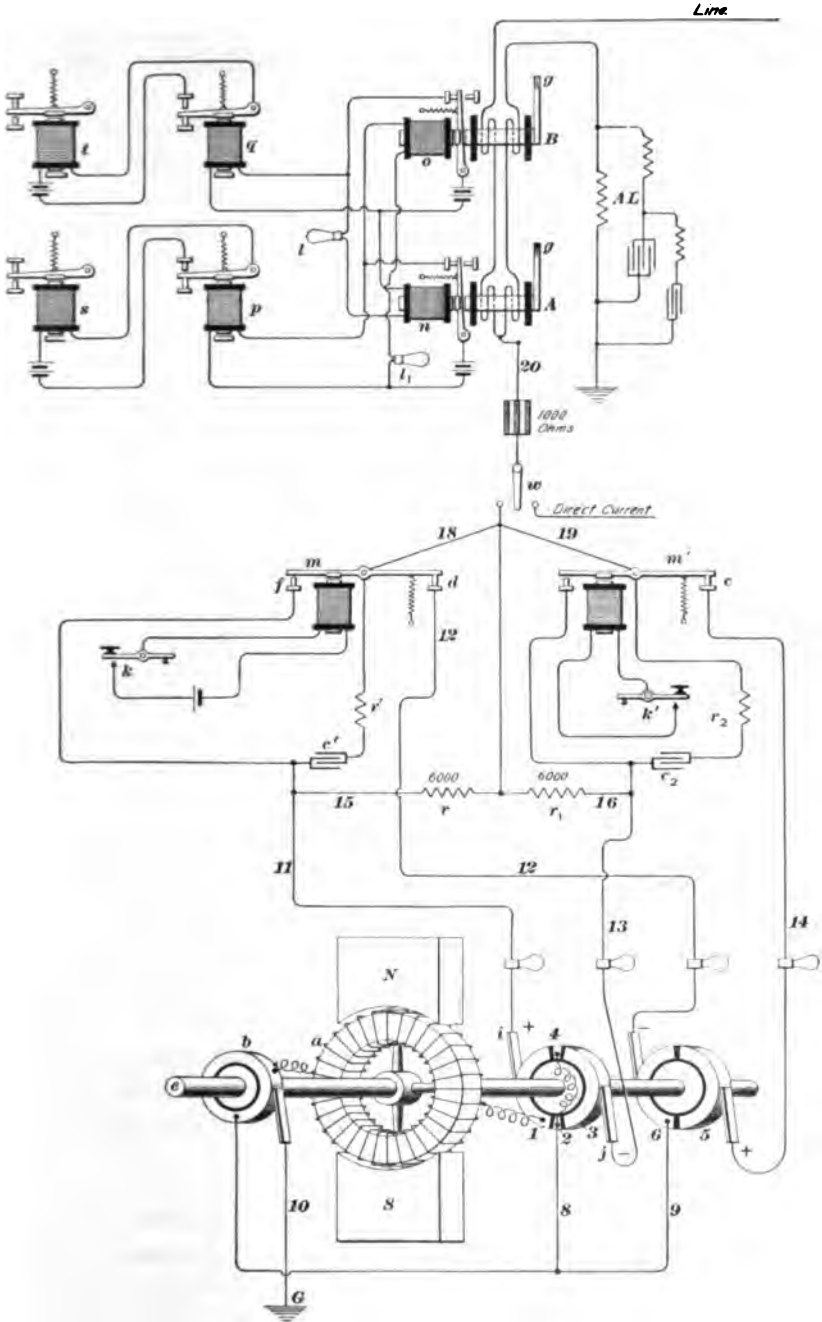


Fig. 2

13. Apparatus Used.—Fig. 3 represents the current generator and the transmitting and receiving apparatus at one station. One terminal of the armature winding *a* of the alternating-current generator is connected to a ring *b*, which is insulated from the shaft *e* of the dynamo; the other terminal of the armature is connected to segment *1*. The segments *1*, *2*, *3*, and *4* constitute a hub that is rigidly fastened to, but insulated from, the shaft *e*. On the periphery of the hub rest two brushes *i* and *j*, which are connected, respectively, with conductors *11* and *13*. As shown, one armature terminal is connected through the segment *1* and the brush *i* with wire *11*, while the segment *3*, which is insulated from segment *1*, is connected through the brush *j* with the wire *13*. The segments *2* and *4*, which are insulated from *1* and *3*, are always connected together and with the hub *b* by the wire *8*, and thence to earth by the wire *10*. The wires *8* and *9* are insulated from the shaft, but are fastened to and rotate with it. In some sets, the two segments *4* and *2* and wire *8*, are omitted.


Line
g
B
AL
g
A
t
q
o
l
s
p
n
l_1
20
1000 Ohms
w
Direct Current
18
19
m
m'
f
d
c
12
k
k'
r'
r_2
c'
c_2
6000
6000
15
r
r_1
16
11
12
13
14
N
S
b
a
i
+
4
e
1
2
3
j
6
5
+
10
8
9
G

9

FIG. 3

There is also placed on the shaft *e* a hub composed of segments *5* and *6*, segment *6* being permanently connected, by conductor *9*, through the hub *b* to the ground, while segment *5* affords an insulated terminal either for wire *12* or *14*, according to its position. By means of the hub *5*–*6*, therefore, a ground connection is afforded from the main line for currents received from a distant station, through either wire *12* or *14*.

14. When, as in the position shown, the wire *12* is connected through a brush with segment *6*, the main line is connected through the wire *18* – back contact *d* – wire *12* – segment *6* – wire *9* – hub *b* – wire *10* to ground *G*. After a half rotation of the dynamo armature, however, and when segment *6* is in contact with the brush to which wire *14* is joined, the main line is given a ground connection through wire *19* – back contact *c* – wire *14* – segment *6* – wire *9* – hub *b* and wire *10*. On closing the key *k*, connection between the armature lever *m* and conductor *12* will be broken. But in one position of the dynamo armature, a ground connection will then be afforded by way of wire *18* – front contact *f* – wire *11* – segment *1* – dynamo armature *a* – hub *b* – wire *10*; and in another position, when wire *11* touches either segment *4* or *2*, there will be a ground connection through wire *8* – hub *b* – and wire *10*.

During that part of the rotation when the brush *i* rests on segment *3*, there will be no connection between wire *11* and the ground, because segment *3* is insulated, but a path to ground will be afforded, as before, through wire *14* – segment *6* – and conductors *9* and *10* to the ground *G*. Thus, while the dynamo armature is making a certain half revolution, the front stop and back stop of one transmitter are both connected to ground, one by way of the armature, the other directly. At the same time, the front stop and back stop of the other transmitter are both disconnected entirely from the ground.

During the next half revolution, however, these connections are all reversed. Thus one transmitter has control of the strength of the current pulses while positive pulses are being generated, and the other while negative pulses are being generated.

15. When the key *k* is depressed, positive pulses, like those shown in Fig. 2 (*a*), will be transmitted from the dynamo through segment *1* – brush *i* – wire *11* – front stop *f* – armature lever *m* – and conductors *18* and *20*. The length of the pulses will be somewhat less than a full positive wave, depending on the width of segments *4* and *2* and their surrounding insulating material. When segment *1* is in contact with brush *i*, the pulse generated is transmitted to the line; but when the shorter segments *2* and *4* are brought into contact with brush *i*, the line will be disconnected from the dynamo and grounded, thus affording the line an opportunity to discharge. Furthermore, the armature *a*, when in contact with brush *i*, is disconnected from brush *j* and wire *13*, so that while wire *11* is receiving a positive pulse no current will flow out over wire *13*. At the next half rotation, however, segment *1* is brought into contact with the brush *j*, and a negative pulse, which is then being generated in the armature, will be transmitted through wire *13*. Thus, as the armature rotates, wires *11* and *13* are alternately connected with the armature of the dynamo, and are fed alternately, the former with positive and the latter with negative pulses, while the main line at the termination of each positive and negative pulse is disconnected from the dynamo and is connected to earth to permit it to discharge.

The wires *11* and *13*, while ready to receive pulses from the dynamo, will not be fed with full currents except when the armature levers *m* and *m'* touch their front contacts. If both keys *k* and *k'* are depressed at the same time, the two conductors *11* and *13* will receive strong positive and negative pulses, as just described. These branches, however, will receive considerable current, regardless of the position of the levers *m* and *m'*, from the fact that connections to the main line are provided by the wires *15* and *16*, the particular purpose of which will be more fully described later.

16. Receiving Apparatus.—The two relays *A* and *B*, Fig. 3, are each provided with permanent horseshoe magnets *g*, soft-iron cores, and coils *h*, as shown in Fig. 4. It may be assumed that relay *A* at the distant station is closed by the depression of key k at the transmitting station, and B by the depression of key k'. The cores and permanent magnets are so arranged that the positive pulses sent to line on the depression of the key at the distant station corresponding to k will add to the permanent magnetism of A and will neutralize or diminish that of B, while by the depression of the key at the distant station corresponding to k', the permanent magnetism of A will be diminished and that of B increased. By this means, the depression of key k at the transmitting end will attract the armature of relay A at the receiving station, while the armature of B will be attracted on the depression of key k'. Also, on the simultaneous depression of both keys k and k' and the transmission of strong successive positive and negative pulses over the main line, the armature of relays A and B at the receiving end will both be attracted to a signaling position.

FIG. 4

But it is to be noted that on the simultaneous transmission of positive and negative pulses, positive pulses will not act on the positive relay nor negative pulses on the negative relay as they would if only positive pulses or only negative pulses were being transmitted, from the fact that a rapid succession of positive and negative pulses through the coils of an electromagnet will tend to produce a neutral, or non-magnetic, effect; whereas, positive or negative pulses alone will each produce strong magnetic actions. To overcome this difficulty, auxiliary electromagnets n and o, the branch circuits *15* and *16*, and the resistances r and r_1 are necessary on long circuits, although in the case of shorter lines the branches *15* and *16* may be omitted. Generally, two carbon rods of 6,000 ohms resistance each are used at r and r_1.

17. Operation.—If positive pulses only are received from a distant station, the armature of relay A, Fig. 3, will be attracted, thus breaking the local circuit, including the electromagnet o, but the local circuit, including the electromagnet n, will remain closed and will still exert a retracting pull on the armature of A.

That is to say, if only positive pulses are received from the distant station, the pull of A on its armature is sufficient to overcome the pull of the opposing electromagnet n and the spring. Likewise, if only negative pulses are received from the distant station, the pull of B on its armature is sufficient to overcome the pull of o, as has just been described in respect to the armature of A under the influence of positive pulses alone. Thus on the transmission of only positive pulses for one message, or of only negative pulses for the second message, the armature of A or B, respectively, will be attracted by their retracting magnets n or o, respectively, but with insufficient force to hold the local circuits closed.

18. If, however, both positive and negative pulses, like those shown in Fig. 2 (c), are transmitted from a distant station, the armatures of A and B, Fig. 3, will both be attracted and the circuits of both o and n will be broken, thereby leaving the armatures subject only to the influence of the electromagnets A and B. In this case, the magnetism of A and B is much weaker than if the relays were subject to pulses of only one polarity, but they are still able to pull their armatures with a force almost equal to that which they would have under the influence of pulses of only one polarity, with the local circuits through the retracting magnets n and o closed.

To still further equalize the actions of relays A and B under the influence of pulses of one or of both polarities, the branches *15* and *16*, with the resistances r and r_1, are provided. By this means positive and negative currents will at all times be transmitted, although they will be of much less strength than are those due to closing one or both keys. Also, pulses from the dynamo will be constantly directed to the line, but owing to the resistances r and r_1 they will be of comparatively small strength. These weakened pulses, when received from a distant station, will flow through the main-line coils of A and B and will produce an effect tending to neutralize the effects of stronger currents of one polarity. For example, if at the distant station the key k is depressed, strong positive pulses will flow through the main-line coil of relay A. At the same time, however, owing to the presence of the resistance r_1 in the branch *16* at the distant station, weakened negative pulses will be received in alternate order, thereby tending to neutralize, in a degree, the magnetism produced by the stronger positive pulses. Thus, not only is the armature of the relay *A* under a retractive force from the magnet *n*, but the magnetism that would be produced in *A* by the strong positive pulses will be considerably reduced by the weakened negative pulses. By both of these agencies, the armature of *A* will be under substantially the same tendency to move toward the front contact as when strong positive and negative pulses are alternately transmitted.

19. In Fig. 3, *AL* represents the ordinary artificial line of a duplex or quadruplex system, while at the left are represented repeating sounders *p* and *q* and reading sounders *s* and *t*, such as are used in some quadruplex systems where the main-line relays close their local circuits on the back contacts. The local receiving circuits may be arranged so that no intermediate repeating sounders are necessary. Branches, including condensers and rheostats, are placed around the front contacts of the transmitters and serve to dissipate sparks arising at such points. The branch around the front contact of *m* includes the condenser c' and the resistance r', while the branch around the front contact of m' includes the condenser c_2 and the resistance r_2. Branches *15* and *16*, containing resistances *r* and r_1 also assist in eliminating sparking at the contacts.

20. The apparatus may be arranged on the bridge plan instead of as a differential system. In this case, the relays *A* and *B* will have only one winding, instead of a differential winding; they will be connected in the cross-branch of a bridge, the arms of which consist of the main line, the artificial line, and two more arms, each of which contains a resistance. The arrangement will be similar to that of a bridge duplex system. The resistance will be so adjusted as to compel the current from the home transmitting apparatus to divide between the line and artificial line in such a ratio as to produce no difference of potential at the terminals of the cross-branch that contains the two relays A and B. The transmitting apparatus will be exactly the same as shown in Fig. 3. The windings p, o and q, n are connected in parallel with a lamp l in each relay circuit to produce the desired division of current between the relay and the repeating sounder. A three-point switch w is placed in the circuit so that the relays can be readily adjusted with direct current, which gives better results than adjusting altogether with alternating current.

BARCLAY-ROBERSON ALTERNATING-CURRENT QUADRUPLEX

21. Improvements.—One serious objection to the Roberson quadruplex was the fact that it required a small and spe-

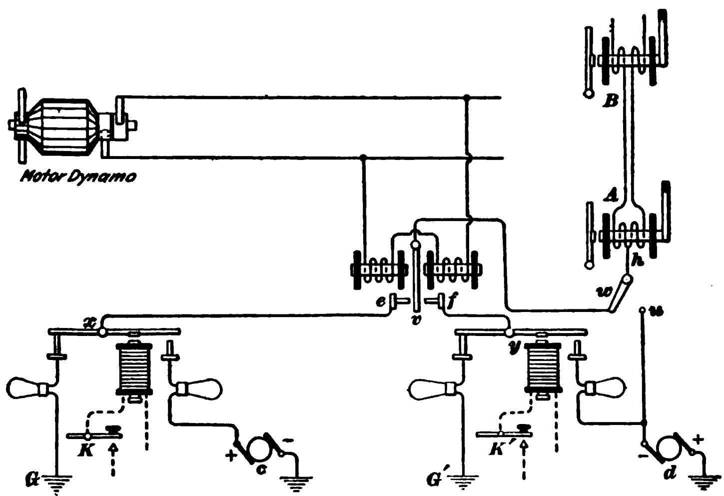


FIG. 5

cially constructed dynamo for each end of every line so worked, and very small dynamos do not operate very steadily or efficiently. This objection has been overcome by J. C. Barclay's arrangement of the transmitting apparatus shown in Fig. 5. In the Roberson quadruplex, an alternating current was supplied to the line through the contacts of the transmitter. In the improved arrangement, however, the alternating current is used merely to keep the tongue v of a polar relay, called in this case a *vibrator*, vibrating uniformly and in synchronism with the current alternations. While the tongue touches one contact *e* of the vibrator, the point *h* is either grounded at *G* or connected to the positive terminal of the direct-current dynamo *c*; while the tongue touches the opposite contact *f* of the vibrator, the point *h* is either grounded at *G′* or connected to the negative terminal of another direct-current dynamo *d*. Thus, with both transmitting keys *K* and *K′* open, the point *h* is grounded alternately through the back contacts of the two transmitters. With one key closed, the point *h* is in a position to receive direct-current impulses of one polarity only and is grounded between each impulse. With both keys closed, the point *h* is in a position to receive direct-current impulses alternately in opposite directions. As the armature *v* vibrates very rapidly, each dot or dash consists of quite a number of direct-current impulses. One motor-dynamo supplies enough alternating current to operate all the vibrating relays required in any one office and the regular quadruplex, direct-current, dynamos *c* and *d* and transmitters *x* and *y* may be used.

22. Adjustment of Vibrator.—In order that the vibrating armature may allow the circuit to receive an equal current from each direct-current dynamo *c* or *d*, all contact points must be kept bright and an even pressure must be exerted by the vibrating armature on each contact point *e* and *f*. If necessary, the magnets of the relay *v* must be readjusted so that the current received through one contact *f* shall be equal to that received through the other contact *e*. To make this adjustment, an ammeter should be inserted in the artificial-line circuit and the current noted, first, with one key *K* closed, and then with the other key *K′* closed. If these values are not equal, the sum of the two readings divided by 2, is the value to be obtained. To determine which way to move the magnet cores of the relay *v* to equalize the currents, close one key and exert a slight pressure with the finger on one stop toward the vibrating armature and note whether the result is better or worse; if the smaller current is flowing, it should be increased, if the larger current is flowing it should be decreased. Then move the magnet in the proper direction until this current is equal to the average value previously determined; both polarities should then be tested and the currents should be equal in strength. The current from each direct-current dynamo should remain equal in strength after the vibrator *v* has been once properly adjusted.

BALANCING ALTERNATING-CURRENT QUADRUPLEX

23. To balance the alternating-current quadruplex, after having adjusted the vibrator, first open the keys on both sides at both the home and the distant stations, placing the lever *w*, Fig. 5, in the position shown, thereby connecting each end through contacts *e* and *f* to ground *G* or *G'*. Turn down one relay spring until the relay just stands open. Now turn the lever *w* to the other contact *u*, thereby connecting a source of direct current in the circuit, and adjust the artificial-line rheostat in the usual way until the same relay remains open.

Then connect with the source of pulsating current by turning the lever *w* to the left, as shown, and closing one key. The relay will usually close owing to the unequal amount of the discharge from the line and artificial line. Adjust the condensers and retardation coils in the artificial line until the relay remains just open, as before. A slight change in the retardation coil affects the relay almost as much as an alteration in the capacity of the condenser. The readjustment of the retractile spring and magnet of the relay to properly receive the incoming currents usually requires some experimenting before it is successfully accomplished. The other relay is adjusted in a similar manner. After having once been adjusted properly, the relays seldom require readjustment when new balances are made, unless considerable alteration has occurred in the balance.

24. Regulating Permanent Magnetism.—For regulating the permanent magnetism to suit the strength of the incoming current, there is an iron cross-bar slide near the base of the steel horseshoe. The normal position of this cross-bar in dry weather is close against the brass cross-bar, that holds the relay cores firmly in position. In damp weather, the slide should be raised a little toward the bend in the steel magnet; the proper position being determined by trial. When the small relay magnets that are connected in the local circuits have once been properly adjusted, they seldom require any attention.

25. Measuring the Currents.—The current can be measured with an ammeter in the usual way. To measure the home current have both keys at the distant end opened, thereby grounding that end of the circuit. Then close one of the home keys, insert the ammeter wedge at the main-line switchboard, and read the ammeter. To measure the current of opposite polarity, open the key last closed, close the other key, and read the ammeter.

To measure the incoming, or distant, current, open both home keys, and read the ammeter, located as before, first with one and then with the other distant key closed. The proper strength of current should be about 25 or 30 milliamperes.

26. Cushion Sounders.—For repeating sounders, so-called cushion sounders should be used, as they seem to take up the vibrations due to the pulsating current and give clear and distinct signals. The repeating cushion sounder has a bar lever that engages two small springs which prevent the usual jar or rebound that occurs when a solid bar strikes a fixed contact point. The pole changer, or *transmitters*, as they are often called, need not have their contacts adjusted as closely together as in the ordinary quadruplex systems; for better results are secured when they are given a reasonable amount of play.

COMBINATIONS OF REPEATERS AND MULTIPLEX SETS

MULTIPLEX REPEATERS

POLAR DUPLEX REPEATERS

27. Dynamo Arrangement.—It is a very simple matter to connect two duplex sets so that the receiving side of one set will repeat into the sending side of another, and the receiving side of the second set will repeat into the sending side of the first. Two duplex sets, arranged to repeat in this manner, are shown in Fig. 6. Each set is arranged as usual when dynamos are used to supply the current. The dynamo *D* (a 23-volt machine in Western Union offices) supplies current for all local circuits. With the switch arms *o*, *q*, *o'*, *q'*, and *F* turned to the left and F_1 to the right, the polar relay *PR* in set No. *1* controls the pole changer PC_1 in set No. *2*, and the polar relay PR_1 in set No. *2* controls the pole changer *PC* in set No. *1*. The two sets are connected together through the jacks and wedges *LS* and LS_1 at the loop switchboard. The receiving side of one set becomes the sending side of the other set; hence the dot lines are changed to dash lines and the dash lines to dot lines at the lamps in the cord circuits between the two spring jacks *LS* and LS_1. The incoming signals from the east line operate the polar relay *PR*, and this in turn operates the pole changer PC_1; thus the signals coming in over the east line are repeated into the west line. Similarly, signals coming in over the west line are repeated into the east line.

When the two sets are in operation as a duplex repeater, there is no need of the sounders *S* and S_1; therefore, by closing the switches *H* and H_1, the sounders may be short circuited, their resistance cut out of the circuit, and the current increased somewhat. Switches for this purpose are quite convenient,

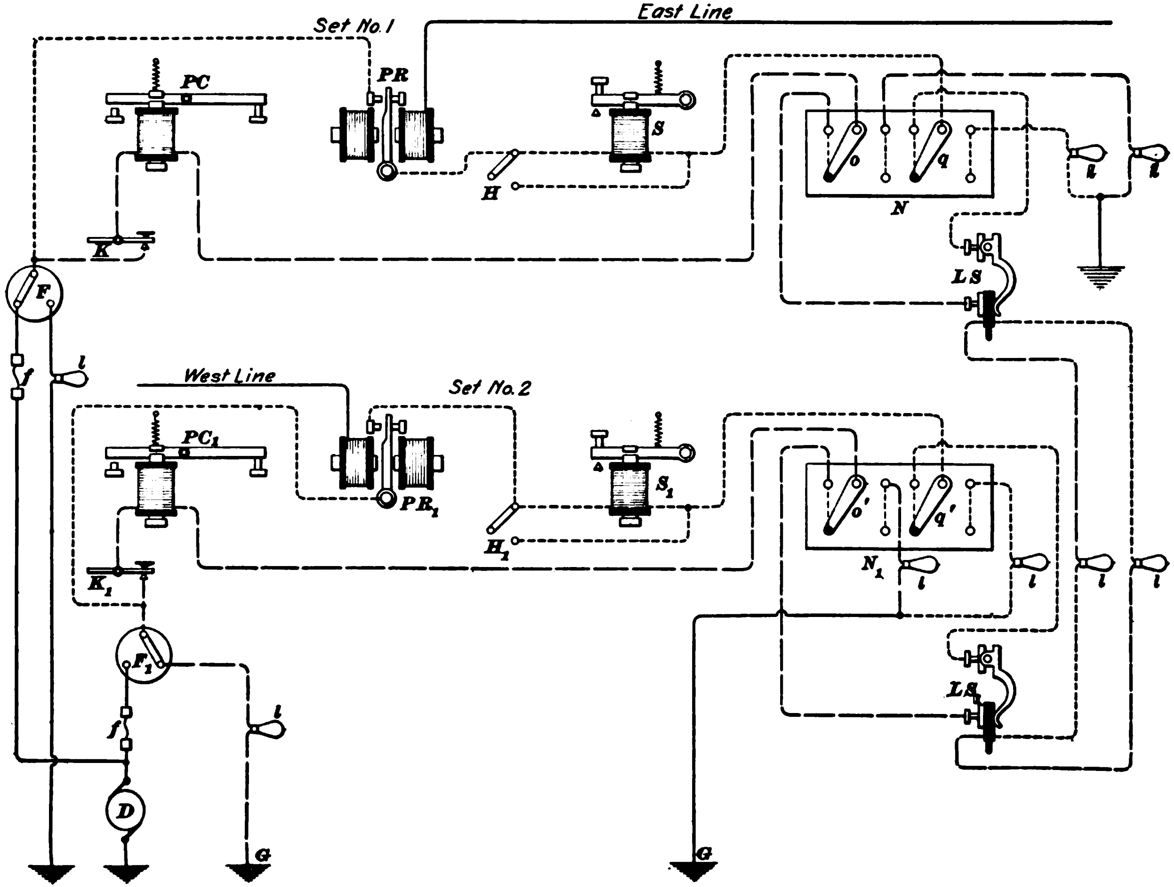

Set No. 1
East Line
PC
PR
S
H
K
N
o
q
LS
F
f
l
West Line
Set No. 2
PC1
PR1
S1
H1
K1
N1
o'
q'
LS1
F1
D
G

FIG. 6

especially where gravity cells are used for local batteries. The two sets may be readily disconnected and arranged in two entirely independent sets, although supplied with current for the local circuits from the same dynamo *D*. To do this, the switch arms *o*, *q*, *o'*, and *q'* should be turned to the right and the switches *F* and F_1 to the left.

28. Battery Arrangement.—In offices where gravity batteries are used, the polar duplex may be arranged as shown in Fig. 7. The arrangement is exactly the same as in Fig. 6 except that the wires *e*, *f*, *g*, and *h* run through jacks at the loop switchboard to gravity batteries, instead of through three-point switches on the desk to a dynamo. Also, no lamps are required because the correct number of cells are supposed to be used in the batteries *B* and B_1 to give the proper current. The batteries *B* and B_1 may be main-line batteries with one terminal of each grounded, or they may be intermediate batteries; in the latter case they will not be grounded, but will be connected as shown by the lines *a b* and *c d*. In the former case care must be taken to connect the proper pole of each battery to the wedges, so that the batteries will not oppose one another. If one set of batteries, *B*, for instance, is strong enough, both sides of the wedge in the jack LS_3 should be simply grounded or else connected with the negative poles of the batteries *B* at *a* and *c*. The switch arms *o*, *q*, *o'*, and *q'* are used in the same manner as explained in connection with the dynamo arrangement shown in Fig. 6.

DIRECT-POINT POLAR-DUPLEX REPEATER

29. Theoretical Diagram.—In Fig. 8 is shown a diagram, with the practical details omitted, of the **direct-point, polar-duplex repeater** for use in polar-duplex circuits and in the polar side of quadruplex sets. This apparatus is also called simply the **polar-duplex repeater.** By this arrangement, which has proved very successful, the two pole changers formerly required in the polar-duplex repeaters are eliminated. Each polar relay is differentially wound and one winding of each is connected through an artificial line to ground. The

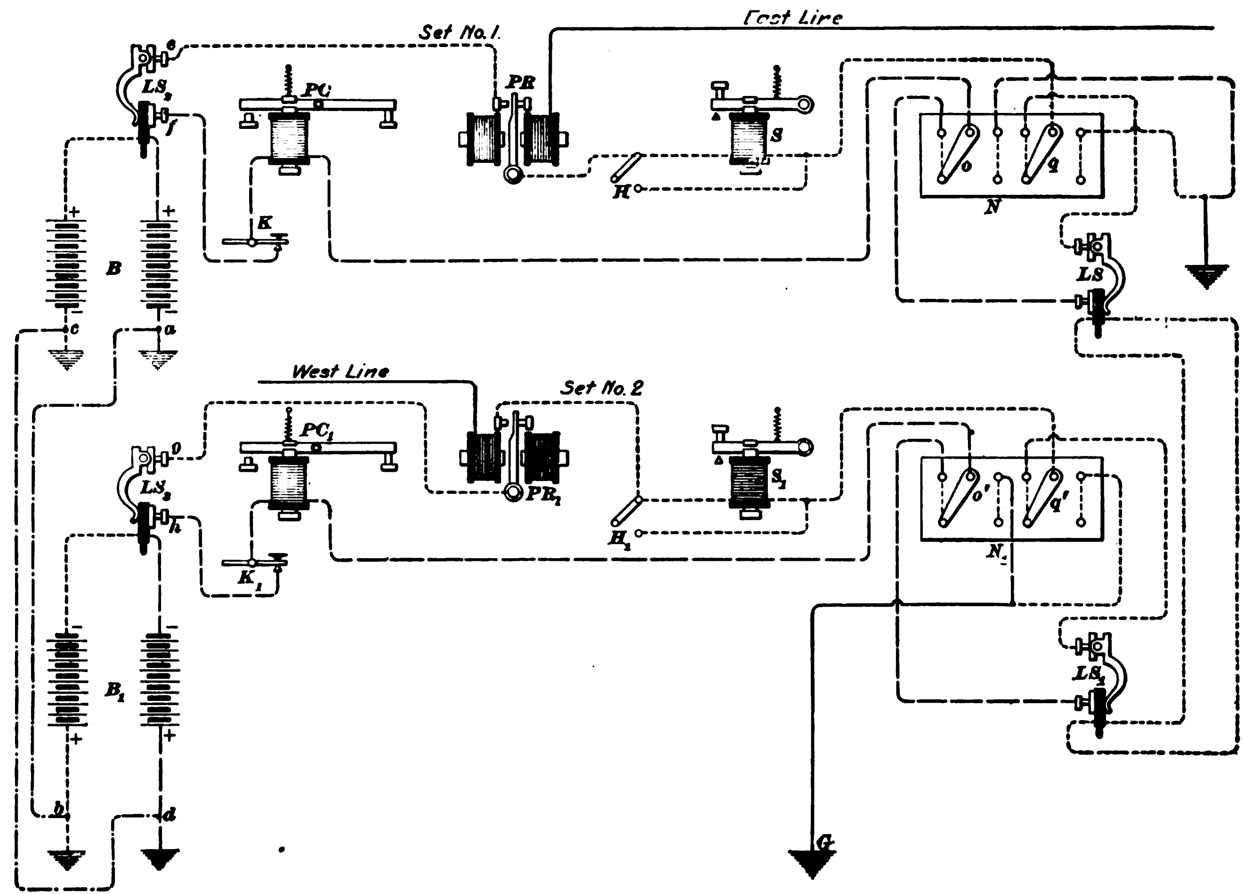

East Line
Set No. 1
PC
PR
S
H
K
LS
LS₂
e
f
B
a
c
N
o
q
West Line
Set No. 2
PC₁
PR₁
S₁
H₁
K₁
LS₃
LS₁
g
h
B₁
b
d
N₁
o'
q'
G

Fig. 7

middle point of the winding of each relay is connected to the armature of the other relay. Four main-line dynamos of the same voltage are shown, but only two, one of each polarity, are actually used. Regular duplex sets are connected at the distant ends of the east and west lines. Normally, the negative terminals of all main-line dynamos at both ends and at the repeating station are connected to the circuit and the coils are so connected that the polar-relay armatures rest against their back stops f and f_1.

30. Operation.—Let it be assumed that the keys are all in normal position, and that a current flowing from points m and m_1 toward the lines and artificial lines is a negative current. A negative potential being applied at the ends of the east and

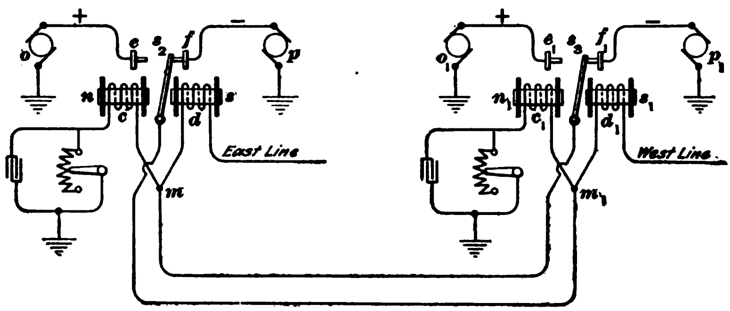


FIG. 8

west lines and at points f and f_1, there will be no current flowing through the line coils d and d_1, but there will be a negative current of unit strength through the artificial-line coils c and c_1, which will so polarize the relay cores as to cause the south-polarized armatures s_2 and s_3 of the polar relays to rest against the back stops f and f_1. If the eastern key is now depressed, a positive potential will be applied at that end of the eastern line; this will put the positive dynamo at the eastern station and the negative dynamo p_1 at the repeater station in series, producing a current of -2 units (circulating counter-clockwise when looking at end s) in the line coil d, which produces at the end of the core opposite s a south pole that is strong enough to repel the south-polarized armature s_2 against the stop e, in spite of the −1-unit current (circulating counter clockwise when looking at n) in the coil c that produces a south pole in the end of the core opposite n. The positive dynamo o is now connected to the point m_1, the current through the artificial-line coil c_1 is reversed, becoming +1 unit (circulating clockwise when looking at n_1 and producing a north pole of 1 unit strength at the end of the core opposite n_1), while the current through d_1 becomes +2 units (circulating clockwise when looking at s_1 and producing a north pole of 2 unit strength at end opposite s_1) which results in no change in the polarity of this polar relay and hence the armature s_3 is not moved from contact f_1. There is flowing, however, a current of +2 units in the west line, which causes the polar relay at the distant end of the west line to operate and thus close its local-sounder circuit. In a similar manner, it may be shown that closing the western key only, will produce a signal in the polar relay at the distant end of the eastern line.

31. If the western key is closed while the eastern key is closed, the current in each artificial-line circuit at both the western and eastern stations becomes +1 unit and the currents in both line circuits become zero; hence, the two polar relays at the end stations close their local circuits. This condition produces the following results at the repeater: The current in the western line and in coil d_1 is reduced from +2 units to zero, thereby allowing the current of +1 unit in coil c_1 to reverse the polarity of the relay and cause the armature s_3 to move against the stop e_1, which reduces the current in coil d and the eastern line from −2 units to zero and reverses the current in coil c from −1 unit to +1 unit. This condition does not produce a reversal of the polarity of this relay, hence no movement of the armature s_2 is produced, but it does cause a reversal of polarity of the polar relay at the distant end of the eastern line and, therefore, causes a signal to be produced at that office. This repeater seems to give the desired results with the least apparatus.

32. Postal Telegraph-Cable Direct-Point Polar-Duplex Repeater.—In Fig. 9 (a) is shown the theoretical

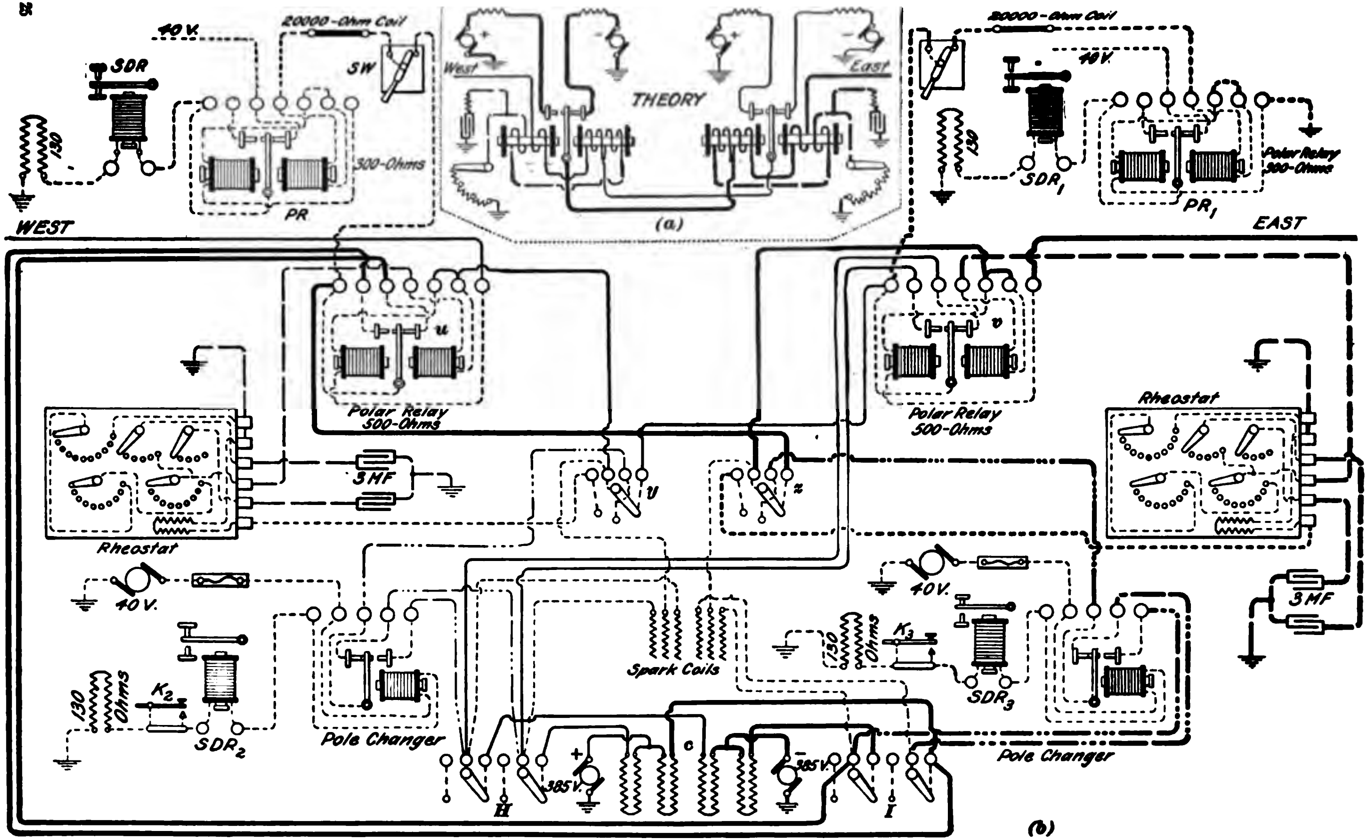

40 V.
SDR
20000-Ohm Coil
SW
130
300-Ohms
PR
WEST
West
East
THEORY
(a)
20000-Ohm Coil
40 V.
130
SDR1
Polar Relay 300-Ohms
PR1
EAST
u
v
Polar Relay 500-Ohms
Polar Relay 500-Ohms
Rheostat
Rheostat
3 MF
3 MF
y
z
40 V.
40 V.
Spark Coils
130 Ohms
K3
SDR3
130 Ohms
K2
SDR2
Pole Changer
Pole Changer
385 V.
385 V.
c
H
I
(b)

FIG. 9

diagram of the direct-point polar-duplex repeater used by the Postal Telegraph-Cable Company. It is the same as that just explained, except that the differential winding of each polar relay consists of four coils; two coils (one on each core) are in the line circuit and the other two coils (one on each core) are in the artificial-line circuit.

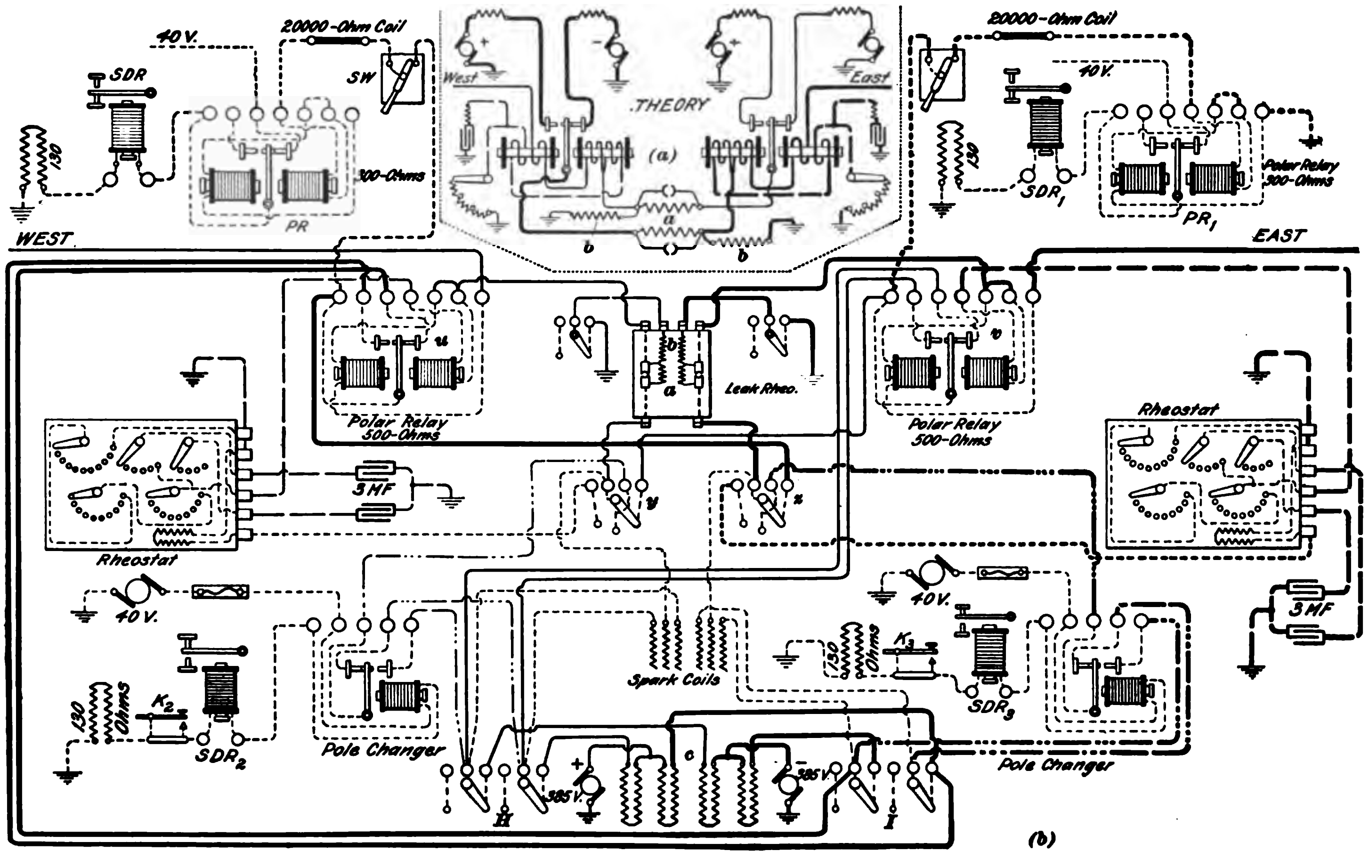
In (*b*) is shown the actual arrangement of the apparatus. The six-point power switches *H* and *I* are used to connect and disconnect the 385-volt, main-line dynamos, of which there are two, one of each polarity. Two pole changers, controlled by keys K_2 and K_3 and other necessary apparatus are included with this set so that each side may be used independently, thus giving two independent polar-duplex sets when they are needed more than the repeater.

When the repeater is in use, switches *y* and *z* are turned to the right; when two independent duplex sets are desired these switches are turned to the center position; they thereby connect the levers of the two pole changers to the middle of the differential windings of the corresponding 500-ohm polar relays, while the pole changers are controlled by the keys K_2 and K_3. The sounders SDR_2 and SDR_3 are used by the sending operators to read their own outgoing signals.

33. For balancing and adjusting the 500-ohm polar relays and artificial lines, the switches *y* and *z* are turned to the left. In order to read the signals passing through the repeater, the 300-ohm polar relays *PR* and PR_1 are connected in such a manner as to be controlled by the 500-ohm polar relays *u* and *v*, respectively. The 300-ohm polar relays have both windings connected in series and merely act as polar relays in a double-current telegraph system. These relays are connected from the armatures of the 500-ohm polar relays through a 20,000-ohm resistance to ground; the high resistance is used because these relays are in a shunt circuit from the main-line circuit to ground and are operated by the high-potential main-line dynamos. On each of these relays is a three-point switch by means of which the sounder may be operated from either contact of the relay. The same result may be accomplished by using a .5-microfarad condenser in place of the 20,000-ohm resistance. The 300-ohm polar relay may be eliminated when the condenser is used, the circuit being run from the 500-ohm relay armature through the condenser and sounder to ground, the sounder armature and contacts being adjusted so that the signals are made on the upper stop.

34. The sparking at the 500-ohm polar relay and pole-changer contacts is reduced by the Johnson spark coils. Otherwise, this sparking would be a serious trouble each time the high potential produced by the main-line dynamo was broken. For the proper operation of a direct-point polar repeater it is necessary that the same polarity of all main-line dynamos be connected to the circuit when all keys are in their normal, or at rest, position. To accomplish this, and for the sake of uniformity, at all Postal Telegraph-Cable offices, the negative poles of the main-line dynamos must be connected to the lines and the positive poles of the main-line dynamos must stand open when the polar-relay armatures are resting on the right side.

35. Leak Duplex Repeater.—The leak duplex repeater used by the Postal Telegraph-Cable Company is shown in Fig. 10. In (*a*) is shown the theoretical circuit and in (*b*) the actual arrangement of all the apparatus. This duplex repeater operates in practically the same manner as the same company's direct-point polar relay; in fact, it seems to be merely an improvement or modification of the other. The modification consists of added resistance *a* in series with each dynamo and leak resistances *b* between the line side of the added resistances and the ground. The added resistances can be short-circuited by a peg and the leak coils can be disconnected by a switch. Thus, dynamos of a higher voltage than necessary, but which may be supplying longer duplex or quadruplex circuits, can be made to furnish this leak duplex repeater with a suitable current. In all other respects the arrangement and operation of all apparatus is the same as in the direct-point polar duplex previously described. With the exception of the connections of the leak rheostat, the circuits are otherwise identical with those shown in Fig. 9.



WEST
EAST
SDR
40 V.
20000-Ohm Coil
SW
300-Ohms
PR
130
THEORY
(a)
West
East
a
b
SDR1
PR1
Polar Relay 300-Ohms
Polar Relay 500-Ohms
u
v
Leak Rheo.
y
z
Rheostat
3 MF
40 V.
SDR2
K2
130 Ohms
Pole Changer
SDR3
K3
Spark Coils
385 V.
c
II
I
(b)

Fig. 10

36. Western Union, Direct-Point, Polar-Duplex Repeater.—In Western Union offices, the direct-point, polar-duplex repeater is arranged as shown in Fig. 11. With the switches *y* and *z* turned toward the left, the set is arranged as a direct-point polar-duplex repeater; the pole-changer transmitters are then cut out. With the switches *y* and *z* turned toward the right, the main-line dynamos are shifted through

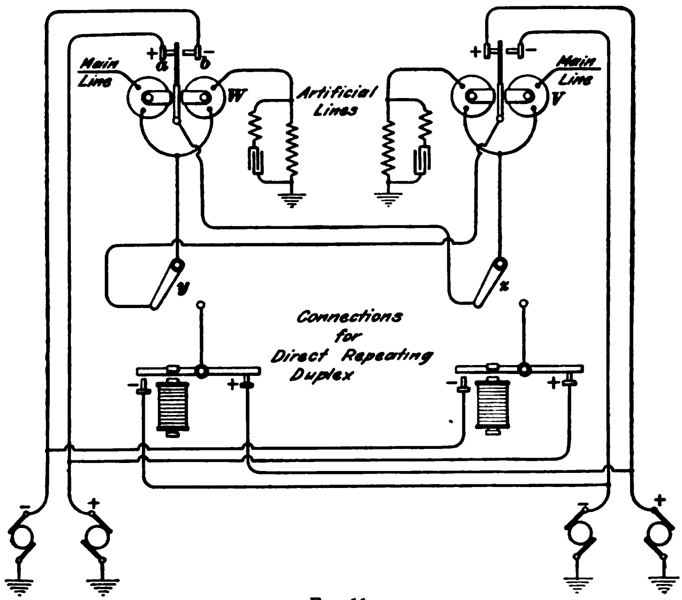


FIG. 11

the pole-changer contacts to the polar-relay windings, so that the apparatus now constitutes two independent duplex sets. The attendant uses this arrangement to balance the sets or to converse with the operator at either end. For the latter purpose, the Barclay polar relays are provided with second contact tongues insulated from the first, or repeating, tongues and arranged to control ordinary sounders in the usual manner. The extra tongues, the contacts, and the local-sounder circuits are not shown in this figure.

37. Barclay Direct-Point Polar Relay.—In general construction, the Barclay direct-point polar relay is exactly like the Western Union standard, or Freir, polar relay, except that instead of a single contact arm there is an additional light insulated spring *f*, as shown in Fig. 12, for the local contact. The regular contact *o* closes a circuit on each side in order that it may act as the pole changer for the opposite side of the duplex repeater. The slide for centering the armature between

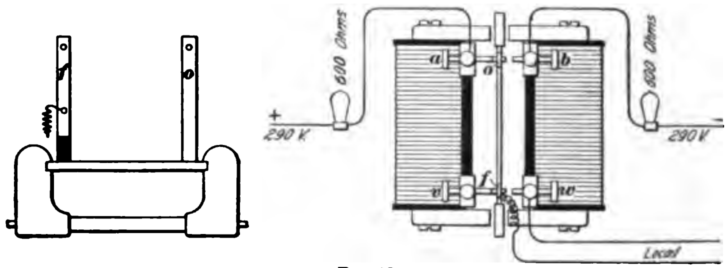


FIG. 12

the contact posts is large and all four contact posts *a*, *b*, *v*, and *w* move horizontally on the same slide, although insulated from each other. The Barclay direct-point repeating polar relay is generally used in a regular duplex repeater set, but, where the polar side of a quadruplex set is worked through regularly, it may be used there also.

QUADRUPLEX REPEATERS

38. It is sometimes necessary on long circuits to repeat from one quadruplex set into another. This can readily be done by connecting the repeating sounder on the common side of the first set so that it will operate the transmitter of the second set, and the repeating sounder of the second set so that it will control the transmitter of the first set. On the polar sides, the polar relay of the first set controls the pole changer of the second set, and, conversely, the polar relay of the second set controls the pole changer of the first set.

If the wires are in good condition, it is immaterial whether the polar side of one set repeats into the polar or common side of the other set. If, however, conditions are such that the polar side of two quadruplex sets are working better than the common sides, it might be better to repeat from the polar side of one set into the polar side of another, and from the common side of one into the common side of the other. By doing this, one side is working in good condition, while the other side may be working in a more or less indifferent manner; then if necessary the poorer side may be abandoned and still leave the other side in workable condition. On the other hand, if the polar side of one set repeats into the common side of the second, and the polar side of the second repeats into the common side of the first, both sides may work indifferently, if both common sides are not in first-class condition. The advantage of one or the other method will depend on how poor one side is working.

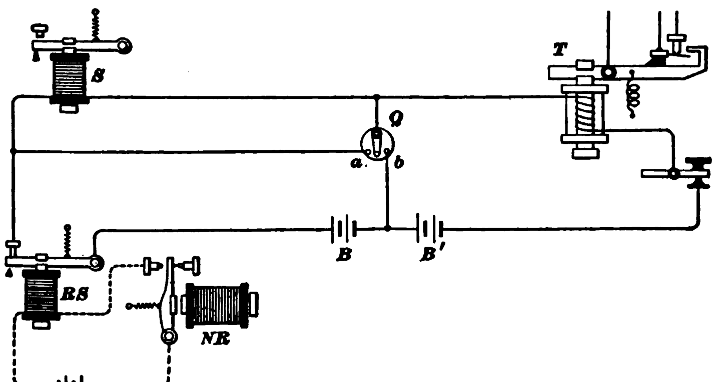


FIG. 13

39. In Fig. 13 is shown a diagram of connections, where gravity batteries are used, whereby the repeating sounder *RS* of one set controls the transmitter *T* of another set. The switch *Q* is so connected that when the arm rests on contact button *b*, the two sets are working independently. When the arm of the switch *Q* is in the middle position, the two batteries are both in series with the transmitter *T* and the sounder *S*; this enables the attendant operator to read the signals by means of the sounder *S*. When the arm of the switch *Q* is placed on the contact button *a*, the two batteries *B* and *B′* are connected in series with the transmitter *T* as before, but the sounder *S* is short-circuited. If the current is too strong with the sounder *S* short-circuited, it may be left in the circuit. The arrangement between the two sets on the polar side is so similar to this that it is unnecessary to show it here. The neutral relay *NR* controls the repeating sounder *RS*, which in turn controls the transmitter *T*; thus incoming signals operating the neutral relay are repeated by the transmitter into another line.

MULTIPLEX SINGLE-WIRE REPEATERS

USE OF REPEATERS

40. It is often desirable to arrange a duplex or one side of a quadruplex system, in connection with a single wire running to another office, so that the message being received over the multiplex system may be sent over the single wire to the branch office, and so that the branch office may send through the multiplex apparatus at the nearer station to the distant multiplex station. An arrangement of apparatus that will accomplish this is very convenient and often very necessary, and is known as a **multiplex single-wire repeater.** An arrangement of apparatus for accomplishing this same purpose in connection with city branch-office lines is known as a *defective-loop repeater.*

41. Defective-Loop Repeaters.—Large telegraph companies frequently rent out lines to brokers and others. Where only one wire is rented to a broker, it is sometimes desirable or necessary that the subscriber for this rented wire shall be connected to one side of a duplex or a quadruplex set. The apparatus must then be arranged so that the party renting the wire can send or receive over the one wire. Furthermore, it sometimes happens that one side of a branch-office loop will be out of order or defective. It is then desirable to arrange the apparatus so that the branch office may send or receive over the remaining good leg of the branch-office loop. By arranging the apparatus so that this can be accomplished, much time is saved while the defective leg is being repaired. In either of these cases, an arrangement to accomplish the desired purpose is usually designated as a **defective-loop repeater,** because it is so often used to utilize the good leg of a temporarily disabled branch-office loop.

The branch-office loop arranged in this manner cannot of course be worked double, that is, one message cannot be sent and another received simultaneously over the one wire; but a single wire, that is, one arranged so that messages can be sent either way, but not in both directions at the same time, is better than none at all, and as such it must be considered. A device of this kind should be kept at all main offices where loop circuits are connected with multiplex sets, for use in case of emergency.

42. To Prevent Repeating Back.—In all repeaters used in connection with multiplex systems, it is essential, of course, that means be provided to prevent the repeating back of a message to the original sending station. In multiplex single-wire repeaters, this is usually accomplished by the application of the Toye-repeater principle, whereby a resistance is substituted in place of a branch-office circuit, when that circuit is opened; or by the Downer arrangement, whereby an extra battery is included in the higher resistance circuit; or by using half of almost any of the standard single-wire repeaters. The Downer, Moffat, and half repeaters may all be classed as defective-loop repeaters.

DOWNER REPEATER

43. An arrangement of apparatus and circuits called the **Downer repeater** is shown in Fig. 14. The only apparatus not already required in the multiplex set is the repeating transmitter that is operated by the polar relay. The polar relay and the pole changer shown here belong to a regular duplex or quadruplex set.

44. Operation.—When the arm of the switch Q rests on one contact button *1*, the pole changer may be controlled, as usual, by an operator at the key K; in this position of the switch, the branch-office circuit is cut out. When the arm of the switch Q is placed on the other contact button *2*, the branch-office operator receives whatever messages come through the polar relay and repeating transmitter; or by manipulating his key K_2, he can send a message through the pole changer to the distant office—provided the polar relay is receiving no message and is closed. The operation of the polar relay opens and closes the branch-office line at the stop c, but, although it does open and close the branch-office line at this point, it does not open the circuit through the magnet of the pole changer, because the tongue b touches the lever a before it is pulled away from the stop c. Hence, the pole changer is not operated.

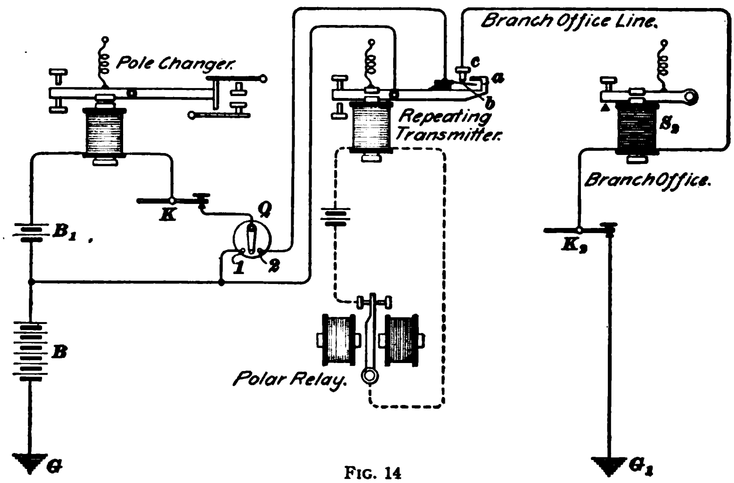


FIG. 14

When the repeating transmitter is closed, the circuit may be traced from G through the batteries B and B_1 – magnet of pole changer – key K – switch Q – contact button *2* – tongue b – stop c – branch-office line – sounder S_2 – key K_2 – ground G_1, back to the starting point G. When the repeating transmitter, which by the way is a continuity-preserving transmitter, opens, the tongue b comes in contact with the lever a and keeps the magnet of the pole changer closed through the following circuit: the battery B_1 – magnet of pole changer – key K – switch Q – contact button *2* – tongue b – lever a of the repeating transmitter, back to the battery B_1.

45. The number of cells in the batteries B and B_1 are so proportioned that the current through the magnet of the pole changer is the same in both positions of the repeating transmitter. Hence, the operation of the polar relay, which causes the repeating transmitter to send the message on to the branch office, does not operate the pole changer. When the branch-office operator wishes to send a message, the polar relay must remain closed in order to keep the repeating transmitter closed. In this position of the repeating transmitter, the tongue b rests against the stop c and the lever a is insulated from both b and c. The pole changer can now be controlled by the key K_2 or K. Thus, it is evident that the branch-office operator may receive a message from one corner of the quadruplex set, or from the receiving side of a polar-duplex set, without the message being repeated back through the pole changer to the original sending station, and, furthermore, he may send a message to the distant quadruplex station through the pole changer.

MOFFAT'S DEFECTIVE-LOOP REPEATER

46. Battery Arrangement.—The principle of **Moffat's defective-loop repeater** is well illustrated in Fig. 15. It is an application of the Toye-repeater principle; namely, the substitution of a resistance in place of the branch-office line circuit when the repeating transmitter opens. The arrangement shown illustrates the application of this principle to a polar duplex or to the polar side of the quadruplex system. It may also be applied to the neutral side of the quadruplex, in which case the pole changer and polar relay, shown in the figure, will be replaced, respectively, by the transmitter and repeating sounder on the common side of the quadruplex, the repeating transmitter magnet being connected to the back stop of the repeating sounder.

The Moffat defective-loop repeater is generally used where the resistances of all loops are approximately equal. In this case, the repeater is ready for instant operation the moment the two loops are inserted in the respective jacks at the loop switchboard, and it seldom requires attention or readjusting.

47. Operation.—The operation of the Moffat defective-loop repeater is as follows: When a message is coming over the quadruplex wire and through the polar relay, whose local circuit passes through the magnet of the repeating transmitter, the latter is operated. Thus, the circuit to the branch office is opened and closed at the stop *c* of the repeating transmitter, and hence the message may be read from the sounder *S*.

Although the repeating transmitter opens and closes the branch-office circuit, it does not open and close the circuit

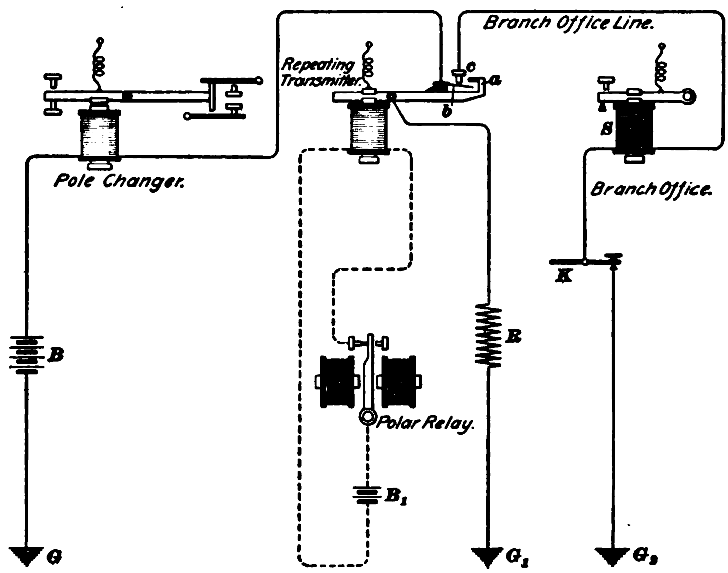


Fig. 15

through the magnet of the pole changer. In the closed position of the repeating transmitter, the circuit through the pole changer is closed through the tongue *b* and contact *c*, and the circuit may then be traced as follows: From ground *G* through battery *B* – pole-changer magnet – tongue *b* – contact *c* – branch-office line – sounder *S* – key *K* – ground G_2, back to the original starting point *G*. The current in this circuit is sufficient to keep the pole changer closed. When the repeating transmitter is open, the pole changer will still be kept closed by a current in the following circuit: From ground G through battery B – magnet of pole changer – tongue b – lever a – resistance R – ground G_1, back to the starting point G.

48. The resistance R is made equal to that of the branch-office circuit, so that the same current will flow through the pole-changer magnet in both the open and closed position of the repeating transmitter. Furthermore, the repeating transmitter is a continuity-preserving device; consequently, the pole-changer circuit is not even opened when the repeating transmitter shifts from the open to the closed position, or vice versa. It is very necessary that the pole-changer circuit shall not be operated when a message is being received through the polar relay. If this were not so and the operation of the polar relay should operate the pole changer, the message coming through the polar relay would be sent back by the operation of the pole changer to the same station from which it was sent.

49. To Send From Branch Office.—When the operator at the branch office is sending a message through the repeating office to the other end of the multiplex system, no message can be received over the polar relay, and it remains in its normal closed position, which causes the tongue b, Fig. 15, to remain in contact with the stop c. The operation of the key K will, in this position, of the repeating transmitter, open and close the circuit containing the magnet of the pole changer; hence, the operator at the branch office can send a message through the near end of the multiplex system to the far end of the same system. Thus, the operator at the branch office can both send and receive through a duplex system or either side of a quadruplex system over one line wire.

50. Dynamo Arrangement.—The arrangement of Moffat's defective-loop repeater in Western Union offices, where dynamos are used, is shown in Fig. 16. The branch-office circuit is connected through a wedge to the loop switch LS_1, and the common side of the quadruplex is connected to the loop switch LS. The repeating apparatus consists merely of a repeating transmitter RT, two lamps l and l_1, the sounder S, and the key K. The latter two instruments enable the

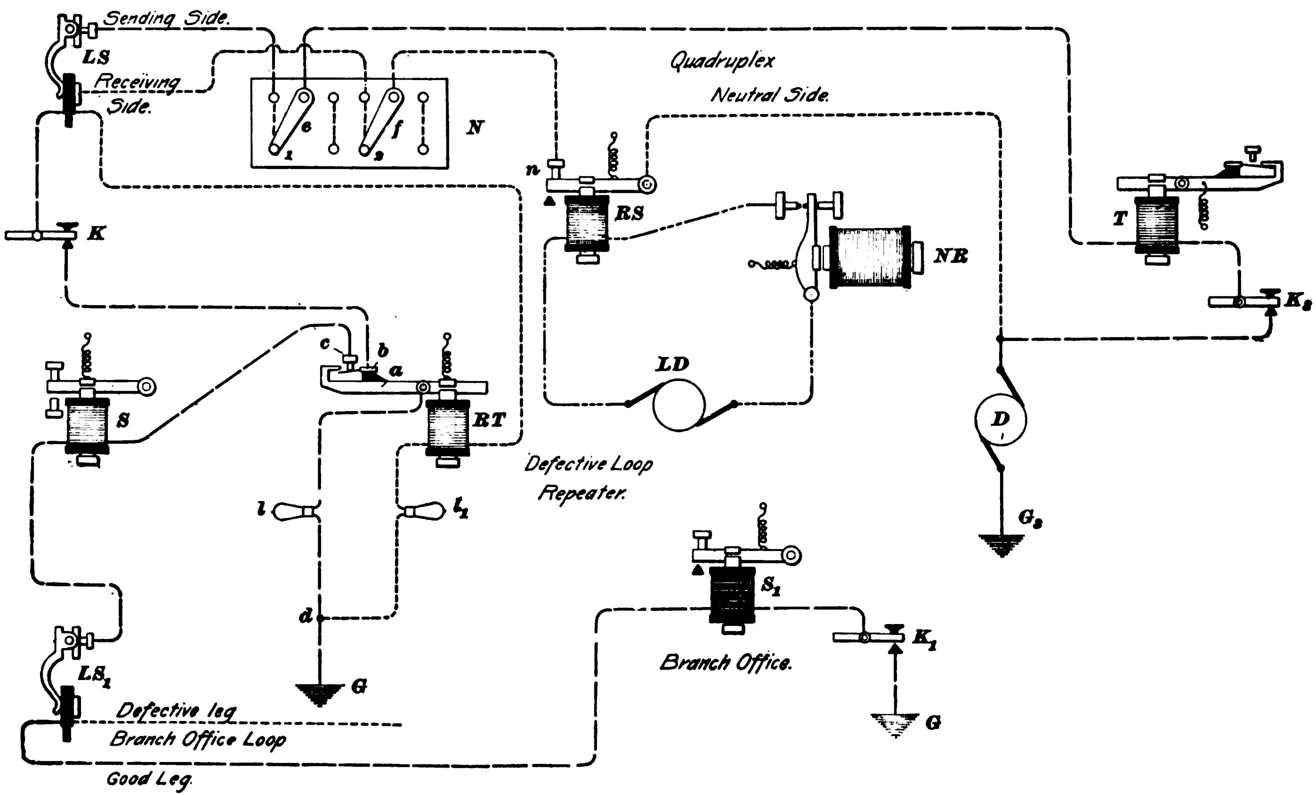

Sending Side.
LS
Receiving Side.
N
e
f
1
2
Quadruplex
Neutral Side.
n
RS
NR
T
K
K_2
c
b
a
S
RT
LD
D
Defective Loop Repeater.
l
l_1
G_2
S_1
d
G
K_1
LS_1
Defective leg
Branch Office Loop
Good Leg.
Branch Office.

FIG. 16

attendant operator at the repeating office to receive and send as well as to adjust and balance the system. The arms of the switch N rest upon the contact buttons *1* and *2* when the quadruplex apparatus is used in connection with the defective-loop repeater. It will be noticed that the repeating sounder RS, instead of being connected to the reading sounder on the common side of the quadruplex, is connected directly with the switch N so that it controls the repeating transmitter. The repeating sounder is so connected that when it is in operation it opens and closes the good leg of the branch-office loop at the stop c, but it does not open the sending side that passes through the quadruplex transmitter T. This is very necessary in order to prevent the operation of the transmitter T and the repeating of the message coming through the neutral relay NR back to the original sending station.

51. When the local circuit of the repeating sounder is open at n, the repeating transmitter will open the good leg of the branch-office circuit at c, and the sending side may be traced from G_3 through the dynamo D – key K_3 – transmitter T – switch arm e – contact button *1* – loop switch LS – key K – the tongue b – lever a – lamp l – ground G, back to the starting point G_3.

When the repeating sounder RS is closed at n, as shown in the figure, the repeating transmitter RT will close, causing the tongue b to make contact with the stop c. The circuit through the transmitter T is now closed through the good leg of the branch-office circuit, instead of through the lamp l. The sending side may now be traced from ground G_3 – dynamo D – key K_3 – transmitter T – switch arm e – loop switch LS – key K – tongue b – stop c – sounder S – loop switch LS_1 – good leg of branch-office loop – branch-office sounder S_1 – key K_1 – ground G, and back to the starting point G_3. Thus, the sending circuit through the magnet of the quadruplex transmitter T is kept closed and the current is kept the same in strength in both positions of the repeating transmitter RT. This is accomplished by making the resistance of the lamp l equal to that of the good leg of the branch-office loop, which it replaces when the repeating transmitter RT opens. Hence, the branch office may receive a message coming through the neutral relay; furthermore, the branch-office operator may send a message through the transmitter T, provided the repeating transmitter RT is kept closed by the repeating sounder RS. This defective-loop repeater may also be used on the polar side of the quadruplex or in connection with the polar duplex.

52. The lamp l_1, Fig. 16, has such a resistance that current furnished by dynamo D will have the proper strength for working the repeating transmitter RT. When the magnet coils of transmitters T and RT are equal in resistance, as they usually are, lamps l and l_1 will each have the same resistance; consequently, these two lamps l and l_1 may be replaced by one lamp, if it is connected between the point d and ground G.

As the branch-office line wire is used for both receiving and sending, it is evident that the branch-office key K_1 must be in the half of the loop used. Hence, should the sending leg of the loop fail, the branch-office operator must reverse the sending and receiving sets, or else he must cut in his key in the receiving or good leg of the loop. The chief operator at the loop switch merely reverses the wedge of the branch-office loop in order that the good leg of the branch-office loop will face outwardly.

HALF REPEATERS

INTRODUCTION

53. Where it is necessary to connect a polar duplex or one side of a quadruplex set with a main line, so that the distant end of this main line may both send and receive through one wire from the polar duplex, or the one side of the quadruplex, the **half repeater** may be used. This accomplishes for the long main line the same object as the defective-loop repeater does on short lines. The defective-loop repeater is not very suitable for use on long lines because the resistance of a long line is constantly changing more or less, whereas the half repeater is satisfactory.

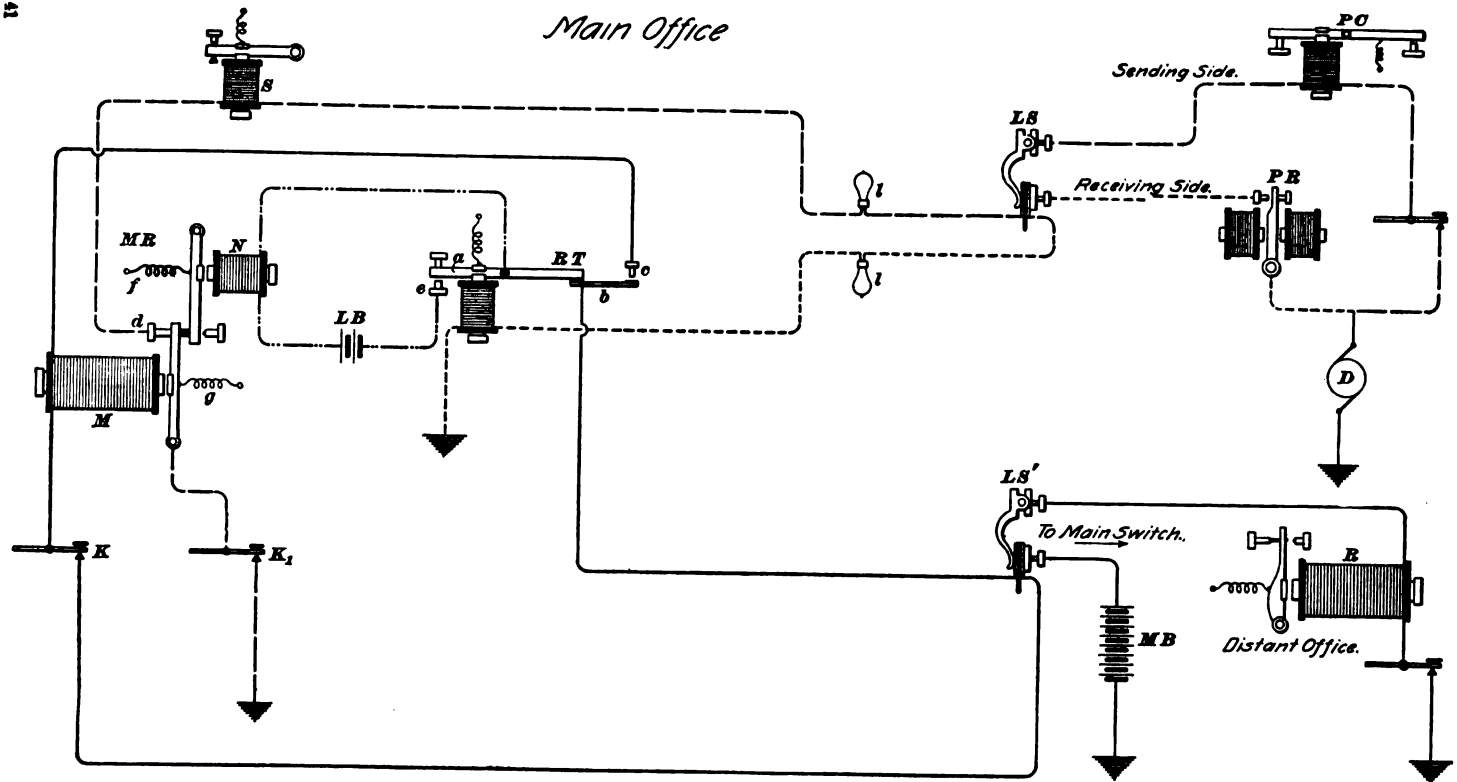

Main Office
S
PO
Sending Side.
LS
Receiving Side.
PR
l
l
MR
N
f
d
a
RT
o
e
b
LB
M
g
D
LS'
To Main Switch.
R
K
K1
MB
Distant Office.

FIG. 17

HALF-MILLIKEN REPEATER

54. Fig. 17 shows the **Half-Milliken repeater** connected through a loop switch *LS* with the duplex set, and through the loop switch *LS'* with the main battery, a main line, and a distant office. In a large office, the loop switch *LS'* would be connected by means of a flying loop to a main switchboard, to which the main line and the main battery are connected. The Half-Milliken repeater consists of the Milliken double relay *MR* and a repeating transmitter *RT*. The sounder *S* and the keys *K* and K_1 are used for the convenience of the operator at the repeating station in reading the signals, adjusting the instruments, and communicating with the two distant offices. The Half-Milliken repeater is located at the main office containing the loop switches *LS* and *LS'*, the main battery *MB*, and the polar relay *PR* and the pole changer *PC*, which belong to a duplex or a quadruplex set.

55. Operation.—In their normal condition all circuits are closed. Suppose that the polar relay is receiving a message over a duplexed wire. The opening of the polar relay *PR* will open the repeating transmitter *RT*. This will open the circuit containing the magnet *M* at *c* and the circuit containing the magnet *N* at *e*. But the spring *f*, being stronger than the spring *g*, will hold the circuit closed at *d*. Thus, the sending side is not opened when the receiving side opens. However, the opening of the circuit at *c* opens the main-line circuit, and hence the distant-office relay *R* opens when the polar relay *PR* opens. Closing the polar relay will restore all circuits to their normal closed position.

Suppose now that the distant office desires to send through the sending side of the duplex set. The distant office will open his key, thereby cutting off the current from the magnet *M*, and as the circuit through *N* has not been opened, the armature of the relay *M* will open the sending side of the duplex set at *d*. This will open the pole changer *PC* and, therefore, send a space from this main, or repeating, office over the duplex wire to the polar relay at the distant main office where the other end of the duplex set is located. When the distant office again closes his key, all circuits will be restored to their normal closed position, thus sending a dot or dash to the distant main office. It has therefore been shown that the distant office is able to both send and receive by means of the Half-Milliken repeater through the duplex, or one-half of a quadruplex, set to the main office where the other end of the multiplex set is located. Moreover, this message may also be read on the sounder S at the main, or repeating, office.

HALF WEINY-PHILLIPS REPEATERS

56. Repeater With Battery Local Circuits.—In Fig. 18 is shown the **Half Weiny-Phillips repeater** with the local

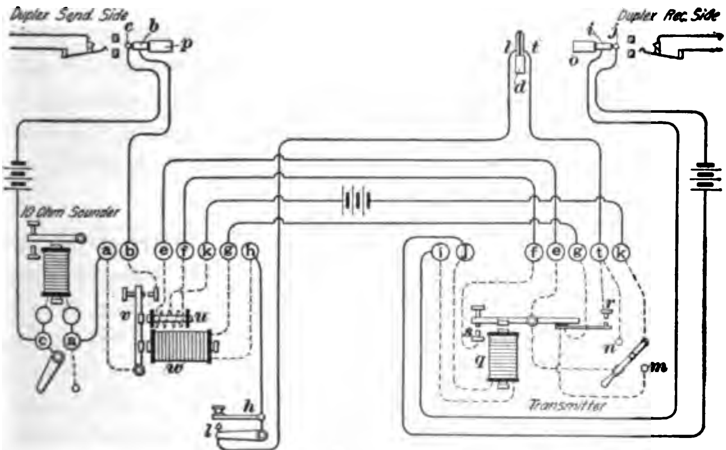


FIG. 18

circuits operated by batteries. In each battery enough cells should be used to secure good firm signals. The wiring is arranged so that by inserting the wedge *d* in a spring jack at the switchboard and turning the transmitter switch to connect points *n* and *m*, the relay and sounder may be used as a simple Morse set when the half repeater is not needed. To use the half repeater, the transmitter switch is put in the position shown, the plug *o* is inserted in a jack connected to the local receiving circuit of a duplex or quadruplex set, the plug *p* is inserted in a jack connected to the local sending circuit of a duplex or quadruplex set, and the wedge *d* is connected through a spring jack to a battery having one terminal grounded and to the line to which it is desired to connect the local duplex sending and receiving circuits.

57. Operation.—Signals coming from the receiving side of the duplex set control the transmitter magnet *q*. These cause the latter to open at *s* one-half of the coil *u*, which causes this small magnet to hold the armature *v* when, a moment later, the large coil *w* and the line connected to the wedge *d* has its circuit opened at *r*. Thus, the message is repeated over the main line coming to *d* without opening the sending side of the circuit. When the operator at the distant end of the main line sends, only the coil *w* is affected, hence it repeats the signals into the sending side of the duplex circuit without affecting the receiving side. Thus, the distant operator on the main line can receive or send through the duplex line, although he cannot, of course, both receive and send messages at the same time. Binding posts and terminals similarly lettered are connected together.

58. Half Weiny-Phillips Repeater With Dynamo Local Circuits.—In Fig. 19 is shown the half Weiny-Phillips repeater with the local circuits operated by current from a dynamo. The 10-ohm sounder *S* may be silenced by closing the switch *C* which merely short-circuits it. With the switches *A* and *B* thrown to the right, the terminals *b* and *c* of the relay-contact-and-sounder circuits are connected to a pin jack whose contact springs *o* and *p* are extended through a plug to the sending side of the duplex or quadruplex circuit. The transmitter coil is connected to a pin jack whose contact springs *q* and *r* are similarly extended to the receiving side of the duplex or quadruplex circuit. Thus, the receiving and transmitting circuits may both be extended to another part of the same office or to a branch office.

With the switches thrown to the left, the sounder *S* is controlled by the relay and supplied with current from the 40-volt dynamo connected to binding post *n* and connected to ground through a 180-ohm resistance *v*. The transmitter coil is

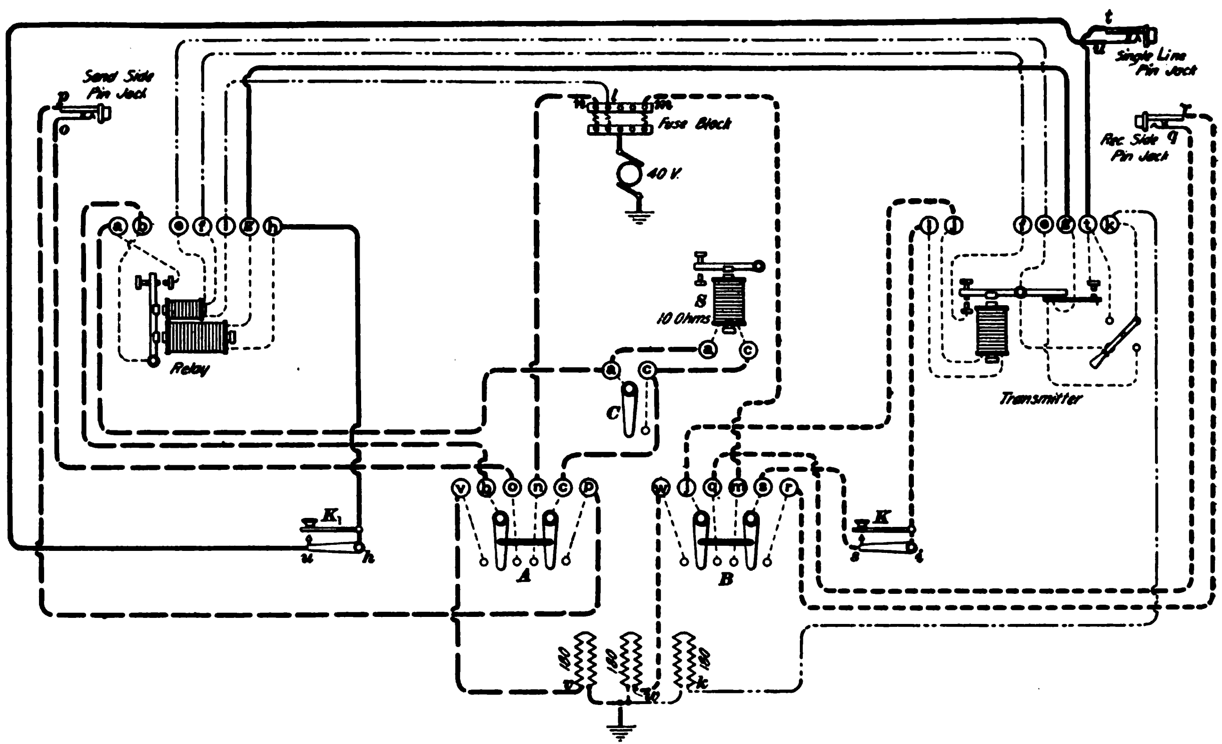

Send Side
Pin Jack
Single Line
Pin Jack
Rec. Side
Pin Jack
Fuse Block
40 V.
S
10 Ohms
Relay
Transmitter
C
A
B
K
K_1
180
180
180

Fig. 19

similarly supplied with current and may be operated by means of the key *K*. A key K_1 is included in the relay circuit which runs to the springs *t* and *u* of a single-line pin jack so that it may be connected in any circuit desired. This half repeater may be used in the same manner as any half repeater. The operation of this repeater is the same whether dynamos or batteries are used in the local circuits.

DILLON HALF REPEATER

59. The Dillon half repeater, claimed to be very satisfactory by its inventor, Mr. James B. Dillon, is shown in Fig. 20. The apparatus required is a relay *R*, a transmitter *T*, and a repeating sounder, or relay, *RS*. As the dynamo *D* supplies the current for the local magnet coils, the quadruplex or duplex

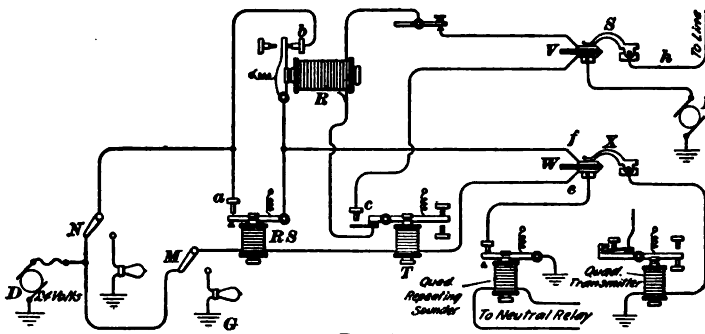


FIG. 20

local circuits should be connected to ground through the usual desk switch, which is not, however, shown. The contact point *a* of the repeating sounder should be set very close to the lever, so that, when the repeating-sounder and transmitter circuits are opened by the quadruplex neutral relay, the contact *a* shall be closed before the quadruplex transmitter circuit can be opened at the relay contact *b*. The transmitter armature should be closer to its core than the armature of the repeating sounder, but the contact *a* should be closer to its lever in order that the repeating sounder *RS* may release its armature first and close its contact *a* before the transmitter contact *c* is opened;

also, so that the transmitter *T* may attract its armature and close the contact at *c* before the repeating sounder will attract its armature and open contact *a*. One circuit is extended through a wedge *W* and jack *X* to the local circuits of one side of a quadruplex set and another circuit through a wedge *V* and jack *S* and the main switchboard, which is not shown, to a main-line battery or dynamo *D'* and to the single-line wire.

60. Operation.—When the quadruplex repeating sounder opens the circuit containing the transmitter *T* and repeating sounder *RS*, contact *a* is first closed, then contact *c* is opened, thereby opening the main line and relay *R*. The latter releases its armature and opens contact *b*, but contact *a* has already been closed so that the quadruplex transmitter is not affected. When the quadruplex repeating sounder closes the circuit of the transmitter *T* and repeating sounder *RS*, the main-line and relay circuit is closed at contact *c*, then the contact *b* is closed and contact *a* opened. Thus signals received on the quadruplex relay are sent out over the single main line without affecting the quadruplex transmitter.

When the distant single-line office opens its key, the relay *R* opens contact *b*, thereby opening the circuit of the quadruplex transmitter. Closing the distant key, causes relay *R* to close contact *b*, thereby closing the quadruplex transmitter. Thus signals produced by the operator at the distant end of the single main line are repeated through the quadruplex transmitter over the quadruplex line.

61. Two of these half repeaters may be used as a full repeater by connecting the wedge *W* in a spring jack leading to another spring jack in which a similar wedge of another half repeater is inserted in a reversed position and turning the switch *M* on both sets to the right, or grounded button, leaving the switch *N* on both sets turned to the left. One local circuit may be traced from *D* through switch $N-b-f-e$ side of other wedge (not shown here) – unshown transmitter and repeating sounder – *M* switch of other set to ground. The other local circuit may be traced from ground *G* through switch *M*

– *RS* – *T* – *e* – *f* side of other wedge (not shown here) – the *b* contact of unshown relay – the unshown switch *N* – dynamo of the other set to ground. One line would be connected to *h* and the other line to a similar point associated with the other set.

CARE OF MULTIPLEX SINGLE-WIRE REPEATERS

62. The repeating transmitters of multiplex single-wire repeaters must be kept in good order, the contacts must be kept clean, and the tongue of the transmitter must not be too stiff. If the contacts of the repeating transmitter become dirty, a message coming over the polar relay or the neutral relay may be repeated back through the pole changer or transmitter to the original sending station, because a dirty contact may prevent the repeating transmitter from holding the pole changer or transmitter of the multiplex set closed when a message is coming through the polar or neutral relay. In case a single-wire repeater is used at both ends of the multiplex system, utter confusion might result from defective contacts on both repeating transmitters.

The second source of trouble may be due to the fact that the current through the pole changer or transmitter of the multiplex set is not the same in the two positions of the repeating transmitter. This may be due to a weakening of one of the batteries, or to the fact that the resistance used in repeaters (depending on the principle used in the Toye repeater) to take the place of the branch circuit in the open position of the transmitter is not properly adjusted. If the two currents are unequal for either of these reasons, and if the spring of the pole changer or transmitter of the multiplex set is adjusted properly for the stronger current, the instrument may open when the weaker current passes through it instead of remaining closed as it should. This, of course, may be avoided by making the strength of the current through the pole changer or transmitter of the multiplex set the same in both positions of the repeating transmitter.

If the tongue of the quadruplex transmitter is too stiff, it will not break contact properly with the lever, as it should do, when the repeating transmitter is opened; especially will this be the case should the local battery in the quadruplex transmitter be weak at the same time. In addition to these faults are the faults due to the improper adjustment and balance of the duplex or quadruplex system itself; these have already been given in connection with the adjustment and balancing of the quadruplex system.

MISCELLANEOUS ARRANGEMENTS OF MULTIPLEX SETS

ARRANGEMENT OF LOCAL CIRCUITS ON CANADIAN PACIFIC RAILROAD

63. On the Canadian Pacific Railroad, some local sounders, pole changers, and transmitters are wound to a resistance of 20 ohms. They could all be connected in multiple to a 6-volt dynamo, but in nearly every office where dynamos are used, the local circuits of the multiplex sets are connected as shown in Fig. 21. Each half of the quadruplex set, or half-repeater, is treated as a duplex set. By resistance coils each local circuit of the multiplex and repeater sets is brought up to 100 ohms resistance and the local-circuit dynamo gives from 20 to 25 volts, the former voltage being usually found to be sufficient.

The lower half of the figure shows one set as ordinarily arranged. Starting from the dynamo D, the receiving circuit passes through the contacts on the relay PR_1 - 20-ohm sounder S_1 - 80-ohm coil - ground G_1, back through G to dynamo D. A branch, or leg, passes through jack J_1, but is open at c. The sending circuit may be traced from the dynamo D through the switch n_1 - key K_1 - 20-ohm pole changer PC_1 - switch m_1 - wedge W_1 - back contact e of jack J_1 - 80-ohm coil - ground g_1, back to dynamo D

64. Local Circuit Extended to Branch Office.—To extend the local circuits of a duplex set to a branch office, the loop wedge W_3 is inserted in the spring jack on top of the wedge W_2, the switch m_2 is turned up and the switch n_2 down,

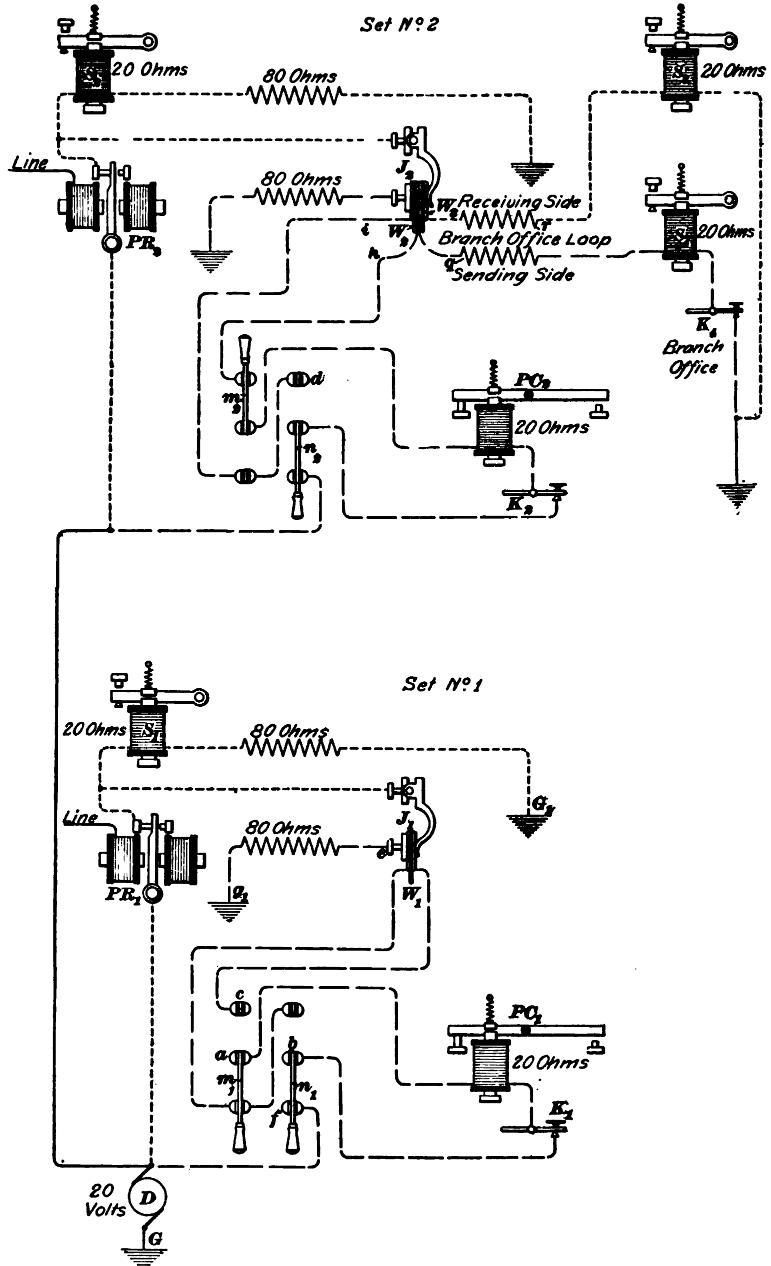

Set No. 2
20 Ohms
80 Ohms
20 Ohms
Line
80 Ohms
Receiving Side
Branch Office Loop
Sending Side
PR2
20 Ohms
K4
Branch Office
PC2
20 Ohms
K2
Set No. 1
20 Ohms
S1
80 Ohms
Line
80 Ohms
G1
PR1
W1
PC1
20 Ohms
K1
20 Volts
D
G

FIG. 21

as shown in the upper portion of Fig. 20. The circuits are then as follows: Receiving side; dynamo D - polar relay PR_2— sounder S_2 - 80-ohm coil - ground; also from the relay contact through the leg to the top of the jack J_2 - front of wedge W_2 - coil r - receiving side of branch-office loop - branch-office sounder S_3 to ground. The resistance coil r is adjusted so as to give the circuit a total resistance of 100 ohms from the wedge to the branch-office ground. The sending side; dynamo D - switch n_2 - key K_2 - pole changer PC_2 - switch m_2 - front of wedge W_2 - back of wedge W_3 - coil q - sending side of branch-office loop - branch-office sounder S_4 - key K_4, to ground. The resistance from the wedge to the branch-office ground is 80 ohms, including the sounder S_4. The resistance of the pole changer PC_2 is included in this circuit, thus making the total resistance 100 ohms, the same as on the receiving side.

65. One Set Repeating Into Another.—To work these sets as repeaters, the wedges of the two sets are exchanged, wedge W_1 of the No. *1* set being inserted in jack J_2, wedge W_2 in jack J_1, and the table switches m_1, m_2, n_1, and n_2 turned up. The circuit may then be traced from the ground G through the dynamo - contacts of relay PR_1 - sounder S_1 - 80-ohm coil to ground G_1; also from the relay contact to the top of the jack J_1 - front of wedge W_2, which is now supposed to be inserted in the jack J_1 - wire h - switch m_2 - pole changer PC_2 - key K_2 - switch n_2 to d - wire i - back of wedge W_2 - lower part e of jack J_1 - 80-ohm coil to ground g_1. The circuits from No. *2* set are the same. A break at the contacts of either relay will open its sounder and also the pole changer of the other set. Thus signals received from the line on No. *1* set are automatically transmitted over the line connected to No. *2* set and vice versa.

66. In many places on Canadian Pacific lines, storage batteries are used in place of dynamos, in which case no resistances are inserted in the local circuits but extra cells are used, providing the necessary power when the quadruplex or duplex systems are extended to branch offices. When storage cells are used for main batteries, a switch, consisting of a series of spring jacks and wedges, is so designed that the jack is normally open and a wedge when reversed cannot be inserted. The negative pole of the battery is connected to the top of a wedge and the positive pole to the bottom. It is predicted that shortly storage cells will replace gravity batteries even for locals at wayside stations; the storage cells will be charged at some central point and distributed by train to the wayside stations.

REPEATER WITH RELAYS IN BRANCH-OFFICE LOOP

67. Where it is necessary to connect a number of branch offices or a long line in circuit with a polar duplex or one side of quadruplex set, relays must be used in place of the sounders for the same reason that relays are used on main lines. The branch-office circuit is then equivalent to a long main line, but the magnet of the pole changer or transmitter of the multiplex set cannot be connected directly in the branch line, but must be operated by a relay whose magnet is in the branch line.

Sometimes, six or eight offices are connected in one branch-office circuit in connection with a duplex or one side of a quadruplex set. Where this is the case, relays should be used and the apparatus connected as shown in Fig. 22. The Toye-repeater principle is used here. Practically the only difference between this and the defective-loop repeater shown in Fig. 16 is a substitution of relays for sounders at the branch offices and the use of a relay *R′* at the repeating office for controlling the quadruplex transmitter. When a return circuit, as shown here, is used, instead of grounding the circuit after passing through the last branch office, a resistance box *Rh* may be used. This box allows the resistance of the branch-office loop to be increased so that ordinary relays suitable for use with the main-line battery *MB* or a dynamo may be used.

Evidently the resistance of *Rh′* should be equal to the total resistance of the branch-office circuit back to the point *a*. In case the branch-office circuit is grounded and there is no return wire *b a*, only one resistance box *Rh′* will be necessary, and its resistance should be made equal to the resistance of the one branch-office wire and all the branch-office relays

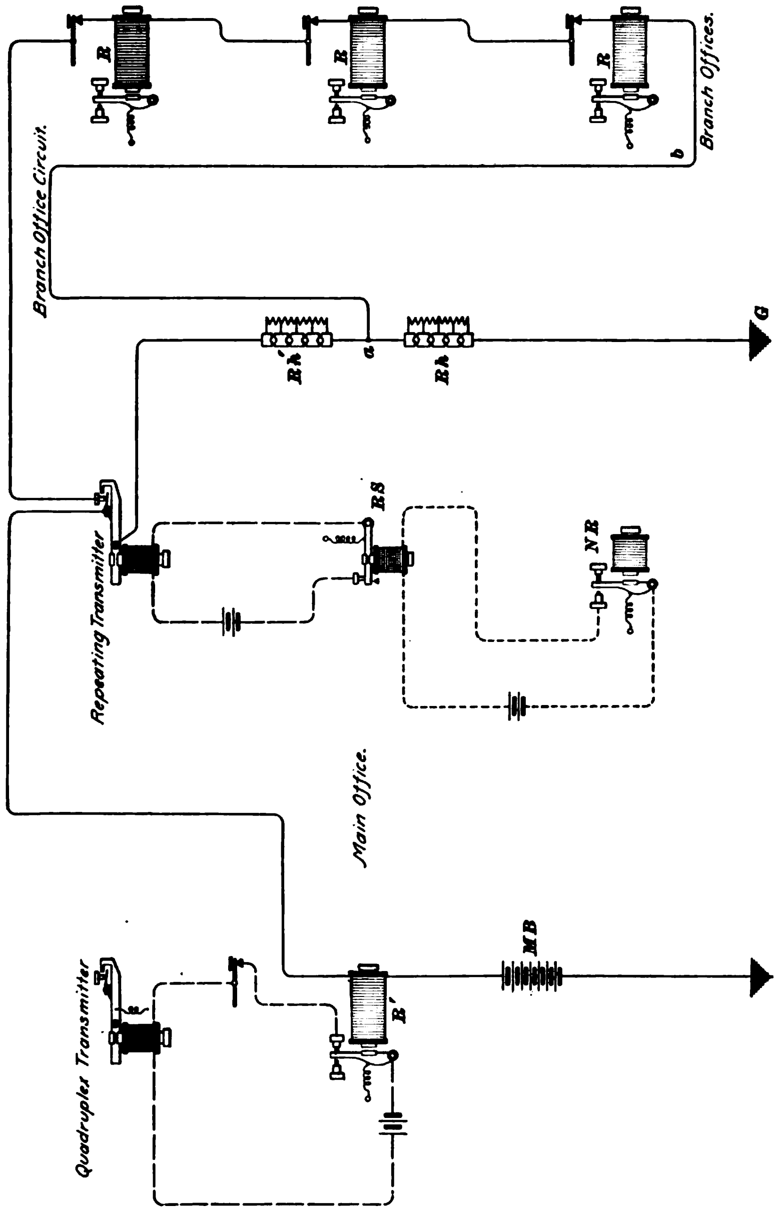

Branch Office Circuit.
R
R
R
b
Branch Offices.
Rh'
a
Rh
G
Repeating Transmitter
RS
NR
Main Office.
Quadruplex Transmitter
R'
MB

Fig. 22

to the ground at the most distant branch office. The resistance Rh', as in the Toye repeater, causes the relay R' and, consequently, the quadruplex transmitter to remain closed when the repeating transmitter is open.

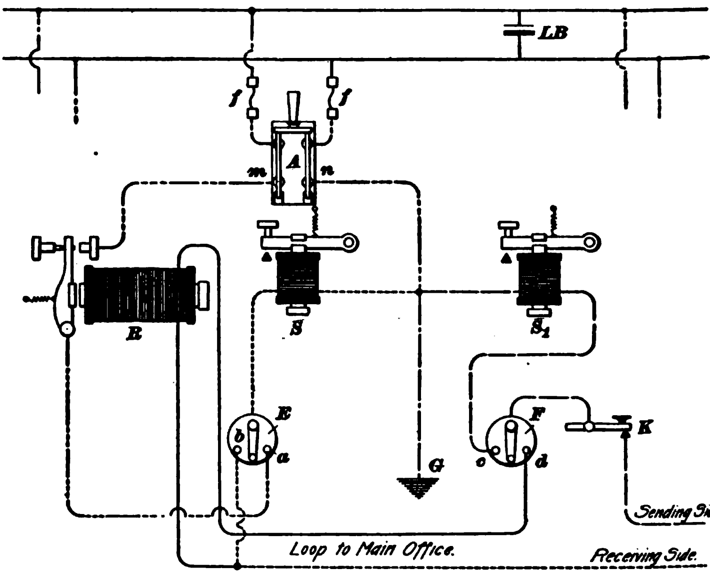


FIG. 23

BRANCH-OFFICE SINGLE OR DUPLEX ARRANGEMENT

68. Fig. 23 shows an arrangement whereby the apparatus at a branch office may be used in a single or duplex circuit. When the switches E and F are turned to the left, the apparatus is arranged to work on the sending and receiving sides of the duplex set at the main office. In this case the sending side may be traced through the key K – switch F – contact button c – sounder S_1 to ground G; and the receiving side through the contact button b – switch E – sounder S to ground G.

To use the key K, relay R, and the sounder S as a single Morse set, the switches E and F are both turned to the right. Then the circuit may be traced from the sending side of the loop through the key K – switch F – contact button d – relay R

to the receiving side of the loop. With the switches in this position, the sounder S_1 is on open circuit. Thus, in the circuit from the main office there is now only the key K and the relay R, which controls the sounder S.

The local circuit containing this sounder is supplied with current from the local battery LB, which is arranged here as it would be if it were a storage battery that supplied several local circuits. If a gravity battery were used, it would be connected between the points m and n and no switch A would be necessary. It would supply only this one local circuit.

MULTIPLEX TELEGRAPHY

(PART 2)

MULTIPLEX REPEATING CIRCUITS

BRANCH-OFFICE CONNECTIONS WITH REPEATERS

DILLON BRANCH-OFFICE QUADRUPLEX REPEATER

1. James B. Dillon has devised an arrangement suitable for use in Western Union offices by which a branch-office loop may be connected in circuit with the multiplex apparatus at a repeating station, in such a manner that the terminal offices on the multiplex sets may work single, but without interference from the branch office, although the latter is able to hear and break either terminal of the multiplex that may be sending. Thus, the branch office can take a drop copy without requiring help in order to break one of the distant senders, and the branch office can send to both terminal offices. Such an arrangement is often of considerable use to chief operators in large offices where newspapers desire to send the same copy to two stations by repeating through the office where the newspaper branch-office loop terminates. The difficulty with most of the temporary arrangements made for this purpose is that, while the newspaper office can send to both terminals at once, the latter cannot hear each other, which frequently leads to confusion.

2. Arrangement of Apparatus.—The arrangement and connection of the apparatus that were devised by Mr. Dillon

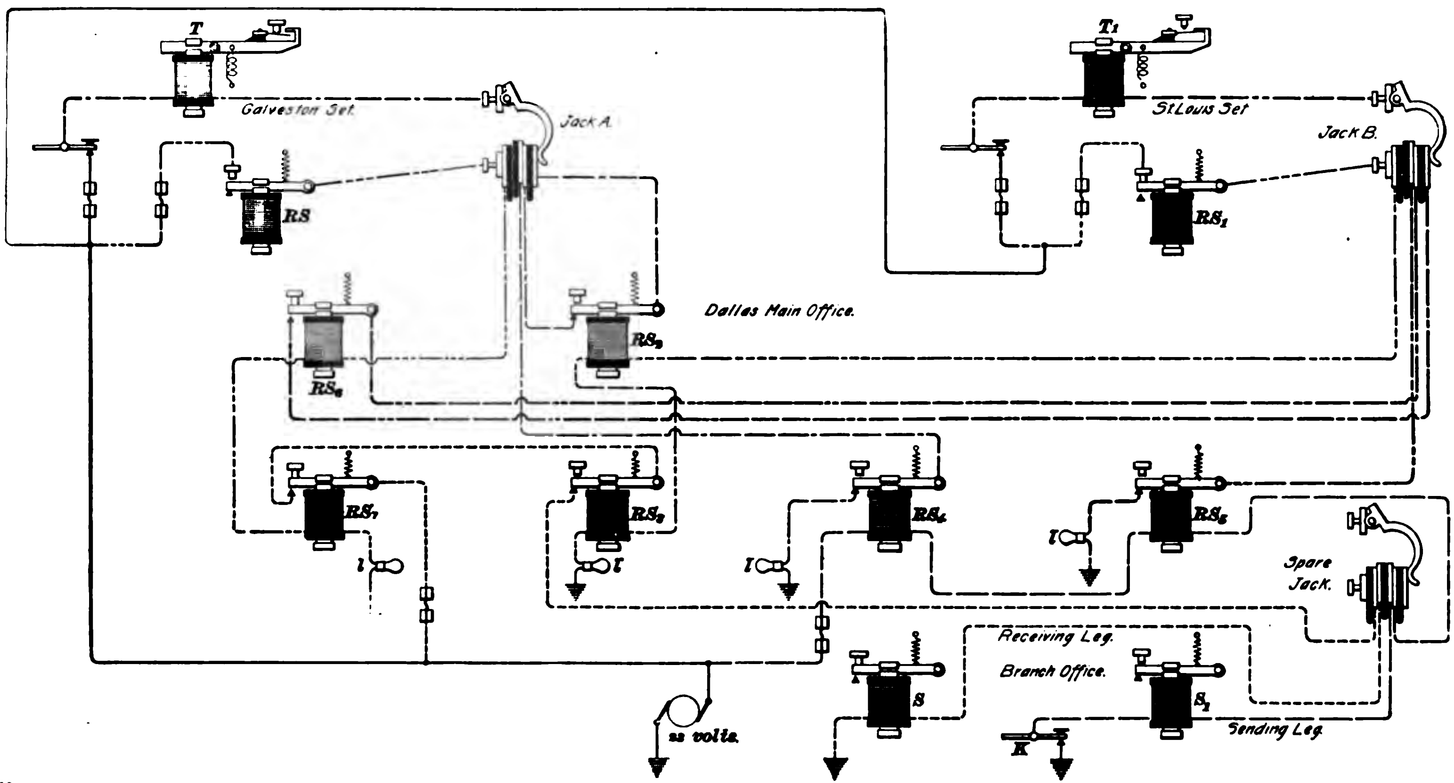

T
Galveston Set
Jack A.
RS
RS6
RS3
Dallas Main Office.
T1
St Louis Set
Jack B.
RS1
RS7
l
RS2
I
RS4
I
RS5
I
Spare Jack.
Receiving Leg.
Branch Office.
S
S1
K
Sending Leg.
22 volts.

FIG. 1

to accomplish the desired object are shown in Fig. 1, in which only the local connections are shown. The transmitter T and the repeating sounder RS represent the apparatus on the common side at the Dallas main office of a quadruplex system extending from Dallas to Galveston. Of course the apparatus on the polar side can be substituted in place of that shown here on the common side. The transmitter T_1 and the repeating sounder RS_1 constitute the apparatus on the common side at the Dallas main office of the quadruplex system between Dallas and St. Louis. The quadruplex apparatus is shown connected to the jacks A and B, as in most Western Union offices.

3. Operation of Dillon Arrangement.—In the Dillon arrangement, all circuits are normally closed. Opening the key in the transmitter circuit at the distant Galveston office will open the local circuits controlled by the repeating sounders RS, RS_6, and RS_7. This will cause the message to be heard at the Dallas main office on sounders RS_6 and RS_7. Furthermore, the operation of the repeating sounders RS_6 will cause the message to be repeated through the quadruplex transmitter T_1 of the St. Louis set at Dallas to St. Louis, and the operation of the repeating sounder RS_7 will cause the message to be heard on the sounder S in the receiving leg at the branch office. Operating the transmitter key at the distant St. Louis office will operate the repeating sounders RS_1, RS_2, and RS_3. Thus the message will be heard in the main office at Dallas on sounders RS_2 and RS_3. Furthermore, the operation of the repeating sounder RS_2 will evidently operate the transmitter T in the Galveston set at Dallas, causing the message to be sent to Galveston, and the operation of the repeating sounder RS_3, provided sounder RS_7 remains closed, will cause the message to be sent through the receiving leg of the branch-office loop to the branch-office sounder S.

4. Double Sending Between Terminal Stations. Operators at Galveston and St. Louis can send simultaneously, provided the key K, Fig. 1, in the branch-office sending leg is closed, and the messages will be repeated properly at Dallas. Thus, the two ends can work double, provided the branch-office key is kept closed. However, the branch office cannot, in this case, read either message because the two messages will interfere with each other in the receiving leg of the branch-office loop, due to the simultaneous operation of the two sounders RS_7 and RS_3. If the branch office sends by operating the key K, then the repeating sounders RS_4 and RS_5 are operated. The operation of sounder RS_4, provided sounder RS_2 remains closed, causes the message to be repeated through the transmitter T of the Galveston set at Dallas to Galveston. Similarly, the operation of the repeating sounder RS_5, provided sounder RS_6 remains closed, causes the message to be repeated through the transmitter T_1 of the St. Louis set at Dallas to St. Louis. Hence, the branch office can send to both ends of the main circuit by operating the key K in the sending leg at the branch office. When the branch office is sending, the local circuits of both repeating sounders RS and RS_1 must remain closed in order to keep sounders RS_6 and RS_2 closed; hence, no message can be received either from Galveston or St. Louis while the branch office is sending and, therefore, in this case the line can only be worked single. Thus, any one of the three offices, St. Louis, Galveston, or the branch office in Dallas, can send to the other two by working the line single; and the two terminal offices, St. Louis and Galveston, can work the line double if the message is not intended to be received at the branch office in Dallas and provided the branch-office key in the sending leg is kept closed.

POSTAL TELEGRAPH BRANCH-OFFICE QUADRUPLEX REPEATER

5. The same result obtained by the arrangement of the apparatus given in Fig. 1 may be accomplished in a much simpler manner by the arrangement shown in Fig. 2, which may be used in Postal Telegraph offices. For the sake of simplicity, all switches have been omitted. The apparatus in the upper part of the figure is located at the Dallas repeating office and represents the polar duplex, or the polar side of a quadruplex set, the other end of which is in St. Louis. The apparatus in the middle represents a polar duplex, or the polar

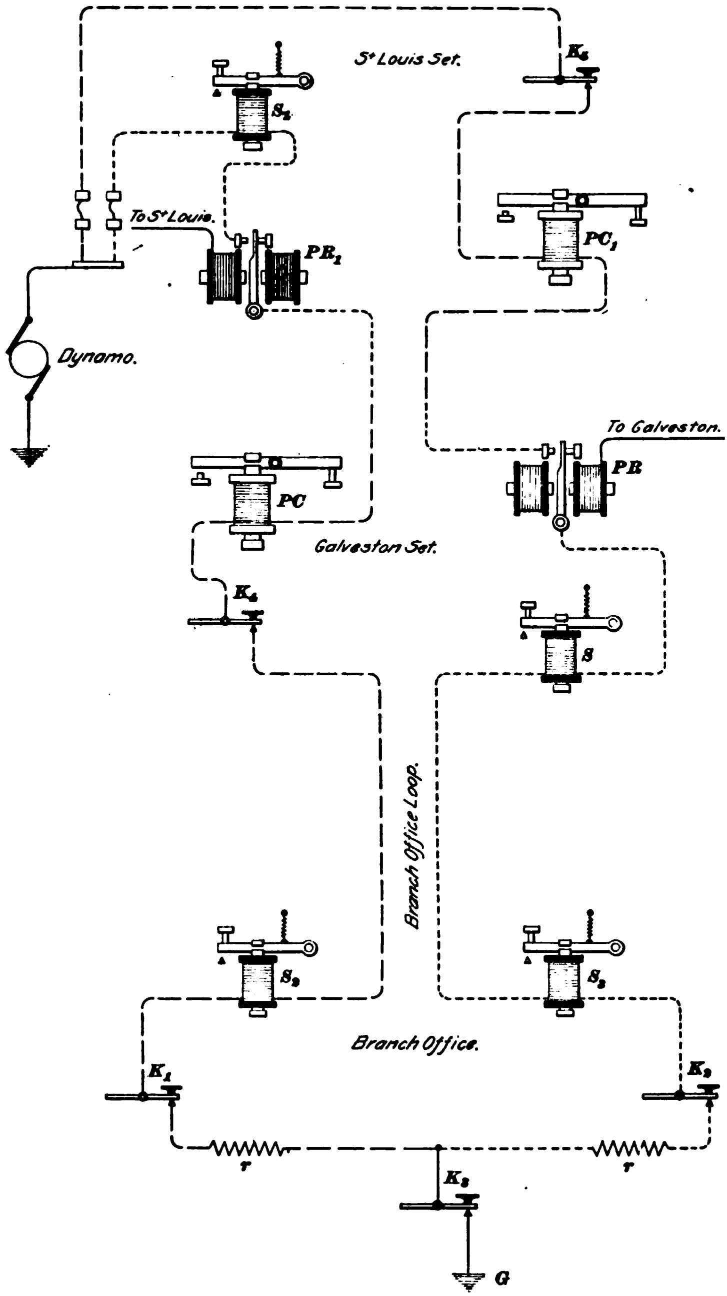

S^t Louis Set.
K5
S1
To S^t Louis.
PR1
PC1
Dynamo.
To Galveston.
PB
PC
Galveston Set.
K4
S
Branch Office Loop.
S2
S3
Branch Office.
K1
K2
r
r
K3
G

Fig. 2

side of a quadruplex set, the other end of which is in Galveston. As in Fig. 1, only the local connections are here shown. The only extra piece of apparatus used is the key K_3 at the branch office. It is connected, as shown, between the junction of two resistance coils r and r and the ground G. The resistance coils r and r are adjusted to give all local instruments their required current. These two resistances can be located at the main office instead of at the branch office.

6. Operation.—The operation of the key K_3, Fig. 2, sends the message to the repeating office at Dallas, to St. Louis, and to Galveston. For, opening the key K_3 opens the circuit through the magnets of both the St. Louis and the Galveston pole changers PC_1 and PC, respectively, at the Dallas repeating office; hence, the message is repeated through these pole changers to St. Louis and Galveston. Operating the key K_1 at the branch office sends the message to the Dallas repeating office, where it operates the pole changer PC and so repeats the message to Galveston. Operating the key K_2, similarly, sends the message to the Dallas repeating office and to St. Louis. Evidently, a message may be sent from the Dallas repeating office to the branch office and to Galveston by operating the key K_4; similarly, a message may be sent from the Dallas repeating office to the branch office and to St. Louis by operating the key K_5.

7. The operation of the pole-changer key at St. Louis will send the message to the Dallas repeating office and to the branch office, the message being received on the sounders S_1 and S_2, respectively; and by the repeating action of the pole changer PC, the message will also be sent to Galveston. Similarly, Galveston can send to the Dallas repeating office, the branch office, and to St. Louis; furthermore, St. Louis and Galveston can be sending simultaneously and each message will be received at the Dallas repeating office, at the branch office, and at one of the two terminal stations. When the branch office sends by means of the key K_3, the line between Galveston and St. Louis can only be worked single.

The arrangement given here enables an operator at the branch office to send to the repeating office and to either terminal station by the key K_1 or K_2, or to the repeating office and to both terminal stations by key K_3. Furthermore, he can hear the message sent from both ends when they are working double. Consequently, there should be no confusion at any time due to the operator at either end or in the branch office not hearing the others sending.

DOUBLE-LOOP REPEATER

8. It is sometimes desirable to connect two branch offices with a duplex set or one side of a quadruplex set at the main office in such a manner that both branch offices may receive

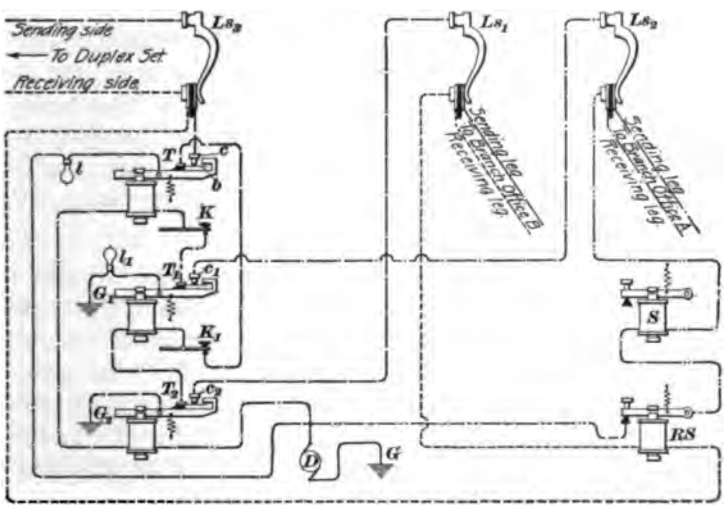


Fig. 3

the message coming over the receiving side of the multiplex set, and also allow either branch office to send to the other branch office and through the sending side of the multiplex set at the nearer main office to the distant main office. An arrangement of apparatus that will accomplish this is called a **double-loop repeater.** Fig. 3 illustrates a double-loop repeater that is frequently used by the Western Union

Telegraph Company. It consists of three transmitters, a repeating sounder, and one ordinary sounder. As in all repeaters, it is very necessary that the opening of the key in the sending circuit at either branch office or at the repeating station shall not leave the sending circuit open at the repeating station.

9. Operation of Double-Loop Repeaters.—In explaining the operation of the double-loop repeater, it will be assumed that all circuits are in their normal condition; that is, closed. Suppose now that the polar relay in the duplex set connected to the loop switch Ls_3 in Fig. 3 opens the receiving side; this will cut off the current from the magnet of the repeating sounder *RS* and also from the sounder in the receiving leg at the branch office *B*. Furthermore, the opening of the repeating sounder *RS* will cut off the current from the sounder *S* and also from the sounder in the receiving leg at the branch office *A*. Hence, the opening of the circuit at the polar relay has cut off all current from the receiving legs of the two branch-office loops and from the sounder *S*. This sounder *S* enables the attendant to read the signals in order to judge whether the circuit is working properly and to communicate with the branch office.

10. Suppose that the branch office *A* desires to send to the branch office *B* and through the sending side of the duplex set to the distant main office. When the key in the sending leg at the branch office *A* is opened, there will be no current through the magnets of the transmitters *T* and T_2, thus allowing these two transmitters to open. The opening of transmitter *T* will open the sending side of the duplex set at contact stop *c* and, hence, operate the sending side of the duplex set. When the transmitter *T* opens, however, the tongue of the transmitter is connected through the lever, lamp *l*, and dynamo *D*, to the ground *G*. As the lamp *l* has a resistance equal to that of the sending side of the duplex set that was cut out at *c*, the current flowing through the magnet of the transmitter T_1 will remain constant and thus the transmitter T_1 will be kept closed. This is essential in order that the sending circuit from the branch office *A* shall not be opened at the repeating station. The opening of the transmitter T_2, by disconnecting the tongue from the contact stop c_2, opens the sending leg running to the branch office B; and by connecting the tongue to the ground G_2, the opening of the transmitter T_1 has been prevented by the substitution of a circuit to the ground G_2 for the sending leg from c_2 through the branch office B. Thus opening the key in the sending leg at the branch office A opens the sending leg to the branch office B and the sending side of the duplex set, but does not open the sending leg of the branch office A at the repeater. No lamp is required between the lever of the transmitter T_2 and the ground G_2, because the lamp l is in the circuit between G_2 and the dynamo whenever the transmitters T and T_2 are open.

11. Suppose that the circuits are again in their normal closed condition and that the key in the sending leg at the branch office B is opened. This will open the circuit through the transmitter T_1 and also through the sending side of the duplex set. Opening the transmitter T_1 opens the sending leg to the branch office A at contact c_1, but the tongue of this transmitter T_1 comes into contact with the lever and makes a connection through the lamp l_1 with the ground G_1, thus keeping the transmitters T and T_2 closed. Thus, the opening of the key in the sending leg at the branch office B has opened the sending leg running to the branch office A and also the sending side of the duplex set. Furthermore, the operation of the transmitters has not opened at the repeating station the sending leg from the branch office B. Thus, both branch offices may receive a message from the receiving side of the duplex set and either branch office may send to the other branch office and through the sending side of the duplex set to the distant main office.

12. Western Union Double-Loop Repeater.—The standard Western Union arrangement of the instruments forming this double-loop repeater is shown in Fig. 4. The instruments are lettered the same in both figures. As the repeater occupies only a space of about 15 inches square, a number of such sets can be placed on a small shelf. By always using this standard arrangement, having the two transmitters T and T_2, whose magnet coils are connected in series placed on the left alongside each other and the third transmitter T_1 on the right by itself, a quadruplex attendant is soon able to tell, in case of trouble, which loop is out of order. This double-loop repeater should only be used where the resistances of all loops are approximately equal; in such cases the repeater is ready for use as

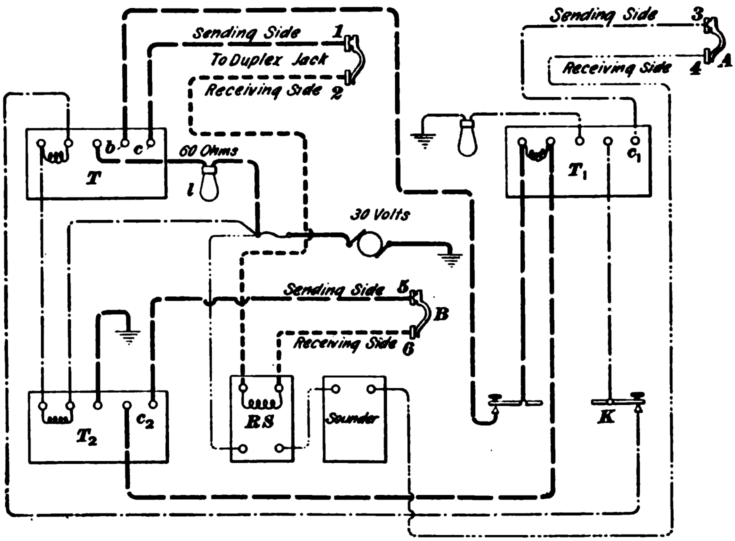


Fig. 4

soon as the branch-office loop wedges are inserted in the proper spring jacks; a readjustment of the repeater is seldom necessary.

KENDRICK'S BRANCH-OFFICE DROP IN DUPLEX REPEATER

13. Description.—In Fig. 5 is shown an arrangement used by George H. Kendrick, and illustrated in the Telegraph Age, for connecting a branch-office loop in circuit with a duplex repeater in such a manner that the branch-office operator can control either or both of the transmitters at the repeating station, thereby making his signals audible at either or both of the terminal stations. The branch-office operator

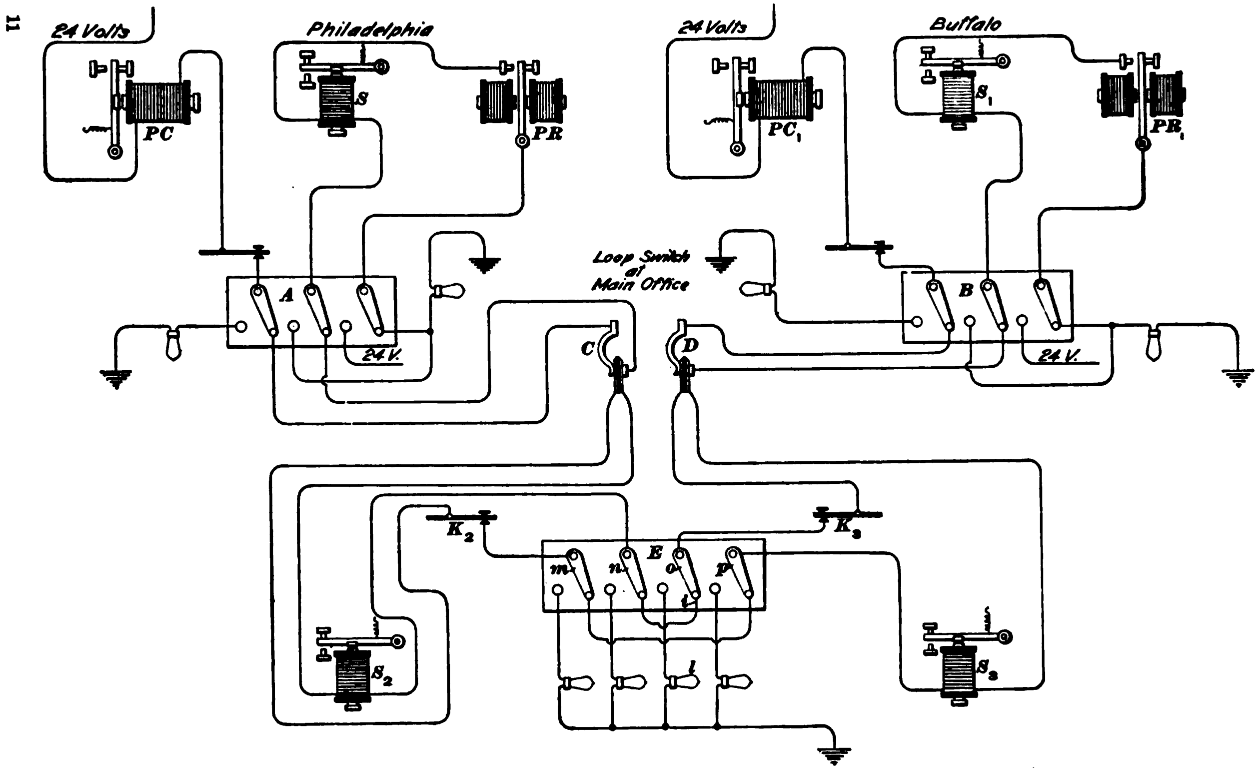

24 Volts
PC
Philadelphia
S
PR
A
24 V.
Loop Switch
at
Main Office
C
D
24 Volts
PC₁
Buffalo
S₁
PR₁
B
24 V.
K₂
K₃
E
m
n
o
p
t
l
S₂
S₃

Fig. 5

can hear the signals going both ways through the repeater. This arrangement has proved useful on fast-broker's circuits between large cities.

The diagram does not show the terminal duplex sets located, say at Philadelphia and Buffalo, but it does show the duplex repeater located, say at the main office in Scranton, the necessary switches A and B, loop jacks and wedges C and D in the main Scranton office, and the switch E, sounders and keys in the Scranton branch office. With the switches in the position shown, the polar relay PR on the Philadelphia side controls the sounders S and S_2 and the pole changer PC_1 on the Buffalo side; while the polar relay PR_1 on the Buffalo side controls the sounders S_1 and S_3 and the pole changer PC on the Philadelphia side. Therefore, the branch-office operator may copy either or both messages passing between Philadelphia and Buffalo.

14. If the branch-office operator desires to break in at the end of a message so that he can send a message to Chicago, he will turn arm m to the left and, by using key K_2, inform the receiving operator at Philadelphia of his intention. Then he will return arm m to its present position, while the sending operator at Philadelphia, if he consents to it, merely closes his key and the branch-office operator sends to Buffalo by using key K_3, which operates the pole changer PC_1. If the Philadelphia sending operator does not want to give up the circuit and holds his key open, the branch-office operator can turn arm o to the left, thereby opening at i the local circuit of the polar relay and rendering this local circuit useless, while the circuit he desires to use is connected through lamp l to ground and he can send to Buffalo without being interrupted. Furthermore, this will not interfere with the sending of messages from Buffalo to Philadelphia, except while the branch office is informing Philadelphia that he desires to send to Buffalo. But the Philadelphia operator cannot break Buffalo until the branch-office operator restores lever o to its normal position, which he will do as soon as he finishes his message to Buffalo. In a similar manner, the branch-office operator can send to

Philadelphia, pushing lever *m* to the left only in case the Buffalo sending operator will not yield the circuit and close his key.

The switch *E* is also useful in case the circuit becomes unworkable on either side of the repeater office. For, by throwing the switch levers *m*, *n*, *o*, and *p* to the left, the branch office can receive and send messages to either or both terminal stations. By throwing the levers of switches *A* and *B* to the left, the branch office is cut out and the duplex repeater becomes two terminal and independent duplex sets.

15. Dillon's Connections for Grounded Loop and Single Wire With Duplex.—In Fig. 6 is shown an arrangement, devised by J. B. Dillon, of a Milliken relay and transmitter with a single main line, two wires to a branch office, and a duplex set or one side of a quadruplex set. This arrangement enables the distant main-line operator to control the duplex or quadruplex transmitter and the sounder *S* at a branch office; or for the duplex or quadruplex relay to send its message to the single-line office and to the branch-office sounder *S'*; or for the branch-office operator, by the use of key *K'*, to send to the distant single-main-line office and to control the duplex or quadruplex transmitter. In this case no message can be received through the quadruplex relay.

16. Operation.—Operating the key in the distant office on the single line, operates the repeater magnet *m*, which repeats the message to the quadruplex transmitter and to the branch-office sounder *S*. The branch-office operator can break by opening the key *K'*, which opens the circuit of the sounder *S'* and the transmitter *t* and hence also the single line at *a* and the quadruplex transmitter at *b*. If the distant quadruplex receiving operator wishes to break, he opens the transmitting key at his end, which causes the quadruplex relay at this end to open the circuit through sounder *S'* and the transmitter magnet *t*, thereby also opening the main-line circuit at *a*.

The quadruplex relay operates the sounder *S'* and transmitter *t*, which causes the message to be repeated over the single line, the Milliken repeater remaining unaffected, because the circuits through both its magnets are opened by transmitter *t*. The distant single-line operator, by breaking while the transmitter is energized, causes the magnet *m* to open at *b* the circuit of the sounder *S* and the quadruplex transmitter,

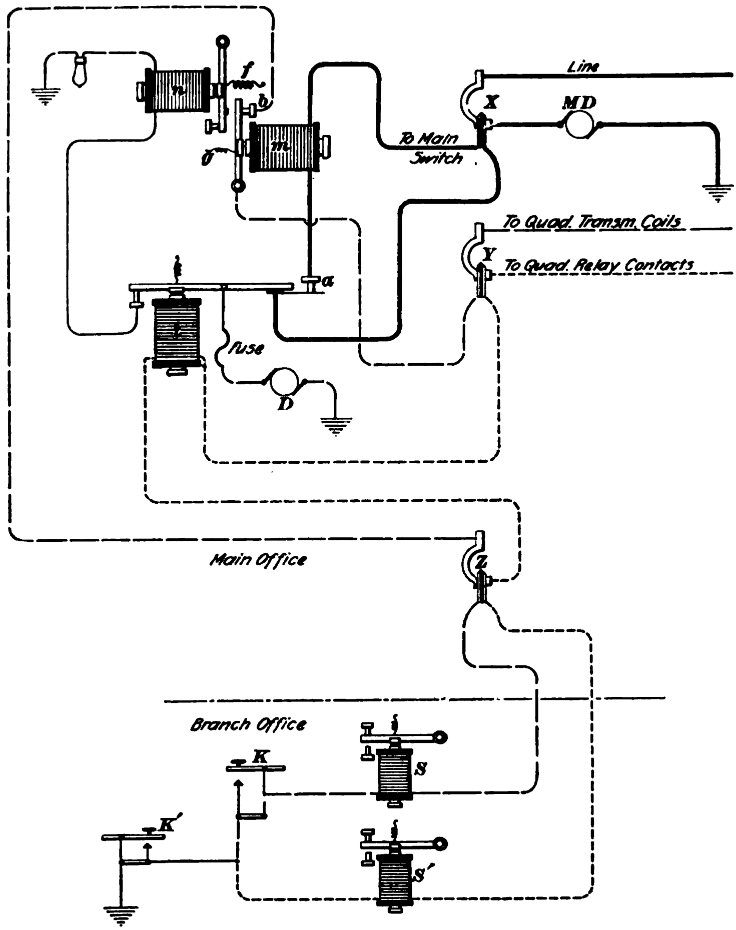


Fig. 6

which the attending quadruplex operator must watch. The branch-office operator breaks by opening key *K'*, which not only opens the circuit through the sounder *S* and the quadruplex transmitter, but also breaks up the signals being received from the quadruplex relay; hence, the transmitter *t* breaks up the signals going to the distant single-line office.

17. The branch-office operator, by means of the key *K*, operates only the quadruplex transmitter. But by using the key *K'* he operates the sounder *S'* and the transmitter *t*, thereby repeating the message over the single line, and furthermore, the Milliken relay, by holding contact *b* closed, allows the operation of the quadruplex transmitter and the sounder *S*. The distant single-line operator by breaking will open the circuit of the magnet *m* and break up the signals produced by the quadruplex transmitter and also by the sounder *S*. The distant quadruplex receiving operator breaks by opening the transmitting key at his end, thereby opening the quadruplex relay, the sounder *S'*, and the transmitter *t*, which breaks up at *a* the signals going to the single line.

The Milliken apparatus as connected in Fig. 6 can still be used as an ordinary half repeater by removing the wedge from the loop jack *Z* and substituting therefor a wedge that will connect both sides of the spring jack *Z* to ground.

THREE-WIRE REPEATERS

KITTON THREE-WIRE REPEATERS

18. Description.—The object of a three-wire repeater is to enable an operator on one main line to send to two operators on two other main lines and also to enable any operator who may be receiving to break the sending operator. In Fig. 7 is shown a **three-wire repeater** arranged for operation by a dynamo. This arrangement was devised by Frank Kitton for the Western Union Telegraph Company and was described in the Telegraph Age. In Fig. 8 are shown the local connections of this arrangement when gravity batteries are to be used; the main-wire connections are omitted in order to make the diagram as clear as possible. As arranged, there is practically one battery for each coil. *B* for coil *WT*, B_1 for coil *ET*, etc. If a low internal-resistance battery is used, such as a storage battery, the positive terminal should be connected to *w* and *x* and the negative terminal to *y* and *z*.

To work three wires into one another usually requires two

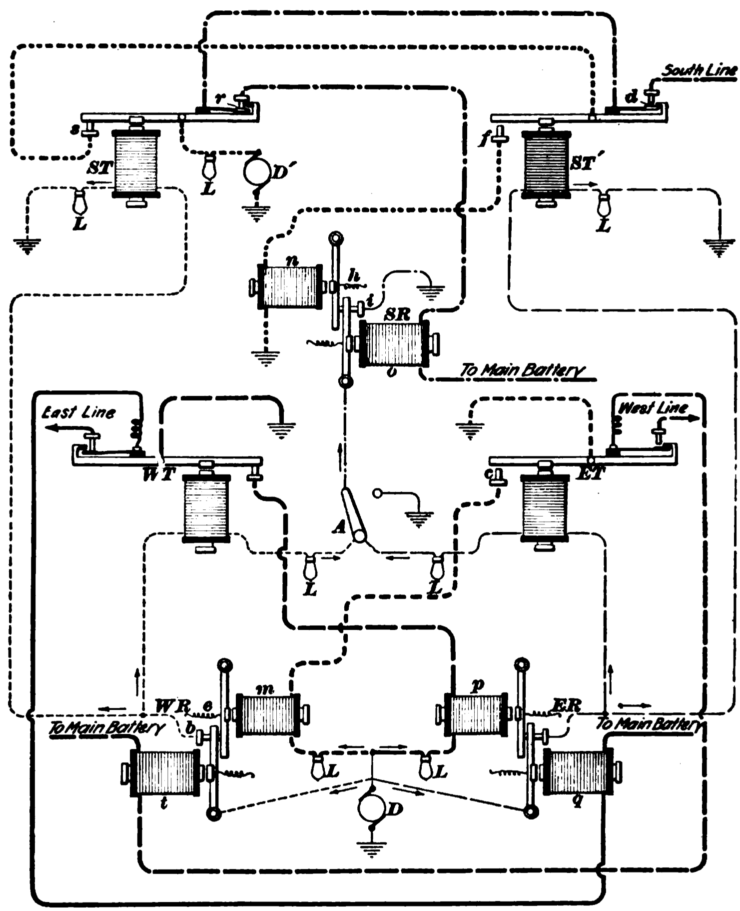


Fig. 7

sets of repeaters; the Kitton arrangement does not, however. Furthermore, this arrangement has the advantage of requiring but one relay in each main line to be kept in adjustment. The Kitton arrangement is said to be adaptable to any of the

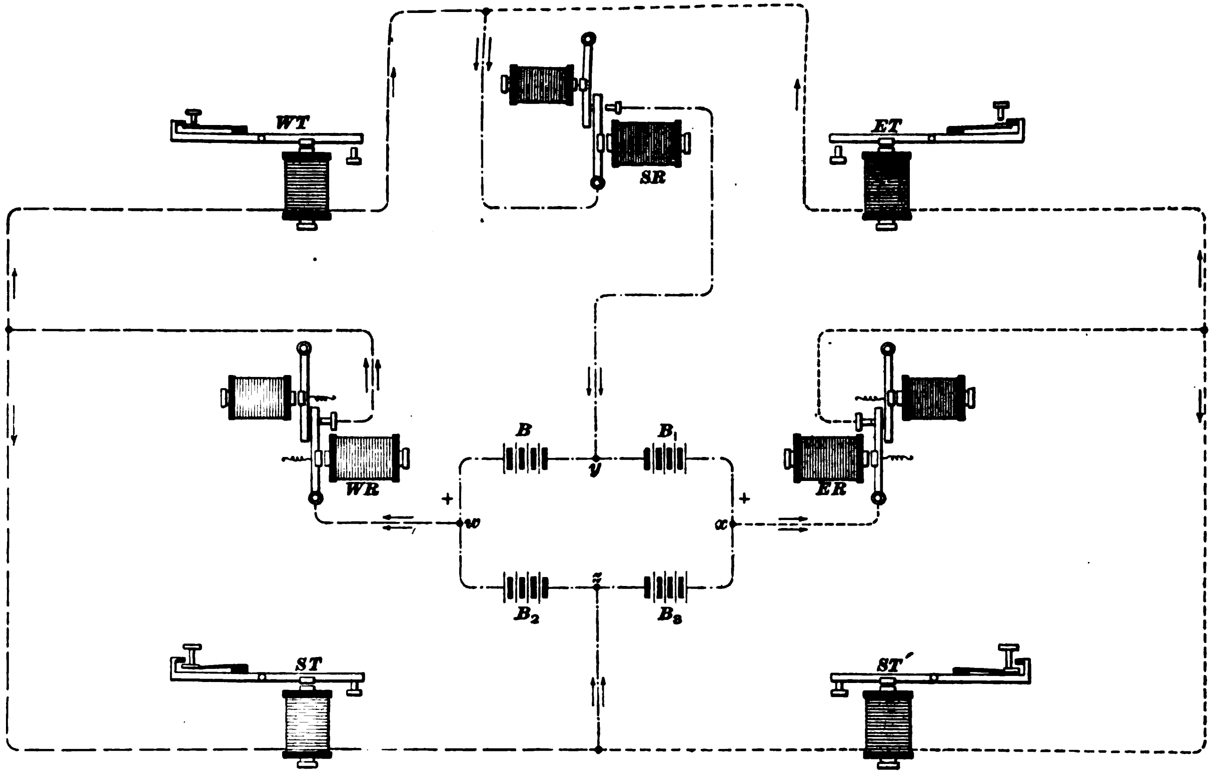


FIG. 8

different forms of repeaters in common use; besides, the principle involved is applicable to the connection of a single wire to two duplex or other systems, or for the working of three duplex wires into each other. It should be noted that the under sides of the hooks of the transmitters are lined with insulating material, or have equivalent insulating points, so that when the transmitter is open the tongue is insulated from the rest of the transmitter.

19. Operation of Kitton Repeater.—Assume that all circuits are in their normal, or closed, positions and that the operator at the distant end of the east line commences to send by opening his key. The eastern relay *ER*, Fig. 7 will release its armature, thereby opening the circuit containing the coils of the eastern transmitter *ET* and southern transmitter *ST'*. Therefore, the eastern transmitter *ET* opens the west line and the circuit containing the coil *m* of the west relay at *c*. Consequently, the heavier spring *e* will hold the armature of the western relay *WR* closed at *b*, which in turn holds the transmitters *WT* and *ST* closed. The demagnetization of the southern transmitter *ST'* opens the south line at *d* and also the circuit containing coil *n* of the southern relay *SR* at *f*. Although the circuit containing coil *o* is also open at *d*, the stronger spring *h* will hold the circuit containing the coils of western transmitter *WT* closed at *i*. Hence, the western transmitter *WT* will not open the east line. Closing the eastern key will close the circuits containing the following coils in the order mentioned: Coils *q*, *ET*, *ST'*, west line, coils *t* and *m*, south line, and coils *o* and *n*, thereby restoring all circuits to their normal, or closed, condition.

20. The operator on the west line may break the sender by opening his key. This opens the following circuits in the order mentioned: coils of *WR*, *WT*, and *ST*, east line and coils *q* and *p* at transmitter *WT*, south line and coil *o* at *r*, and coil *n* at contact *s*; thus, both east and south operators are notified that the west operator has opened his key. Coils *n* and *o* and also *p* and *q* being open, the relays *SR* and *ER* do not open their local circuits, hence the transmitters *ST'* and

ET remain closed, which prevents the opening of the west line. The south line is already open at r and coil n at s, so that the fact that the transmitter ST' remains closed has no effect. The same action takes place when the west operator opens his key while sending. The closing of the west key restores all circuits to their normal, or closed, condition.

HOSKINS THREE-WIRE REPEATER

21. The **Hoskins three-wire repeater,** as used in Dallas, Texas, is shown in Fig. 9. It is said in the Telegraph Age to be very satisfactory. With the switches h and i turned to the left, the apparatus is a three-wire repeater; with these switches turned to the right, an ordinary two-wire repeater set and a half-repeater set are formed. The sounder S' is used merely for convenience in adjusting when the apparatus at the right-hand side forms a half repeater; it forms no part of the three-wire repeater. When this arrangement is used as a three-wire repeater, the repeating sounder S does the work of a relay and sounder. Weiny-Phelps relays are used at R_1, R_2, and R_3.

22. Operation.—Suppose that the switches h and i are turned to the left, that wedges a, b, and c are inserted in jacks, one side of each being connected to the desired line wire and the other side of each through suitable batteries to ground and that all circuits are in their normal, or closed, condition. If the key at the distant end of the line wire coming to a is opened, the main coil of relay R_1 will be deprived of current and the armature l will be released. This will open the circuit of transmitter T_1, which releases its armature, thereby opening at e one-half the winding of coil n. The other half of this coil can then magnetize its core and hold the armature f when, an instant later, the current through the main winding of relay R_2 is interrupted at p, which also opens the line connected to plug b. Opening the circuit at l also opens the circuit through the coil of the transmitter T_3, which opens at d one winding of coil o, so that its armature is not released when,

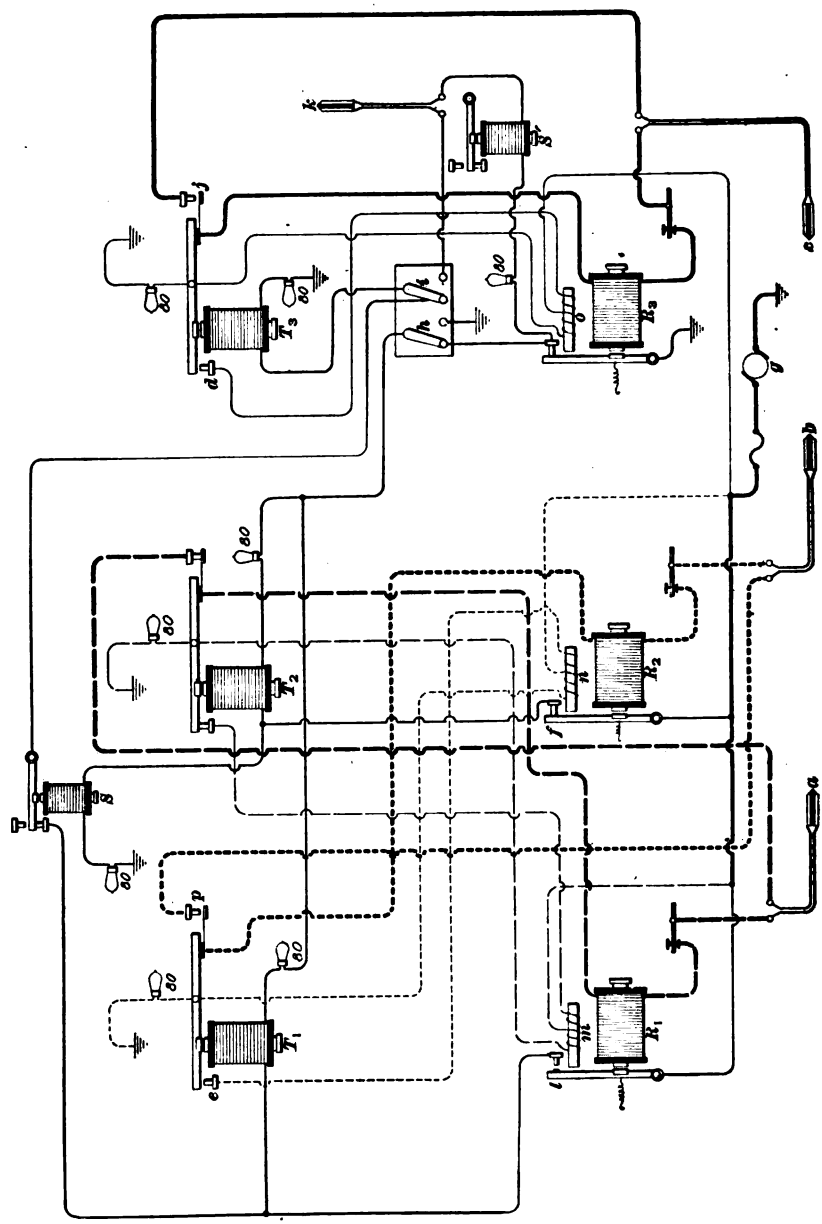


FIG. 9

a moment later, the coil R_3 and line connected to plug c has its circuit opened at j. Thus, the opening of a key on line a, opens lines b and c and leaves the apparatus in such a condition that these line circuits can be closed and all circuits restored to normal condition when the key in line a is closed.

23. Thus, relay R_1 controls transmitters T_1 and T_3 by disconnecting them from the local dynamo g. Relay R_2 controls transmitter T_2 and the repeating sounder S by disconnecting them from the local dynamo g; the repeating sounder in this case breaks the circuit from the contact of relay R_1 through transmitter T_3. Relay R_3 controls transmitters T_1 and T_2 by disconnecting them from ground. The receiving operator on either the b or c line may break the sending operator by opening his key, the action being the same as though the receiving operator commenced to send as soon as the sending operator closed his key.

The operation is similar when the key in line b or line c is used for sending. When the switches h and i are turned to the right and plug k is inserted in a line jack, the Weiny-Phelps relay R_3, transmitter T_3, and sounder S' constitute a half-repeater set between circuits connected to wedges c and k, and the rest of the apparatus constitutes an ordinary repeater between lines connected to wedges a and b.

MISCELLANEOUS ARRANGEMENTS

THREE MULTIPLEX SETS CONNECTED TOGETHER

24. A method of arranging three quadruplex sets in such a manner that they will be in communication with one another when worked as a single line, or where any two can be worked double, provided the third station keeps his key closed, is shown in Fig. 10. This arrangement was given by J. B. Dillon, in the Telegraph Age. The repeating sounders shown can be replaced by transmitters properly connected or by pony relays of the proper resistance. The resistance of the various circuits should be adjusted by the use of lamps or resistance coils to allow the various instruments the proper amount of current.

25. Operation.—If when all keys are closed and quadruplex *A* wishes to work with *B* and *C*, the operation is as follows: Opening the key at the distant office *A* causes polar relay of the set *A* and the repeating sounders *RS* and RS_1 to open, thereby opening the circuits passing through the pole changers of the quadruplex sets *B* and *C*, respectively, thus sending the signal to the distant quadruplex stations *B* and *C*.

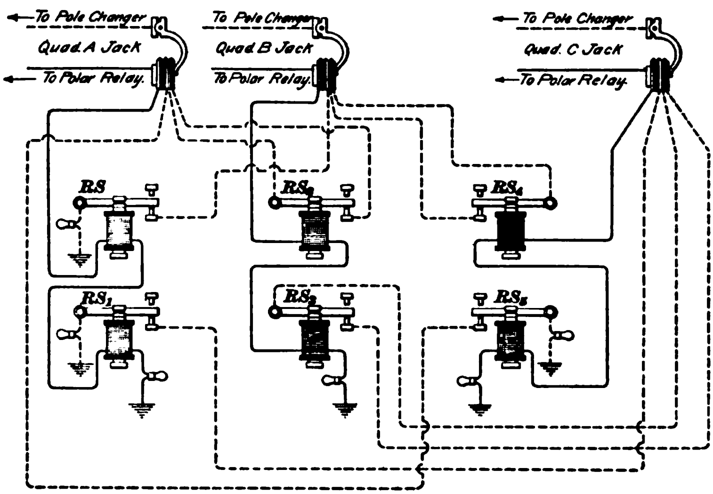


Fig. 10

Should the distant office *B* desire to break, the opening of his key will cause the polar relay of the set *B* and the repeating sounders RS_2 and RS_3 to open, thereby opening the circuits passing through the pole changers of the sets *A* and *C*. Of course, it is understood that the operator at the pole-changer key at the distant office *A* will close his key when he hears the opening of his sounder controlled by his polar relay, and thus permit the office *C*, as well as the office *A*, to hear what the operator at the pole-changer key at the distant office *B* has to say.

Should the distant operator C desire to send, the opening of his key will open the polar relay at the set C and cause the repeating sounders RS_4 and RS_5 to open the circuit passing through the pole changers of the quadruplex sets B and A, respectively. It will thus be seen that each station can hear and converse with any other as a single-circuit arrangement.

26. Two Offices Working Double.—To show how any two offices can work double, provided the third station keeps his key closed, suppose that A and B desire to work double, while the key at the distant office C is kept closed. The path of the current through the pole changer of the A set may be traced through the front wedge in the quadruplex A jack - cord - contact points of repeating sounder RS_2 - back to other side of same wedge - center half wedge - cord - contact points of the repeating sounder RS_5 to the ground. As the repeating sounder RS_2 is controlled by the polar relay of the B set, the distant A operator will then hear what the distant B operator has to say. The path of the current through the pole changer of the B set may be traced through the front wedge in the quadruplex B jack - cord - contact points of repeating sounder RS_4 - cord - other side of same wedge - center half wedge - contact points of the repeating sounder RS to the ground. As the repeating sounder RS, which controls the pole changer of the B set, is in turn controlled by the polar relay of the A set, the distant B operator will hear what the distant A operator has to say.

27. If A and C wish to work double, B must keep his key closed. The repeating sounder RS_1 will then operate the pole changer of the set C, and the repeating sounder RS_5 will operate the pole changer of the set A. Confused signals, due to the sending at both A and C, which operate the repeating sounder RS and RS_4 (as well as RS_1 and RS_5), will pass through the pole changer of the set B; hence, neither message can be read at the distant office B. Should B and C desire to work double, A must keep his key closed.

While the third quadruplex will be practically dead, as far as business is concerned, when the other two are working double, attention is merely called to the fact that doubling is practicable, as explained, should it be desirable to connect three quadruplex sets for special or report matter (worked as a single line).

OFFICE-LOOP CONNECTIONS

28. With the ordinary arrangement of a complete multiplex circuit on each corner of a quartet table, it is not practicable to operate the sets on the brokers' loops after the brokers' offices are closed for the day. According to W. H. Jones, in the Telegraph Age, it is therefore customary, in large tele-

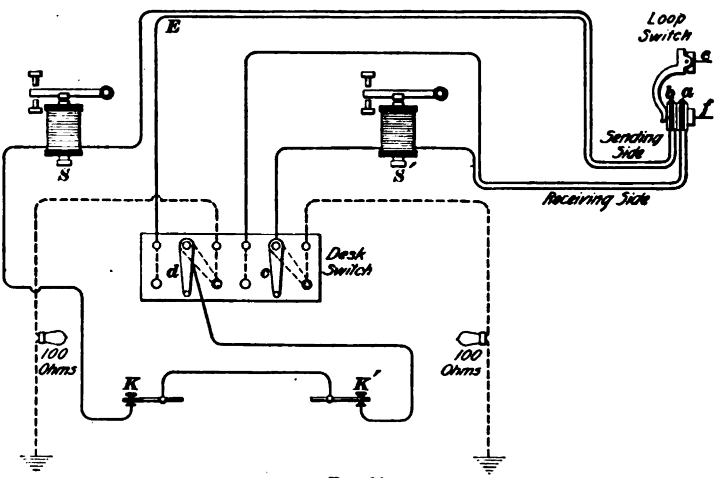


FIG. 11

graph offices, to locate by themselves in one section of the room all duplex and quadruplex sets upon which the brokers' loops are regularly worked. They then receive the special care of an attendant. Then by the office loop shown in Fig. 11, the apparatus may be extended to and spread out upon a full desk in the operating department where it may be used when no longer required by the brokers. The wire *e* connects through the coils of a pole changer or transmitter and suitable battery or local dynamo to the ground, while wire *f* connects through the receiving contacts of a polar relay or repeating sounder on the common side of a quadruplex set and a suitable battery or local dynamo to the ground. When the wedges *a* and *b* are inserted in a loop switch, as shown, and the switch arms *d* and *c* are turned to the right, the sounder *S* and keys *K* and *K′* are connected in the sending side of the multiplex set and the sounder *S′* in the receiving side of the same multiplex set. As this set is now being used in place of a regular broker's loop measuring about 100 ohms, it is necessary to include in each leg a 100-ohm resistance lamp or the current will be too large.

29. If this set is to be used while the broker loops are in use, the wedges *a* and *b* will be withdrawn from the broker multiplex-set jack and inserted singly or together in some other jack at the loop switchboard. If wedge *b* alone is inserted in a jack, connected to a branch office for instance, and the switch arm *d* is turned to the left, the sounder *S* and key *K* may be used as a branch-office sounder set. If both wedges *a* and *b*, placed together as shown, are inserted in a similar jack and both switch arms *c* and *d* are turned to the left, the two sounders and keys are merely connected in series in the branch-office line and the addition of the 4 ohms in the sounder *S′* in such a circuit will not appreciably reduce the current.

SPLIT LOOPS

30. A method of splitting a loop suitable for use in connection with a baseball, race track, or other branch office is shown in Fig. 12. In the loop at the branch office are two relay or main-line sounder sets, as usually connected. The arm *b* of the switch, which is the only extra device required, is normally in the middle position here shown. The loop is split, that is divided into two independent line circuits with ground returns, by turning the arm *b* of the switch to contact *a*, which is connected to ground. With the arm *b* turned to *c*, the upper relay set is cut out. This shunt arrangement is not always provided and is used merely to allow the removal of the upper set without disturbing the lower set, which may be in use at the time.

At the main office, the line wires run to spring jacks and straps on the main switchboard, by which arrangement the two line wires may be used as a loop or as two single wires.

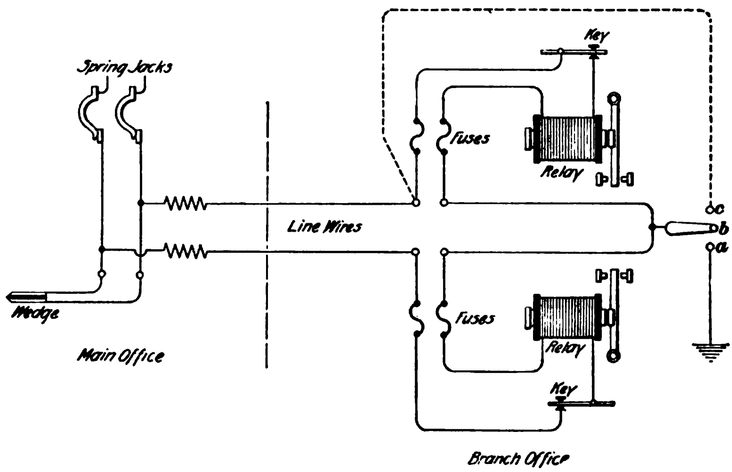


FIG. 12

Across the binding posts on the back of the switchboard is connected a flexible cord terminating in a wedge on the front of the switchboard. By inserting this wedge in the proper jack, the branch-office loop can be connected to any desired line, or the branch-office line wires may be connected by inserting the wedge in the proper loop-switch jack to the local circuit of a duplex set, so that by splitting the loop by turning the switch arm *b* to contact *a*, and using suitably wound instruments and resistances, the two branch-office wires may be worked as the two legs of the duplex.

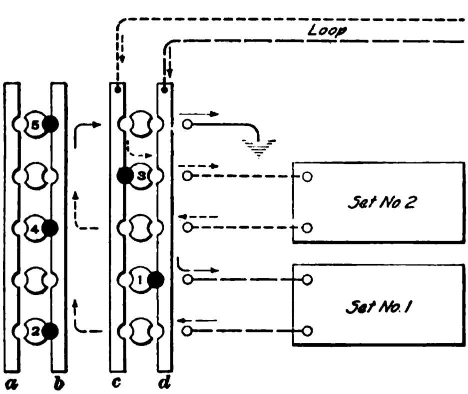


FIG. 13

31. Two other methods of splitting a loop that require no special apparatus are shown in Figs. 13 and 14. In Fig. 13 is shown an arrangement at a branch office where the line wires forming the loop terminate in the vertical straps *c* and *d* of an ordinary switchboard. For this arrangement the switchboard must have at least one pair of spare straps, as *a* and *b*; then by inserting pegs at *1*, *2*, *3*, *4*, and *5*, the loop is grounded between the two relay sets and incoming currents over both legs go to ground as indicated by the arrows.

In Fig. 14, the loop wires are shown terminating in a jack. Ordinarily two relay sets are connected in the loop by inserting wedges *a* and *c* in the jack; to split the loop, it is merely necessary to insert a wedge *b*, which has both sides connected to ground, between wedges *a* and *c*.

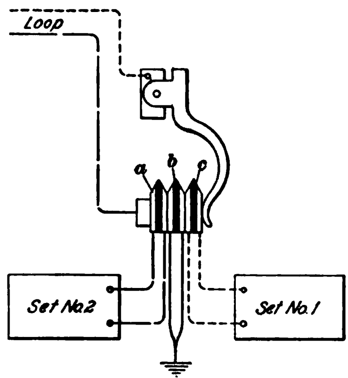


FIG. 14

BRANCH-OFFICE SIGNALING DEVICES AND CIRCUITS

SIGNALING DEVICES

NECESSITY FOR SUCH DEVICES

32. Where wires are rented to brokers or others, it is necessary in order to report any trouble that may occur in their circuits that they shall be able at all times to signal the main office, which is responsible for the condition of the line. *Vibrating bells* or *buzzers* are generally used in connection with these branch-office signaling circuits. The only difference between a vibrating bell and a buzzer is that, in the case of the bell, the vibrating armature of the electromagnet is allowed to tap a gong, whereas in the buzzer it merely vibrates between two stops. The construction and operation of the annunciators that are used in this connection will be clear from the diagrams in which they are shown.

VIBRATING BELL

33. Construction.—The bell used for battery call work is usually of the type known as the **vibrating** or **trembler bell**, one form of which is shown in Fig. 15. The hammer of this bell is arranged so as to vibrate rapidly back and forth and to strike the gong at each vibration, producing a continuous succession of sounds. The essential parts of the bell are two electromagnets D and D' having cores F and F' of soft iron secured to a soft-iron yoke piece Y and a soft-iron armature G mounted by means of a flat spring S secured to a post P, so as to vibrate freely in front of the cores F and F'.

The armature carries a hammer, as shown, adapted to strike the gong a sharp blow when the armature is pulled toward the magnet cores. If the circuit through the magnets passed from one binding post *T* through the coils directly to the other binding post *T′*, closing the circuit containing a suitable battery would cause the hammer to strike the gong a single blow. A succession of blows might be produced by rapidly making and breaking the circuit at the point from which the signal was being sent; but this would be an unsatisfactory method.

34. In order to obtain a rapid and continuous succession of strokes as long as the terminals of the battery are connected to the two binding posts *T* and *T′*, the armature of the bell is so arranged as to make and break the circuit by its own vibration. The circuit between the binding posts of the bell is made as follows: From the binding post *T*, which is insulated from the frame of the bell, a wire leads to one terminal of the coils *D* and *D′*, which are connected together in series. A wire leads from the other terminal of *D′* to the metallic post *N*, which is insulated from the metal framework and provided with a contact screw *M*. While the armature is at rest, a contact spring *X*, carried by the armature, rests against the contact screw *M*, thus carrying the circuit to the armature and the post *P*. This post *P* is connected with the frame of the bell, as is also the post *T′*, so that the circuit from *D* to *T′* is completed through the metal frame itself. When a current is sent through the coils, the armature will be drawn forwards, thus causing the hammer to strike the gong. This movement, however, will break the circuit by causing the spring *X* to move out of contact with the screw *M*. This interrupts the

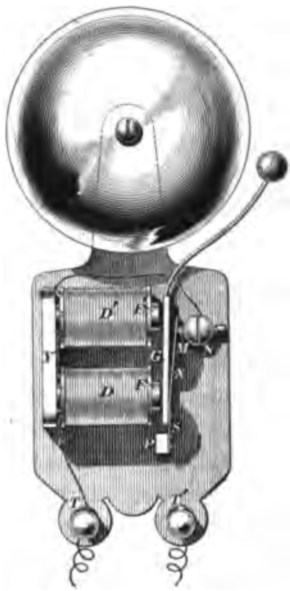


FIG. 15

flow of current through the coils, and therefore allows the armature to spring back, it being no longer attracted by the magnet cores. In doing this, contact is again made between the spring *X* and the screw *M*, thereby completing the circuit and again energizing the magnets, thus producing another stroke of the hammer. This process is repeated as long as the battery circuit remains closed. The spring *X* is provided so that the circuit will not be broken quite as soon as the armature starts to move toward the cores. Its function is to prolong the time during which the circuit is closed, so as to allow the magnets to exert a pull on the armature until the hammer is almost in contact with the bell.

35. Design of Bells.—Vibrating bells are manufactured in almost numberless styles, many of which are of exceedingly poor design, from both mechanical and electrical standpoints. A good battery bell should be so well constructed that none of its parts are likely to work loose because of the rapid and violent vibration of the hammer. The point of the screw *M* and the surface on the spring *X* should be tipped with platinum, in order that the surface of the contacts may keep clean. Platinum will not corrode under ordinary atmospheric conditions, neither is it much affected by the electric spark, which is sometimes very heavy between these contacts. Silver, being cheaper, is frequently used in place of platinum, and is superior to copper, brass, and iron. The screw *M* should be provided with a locknut, or with some other means of locking it securely in any position to which it has been adjusted. If this is not done, the vibration of the armature will cause the screw to gradually work back until finally it reaches a point where the spring *X* will not make contact with it. This locking is sometimes accomplished by splitting the post *N*, so that the screw threads in the two halves exert a combined action on the screw, due to the elasticity of the parts of the post.

36. Prevention of Sticking.—The armature must not come into actual contact with the poles of the electromagnet, as the residual magnetism will cause it to stick and not allow the spring *S* to move it back at once or at all. Therefore, a thin strip of copper should be secured to the surface of the armature that would otherwise come in contact with the poles, or a small pin of brass or copper may be inserted into the ends of the poles in such a manner that it will project slightly beyond the pole surfaces. As either of these methods will prevent actual contact between the iron surfaces, they will eliminate this tendency to stick, which is particularly great where the magnets and armature are not of the best quality of soft-annealed iron, because hard iron retains its residual magnetism with more tenacity. In a first-class bell these parts are made of the softest grade of wrought iron, so as to be readily demagnetized when jarred by the striking of the armature against the cores.

37. Adjustment of Bells.—The adjustment of vibrating bells is a very simple matter, for usually the turning of the screw *M* until it occupies the desired position is all that is required. The best position may be determined by gradually turning this screw, while the circuit is closed, until the hammer vibrates in such a manner as to produce a succession of hard, sharp blows against the gong. If the screw *M* is too far back, the circuit will be opened before the armature has acquired sufficient momentum to carry the hammer to the gong; or it may be so far back as not to allow the circuit to be completed at all. On the other hand, if the screw is too far forwards, the spring *X* will not be pulled away, and the circuit will not be broken; or else the break will occupy such a short space of time that the hammer will not be allowed to recede far enough to strike a proper blow upon the gong. If the adjustment by means of the screw *M* does not produce the desired results, it may be that the armature *G* does not occupy a proper position with respect to the poles of the magnet. When the hammer rests against the gong, the distance between the armature and each of the pole pieces should be approximately the same. This adjustment, as a rule, may be made by bending the spring *S* slightly or by shifting the position of the magnets.

38. Sometimes the surface of the gong against which the hammer strikes does not occupy such a position as to allow the hammer to strike it at the proper moment. If the gong in Fig. 15 is too far to the right, the hammer will strike before the armature has moved far enough toward the pole pieces to allow them to attain the maximum pull. If the gong is too far to the left, then the armature will strike the pole pieces before the hammer strikes the gong; in either case a loss of efficiency will result. This may be remedied by bending the rod on which the hammer is mounted, but in many cases a better way is to turn or move the gong itself on its standard. These gongs are usually somewhat eccentric, due to imperfections in their manufacture, and therefore by turning them the surface against which the hammer strikes may be brought into the correct position.

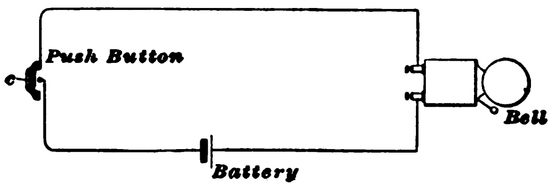


FIG. 16

39. Bell Circuit.—In Fig. 16 is shown a vibrating bell connected in circuit with a battery and push button. By pushing the button, the circuit is closed at *c*, thus allowing the action already described to take place. This circuit is such as would be used for an ordinary push-button call for almost any purpose.

BRANCH-OFFICE SIGNALING CIRCUITS

HURD BRANCH-OFFICE SIGNALING CIRCUIT

40. Loops that are extended to branch offices are usually connected through an annunciator at the main office. These annunciators are all grouped at one board, where they are looked after by an attendant. The method devised by J. B. Hurd is shown in Fig. 17. At the branch office there is a three-point switch *Q* that ordinarily remains in a central position, thus insulating the ground *G*. Ordinarily, the current through the branch-office loop apparatus has not sufficient strength to attract the armature *d* of the main-office annunciator *A*. Thus, the annunciator shutter *e* is ordinarily held up by the hook on the front end of an arm that is rigidly fastened to the armature *d*. However, should the branch-office operator desire to attract the attention of the attendant at the main-office annunciator board, he will turn the arm of the switch *Q* to the contact button *c* so as to ground the low-resistance side of the circuit. This cuts out one wire of the branch-office loop and the branch-office instruments and thus allows enough current to flow from the main battery *MB*,

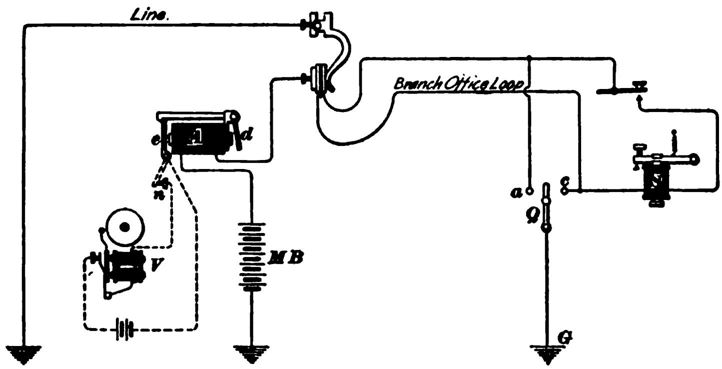


FIG. 17

through the coil of the annunciator *A*, one wire of the loop circuit, and the ground to drop the shutter *e* to the dotted position against the contact stop *n*.

The shutter of the annunciator is usually arranged so that when it falls, a local circuit containing a buzzer or bell and a battery will be closed, thus attracting the attention of the attendant. The switch *Q* is provided with two contact buttons *a* and *c* so that ground can be connected to either side of the circuit. Thus, in case the two sides of the branch-office loop are reversed at the main office, the branch-office operator can still operate the annunciator. Behind shutter *e* is the name of the branch office that is connected to this annunciator whose magnet is usually of low resistance, about 2 or 3 ohms.

BELL IN LINE CIRCUIT

41. An arrangement used by the Postal Telegraph-Cable Company whereby the branch-office operator can ring a bell located at the main office is shown in Fig. 18. The key at the branch office has the circuit closer removed, so the bell at the main office cannot be left ringing. When this branch-office line is not in use, the switch *W* is left turned to the right, thus cutting out the 10-ohm relay and inserting the 10-ohm call

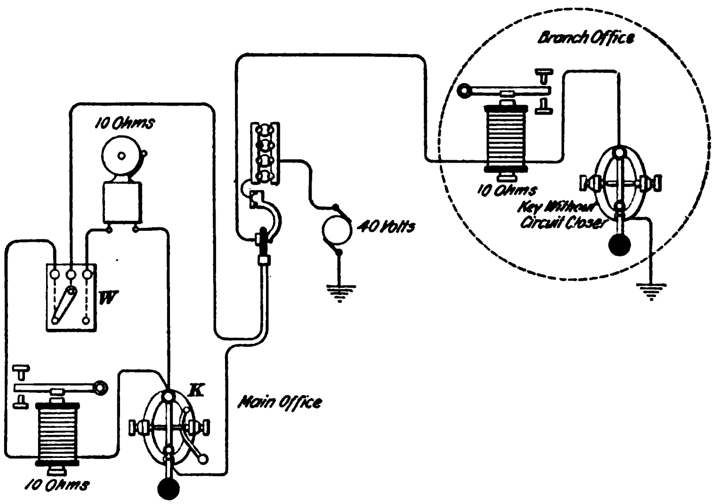
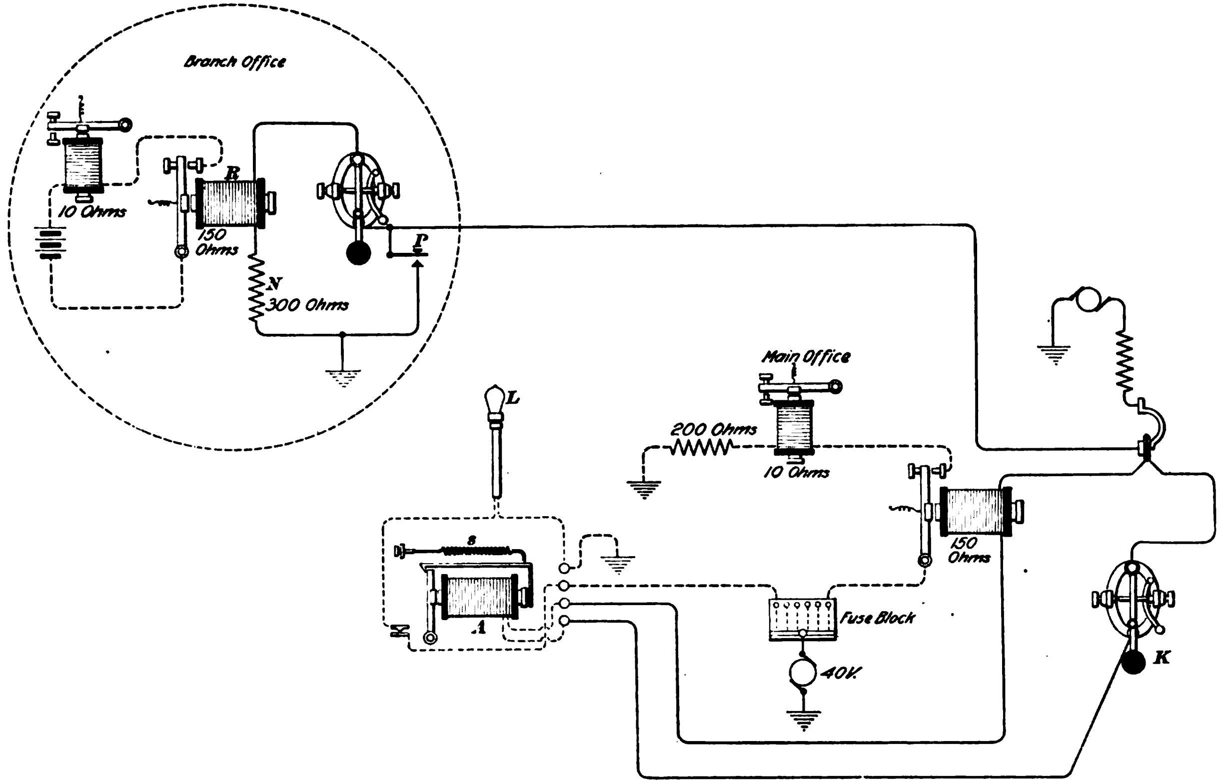


FIG. 18

bell in its place. Closing the branch-office key will then ring the bell; the main-office attendant can reply by shifting the switch to the left and using his key *K* while the branch-office operator holds down his key. The branch-office operator then makes known the connection he desires, the attendant makes the connection, and the call bell apparatus at both offices is cut out.



Branch Office
10 Ohms
R
150 Ohms
N
300 Ohms
P
L
s
A
Main Office
200 Ohms
10 Ohms
150 Ohms
Fuse Block
40V.
K

FIG. 19

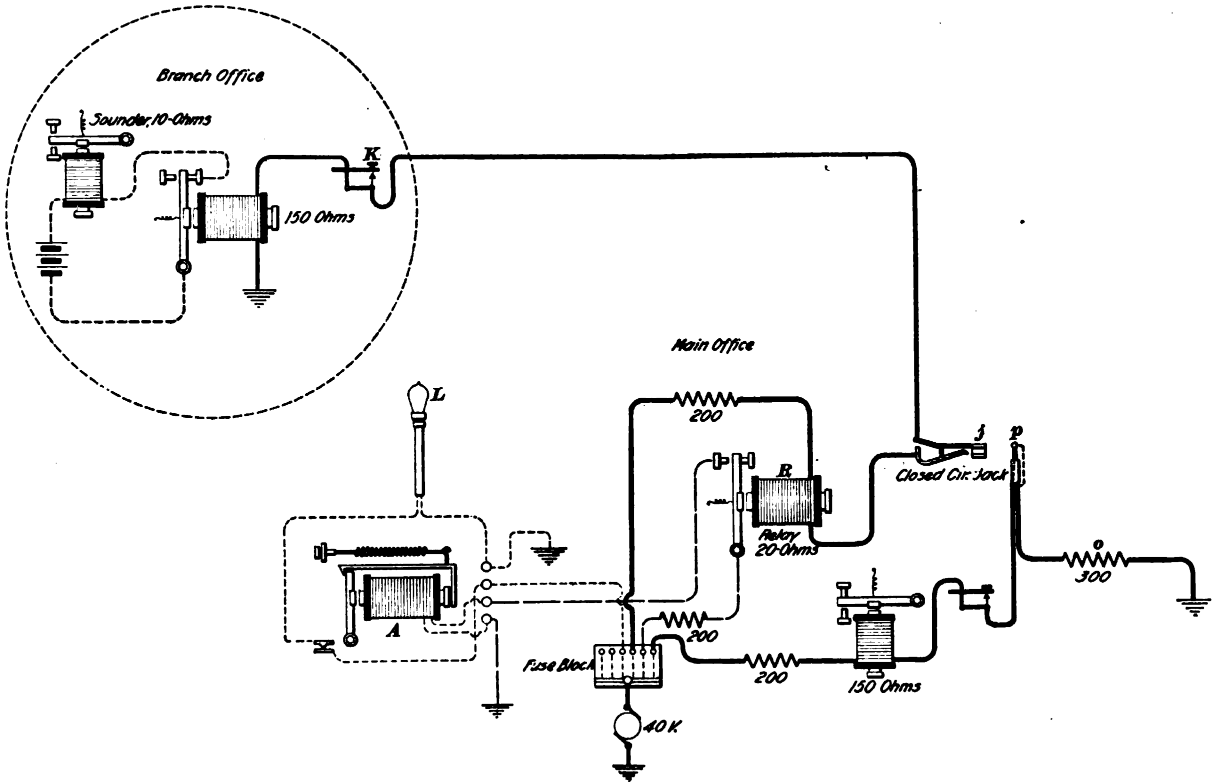

Branch Office
Sounder, 10-Ohms
150 Ohms
K
Main Office
L
200
R
Relay 20-Ohms
j
p
Closed Cir. Jack
o
300
A
200
200
150 Ohms
Fuse Block
40 K

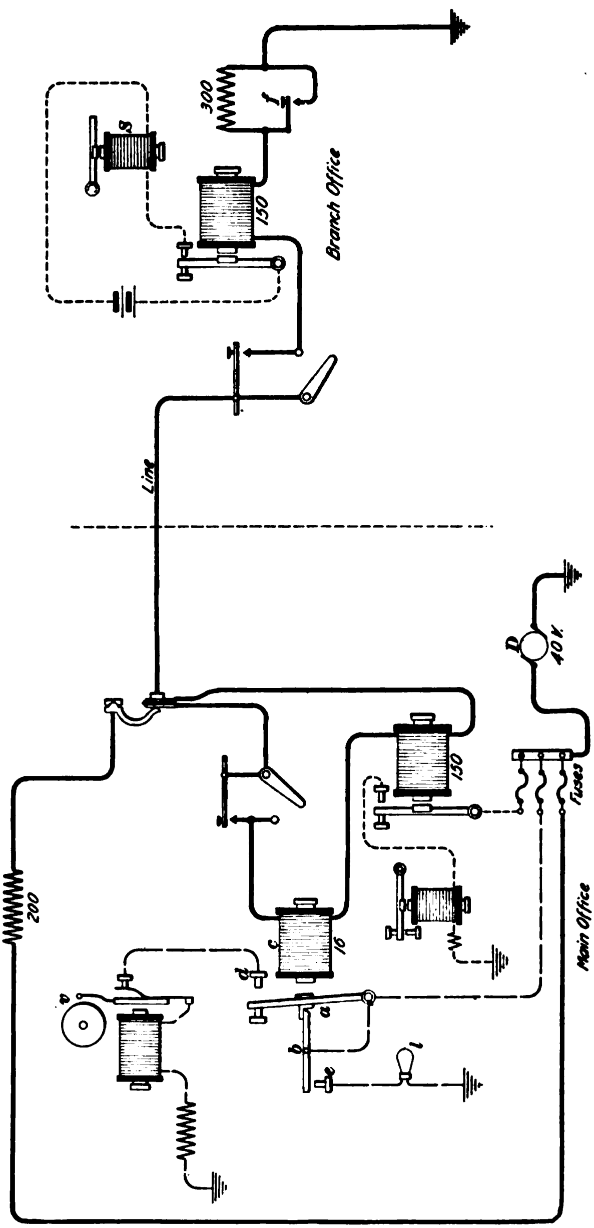
Fig. 20

ANNUNCIATOR IN LINE CIRCUITS

42. In order that a branch-office operator may call up the main office at any time by lighting a lamp, the arrangement shown in Fig. 19 is used by the Postal Telegraph-Cable Company. The apparatus required for this purpose is an annunciator *A* and an 8-candlepower, 40-volt lamp *L* at the main office and a push button *P* and resistance *N* at the branch office. The tension of the spring *s* is such that the annunciator cannot attract its armature when the normal line current is passing through it. But as pressing the push button *P* at the branch office short-circuits the 150-ohm relay *R* and the 300-ohm resistance coil *N*, the line current is increased sufficient to overcome the action of the spring *s* and the annunciator attracts its armature. The attraction of the armature allows the shutter of the annunciator to fall, thereby closing the circuit of the lamp *L* and causing it to light and stay lit until the attending operator restores the annunciator shutter. This signal lamp *L* is usually mounted directly above the annunciator. The office attendant uses the key *K* when replying to the call.

ANNUNCIATOR IN LOCAL CIRCUIT

43. In Fig. 20 is shown an arrangement of branch-office signaling circuits somewhat similar to the one already described. This method is employed by the Postal Telegraph-Cable Company on short wires from a main office to branch offices where the service is such that an operator is not assigned to the circuit continuously, although the arrangement may be applied to any similar circuit. The lamp annunciator *A*, which is controlled by a back-contact relay *R*, is mounted on the operating table at the main office. When the line is opened at the branch-office key *K*, the armature of the relay *R* falls back, thereby causing the annunciator shutter to drop and the 8-candlepower, 40-volt lamp *L* to light and remain lighted until the shutter is restored. When the main-office operator answers the call, he inserts a plug *p* in the jack *j*, thereby connecting in the line circuit a key, a 150-ohm sounder, or relay and sounder,



300
f
S
150
Branch Office
Line
D
40 V.
150
Fuses
Main Office
200
c
16
d
a
b
e
l
v

FIG. 21

and a 200-ohm resistance. At the same time, he disconnects the annunciator relay *R* from the line and connects it, through a 300-ohm resistance *o* to ground. This causes the annunciator relay *R* to attract its armature, so that when the operator restores the annunciator shutter, it will remain restored and the lamp will be extinguished. When the operator removes the plug *p* from the jack *j* after receiving the message, the annunciator relay *R* is again connected in the line circuit. Often several such annunciators and their signal lamps are mounted on one table where one or more operators attend to the calls.

HANCOCK-CARROLL BRANCH-OFFICE SIGNALING CIRCUIT

44. The **Hancock-Carroll branch-office signaling circuit** is very similar to the arrangement just described, except that the branch-office operator rings a bell in addition to lighting a lamp. The bell rings, however, only as long as the branch-office push button is closed but the lamp remains lighted until the call is attended to. In Fig. 21 is shown the arrangement of this circuit which is intended only for short single lines to local branch offices. Its special feature is the low-wound (16-ohm) Carroll relay *c* that is connected in the main-office loop. This relay has not a sufficient number of ampere-turns to cause it to be operated by the normal line currents. But pressing the push button *f* at the branch office short-circuits the 300-ohm resistance coil and allows enough increase in the line current to make the relay *c* pull its armature *a* against the stop *d*. This closes the circuit and rings the bell *v*; at the same time the lever *b* is allowed to fall against the stop *e*, thus closing the circuit and causing the lamp *l* to light.

When the branch-office operator releases the push button *f*, the armature *a* leaves stop *d*, thereby breaking the circuit and discontinuing the ringing of the bell. But the projection of the armature falls against the end of the lever *b* and prevents the light being extinguished. The main-office operator restores the circuit to its normal condition by raising the front end of the lever *b*, which puts out the light and allows the armature to hold the lever *b* in the position shown.

BROKERS' CALL CIRCUIT

45. In Fig. 22 is shown a **broker's call circuit** as described in the Telegraph Age by W. H. Jones. When a broker wants to use the circuit, the main line is momentarily grounded at the broker's office, thereby allowing a sufficient increase in the current to cause the line coil on the relay *R* to pull up its armature in spite of the rather stiff tension spring with which it is provided. This lower-resistance branch-office ground

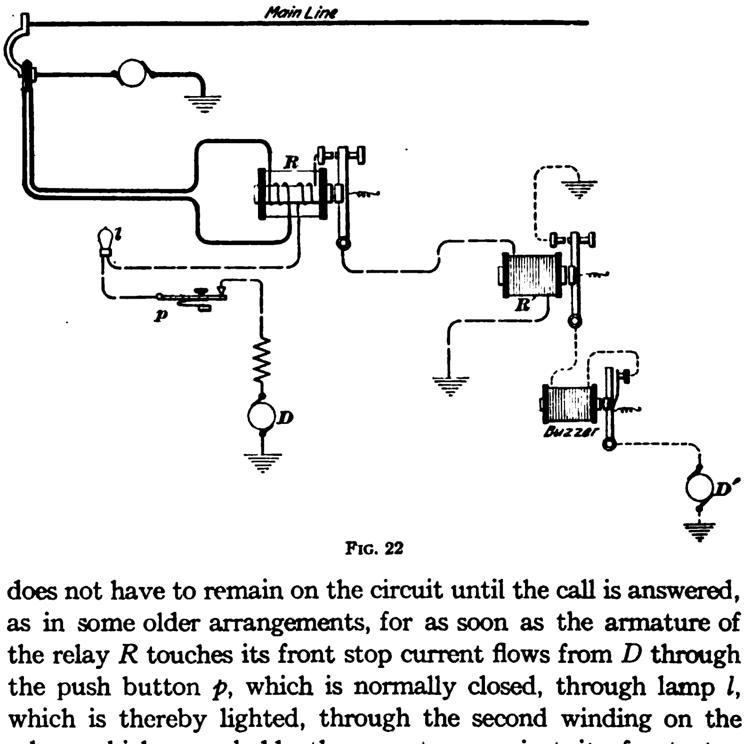


Fig. 22

does not have to remain on the circuit until the call is answered, as in some older arrangements, for as soon as the armature of the relay *R* touches its front stop current flows from *D* through the push button *p*, which is normally closed, through lamp *l*, which is thereby lighted, through the second winding on the relay, which now holds the armature against its front stop even if the current in the line coil is reduced to zero, and through the small relay *R'*, which in turn closes the circuit for a buzzer.

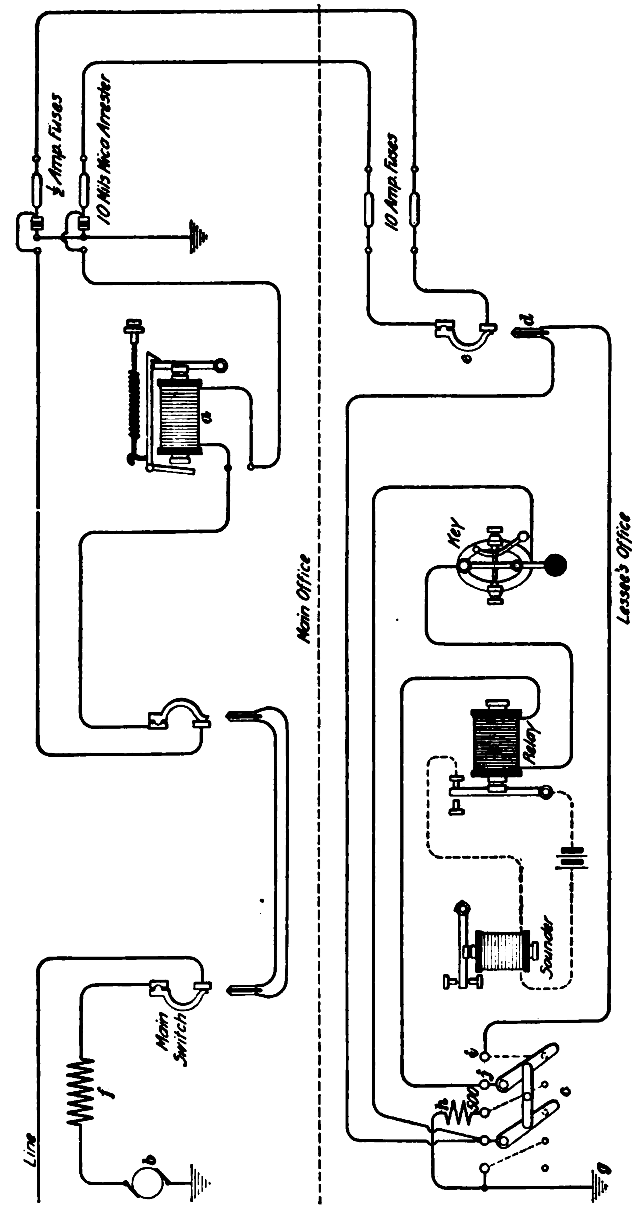
46. The wire chief, upon hearing the buzzer, looks for an illuminated red lamp *l*, which projects through the face of his switchboard immediately below the broker's spring jack, and presses the push button *p* associated with that broker's circuit. This puts out the lamp and restores all relays to normal condition. The wire chief immediately attends to the call, thereby saving time and dispensing with the services of watchers and office messengers. The two small cylinder-shaped relays and buzzer for each circuit, require but little room and are usually grouped together in a convenient place behind the main-wire switchboard. The long, slim, red lamp *l* may be quickly removed and placed underneath any other main-line spring jack in case the original wire is to be changed, as in making patches.

As is often done, the broker could signal a wire chief by grounding the conductor and thus lighting the regular resistance lamp on the switchboard, but this is unsatisfactory because to keep the lamp lighted, he must allow his ground to remain on the circuit, which is bad for both the instruments and the conductor.

ANNUNCIATOR AND LEASED-LINE CONNECTIONS

47. Straight-Wound Annunciator.—In Fig. 23 are shown the connections of an annunciator having a single winding, and hence called a **straight-wound annunciator,** and the wiring of leased lines in the Postal-Telegraph Cable Company's main and lessee's offices. The upper portion of the figure shows the wiring in the main office, including the annunciator, switches, lightning arrester, and fuses. The lower portion of the figure shows the wiring in the lessee's office, including the fuses, switch, instruments, and the *five-point switch c*, so called because it has five binding posts.

With the wedges in the jacks and the switch *c* thrown to the right, as shown, the lessee's key and relay are connected in series with the two line wires, one of which is connected to the dynamo *b* and the other to the main-line wire. Thus, the main office supplies the main-line current, which is not ordinarily strong enough to operate the annunciator *a*. By throwing the switch *c* part way to the left, the line wire that passes through the annunciator *a*, resistance *f*, and dynamo *b* to ground at the



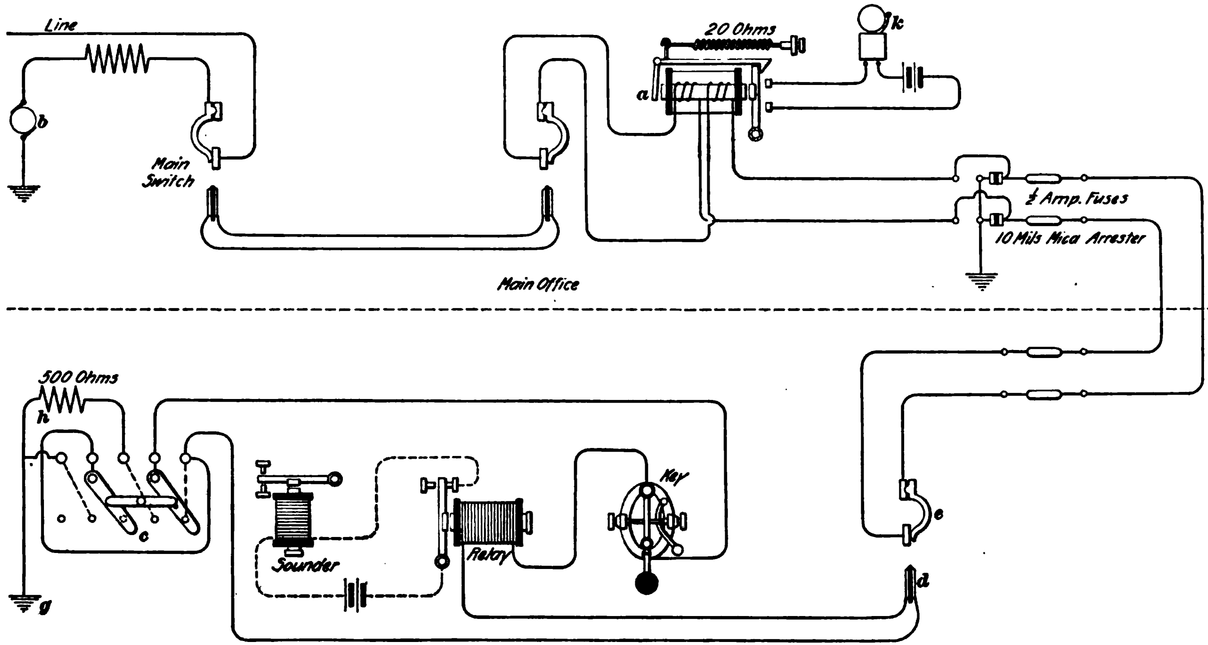
Line
Main Switch
¼ Amp. Fuses
10 Mils Mica Arrester
Main Office
10 Amp. Fuses
Key
Relay
Sounder
Lessee's Office

FIG. 23

main office is directly grounded in the lessee's office at *g* through the left-hand arm of switch *c*, thereby short-circuiting the lessee's office relay, key, and the 500-ohm resistance coil *h*. Thus, the current is increased enough to operate the annunciator *a*. To put the ground *g* on the other side of the loop, in case the line wires are reversed at any point, it is merely necessary to reverse the position of the wedge *d* in the jack *e*.

When the switch *c* is thrown all the way to the left current from the dynamo *b* passes through *f* – *a* – *e* – binding post on switch *c* – key–relay – *j* – right-hand arm of switch *c*–resistance *h* – ground *g*. On this switch *c* there is between the lower right-hand buttons an idle button, which is not here shown, and on which the right-hand arm rests in its intermediate position. Where a call is not required, the switch *c* and resistance *h* are omitted; the wire coming to post *i* is then connected to the wire coming to post *j*.

48. Differentially Wound Annunciator.—In Fig. 24 is shown the wiring of a leased line in a Postal Telegraph-Cable Company's main and lessee's offices when a differentially wound annunciator *a* is used to ring a bell *k*. With the wedges in the jacks and the switch *c* thrown to the right, as shown, the lessee's office key and relay are connected across the two line wires, that is, in a loop formed by the two line wires. The line current then circulates in the two windings on the annunciator *a* in opposite directions around its iron core. Hence, the annunciator is not operated and furthermore the same amount of resistance is inserted in each leg of the loop. When the switch *c* is thrown to the next contact buttons on the left, one side of the loop is directly grounded, while the other side contains the relay and 500-ohm resistance *h*. Thus, the annunciator is unbalanced, that is, one coil receives enough more current than the other coil to operate the annunciator and ring the bell *k*. To put the ground *g* directly on the other side of the loop, the wedge *d* is reversed in the jack *e*.



Lessee's Office

Fig. 24

DUPLEX CALL CIRCUIT

49. An arrangement for calling on a duplex circuit is shown in Fig. 25. An extra neutral relay *NR* and vibrating bell *V* are connected to the circuits, as shown at the west station. The connections will be the same at both stations, but only enough to explain the operation are shown. The spring *s* of the neutral relay is so adjusted that the armature will be held against the front stop *c* as long as the battery or dynamo at

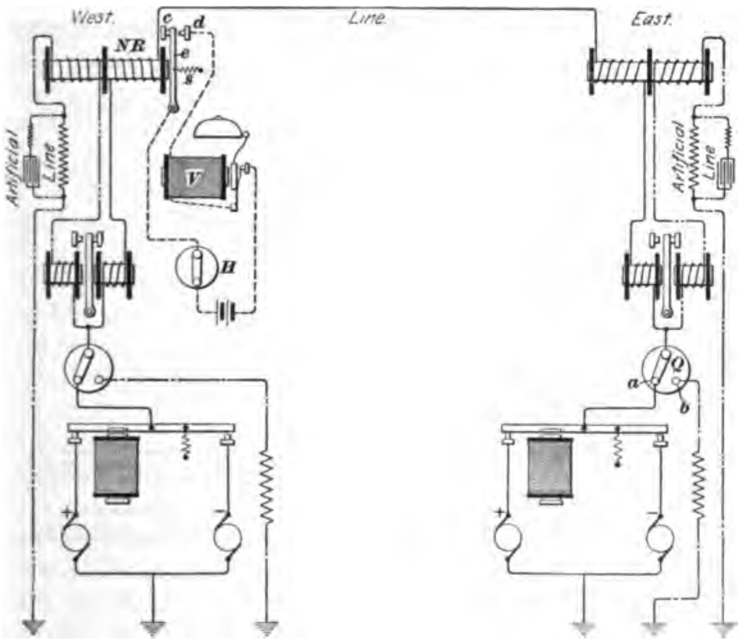


FIG. 25

the distant east station is connected to the line. This is the case while the arm of the switch *Q* remains in contact with the button *a*. If the main battery or dynamo at the distant east station is disconnected and the circuit grounded by turning the arm of the switch *Q* to contact button *b*, the current from the west main battery or dynamo will divide equally through the two differential coils of the extra neutral relay.

The magnetizing effect of one coil will be neutralized by the other and, consequently, the armature *e* will fall against the back stop *d* and cause the vibrating bell *V* to ring as long as the eastern operator allows the arm of the switch *Q* to remain in contact with *b* or until the western operator opens the local bell circuit by means of the switch *H*.

QUADRUPLEX CALL CIRCUIT

50. Where the local sending and receiving circuits on the second side of a quadruplex set are extended to a branch office, the arrangement shown in Fig. 26 is used by the Postal Tele-

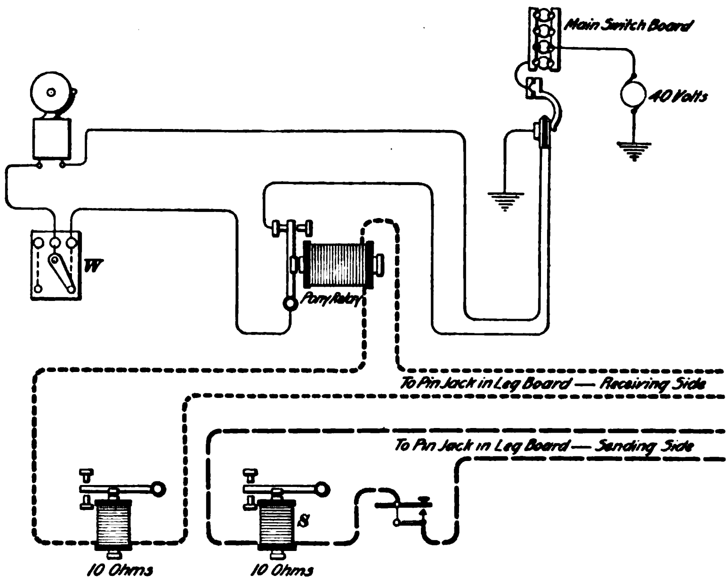


FIG. 26

graph-Cable Company. The sending and receiving sides pass through pin jacks on a leg, or loop, switchboard to the branch office where both circuits are normally closed through sounders and keys. The bell is connected through the switch *W* – back stop of pony relay – wedge – jack – main switchboard to a 40-volt dynamo. Hence, the bell circuit is normally open at the pony-relay contacts because the pony relay is normally in a closed circuit. Opening this receiving circuit at the branch office, causes the pony relay to release its armature and close the bell circuit. The branch office communicates with the main office over the sending side and the main-office attendant makes the connections desired by the branch-office operator.

SIGNALING ON MULTIPLEX CIRCUITS

51. Duplex and Quadruplex Signal Circuit.—The best practice in the operation of multipex-telegraph circuits, according to the Journal of the Telegraph, from which Figs. 27 and 28 and their explanations are abstracted, is to locate the multiplex sets for each city in a selected portion of the main office where they may be most efficiently cared for by attendants who are specialists in this work. The local loops or legs may then be extended to the operating tables, which are equipped with simple Morse apparatus consisting of keys and sounders. Such operating tables may be located in the operating room of the main office, or at a branch office or telegraph subscriber's station in the same city. When any kind of trouble develops on the circuit, the attention of the quadruplex or duplex attendant must be promptly called to it, in order that he may remedy the difficulty by readjustment of the apparatus, or by substituting a good wire for a faulty one. To supersede some present indirect methods of securing attention at such times the signaling systems shown in Figs. 27 and 28 have been devised. They allow an operator who notices trouble on his circuit to immediately notify the multiplex attendant by pressing a push button or switch. This lights the signal lamp l or l_1, as the case may be, at the multiplex set, whether the key f or f_1 at the operating table is open or closed. If the circuit is still workable, the operators may continue to use it, as the signal lamp will not be extinguished until the attendant answers at the multiplex set by opening his key. The closing of the key puts the circuit in condition to respond to another call.

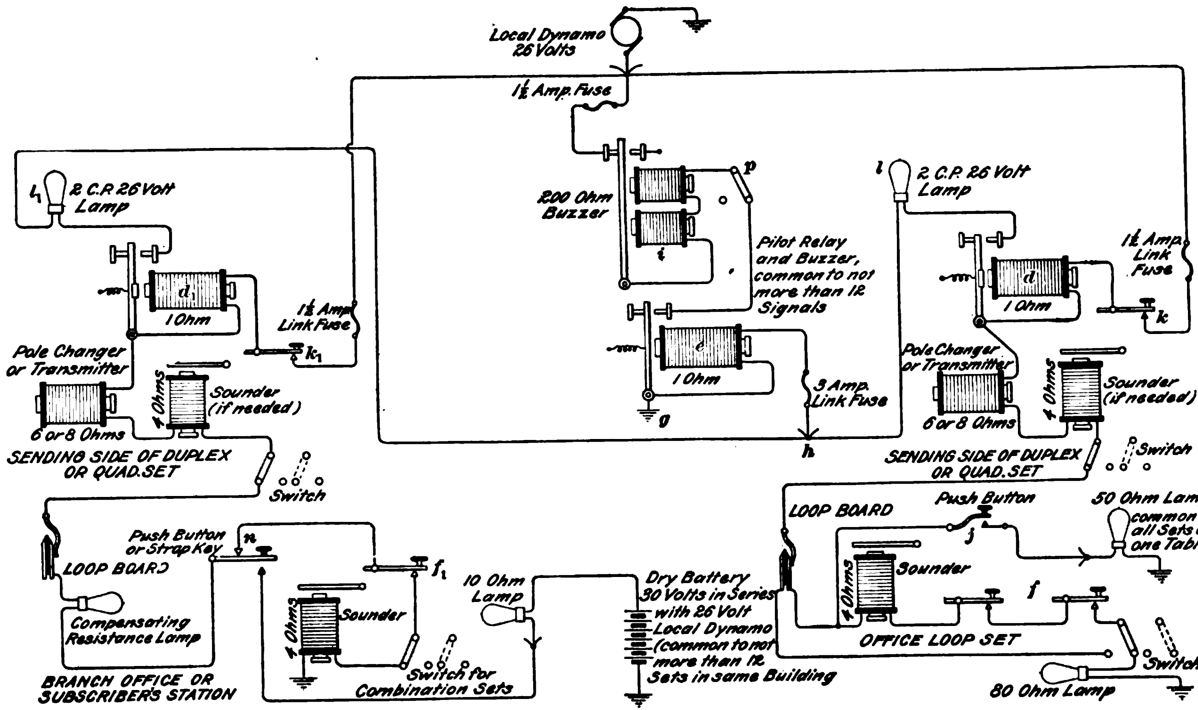

Local Dynamo 26 Volts
1½ Amp. Fuse
200 Ohm Buzzer
Pilot Relay and Buzzer, common to not more than 12 Signals
3 Amp. Link Fuse
1 Ohm
2 C.P. 26 Volt Lamp
1½ Amp. Link Fuse
Pole Changer or Transmitter
6 or 8 Ohms
4 Ohms
Sounder (if needed)
SENDING SIDE OF DUPLEX OR QUAD. SET
Switch
Push Button or Strap Key
LOOP BOARD
Compensating Resistance Lamp
BRANCH OFFICE OR SUBSCRIBER'S STATION
Sounder
Switch for Combination Sets
10 Ohm Lamp
Dry Battery 30 Volts in Series with 26 Volt Local Dynamo (common to not more than 12 Sets in same Building
Push Button
50 Ohm Lamp common to all Sets on one Table
OFFICE LOOP SET
80 Ohm Lamp

FIG. 27

WESTERN UNION DUPLEX AND QUADRUPLEX SIGNAL CIRCUITS

52. In Fig. 27 is shown the signaling circuit for calling quadruplex and duplex attendants. This signaling system depends for its operation on small 1-ohm iron-clad relays d, d_1, and e. For ordinary cases where loops or legs are connected directly to duplex or half-quadruplex sets, one of these relays is connected, as shown, in the sending side at the set. This relay is not affected by the regular working current of about 250 milliamperes, but operates when the current is increased to 350 milliamperes or more. Such an increase of current occurs whenever the signaling push button is depressed at the operating table. This is accomplished in the case of an office loop by having the push button j ground the circuit through the 50-ohm lamp instead of through the regular working path containing the 4-ohm sounder and 80-ohm lamp. At a branch office or telegraph subscriber's station, a three-point push button n is used to cut in the branch circuit a dry battery of suitable voltage and polarity that will increase the current enough to cause the 1-ohm iron-clad relay d_1 to attract its armature and thereby close the circuit containing the signal lamp l_1. The 26-volt dynamo is then in series with relay d_1, pole changer, sounder, compensating resistance lamp, 10-ohm lamp and the dry battery.

53. In each case, the 1-ohm relay, by attracting its armature, locks itself in the closed position due to the 300 milliamperes that can now flow from the 26-volt local dynamo through the key k - relay d - armature - lamp l - relay e - ground. In a similar manner the relay d_1 is closed and locked. Therefore, a single depression of the push button j or n at the operating table will cause the signal lamp to light and to remain lighted, whether the sending circuit is being used or remains opened or closed. To extinguish the lamp l or l_1, the attendant simply answers in the usual way by first opening the key k or k_1, as the case may be, thereby cutting off all current from the sending side, including the signal relay d or d_1, and consequently causing the lamp l or l_1 to go out.

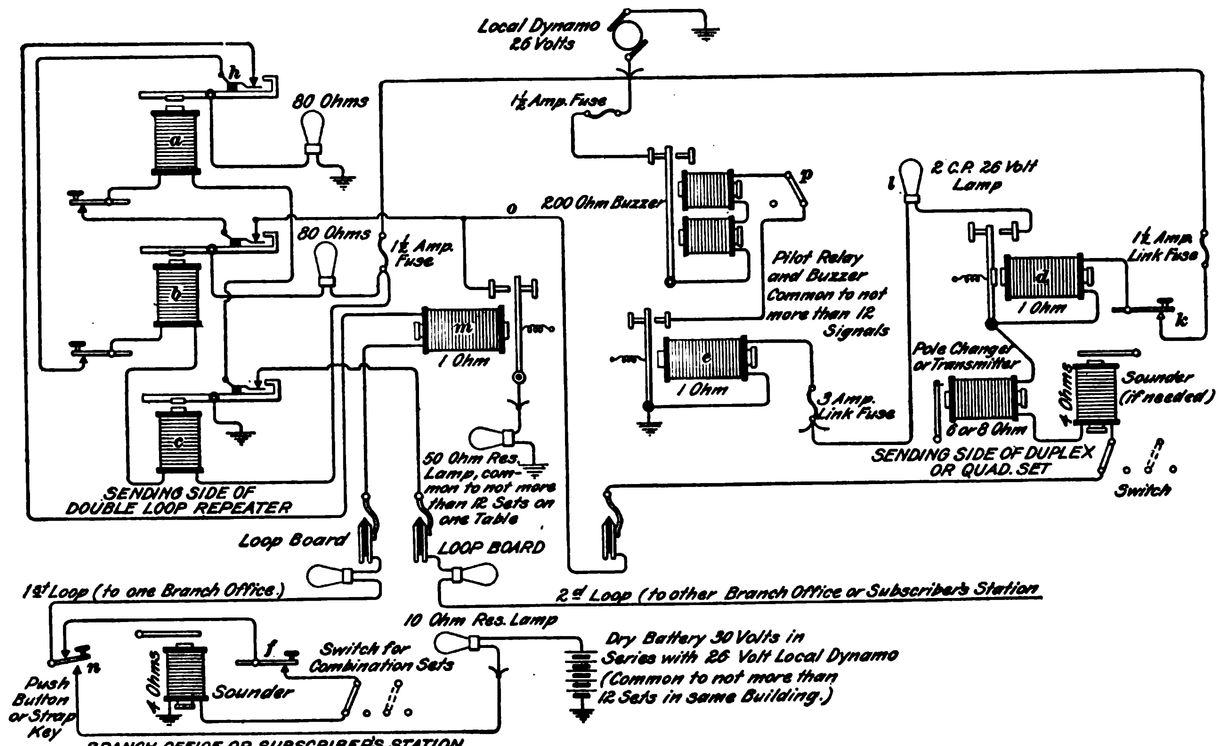

Local Dynamo 26 Volts
1½ Amp. Fuse
80 Ohms
80 Ohms
1½ Amp. Fuse
o
200 Ohm Buzzer
p
Pilot Relay and Buzzer Common to not more than 12 Signals
l
2 C.P. 26 Volt Lamp
1½ Amp. Link Fuse
k
1 Ohm
Pole Changer or Transmitter
6 or 8 Ohm
4 Ohms
Sounder (if needed)
Switch
SENDING SIDE OF DUPLEX OR QUAD. SET
3 Amp. Link Fuse
1 Ohm
1 Ohm
50 Ohm Res. Lamp, common to not more than 12 Sets on one Table
SENDING SIDE OF DOUBLE LOOP REPEATER
Loop Board
LOOP BOARD
1st Loop (to one Branch Office.)
2d Loop (to other Branch Office or Subscriber's Station
10 Ohm Res. Lamp
Dry Battery 30 Volts in Series with 26 Volt Local Dynamo (Common to not more than 12 Sets in same Building.)
f
Switch for Combination Sets
4 Ohms
Sounder
n
Push Button or Strap Key
BRANCH OFFICE OR SUBSCRIBER'S STATION

FIG. 28

54. Pilot Relay.—In order that the attention required at a multiplex set may be promptly made known, even if the attendants fail to notice the lighting of a signal lamp, a pilot relay *e* of the same type as relays *d* and d_1 is inserted between the ground *g* and the point *h*, to which not over twelve similar circuits may be connected. The closing of relay *e*, due to trouble on any one or more of twelve circuits, will cause the 200-ohm buzzer *i* to hum and by looking for the lighted signal lamp or lamps, the attendants can readily locate the circuit or cirtuits requiring their attention. A switch *p* is provided so that the buzzer may be cut out when the number of attendants is sufficient to insure attention when a signal lamp lights.

DOUBLE-LOOP REPEATER SIGNAL CIRCUIT

55. In Fig. 28 is shown the arrangement of the signaling circuit when a double-loop repeater is used to connect the sending and receiving legs to the duplex or quadruplex sets. A 1-ohm iron-clad relay *m* is located on the table with the double-loop repeater. The function of this relay is merely to repeat into the sending circuit of the multiplex set, the signals made by depressing the push button *n* located in the sending leg with which connection is made through the double-loop repeater. This relay *m* is not affected by the current ordinarily passing through it and the first loop, but when the push *n* is depressed the current is sufficiently increased to close relay *m*, thereby reducing the resistance from *o* through contacts of relay *m* to ground enough to close the 1-ohm iron-clad relay *d*, which locks itself, thereby holding closed the circuit of lamp *l* and the 1-ohm iron-clad relay *e*, which in turn closes the 200-ohm buzzer circuit if the switch *p* is closed.

As previously explained, the multiplex attendant puts out the lamp *l* and stops the buzzer by answering with his key *k*, and is not required to go to the double-loop repeater, because the signaling relay *m* at that set restores itself when the push button *n* is released. The operation of this double-loop repeater containing the three transmitters *a*, *b*, and *c* has been explained elsewhere.

TESTING OF CIRCUITS
(PART 1)

MEASUREMENTS OF RESISTANCE, INSULATION, AND CAPACITY

RESISTANCE MEASUREMENTS

WHEATSTONE BRIDGE

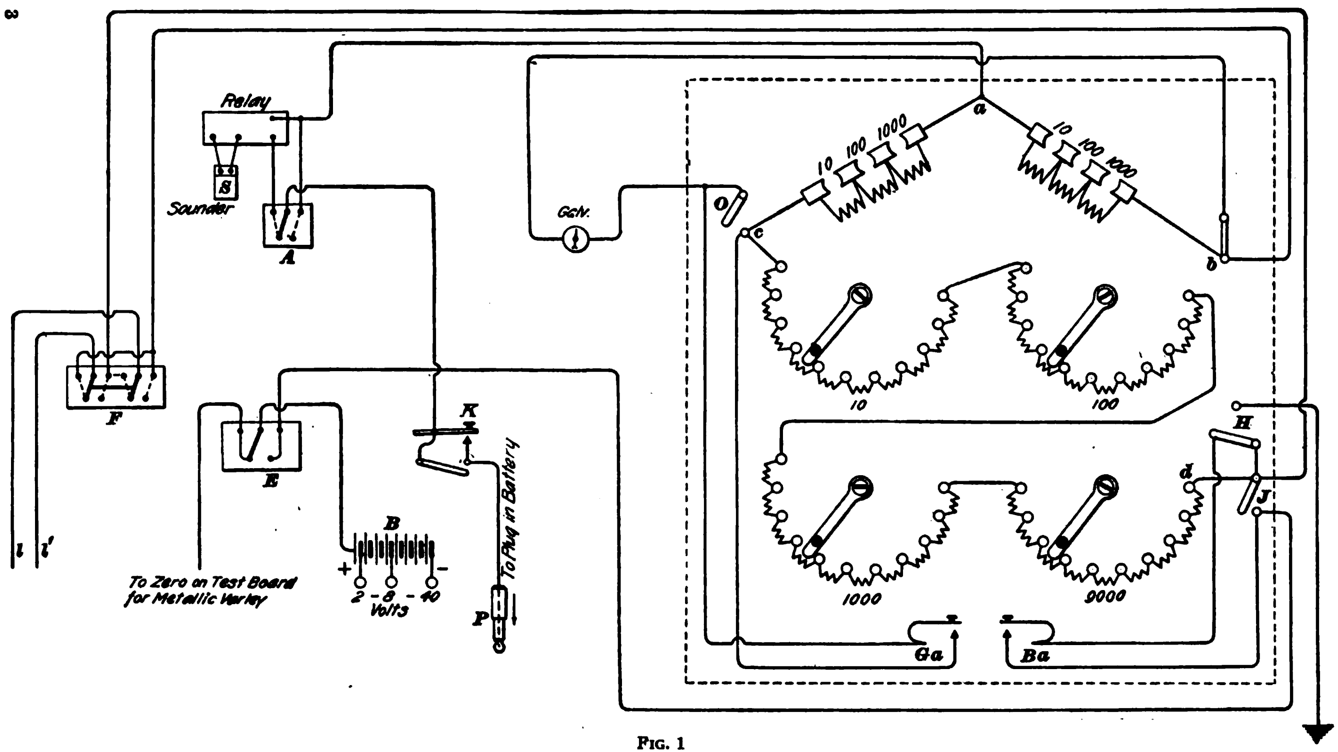
1. The testing of circuits, line wires, and apparatus is an important matter in all branches of electrical work. The methods described in *Electrical Measurements* are, as a rule, directly applicable to general testing, but directions that apply especially to line and cable testing will be given here.

Measurements of resistance are usually made by means of the **Wheatstone bridge,** which is very accurate for all resistances except those that are very large or very small; it is also very simple and portable. The methods of using the Wheatstone bridge have been given in *Electrical Measurements.* However, it may be said that the form of bridge best adapted for general testing purposes has a rheostat capable of being adjusted to any resistance from 1 ohm to about 11,000 ohms. The arms by which the ratio is obtained should be capable of having the values of 10, 100, and 1,000 ohms, so that it will be possible to obtain multipliers from $\frac{1}{100}$ to 100.

2. Some form of D'Arsonval galvanometer is best suited for ordinary resistance measurements; it is preferably mounted in the same case as the resistance coils of the bridge and with the keys for opening and closing the galvanometer and battery circuits. In some portable bridges, a battery is mounted in the same case with the other parts of the apparatus, thus adding greatly to the ease with which rapid tests may be made, inasmuch as it is not necessary to carry extra batteries and connect them up every time a test is to be made.

BRIDGE-TESTING SETS

3. A. T. and T. Co.'s Bridge Set.—In Fig. 1 is shown a testing set including a Wheatstone bridge, galvanometer, and various keys used by the American Telephone and Telegraph Company. The arms *a b* and *a c* are the ratio arms and *c d* is the rheostat, or balance arm. This last consists of four rotating arms; the first one controls the use of ten 1-ohm coils, the second one controls ten 10-ohm coils, the third one controls ten 100-ohm coils, and the fourth one controls nine 1,000-ohm coils. These arms are said to give fully as low resistance contacts as plugs, and they are more convenient. By means of a switch *J* the battery key *B a* may be short-circuited, that is, permanently closed. By a similar switch *O* the galvanometer key *G a* may be short-circuited. By means of a switch *H* the point *d* may be connected to ground. By the switch *A* the telegraph relay may be short-circuited and thus cut out of the battery circuit. The battery circuit may be opened or closed by a telegraph key *K*. By the switch *E*, the positive terminal of the battery may be connected to the point *J* when the arm is turned to the right; when the arm is turned to the left, the positive terminal of the battery is connected to a so-called zero contact on the test board. The latter contact may be grounded. A switch *F* permits the connections between the two line wires *l* and *l'* and points *b* and *d* to be reversed. By means of the plug *P* and three suitable jacks connected to three points along the battery, 2, 8, or 40 volts may be obtained for testing.



Relay
S
Sounder
A
F
E
K
B
+
-
2 - 8 - 40
Volts
To Plug in Battery
P
l
l'
To Zero on Test Board
for Metallic Varley
Galv.
O
a
b
c
d
10
100
1000
10
100
1000
10
100
1000
9000
H
J
Ga
Ba

FIG. 1

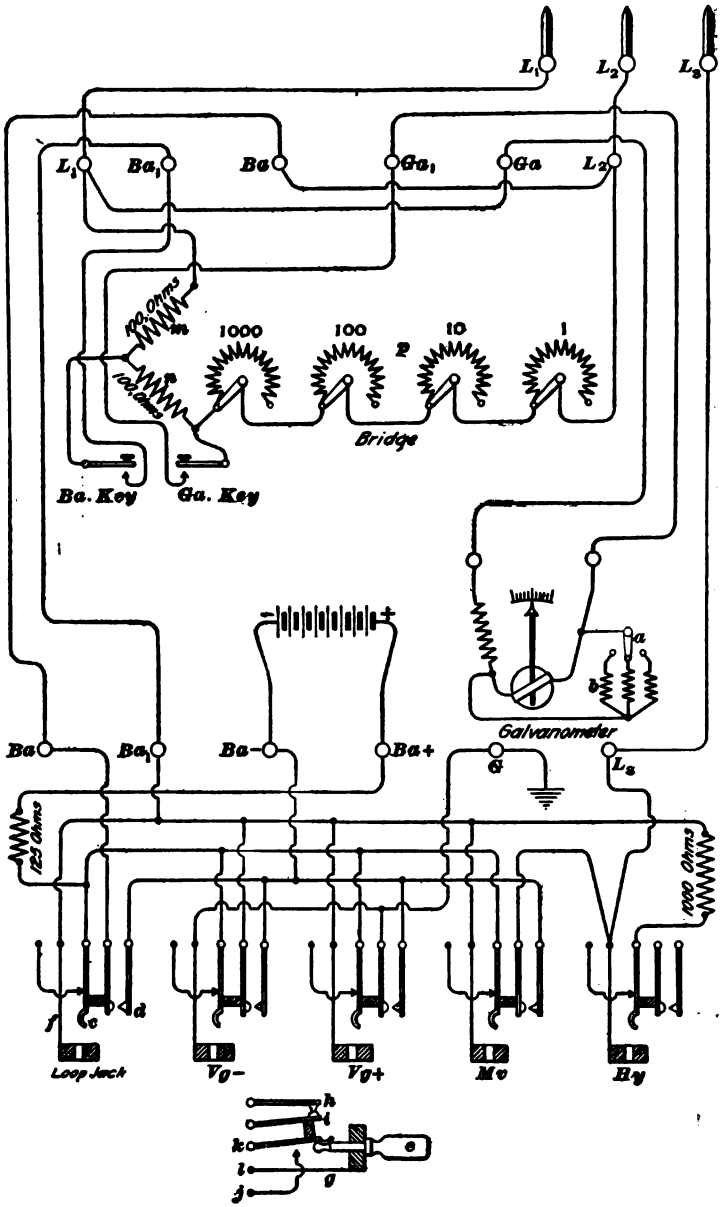

L1
L2
L3
Ba1
Ba
Ga1
Ga
100 Ohms
m
n
1000
100
10
1
P
Bridge
Ba. Key
Ga. Key
a
b
Galvanometer
Ba
Ba-
Ba+
G
125 Ohms
1000 Ohms
f
c
d
Loop Jack
Vg-
Vg+
Mv
Hy
h
i
k
l
j
g
e

FIG. 2

4. Western Union Bridge Set.—In Fig. 2 is shown an arrangement of Wheatstone bridge, galvanometer, battery, jack-box, and switchboard cords intended for the use of Western Union switchboard attendants, or wire chiefs, in making tests of overhead lines. A special form of Wheatstone bridge, termed a *Varley bridge*—probably because it can be so conveniently used for making Varley-loop tests—is employed. Each balance arm m and n consists of a single 100-ohm unadjustable resistance and the rheostat arm p consists of four sets of resistances with sliding arms to adjust their values. The reading opposite any position of any arm gives the resistance in that set. The galvanometer has three shunt resistances b, any one of which may be used to vary its sensitiveness by means of the switch a.

5. The jack-box, shown in the lower part of the figure, contains five jacks, a 125-ohm resistance, which is connected in series with the battery of twenty dry cells to prevent the flow of an excessive current, and a 1,000-ohm resistance to be used in certain tests. The switchboard wedges L_1 and L_2 are connected with the bridge and the wedge L_3 with the jack-box by means of 6-foot flexible single-conductor cords. The positive terminal $Ba+$ of the battery is connected through 125 ohms to each c spring of each jack and the negative terminal $Ba-$ to each d spring, except at jack Hy. At g is shown one of the jacks with a metal peg e, called a *connecting plug*, inserted in it, thereby disconnecting spring k from spring j, but connecting k through the metal of the peg with the terminal l and also connecting together springs i and h.

6. By inserting a connecting plug in the first jack, called a *loop jack*, the positive terminal $Ba+$ of the battery is connected to the terminal Ba_1 on the bridge and the negative terminal $Ba-$ to the terminal Ba on the bridge.

By inserting a connecting plug in jack $Vg-$, the negative terminal $Ba-$ of the battery is connected to the terminal Ba_1 on the bridge and the positive terminal $Ba+$ is grounded. Similarly, by inserting a plug in jack $Vg+$, the positive battery terminal $Ba+$ is connected to the terminal Ba_1 and the negative terminal is grounded.

By inserting a plug in jack Mv, the positive battery terminal is connected to Ba_1 and the negative battery terminal to wedge L_2.

By inserting a plug in jack Hy, the terminal Ba_1 is connected through the 1,000-ohm resistance and jack Hy to wedge L_2.

This bridge can be used for many of the tests to be described later and some of the formulas given may be simplified by remembering that for this bridge $m=n=100$. To measure the resistance of a circuit, the wedges L_1 and L_2 will be inserted in jacks to which the circuit is connected and a connecting plug will be inserted in the loop jack.

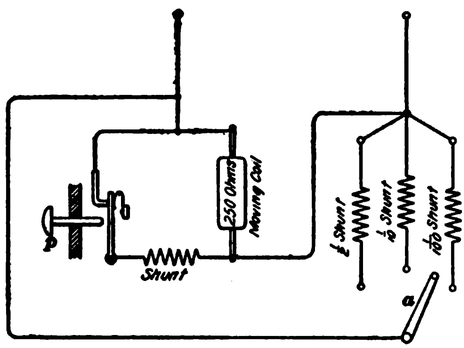
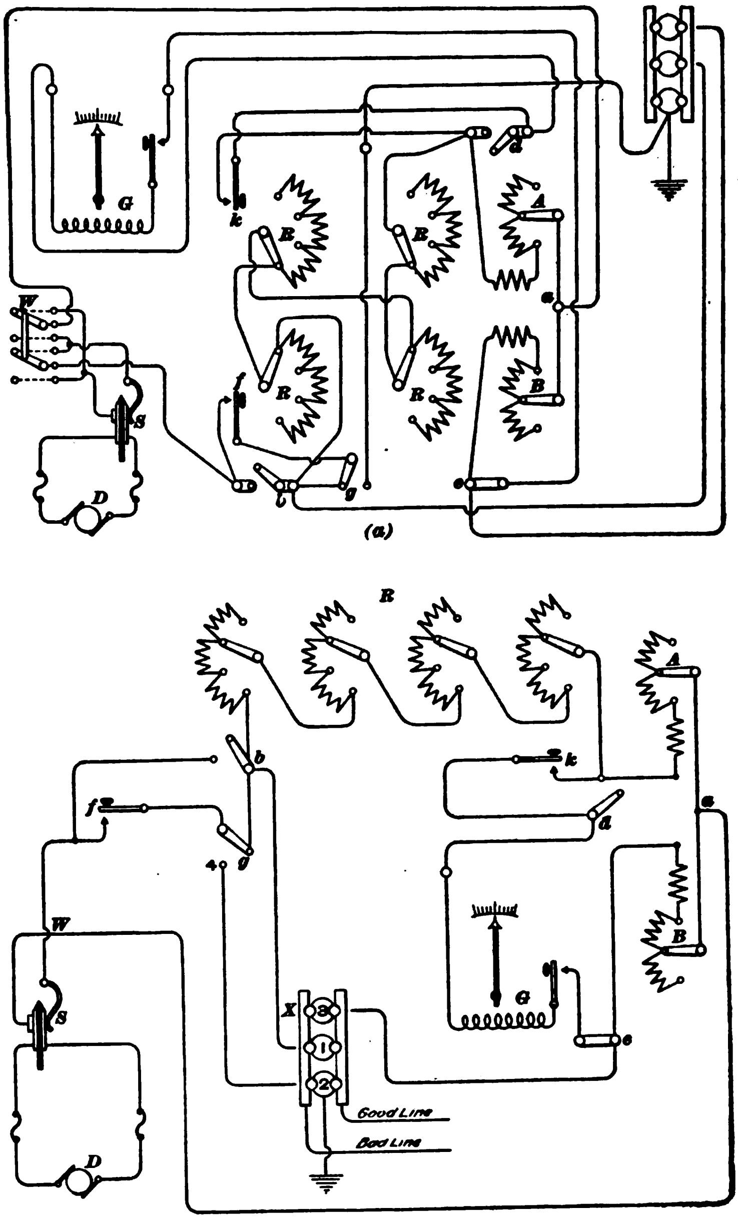


FIG. 3

7. Postal Galvanometer.—In Fig. 3 is shown a Weston galvanometer as constructed and arranged for the Postal Telegraph-Cable Company. The galvanometer itself is a D'Arsonval, the movable coil having a resistance of 250 ohms. Around this coil is a shunt of low resistance, whose circuit can be opened by pressing the key p, when a deflection is to be noted. By means of the switch a, any one of three shunts may be connected across the galvanometer coil; one gives a multiplying power of 2, the next a multiplying power of 10, and the third a multiplying power of 100. The $\frac{1}{2}$ shunt has a resistance equal to that of the galvanometer; the $\frac{1}{10}$ shunt, a resistance $\frac{1}{9}$ that of the galvanometer; and the $\frac{1}{100}$ shunt, a resistance $\frac{1}{99}$ that of the galvanometer.

8. Connections for a Wheatstone Bridge.—Wheatstone bridges with sliding arms for adjusting the resistances,



(a)

(b)

Fig. 4

in place of disks and pegs, seem to be finding favor among telegraph and telephone companies. The sliding contacts are much better constructed than formerly, while the losing and poor fitting of pegs are eliminated. In Fig. 4 (*a*) is shown an arrangement of a Wheatstone bridge and its connections with the switchboard and dynamo, ready for testing a line, while in (*b*) is shown exactly the same circuits arranged in a simpler manner. The same reference letters are used in both views. Leads from a battery or dynamo *D* of suitable voltage for the tests to be made, pass through suitable fuses – a wedge – a spring jack at a leg, or loop, switchboard *S* – a reversing switch *W* to the Wheatstone bridge testing set.

9. The key *f* may be used to close the battery circuit in a Wheatstone bridge; switch *g* by turning it to contact *4* may be used to ground one side of the dynamo circuit; switch *b* may be used to short-circuit both key *f* and switch *g* when the latter is in the position shown. The point *b* forms the junction of the rheostat arm *R*, which consists of four sections of adjustable resistances, and the line upon which some measurement is to be made. As *A* and *B* each contain three coils, usually 10, 90, and 900 ohms, each position of the arm may have 10, 100, and 1,000 ohms. These constitute the balance, or ratio, arms of the bridge and the galvanometer is connected across them, that is, to points *d* and *e*, as usual in a Wheatstone bridge. At *d* is a switch for short-circuiting the usual galvanometer key *k*; there is also a switch on the galvanometer itself.

10. For loop measurements, good and bad lines running to the same place will be connected in the usual manner to the vertical straps at this part of the main switchboard. For one of the measurements in the Varley loop and other tests, which will be explained later, the switch *g* is turned to point *4* and pegs put in holes on the right of *1* and on the left of *3*. To measure the resistance of a bad wire to a ground on it, or to a distant office where it is purposely grounded, and for one measurement in the Blavier and some other tests to be explained later, put pegs in holes on the right of *1* and *2*, and on the left of *3*, leaving the switches as shown here.

RESISTANCE OF LINES AND GROUNDS

11. High Resistance by Wheatstone Bridge.—A resistance x that is somewhat too high to be measured by a given Wheatstone bridge in the ordinary way, may still be determined by connecting it in parallel with as high a resistance y as can be conveniently and accurately measured with the bridge, and measuring their joint resistance z; then,

$$x = \frac{y\,z}{y-z}$$

When y can be accurately measured and x is not too high, this is a very good method and it may also be used to check up resistances that have been measured separately.

12. Measurement of Line Resistance.—In measuring the resistance of a line by means of the Wheatstone bridge, the terminals of the line circuit should be connected in the unknown arm of the bridge. Sometimes, in the case of a grounded circuit, earth currents interfere to such an extent as to render accuracy impossible. In this case, if a parallel wire having a known resistance is available, it may be connected at the distant end to the wire to be measured, and the resistance of the two in series measured. The resistance of the first will then be the difference between the total measured resistance and that of the known wire. Or, if both wires run on the same poles or in the same cable, so as to be of equal length and if both are the same size, the resistance of one may be taken as half the resistance of both as measured.

If the distant end of one line wire can be grounded but cannot otherwise be brought into electrical connection with the bridge, the available end may be joined to one post of the unknown arm of the bridge and the other post of the unknown arm of the bridge and also the distant end of the line wire grounded. Then the resistance of the circuit so formed, which includes the ground resistance, may be measured. The latter will have to be neglected if not known. In Fig. 4, this is accomplished by connecting the line whose resistance is to be measured to point b and grounding its distant end and also grounding point e.

13. Line Resistance When Three Conductors Are Available.—The best method for measuring the resistance of a line wire, where there are three or more line wires or two line wires and a ground-return circuit, between the same two offices is as follows: Let the resistance of the three line wires be x, y, and z, respectively. At the distant station have the ends of x and y joined together, then, by means of a Wheatstone bridge at the home station, measure the resistance of the loop so formed and let it be a ohms. Then have the distant ends of x and z joined and measure the resistance of this loop, calling it b ohms. Similarly, have the distant ends of y and z joined, measure the resistance of this loop, calling it c ohms. Then, $x+y=a$; $x+z=b$; $y+z=c$. From the first equation $x=a-y$ and from the second equation $x=b-z$, then $a-y=b-z$, or $a-b=y-z$. But $y+z=c$. Adding together the last two equations gives $2y=a-b+c$, or $y=\frac{a+c-b}{2}$. Similarly, solving the same equations for x and z gives:

$$x=\frac{a+b-c}{2} \qquad (1)$$

$$y=\frac{a+c-b}{2} \qquad (2)$$

$$z=\frac{b+c-a}{2} \qquad (3)$$

Hence, the resistance of any one or of each one of the three line wires may be calculated from these three measurements.

14. Resistance of Ground-Return Circuits.—The resistance of the ground-return circuit may be measured by the preceding method when there are two line wires between the same two offices. Let the resistance of the two wires be x and y ohms, respectively, and that of the ground circuit be z ohms. Measure the resistance of the loop formed by having the two distant ends of the two line wires joined together and call it a ohms. Then have the x wire grounded at the distant office and measure the resistance between the home ground plate and the home end of the x wire, and call it b ohms. Similarly, have the distant end of the y wire grounded and measure the resistance between the home ground plate and the home end of the y wire, and call it c ohms. Then the resistance of the ground return z may be calculated by formula **3** in the last article. Usually most of this resistance z is located at the contact surfaces between the plates and the ground. The resistance of a good ground return should not exceed about 10 ohms. It is evident that the resistance of the two line wires may also be obtained by substituting the quantities a, b, and c in formulas **1** and **2** in the last article.

Whenever accurate results are desired reverse battery readings should be taken on all measurements and the connections between the bridge and the circuit being measured should also be reversed to secure two readings when the method employed allows such reverse connections to be made; the average of the readings should be used.

EXAMPLE.—It is desired to measure the resistance of two wires x and y, and also the resistance of the ground path z between two stations A and B. The party making the test at A instructs station B to join the wires x and y together. A measurement of the resistance of the loop so formed is made at A with a Wheatstone bridge, giving 2,490 ohms. The operator at B is then instructed to ground the wire x, and the operator at A measures the resistance between his end of the wire x and this ground; this gives 1,270 ohms. The operator at B is then instructed to ground the wire y, and the operator at A finds the resistance between his end of y and his ground to be 1,300 ohms. What is the resistance of each wire and of the ground path?

SOLUTION.—By the formulas in Art. **13**, in which $a = 2{,}490$, $b = 1{,}270$, and $c = 1{,}300$, the resistance of the wire is

$$x = \frac{2{,}490 + 1{,}270 - 1{,}300}{2} = 1{,}230 \text{ ohms. Ans.}$$

$$y = \frac{2{,}490 + 1{,}300 - 1{,}270}{2} = 1{,}260 \text{ ohms. Ans.}$$

The ground path is

$$z = \frac{1{,}270 + 1{,}300 - 2{,}490}{2} = 40 \text{ ohms. Ans.}$$

15. Resistance of Ground.—Before the use of generators, especially in street-car power houses, the resistance of a ground return could be measured without trouble by the usual Wheatstone bridge measurement. To reduce the error in such a measurement due to a difference in potential between two ground plates, the following method is used by the American Telephone and Telegraph Company: Connect the line, whose resistance *r* must be known, measured or calculated, the battery, and the bridge, as shown in Fig. 5. For the galvanometer, a voltmeter or any galvanometer having a scale may be used, as the bridge is not balanced for a zero deflection. The rheostat arm *p* is first cut out, that is, short-circuited, the key *a* left open, and the galvanometer deflection due to the ground current noted. This will usually vary considerably, but the average deflection should be taken. This is to be used as the zero deflection. Now close the key *a* with the positive terminal of the battery to line and insert enough resistance in the rheostat arm *p* to give the same average deflection previously obtained; in other words, balance the bridge to this so-called false zero. Let the resistance of the line and ground return so measured be x. Reverse the battery and again balance the bridge to the same false zero and let this resistance of the line and ground return be y. Then the resistance of the line, the two grounds g and g' and the ground between them is most accurately given by the expression $\frac{2xy}{x+y}$ and hence the resistance of this ground return z is given by the formula

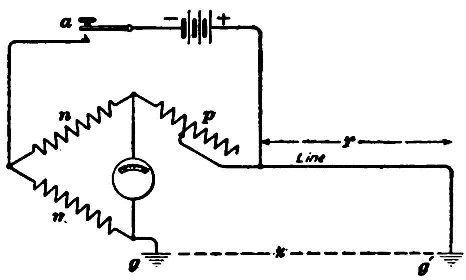


FIG. 5

$$z = \frac{2xy}{x+y} - r,$$

in which r = resistance of the line wire.

If the home ground is a good one, as it should be, z is practically the resistance of the distant ground g', the resistance of the return path usually being negligible compared with the contact resistance between the distant ground plate and earth.

16. Resistance of Ground, Using Receiver.—A method, which is said to be very reliable, for measuring the resistance of a ground, such as the ground terminal in a cable-pole box, is indicated in Fig. 6. The bridge is supplied with an alternating current from the secondary winding of an induction or repeating coil, a few dry cells *b* and a buzzer, which forms an interrupter, being connected in the primary circuit. The telephone receiver takes the place of a galvanometer. The temporary ground, which may be a piece of wire pushed into the ground, should have an appreciable resistance so that some resistance will have to be inserted in the arm *p* to secure a balance. The temporary ground should be 2 or 3 feet from the ground to be measured and the bridge 25 or 30 feet away from both grounds, separate leads, not twisted-pair conductors, being used from the bridge to the grounds. Usually 1,000 ohms can be put in each balance arm *m* and *n*.

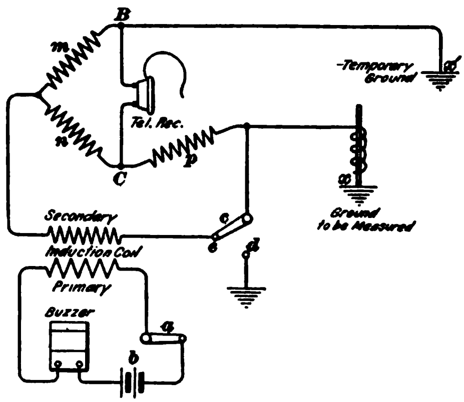


FIG. 6

17. With switches *a* and *c* closed, as shown, balance the bridge. The tone in the receiver will not cease at the balance point, but will be very faint. If the resistance of the temporary ground is x', and the resistance of the ground to be measured is x, then,

$$\frac{m}{n}=\frac{x'+x}{p}$$

The switch c should be moved so as to connect d to e, and the bridge again balanced, if the new values of the bridge arms are m', n', and p', then

$$\frac{m'}{n'}=\frac{x'}{p'+x}$$

These two equations are solved for x as follows: $m\,p=x'\,n+n\,x$, or

$$x'=\frac{m\,p-n\,x}{n} \qquad (a)$$

and $m'\,p'+m'\,x=n'\,x'$, or

$$x'=\frac{m'\,p'+m'\,x}{n'}; \qquad (b)$$

equating (a) and (b), gives $\frac{m\,p-n\,x}{n}=\frac{m'\,p'+m'\,x}{n'}$, or $n'\,m\,p-n'\,n\,x=m'\,p'\,n+m'\,n\,x$, or $m'\,n\,x+n'\,n\,x=n'\,m\,p-m'\,p'\,n$, therefore

$$x=\frac{n'\,m\,p-m'\,p'\,n}{m'\,n+n'\,n} \qquad (1)$$

If, as is usually the case, $n=m$ and $n'=m'$, then

$$x=\frac{p-p'}{2} \qquad (2)$$

Usually it is well to make $m=n=m'=n'$, inserting 10, 100, or 1,000 ohms in each balance arm for both balances and using formula 2.

EXAMPLE.—The resistance of a lightning arrester ground was determined by this method. After 10 ohms was inserted in each balance arm for both balances, one terminal of the secondary winding was connected to the end of the rheostat arm that was connected to the ground to be measured, and the bridge balanced; the rheostat arm then contained 45 ohms. When the terminal of the secondary winding was connected to a good ground instead of to the rheostat arm and the bridge balanced, the rheostat contained 15 ohms. What is the resistance of the desired ground?

SOLUTION.—By substituting the resistances in the balance arm for the two measurements in the formula just given,

$$x=\frac{45-15}{2}=15 \text{ ohms. Ans.}$$

CONDUCTIVITY BALANCE OF WIRES FORMING PAIRS

18. Where two wires constituting a pair of conductors are used for a telephone circuit, it is often very essential, especially in simplex and composite telephone and telegraph systems, that the resistances of the two conductors shall be reasonably equal. The pair of wires is then said to be conductively balanced.

The line should first be cleared of all shunts, bridging telephones, and grounds; then both wires should be short-circuited and grounded at the arrester or elsewhere at the distant end. For a voltmeter, one reading only to 2, 3, or 5 volts, or, better still, a milliammeter reading to about 600 milliamperes should be used. The instrument and a suitable battery, say

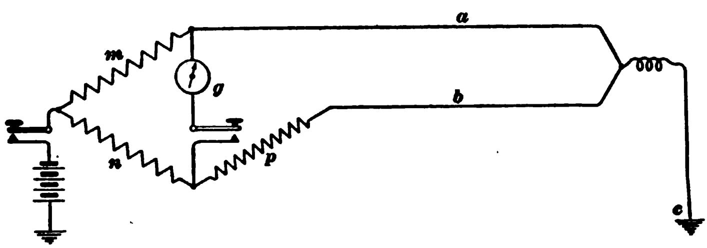


FIG. 7

one giving about 40 volts, should be connected between one line wire and the ground and then between the other line wire and the ground. If the two readings are equal, the line is well balanced as far as the resistance is concerned. The actual resistance of each line wire may be calculated from the voltage of the battery and the reading of the instrument. If the resistances of the wires are not equal, the fact may be due to bad joints or loose connections in one or both sides of the line. Transposing the wires will frequently make the resistances of the two sides of the line more nearly equal.

Another test for the equality of a balance between two wires constituting a pair consists in grounding the two wires at the distant end and connecting a telephone receiver in series with both wires at the testing end. If the line is out of balance, there will be a noise in the receiver due to unequal induction or leakage from neighboring conductors.

19. Method Using Ordinary Arrangement of Bridge. The conductivity balance of two wires forming a pair may be determined as follows: Connect the two line wires *a* and *b* to a bridge, as shown in Fig. 7, and at the distant end have them connected to the same ground *c*. Usually it is best to make the balance arms *m* and *n* of the bridge equal. The resistance that will have to be inserted in the rheostat arm *p* in order to give no deflection of the galvanometer *g* will be the excess resistance of *a* over *b*. If *b* is greater than *a*, the bridge cannot be balanced until the connections of *a* and *b* at

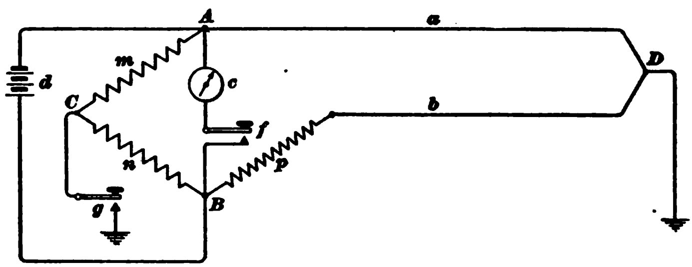


FIG. 8

the bridge are reversed. If the resistances of the two line wires are equal, *p* will be zero for no deflection of the galvanometer.

20. Method Using Special Arrangement of Bridge. The following method, using the bridge arrangement shown in Fig. 8 for determining how much two wires forming a pair are out of balance is claimed by some to be superior to the method just given; although some others do not so consider it. In this arrangement the battery is connected across the same junction points *A* and *B* as the galvanometer *c*, which must be very sensitive to small changes in the strength of currents. Only a few cells can be used in the battery *d*.

To make the measurement, close the galvanometer key *f* and adjust the arms *m*, *n*, and *p* until the galvanometer deflection is not changed when the key *g* is closed. The galvanometer will always show a deflection, but when the bridge is properly balanced, closing or opening the key g will not alter this deflection. Under such conditions there is no difference of potential between the points C and D, hence $\frac{m}{n}=\frac{a}{p+b}$. Usually m can be made equal to n, in which case $p=a-b$, and hence the resistance in p gives the excess resistance of a over b. If b is greater than a, the bridge cannot be properly balanced until the connections of the line wires to the bridge are reversed.

CAUSES OF ERRORS

21. Poor Connections.—It is very important that all connections be properly made. For instance, the introduction of ¼ ohm at an improperly made joint at a distant point where a good and bad wire of No. 22 B. & S. G. are connected together will cause a fault to be located about 16 feet from the correct point. Incorrect connections may usually be detected by a duplicate test or by a check method.

22. Disappearing Ground.—A disappearing ground is generally caused by the testing current turning the slight moisture present into gas. The ground will reappear sometimes by waiting a short time. By using a higher testing electromotive force and making the test quickly, it is sometimes possible to locate the fault correctly. When using a bridge under such conditions, it may be advisable to interchange the connections of the battery and galvanometer; for then only the galvanometer current flows through the fault, and this smaller current is less likely to dissipate the moisture than the larger battery current. By sending a current from a telephone ringing generator through the fault, the ground can sometimes be increased or permanently burned out. The testing apparatus should be disconnected before applying the ringing current. A ground that is sufficient to make a telephone line noisy can usually be located.

23. Inequalities in Line Resistance.—Unless otherwise mentioned, loop methods for locating faults assume that the wires have a uniform resistance per unit length, which is seldom very true and sometimes far from it. Poorly soldered sleeves or other bad joints, slight variations in gauge, inequalities in the temperature of different parts of a line, and unequal twisting of a wire in a cable are causes of inequalities for which it is generally impossible to correct. Resistance variations in long lines can sometimes be calculated and corrections made. Wherever possible a loop should consist of two wires forming a pair so that both wires will be subject to the same conditions of twist and temperature.

24. **Incorrect Line Resistances.**—If calculations of resistances are determined from wire gauges and tables, errors may occur due to all the causes mentioned in the last article. Errors of this kind may be avoided by using the methods and formulas that determine the distance to the fault as a fraction of the total length of the faulty wire or loop; such methods should therefore be preferred when they are applicable.

25. **Two Faults on One Wire.**—Sometimes when making a loop test with a bridge, the inability to secure a balance often indicates two variable resistance faults at different points, or a fault of considerable extent, such as that caused by moisture in 50 to 100 feet of cable. Under such conditions, the accurate location of the fault with a bridge is not likely. Generally the calculated result will be nearest the fault of lowest resistance and in all cases the point located will lie between the two faults. The best way is to cut the cable or line at the point calculated and determine separately the distance to the fault in each section. If tests made from both ends locate the fault at the same point, there is one ground; if they give different points there are two or more faults.

26. **Galvanometer Deflection Unsteady.**—If in making loop tests, the two line wires forming the loop are not on the same pole line, variable and large enough currents are apt to be induced in the loop by neighboring conductors to make the galvanometer deflections unsteady; they may drift from side to side or swing over to one side for a few moments only. When the two wires forming the loop are on the same pole line, which should be the case whenever practicable, the disturbances are

almost entirely neutralized by the compensating effect of one wire on the other.

27. Elimination of Earth Currents.—Earth currents will often render measurements where the ground is used as a part of the circuit, as in the last method, very unreliable. These currents may oppose or aid the testing current. When the earth currents are fairly steady, their effect may usually be eliminated by making a measurement, then reversing the battery and making another measurement; the average of the two measurements should be taken as the correct result. For good results, the earth current should not only be steady but it should also be small compared with the testing current.

Stray currents, which leak into or are induced upon telephone and telegraph wires from neighboring electric-light or

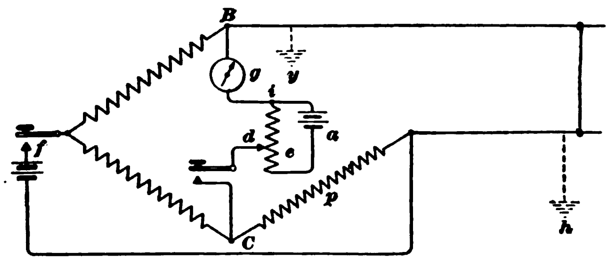


Fig. 9

power circuits are generally irregular and cause irregular deflections of the galvanometer when making tests upon line wires. When stray currents are present, the testing electromotive force should be made as large as possible or safe so that the galvanometer deflections due to the test current may be large enough to make those due to the stray current negligible. If this precaution does not make it possible to make a sufficiently accurate test, it may be necessary to postpone the test until conditions are more favorable; in loop tests it is sometimes possible to make use of another loop.

28. Potentiometer Arrangement for Eliminating Earth Currents.—The potentiometer arrangement, shown in Fig. 9, for eliminating the bad effect of earth currents may be used with fair success. A few cells *a* are so connected, with respect to their polarity, to a rather high potentiometer resistance *e* that by adjusting the slider *d*, no deflection of the galvanometer *g* will be produced when the regular battery key *f* is open and the resistance in the rheostat arm *p* is zero. Under such conditions the difference of potential that will be produced across points *B* and *C* by an earth potential or stray current through poor insulation, or grounds *h* and *y*, is just balanced by the opposing potential between the points *d* and *i* due to the battery *a*. After securing this balance, the bridge is used in any way desired.

INSULATION AND CAPACITY MEASUREMENTS

29. The direct deflection methods, which are fully explained in *Electrical Measurements* are generally used for ordinary insulation and capacity tests of line wires and cable conductors.

When a number of cable conductors are bunched for an insulation test, their insulation resistance when thus connected in parallel is the same as though they were connected in series. To determine the insulation resistance per mile of single conductor, their lengths should be added. For example: Ten conductors tested in a bunch, each $\frac{1}{4}$ mile long, give a total length of $2\frac{1}{2}$ miles. Suppose the insulation resistance measures 500 megohms for the $2\frac{1}{2}$ miles of conductor, then the insulation resistance per mile is $500 \times 2\frac{1}{2} = 1{,}250$ megohms; and as each conductor is $\frac{1}{4}$ mile long, its total insulation resistance is $1{,}250 \times 4 = 5{,}000$ megohms; or, as there are ten conductors having an insulation resistance of 500 megohms, each one has a total insulation resistance of $500 \times 10 = 5{,}000$ megohms, the same result as obtained above in a slightly different manner.

It is found that the insulation resistance of a conductor tested against the sheath and about five or ten other conductors, including the mate of the pair tested, will be practically the same as if all remaining conductors were connected to the sheath. This is fortunate for it is often not possible, especially in a cable in use, to test more than a few pairs.

30. Insulation resistance may be very conveniently determined by means of a voltmeter. A very simple method used by some telephone companies is as follows: A voltmeter whose highest reading is 30 volts, for a 30-volt central-energy telephone system, and having a resistance of exactly 10,000 ohms, is purchased; then 10,000 ohms (the voltmeter alone) when connected across a battery of 30 volts gives a reading of 30. Consequently, a reading of 15 means a total resistance of $2 \times 10{,}000 = 20{,}000$ ohms, or an external resistance of $20{,}000 - 10{,}000 = 10{,}000$ ohms. Similarly, a voltmeter reading of 10 means an external resistance of 20,000 ohms; a voltmeter reading of 7.5 means an external resistance of 30,000 ohms, etc. Or the following general formula may be used:

$$R = r\left(\frac{d}{d'} - 1\right)$$

in which R = desired resistance, which is connected in series with voltmeter;

r = resistance of voltmeter;

d = reading of voltmeter when connected directly across battery used throughout test;

d' = reading of voltmeter when connected in series with resistance R and same battery used in obtaining reading d.

31. The mutual capacity of a conductor varies directly as its length, whether the other conductors in the same cable are connected together in series or in multiple. For example: Ten conductors in a cable ¼ mile long measure .192 microfarad, five being measured against the other five connected to the sheath; what is the capacity per conductor per mile and per conductor? The mutual capacity per conductor per mile is $\frac{.192}{10} \times \frac{4}{1} = .0768$ microfarad. The mutual capacity per conductor, which is ¼ mile long, is $\frac{.0768}{4}$, or $\frac{.192}{10} = .0192$ microfarad.

The mutual capacity varies as the number of grounded conductors only when one wire in each pair are connected together and tested against all other wires connected to the sheath. The capacity of a line or cable conductor cannot be relied upon to be uniform throughout its length; variations of 10 per cent. or more often occur.

LOCATION OF FAULTS

CLASSIFICATION OF FAULTS

32. Faults on a line may be of three kinds: First, the line may be broken; second, an unbroken line may be grounded at one or more points; and, third, an unbroken line may be in contact with another line. The first fault is called a *break* or an *open*, the second a *ground*, and the third, a *cross*.

A **break** may be of such a nature as to leave the ends of the conductor entirely insulated, or the wire may fall or have its insulation impaired so as to form also a cross or ground.

A **ground** or **cross** may be of such low resistance as to form a dead ground or a short circuit, respectively, or it may possess high resistance, thus forming what is termed a *leak*. The location of faults is a matter often involving much ingenuity and mathematical knowledge. A wire whose insulation and continuity are known to be good is termed a *good* wire. Such a wire is usually a great help in locating breaks, grounds, and crosses.

In order not to get inaccurate results due to variation in resistance of line conductors on account of change in temperature, it is well to measure the resistance of a known length at a known temperature and correct its resistance for the temperature at the time of making the test, or else to measure its resistance each week or two. By dividing the distance by the resistance, the feet per ohm is obtained. This may vary 10 per cent. between summer and winter.

TESTS FOR LOCATING A BREAK

NO GOOD WIRES AVAILABLE

33. Measurements Made From One End Only, Using a Condenser.—When there is not a single good wire available, but the total capacity and length or capacity per mile of the conductor is known, the distance to a break may be determined as follows: Let d be the deflection, or throw, of a ballistic galvanometer obtained by charging or discharging through it a condenser of known electrostatic capacity C, and d', the throw when charging or discharging the broken line wire whose capacity is C', using the same battery in each case. Then,

$$C' = \frac{Cd'}{d}$$

Now the electrostatic capacity per mile of the broken line must be known; then, by dividing C' by this electrostatic

TABLE I

ELECTROSTATIC CAPACITY OF WIRE PER MILE

Number and Gauge	Diameter Inch	Capacity, in Microfarad per Mile 30 Feet Above Ground	
		Between One Wire and Ground (Grounded at Both Ends)	Wire to Wire 12 Inches Apart
8 B. & S.	.128	.00958	.00854
9 B. & S.	.114	.00946	.00835
10 B. & S.	.102	.00935	.00818
12 B. & S.	.0808	.00913	.00785
14 B. & S.	.0641	.00892	.00754
16 B. & S.	.0508	.00871	.00726
12 B. W. G.	.109	.00942	.00828
14 B. W. G.	.0830	.00915	.00788

capacity per mile the number of miles to the break is obtained. This electrostatic capacity per mile may be determined by measuring, by the foregoing method, the total electrostatic capacity of the line when it is in good condition, that is, free from breaks, grounds, and crosses, and dividing this total electrostatic capacity by the total length of the line. The electrostatic capacity per mile may be obtained approximately from Table I.

34. The electrostatic capacity of an overhead wire will depend on the number and proximity of other wires, and especially whether any of the neighboring wires are grounded. Where there are a number of grounded circuits on the same pole line, the electrostatic capacity will be higher. It will also vary with the number of insulator supports per mile and

TABLE II

ELECTROSTATIC CAPACITY OF WIRE .104 INCH IN DIAMETER

Between Wire and Ground		Between 2 Parallel Wires	
Height Above Ground Feet	Capacity Microfarad per Mile	Distance Between Wires Inches	Capacity Microfarad per Mile
10	.010600	10	.008503
20	.009796	12	.008218
30	.009379	14	.007992
40	.009105	16	.007806
		18	.007649

the moisture on them. When one overhead wire is grounded at one end and insulated at the other end, the capacity is twice as great as when both ends are grounded, that is, twice as great as the capacity given in the third column of Table I. When a high inductance, such as a high-resistance (1,200-ohm) bridging telephone bell, is connected between one end of the line and the ground, the capacity for high-frequency currents will be very nearly as great as when the end is open and insulated.

35. The capacity C, in microfarads, per mile of one wire .104 inch in diameter, grounded at both ends and suspended at different heights above the ground is given in Table II. If there are two such wires .104 inch in diameter, 1 foot apart, and grounded at both ends, the capacity between either wire and the ground is .01171 microfarad per mile when both wires are 20 feet above the ground, and .0115 microfarad when both wires are 30 feet above the ground.

The capacity, in microfarad per mile, between two wires .104 inch in diameter, and forming one metallic circuit is also given in Table II.

36. Measurements Made From Each End, Using a Condenser.—Another method for locating a break when no good wire is available is as follows: Determine the discharge deflection d from the broken wire at one end of the cable, also the discharge deflection D from a condenser of known capacity C. Then, from the other end of the cable determine the discharge deflection d' from the other end of the broken wire, and the discharge deflection D' from a condenser of the same capacity, or preferably from the same condenser. Let L be the length of the cable; then the distance x to the break is given by the formula:

$$x = \frac{L\,d}{\frac{D\,d'}{D'} + d}$$

This formula may be derived in the following manner: $d : x = D : C$ and $d' : L - x = D' : C$. From which $C = \frac{x\,D}{d}$ $= \frac{(L-x)\,D'}{d'}$; or $\frac{x\,D}{d} = \frac{L\,D' - x\,D'}{d'}$, $\frac{x\,D}{d} + \frac{x\,D'}{d'} = \frac{L\,D'}{d'}$; or $x = \frac{D\,d' + D'\,d}{d\,d'} = \frac{L\,D'}{d'}$; or $x = \frac{L\,D'\,d}{D\,d' + D'\,d} = \frac{L\,d}{\frac{D\,d'}{D'} + d}$.

The same amount of battery must be used for both tests at one end, but the same amount of battery need not be used at one end as at the other. This method gives very satisfactory results.

37. Probably a better way to locate a break when there is no available good wire but where tests can be made from both ends with exactly similar, and preferably the same, condenser, is as follows: At one end, connect as shown in Fig. 10, in which *d* is a vibrating induction coil or buzzer and *c* a condenser, not differing too much in capacity from that of the broken wire. Close the key *b* and adjust the bridge until

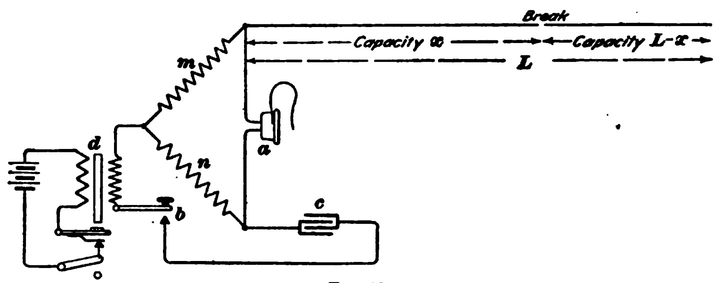


FIG. 10

there is no sound or a minimum sound in the telephone receiver *a*. Let x be the distance to the break and L the total length of the line wire in any units of length, and m and n be the values of the resistance arms for this balance. Then $\frac{\text{resistance } m}{\text{resistance } n} = \frac{\text{capacity } c}{\text{capacity } x}$. The same test is then made from the other end, preferably with the same condenser c, at least with a condenser of exactly the same capacity as c. Let the values of the bridge arms for the balance at the further end be m' and n'. Then $\frac{\text{resistance } m'}{\text{resistance } n'} = \frac{\text{capacity } c}{\text{capacity } (L-x)}$. Solving these two equations for x by first eliminating c, gives, for the distance x to the break in the same units of length as L, the formula:

$$x = \frac{n\,m'\,L}{n\,m' + n'm}$$

ONE OR MORE GOOD WIRES AVAILABLE

38. One Good Wire Available.—The capacity of a part of a wire bears the same relation to the capacity of the whole wire as the length of the part does to that of the whole.

When one good wire, having the same capacity to ground per mile as the broken wire, is accessible, deflections may be taken on the broken wire and on the good wire with the distant end open.

Let d' = throw on broken wire;
d = throw on good wire;
x = distance to break;
L = total length of good wire.

Then,
$$x = \frac{d' L}{d}$$

In a telephone cable, it is best to use the mate of the broken wire as the good wire and to ground to the lead sheath all the conductors except the one from which the deflection is being obtained. At least the mate of the faulty wire should be grounded at the testing end when the discharge deflection of the faulty wire is observed and both ends of the faulty wire should be grounded when the discharge deflection of its mate is being observed.

39. A slight modification of the preceding method, the results obtained by which it may be used to verify, is as follows:

Let d_1 = throw due to charging good wire, whose length is L with distant end open;
d_2 = throw due to charging good wire, to distant end of which is joined farther part of broken wire; this length is $2L-x$;
d_3 = throw due to charging broken wire, whose length is x.

Then, $x : d_3 = L : d_2+d_3-d_1$, or
$$x = \frac{L\,d_3}{d_2+d_3-d_1}$$

That this is true may be seen from the fact that d_2 is proportional to the capacity of $2L-x$; d_3, to the capacity of x; and d_1 to the capacity of L; then $d_2+d_3-d_1$ is proportional to the capacity of $2L-x+x-L$, that is, to the capacity of L.

EXAMPLE 1.—A test was made to find a break in a cable conductor near to which ran a good wire; the throw on the broken conductor was

35 divisions and that on the good wire was 80 divisions. What was the distance to the break, the total length of the cable being 3,100 feet?

SOLUTION.—Substituting in the formula $x = \frac{d' L}{d}$, gives

$$x = \frac{35 \times 3{,}100}{80} = 1{,}356 \text{ ft.} \quad \text{Ans.}$$

EXAMPLE 2.—A break occurs in a cable 3 miles long. It is known that the capacity of the entire conductor was 1.17 microfarads or .39 microfarad per mile. On testing, it is found that with a standard condenser of $\frac{1}{3}$ microfarad and a suitable battery and shunt to the galvanometer, the deflection is 98, while with the same shunt and battery, the deflection obtained from one end of the cable is 141. How far from the testing end is the break?

SOLUTION.—As the deflections are proportional to the electrostatic capacities of the condenser and conductor, $C' = \frac{C d'}{d}$. Substituting the values $C = \frac{1}{3}$, $d = 98$, $d' = 141$ in this formula, gives

$$C' = \frac{\frac{1}{3} \times 141}{98} = .4796 \text{ microfarad}$$

Distance from testing end is $.4796 \div .39 = 1.23$ mi. Ans.

EXAMPLES FOR PRACTICE

1. In a test for the capacity of a cable, the capacity of the standard condenser was 2 microfarads; the throw produced by the condenser was 53 divisions, and that by the cable was 32 divisions. What was the capacity of the cable? Ans. 1.207 microfarads

2. A test was made to locate a break in a cable conductor, a good wire being accessible. The throw on the broken wire was 29 divisions and that on the good wire was 75 divisions; the length of the tested cable was 5,760 feet. What was the distance to the break? Ans. 2,227 ft.

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40. Three Good Wires Available.—A method that has been successfully used for the location of breaks in telephone cable conductors is shown in Fig. 11, in which V and B represent any suitable means for supplying a reversible, interrupted, or alternating current, in this case a rotating device, for reversing rapidly the current from the battery B. The conductor *1* is open at o, while its mate *2* and the pair *3* and *4* are supposed to be good wires; *m* and *n* represent two adjustable arms of a Wheatstone or slide-wire bridge and *R* is a telephone receiver. The connections are made, as here shown, at one end of the cable and the resistance in the arms *m* and *n* adjusted until no sound, or a minimum sound, is produced in the receiver *R*. Then the distance to the fault *o* is given by the formula:

$$x = \frac{n\,L}{m}$$

The wires *1*, *2*, *3*, and *4* should be well insulated at the distant end. For cables 1,000 feet long, the battery *B* should give 60 to 120 volts, and the resistance in the arm *n* may have to be 100 or 1,000 ohms.

The larger the capacity between the wires, the less need be the number of cells at *B* and the less the resistance in the

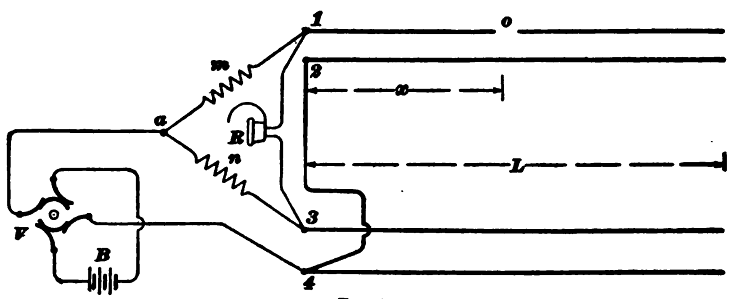


Fig. 11

arm *n*. All wires must be free from grounds and crosses. If the leading wires from the testing set to the cable are suspended in air and are not too long, no correction need be made for them in this or the following method. Generally the leading wires do not have to be considered.

41. Break in Telegraph Cable.—In telegraph or other cables, in which the wires are not grouped in pairs, instead of balancing the capacity of the open wire to its mate against that of a good pair, as just explained, the relative capacities to ground of an open wire and a good wire are balanced. The connections differ only in the use of two wires instead of two pair and in grounding. The connections are shown in Fig. 12, using an induction coil to furnish an alternating current. The usual bridge-galvanometer key *a* and bridge-battery key *b* are shown; *h*, *d*, *e*, *f*, and *g* are cable conductors. One good conductor *g* is connected to the bridge at *c* and is not grounded at either end, but all the other wires are grounded at the distant end. The bridge is balanced and the same formula used

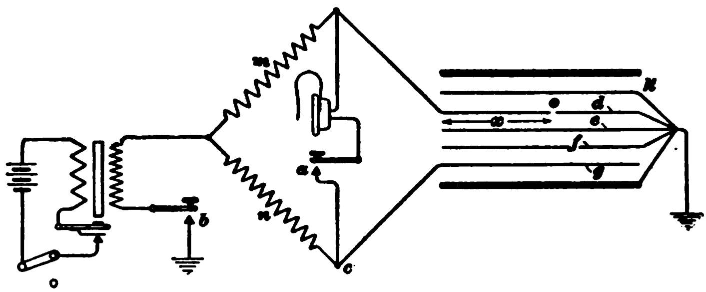


FIG. 12

as explained, in the last article, for determining the distance *x* to the open point *o*. All wires must be free from grounds and crosses.

EXAMPLE.—An open wire in a cable 4,280 feet long was connected as shown in Fig. 12 and a balance was obtained with 647 ohms in the arm *n* and 1,000 ohms in the arm *m*. What is the distance to the open point *o*?

SOLUTION.—By substituting in the formula $x=\frac{nL}{m}$, $x=\frac{640\times 4,280}{1,000}$ $=2,739.2$ ft. from the testing station to the open point. Ans.

42. Evans Method.—It is said that the distance to a break in a line wire that has not become grounded or crossed with another wire may be determined with considerable accuracy by the **Evans method.** In Fig. 13, *I* represents an induction coil; one terminal of the secondary is grounded and the other connected to the point *A*, which is the junction of two resistances, at least one of which, say *n*, must be adjustable. *B A C* may be a high-resistance slide wire, *A* being the point that is adjusted along the slide wire, or *m* and *n* may be the two arms of a Wheatstone bridge. *B E* represents a good wire of similar size and length to the wire $C\ D$, which is open at some point F. The ends E and D are joined together in any convenient manner. A telephone receiver is connected across the points $B\ C$.

43. Adjust the resistance n, or the position of the point A, if $B\ A\ C$ is a slide wire, until the sound produced in the receiver

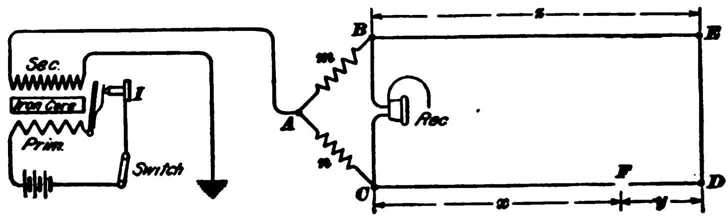


FIG. 13

by the current from the secondary coil, as it charges the open wires, is reduced to zero or at least to a minimum. The bridge arrangement is then balanced so that $m : n = \frac{1}{z+y} : \frac{1}{x}$. The length of a wire is proportional to its capacity, but the opposition of a condenser to an alternating current is inversely proportional to its capacity. Hence, the resistances m and n are inversely proportional to the lengths of the open wires, as stated in the proportion. Solving the proportion for x, gives for the distance along the broken wire to the break F, $x = m\frac{z+y}{n}$. If $z = x + y$, which is usually the case, then $y = z - x$; substituting this for y and solving for x, gives

$$x = \frac{2\,m\,z}{n+m}$$

Both distances x and z must be expressed in the same units of length; miles, feet, or any other unit of length. If a slide wire is used, m is the length of the slide wire between B and A, and n is the length of the slide wire between A and C.

44. Method Requiring a Commutator.—A method for locating a break in one of a pair of wires and requiring a simple commutator is said to be very simple and reliable. Three pieces of sheet metal *a*, *c*, and *e*, Fig. 14, form segments mounted on the cylindrical surface of a drum made of hard fiber, wood, or other good insulating material, and *f*, *g*, *h*, and *i* are fixed brushes arranged so that for about half a revolution of the drum *f* and *g* rest on *c* and *h* and *i* on *e*. For the other half revolution of the drum, the brushes *g* and *h* rest on segment *a*, which is permanently connected through the shaft, or otherwise, with the battery *b*, and brushes *f* and *i* are insulated from all segments. The drum should be turned at a speed of about 15 revolutions per second by a hand crank or by a small motor. The brushes *f* and *i* are connected, as shown, to two suitable resistances *m* and *n* and a galvanometer, thereby

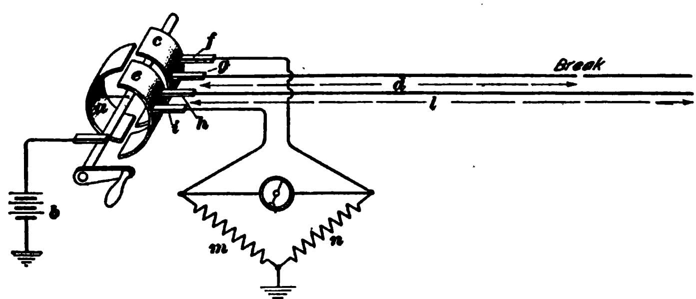


FIG. 14

forming a simple bridge. The brushes *g* and *h* are connected to a pair of line wires, one of which is broken at a distance *d* from the testing station, and both are open at the distant end.

When the brushes *g* and *h* rest on the segment *a*, both line wires receive a static charge from the battery. The charge taken by the broken wire will be proportional to the distance *d* to the break, while that taken by the good wire will be proportional to its total length *l*. When the brushes *f* and *g* rest on *c*, the broken wire will discharge through *n* to ground and the good wire, through *m* to ground. The drum is rotated fast enough to charge and discharge the line wires so quickly that the galvanometer deflection, when the bridge is unbalanced, cannot fall back to zero between impulses. By adjusting *m* and *n* until no deflection of the galvanometer is visible while the drum is being steadily rotated,

$$d = \frac{m\,l}{n}$$

Usually *n* can be made 1,000 ohms.

EXAMPLE.—One wire in a cable 1,200 feet long is open somewhere within the cable. When a balance was obtained by this method, the resistance in *n* was 1,000 ohms and in *m* 680 ohms. Determine the distance from the testing station to the break.

SOLUTION.—Substituting in the formula $d = \frac{m\,l}{n}$, gives the distance to the break as $\frac{680 \times 1{,}200}{1{,}000} = 816$ ft. Ans.

45. Reliability of Capacity Method.—The method for locating a break in a line wire by comparing the capacity of the broken wire with that of a similar good wire is reliable, provided that the insulation resistance is high and the break is so complete that no current passes through the point of rupture. If, however, the cable is moist and the insulation resistance thereby low, capacity methods are not reliable. In using these methods, therefore, it is best to measure the insulation resistance of the broken wire and also of the good wire. If the insulation resistance of the good wire is near 1 megohm, capacity methods are not very reliable; the insulation resistance of the good wire should preferably be about 20 megohms in order to obtain reliable results. Breaks in cables cannot be located as accurately as grounds or crosses under favorable conditions, because the electrostatic capacity is much more non-uniform than the resistance of the wire; in fact, the electrostatic capacity of a conductor in a telephone cable may vary as much as 5 per cent.

46. When a line wire breaks, it generally becomes crossed with another wire that is otherwise in good condition. In such cases, the fault can be located by means of a loop test for a cross or ground. When two wires break and become crossed without touching a third wire, usually one or both of the broken wires will touch the ground, in which case a loop method with the battery grounded may be used to locate the cross.

LOCATING BREAKS WITH ALTERNATING-CURRENT MILLIAMMETER

47. For locating breaks on open-line wires, accurate results may be secured by the use of alternating current, a condenser, and an alternating-current milliammeter. Connect in series between the home end of the line and the ground an adjustable condenser, the alternating-current milliammeter, and the alternating-current generator. Let the line be a good one open at the most distant station and adjust the condenser, or voltage of the generator, to give as large a reading on the milliammeter as practicable. Then with the same voltage, frequency of the alternating current, and condenser adjustment, readings are taken in succession with the line open at all available offices and test poles. From these readings, plot a curve with distances, in miles, to each station as abscissas and the corresponding milliammeter readings as ordinates.

A separate curve must be made along each line of poles. If a line contains any considerable length of cable, a reading should be taken with the line open at each end of the cable. By keeping a record of all subsequent measurements and the actual distance to breaks found by linemen, many new points can be located between offices and the curve changed to run through them also, thus making it more nearly correct.

48. As capacity and insulation resistance is subject to variation, it is advisable, before making a test, to take a reading to an opening on the faulty wire or on a good wire of the same size on the same pole line at the test office nearest the break. If any difference exists between this reading and that for the same distance on the curve, the voltage or condenser is adjusted until the same reading, as shown on the curve for that distance from the same office, is obtained.

A reading is then taken on the faulty wire to the break and its location is determined directly from the curve for that line of poles.

If the test is made from office *A* and the break is between offices *B* and *C*, and if the broken end of the line going to office *C* can be grounded, and the line looped back at office *C* over a good wire to the testing office *A*, check calculations can be made to locate the break more accurately. When both ends of the broken wire show heavy leakage, approximate locations may still be made, provided the wires are not dead-grounded. A direct-current milliammeter and a source of direct current with the negative terminal to line should be used to determine the amount of escape at the break. The ordinary voltmeter is not suitable for this purpose.

49. Within a radius of 150 miles, breaks can be located by this method with an average maximum error of not over 2 miles. Beyond this distance, the accuracy decreases, but it is of great value up to 200 miles; for a greater distance, the curve becomes too flat to be of use. It should be noted, however, that the accuracy of the test depends, to a great extent, on the insulation resistance of the line and a high degree of precision cannot be expected when the wire under test shows heavy leakage along its entire length.

In 1913, this method had been in use for nearly a year on a number of pole lines and had given most satisfactory results. The milliammeter used in connection with these tests has a scale reading from 0 to 75. It is dead beat and when used with condensers is not affected by induction from parallel circuits. Besides being used for breaks on outside lines, the alternating-current milliammeter may be used, by knowing the normal deflection to the end of a cable, to determine quickly if a circuit is open in the cable, in the protectors at the distant end of the cable, or beyond it. It also affords a quick means of locating open fuses in a distant test office.

LOCATING FAULTY POINTS IN SPLIT PAIRS

50. It occasionally happens that a wire belonging to one pair of conductors has been carelessly and incorrectly connected to a wire of another pair at some cable joint or transposition. Both pairs are then said to be split. To locate the faulty point is not always easy. In Fig. 15 (*a*), *s* represents one pair of conductors, *t* another pair, and *2* and *3* are the wires incorrectly joined at *y*. Later an attempt is made to remedy this condition at some other splice *z* in the cable, or perhaps at the main distributing frame or extreme end of the cable. This brings about the condition shown in (*b*), which will still give considerable cross-talk in a long cable and yet each conductor will appear to be in proper condition when tested in the

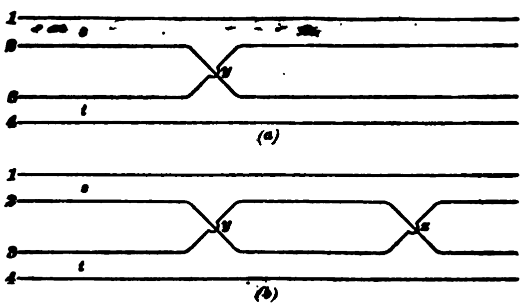


FIG. 15

usual way with a voltmeter or Wheatstone bridge. If only one pair out of the four wires is used, it will be noisy or a source of noise, especially if it is used as a toll trunk. The exploring coil method, which will be explained, has been successfully used to locate the point or points where the pairs are split.

51. Method Requiring One Measurement.—The point at which the *split*, that is, the incorrect connection was made, has been approximately located with much success, according to Adolph Jameston by the following method: In Fig. 16, *w* is a pair of wires in good condition the full length of the cable and *s* is the split pair being tested, the conductor *4* of which is connected with one wire *5* of the other split pair *t* at *y*. A telephone receiver *R* is connected across the arms *m* and *n* of a Wheatstone, or slide-wire, bridge while a buzzer *V* or other means of supplying a variable, or alternating, current is connected to the point *o*. The arms *m* and *n* are adjusted until

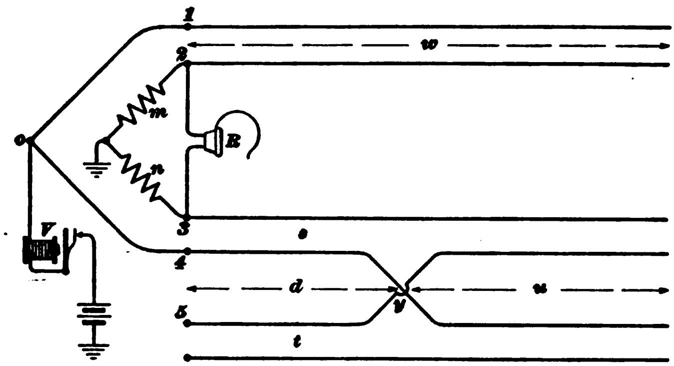


FIG. 16

no sound, or a minimum sound, is heard in the receiver; then *m* and *n* are inversely proportional to the capacities and hence also to the lengths *w* and *d*; that is, $\frac{m}{n}=\frac{d}{w}$, or

$$d=\frac{m\,w}{n}$$

in which *m* and *n* are expressed in ohms or divisions of a slide wire *d* and *w* in feet or any other convenient unit of length.

A more reliable result may be obtained by making the measurement from each end and taking the average of *d* and $w-u$ so found. This test is not infallible, because such things as a slight ground on either conductor of the split pairs, more than one splice in the split pairs, or many branch circuits or leads to terminal heads tapped on either split pair will cause an error in the result. Still, it is claimed that with all these chances for error, it is better than opening the cable indiscriminately until the trouble is found.

52. Method Requiring Two Measurements.—The connections for a method requiring two measurements for the location of the point where two pair are split are given in Fig. 17 (*a*) and (*b*). At *d* is shown a symbol frequently used to designate a source of alternating current. For this test it may be an induction coil with the secondary connected between the point *A* of the bridge and the ground or a buzzer producing an interrupted current will answer the purpose. The conductors *f* and *g* have their distant ends *f′* and *g′* grounded and their mates *e* and *h* are connected to the bridge at the testing station and left open at the distant station, as shown in (*a*).

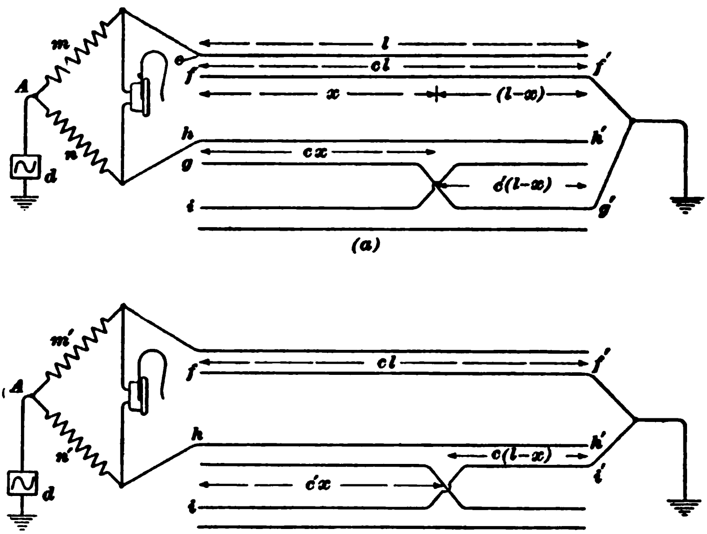


Fig. 17

If l represents the length of one pair of conductors, c the electrostatic capacity of the good pair *e f* per foot and c' the electrostatic capacity per foot between one wire of one pair and one wire of the other pair with which the first pair is split, then $c\,l$ is the total capacity of the good pair $c\,x$, the capacity of the pair *h g* from the testing station to the split point, and $c'\,(l-x)$, the capacity from the split to the distant station between wires g' and h'. When the bridge is balanced,

$$\frac{n}{m}=\frac{c\,l}{c\,x+c'\,(l-x)}$$

If instead of grounding the distant end g' of the conductor $g\ g'$, the distant end i of conductor $i\ i'$ is grounded, as shown in (*b*), and the bridge again balanced, it gives $\frac{n'}{m'} = \frac{c\,l}{c'\,x + c\,(l-x)}$.

Solving this last equation for c' gives $c' = \frac{c\,(m'\,l - n'\,l + n'\,x)}{n'\,x}$.

Substituting this value for c' in the equation for the first balance gives $\frac{n}{m} = \frac{c\,l}{c\,x + \frac{c\,(m'\,l - n'\,l + n'\,x)\,(l-x)}{n'\,x}}$.

Canceling the c and multiplying numerator and denominator by $n'\,x$ gives $\frac{n}{m} = \frac{n'\,l\,x}{m'\,l^2 - n'\,l^2 + 2\,n'\,l\,x - m'\,l\,x}$.

Canceling an l from the numerator and the denominator and clearing of fractions gives $n\,m'\,l - n\,n'\,l + 2\,n\,n'\,x - n\,m'\,x = m\,n'\,x$, and solving for x, the distance to the split, gives the formula:

$$x = \frac{n\,l\,(n' - m')}{2\,n\,n' - n\,m' - m\,n'}$$

For both balances, the same wires may be grounded at the home station instead of at the distant station; that is, the ends f and g may be grounded instead of f' and g', as shown in (*a*), and ends f and i instead of f' and i', as shown in (*b*).

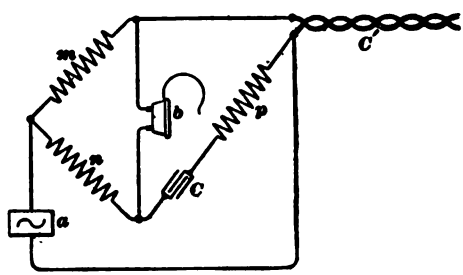


FIG. 18

53. Fisher's Method.—In a paper presented to the American Institute of Electrical Engineers, September, 1908, H. W. Fisher described a method of locating the joints where telegraph-cable conductors were unintentionally transposed and telephone-cable pairs unintentionally split. The arrangement of apparatus that is usually obtainable and may be used for measuring the capacities required in this method is shown in Fig. 18. The resistance arms *m*, *n*, and *p* of a bridge should be wound to have minimum inductance and capacity for good results; *C* is a reliable condenser of known capacity, *a* is a source of alternating current, and *b* is a telephone receiver. The resistance *p* assists in balancing the bridge but does not enter into the calculations. The capacity C' between the two wires joined to the bridge is given by the formula:

$$C' = \frac{n\,C}{m}$$

For a number of similar tests, only *n* and *p* need be varied, hence *m* and *C* remain constant, the ratio $\frac{C}{m}$ may be calculated once for all measurements and when multiplied by *n* gives the capacity C'. But for the tests about to be explained, relative capacities only are necessary, hence if *C* and *m* remain fixed in value, the resistances in arm *n* may be used instead of calculating the capacities $\frac{n\,C}{m}$ in each case in the formula to be given. As the capacities between similarly placed wires in a cable vary from 5 to 10 per cent., very accurate results are not to be expected.

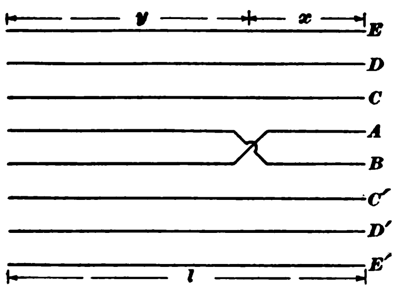


Fig. 19

54. No Wires Between Transposed Wires in Telegraph Cable.—Let Fig. 19 represent a number of wires in a layer of telegraph cable, the two wires *A* and *B* being transposed at a distance *x* from the testing station and *y* from the other end of the cable. The capacity between two wires will be represented by using both letters representing the wires, for instance the capacity between wires *A* and *B* will be designated by capacity *A B*. The general plan is to determine the capacity between adjacent wires and also the capacity between wires C and E, the latter being selected so that the number of wires between C and E is equal to the number between C and B and between C' and A.

55. Measure the capacity between the two wires A and B and let

$$\text{capacity } A\ B=a \qquad (1)$$

Measure the capacity between wires C and E and between C' and B and let their average value be

$$\frac{CE+C'E'}{2}=b \qquad (2)$$

Measure the capacities $C\ A$ and $C'\ B$, determine their average value, and let

$$\frac{C\ A+C'\ B}{2}=c \qquad (3)$$

Finally, measure the capacities $C\ B$ and $C'\ A$, let their average value be

$$\frac{CB+C'A}{2}=d \qquad (4)$$

If l is the total length of the cable, then the

$$\text{capacity per foot of equation (1) is } \frac{a}{l} \qquad (5)$$

$$\text{capacity per foot of equation (2) is } \frac{b}{l} \qquad (6)$$

Now $\frac{a}{l}\,x$ is the capacity of two adjacent wires for the distance x and $\frac{b}{l}\,y$ is the capacity of two wires with one wire between them for the distance y, whereas c is the average capacity between two wires that are adjacent to each other for the distance x and have one wire between them for the distance y, therefore

$$\frac{a}{l}\,x+\frac{b}{l}\,y=c \qquad (7)$$

Similarly, $\frac{a}{l}y+\frac{b}{l}x=d$ (8)

Solving equation (8) for y gives $a y+b x=d l$, $a y=d l-b x$, or

$$y=\frac{d l-b x}{a}$$

and substituting this value of y for y in equation (7) and solving for x gives $\frac{a x}{l}+\frac{b(d l-b x)}{a l}=c$, $a^2 x+b d l-b^2 x=a^2 c l$, $x(a^2-b^2)=a c l-b d l$, or

$$x=\frac{(a c-b d) l}{(a-b)(a+b)}$$

EXAMPLE.—Two wires in a telegraph cable 280 feet long were transposed and measurements gave the following values for the resistances in the arm n of the bridge when balanced: For $A B$, 167 ohms; for $C E$, 132.5 ohms; for $C' E'$, 133 ohms; for $C A$, 148 ohms; for $C' B$, 145.5 ohms; for $C B$, 147.5 ohms; and for $C' A$, 150.5 ohms. What is the distance x to the transposition?

SOLUTION.— $b=\frac{132.5+133}{2}=132.75$, $c=\frac{148+145.5}{2}=146.75$, $d=\frac{147.5+150.5}{2}=149$. Substituting these values in the formula for x gives $x=\frac{(167\times 146.75-132.75\times 149)\times 280}{(167-132.75)\times(167+132.75)}=128.9$ ft. Ans.

The cable was opened and the transposition was found to be 130 ft. from testing station; hence, the formula gave a result only 1.1 ft. too small.

56. Several Wires Between Transposed Wires in Telegraph Cable.—In Fig. 20, let A and B, as before, be the two transposed wires, between which (in the same layer) there are one or more wires. The wire outside of and adjacent to A in the same layer should be marked C and the wire outside of and adjacent to B in the same layer C'. Then mark a wire E, which is so located that there is the same number of wires between C and E as between C and B, and mark a wire E' which is so located that there is the same number of wires between C' and E' as between C' and A. Measurements of capacities can now be made exactly as when there were no wires between the two transposed, except that for capacity $AB = a$ determine the average capacity of several pairs of adjacent wires near but not including A or B. The wires that may be measured for a are CH, HD, $C'H'$, $H'D'$, FG, and $F'G$. Then make the measurements for calculating the values of b, c, and d and calculate the distance to the fault by using the formula for x, in Art. 55.

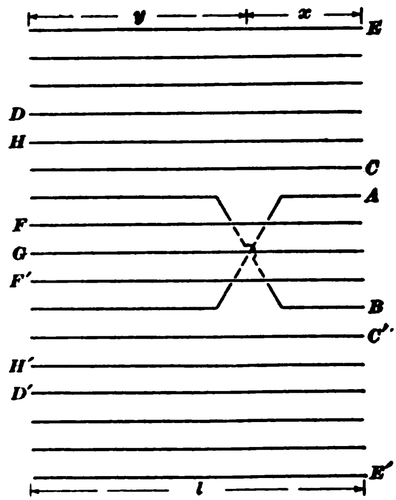


FIG. 20

57. For a check-value of the distance to the transposition, determine a separate set of values for b, c, and d by selecting a wire H such that the number of wires between F and H equals the number between F and B; also a wire H' such that the number of wires between F' and H' equals the number between F' and A. Then,

$$\frac{FH + F'H'}{2} = b, \quad \frac{FA' + F'B}{2} = c, \text{ and } \frac{FB + F'A}{2} = d$$

With these and the previously determined value of a, a check-value of the distance x can be found by using the same formula for x.

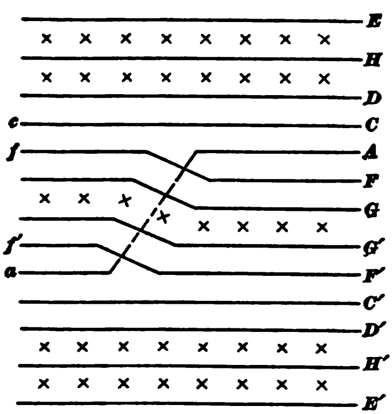


FIG. 21

58. Single Displaced Wire in Telegraph Cable. Fig. 21 illustrates the case of a single displaced wire in a telegraph cable. Select certain wires so that the number of wires between C and E and between C' and E' equals the number between c and a; also the number between F and H and between F' and H' equals the number between f and a. Having tagged the wires as shown, the same measurements previously explained are made, except those involving the wire B, which does not exist here. Therefore, only one-half the number of measurements can be made to get c and d and hence an accurate location of the fault cannot be expected.

59. Split Pairs in Telephone Cables.—No attempt is made to connect pairs where the ends of two telephone cables join in any definite order, in fact the pairs are usually mixed

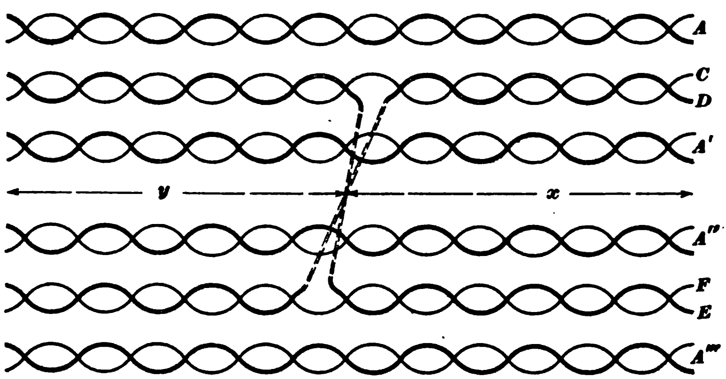


FIG. 22

up as much as possible to make more uniform the capacity of the various pairs. For this reason, H. W. Fisher says it is more difficult to locate split-pair faults accurately and that some methods used are not reliable and give only a rough approximation.

In Fig. 22, let A, A', A'', and A''' represent four good pairs in a telephone cable, C, D, E, and F split pairs, C and F wires correctly connected, and D and E wires cross-connected. First determine the average individual capacity of properly transposed pairs and call this average a. It is not absolutely necessary to take just four pairs, but enough should be measured to insure a good average result. As for telegraph cables, let the capacity

$$\frac{C\,D+E\,F}{2}=c \text{ and } \frac{C\,E+F\,D}{2}=d$$

60. The capacity b given by equation 2 in Art. **55,** can be made fairly uniform throughout the cable by grounding all the wires in the cable, except those used in this test, and then eliminating it from the formula. Mr. Fisher states that, by referring to Fig. 22, it can be said "that the capacity b is equal to the capacity $C\,E$ throughout the distance x added to the capacity $C\,D$ throughout the distance y. Now as a is the capacity of a pair, it can be said that a equals the capacity $C\,D$ throughout the distance x added to the capacity $C\,E$ throughout the distance y. This gives the relation $b=c+d-a$." Substituting this value of b in the formula for x in Art. **55,** gives

$$x=\frac{(a-d)l}{2\,a-(c+d)}$$

which gives the distance x to a split in a pair of telephone-cable conductors. l and x must be in the same units, both in feet, both in miles, or both in meters, etc. The farther the split pairs are apart, the nearer is the fault correctly located. The error, in feet, is much smaller when all the wires not used in the test are grounded on the lead sheath than when all wires are insulated.

TESTING OF CIRCUITS
(PART 2)

LOCATION OF FAULTS

TESTS FOR LOCATING A GROUND

GENERAL TESTS

1. Accidental connections with the ground occur much more frequently than breaks, and are often difficult to locate, especially if more than one ground occurs on the same line wire. When locating, with a Wheatstone bridge, faults having a high resistance, it may be necessary to use a battery containing 50 or more cells. In such cases, care must be used not to overheat or damage the bridge coils. Various methods for locating grounds will be given, as no one method is always applicable.

2. Swings.—When a fault is intermittent, a Morse relay may often be advantageously connected in series with the bridge battery, the relay being so adjusted that when the fault is closed the relay will close the circuit of a sounder or vibrating bell so located as to be readily heard by the one making the test. The battery key is then held permanently closed, but the galvanometer key is closed only when the sounder or bell gives notice that the fault is closed.

3. Ground on a Line of Known Resistance.—Where there is a dead ground on a line having a known length and resistance, it is a simple matter to locate the distance to the dead ground from the testing station. Let f be the known resistance of the line and L the length of the line, in miles; then, if the line wire is uniform in size and material, $\frac{f}{L}$ is the normal resistance of the line per mile. To locate the distance to a dead ground in such a case, measure the resistance between the home end of the line and the ground and let this be a ohms. Then, the number of miles x from the testing station to the dead ground is given by the formula:

$$x = \frac{aL}{f}$$

EXAMPLE FOR PRACTICE

A wire touched the ground so that the resistance in the fault could be neglected. A test was made at the station, and the unplugged resistance in the rheostat amounted to 326 ohms, a ratio of 1 being used in the balance arms. What was the distance to the fault, the resistance of the wire being 16.1 ohms per mile? Ans. 20 mi. 438 yd.

TESTS FROM BOTH ENDS WITHOUT A GOOD WIRE

4. Earth Overlap Method.—Where there is no available good wire and tests can be made from each end of a grounded wire, the earth overlap method may be used. It is especially

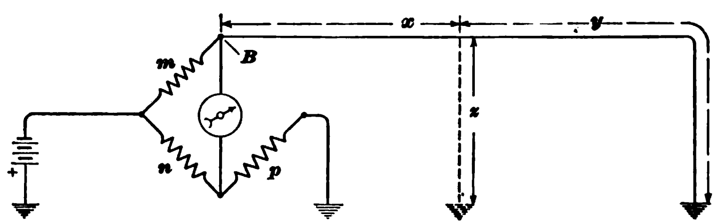


FIG. 1

valuable for the location of high-resistance faults; and is the best practical method for locating grounds in submarine cables, when there is only one ground and no good wire is available. Let x represent the resistance from one end of the conductor to the fault, and y the resistance from the other end of the conductor to the fault. First, measure, with a Wheatstone bridge, the resistance from the x end with the other end grounded, the connections being made as shown in Fig. 1. Call the resistance thus measured a ohms. Then,

$$a=x+\frac{y\,z}{y+z}$$

Second, measure, in the same manner, the resistance of the grounded wire from the other, or y, end with the other end grounded; call the resistance so determined b ohms. Then,

$$b=y+\frac{x\,z}{x+z}$$

Furthermore, if f is the normal or total resistance of the faulty wire, then

$$f=x+y$$

Solving these equations for x and y, gives

$$x=\frac{a\,(f-b)}{a-b}\left[1-\sqrt{\frac{b\,(f-a)}{a\,(f-b)}}\right] \qquad (1)$$

$$y=\frac{b\,(f-a)}{b-a}\left[1-\sqrt{\frac{a\,(f-b)}{b\,(f-a)}}\right] \qquad (2)$$

NOTE.—Formula 1 may be derived as follows:

$$a=x+\frac{y\,z}{y+z}, \text{ or } a\,y+a\,z=x\,y+x\,z+y\,z, \text{ or } z\,(a-x-y)=x\,y-a\,y \qquad (1)$$

$$b=y+\frac{x\,z}{x+z}, \text{ or } b\,x+b\,z=y\,x+y\,z+x\,z, \text{ or } z\,(b-y-x)=x\,y-b\,x \qquad (2)$$

$$f=x+y, \text{ or } y=f-x \qquad (3)$$

Substitute (3) in (1), then

$$z\,(a-f)=x\,(f-x)-a\,(f-x)=f\,x-x^2-a\,f+a\,x=-x^2+x\,(f+a)-a\,f \qquad (4)$$

Substitute (3) in (2), then

$$z\,(b-f)=x\,(f-x)-b\,x=x\,f-x^2-b\,x=-x^2+x\,(f-b) \qquad (5)$$

Divide (4) by (5), $\frac{a-f}{b-f}=\frac{-x^2+x\,(f+a)-a\,f}{-x^2+x\,(f-b)}$

Simplifying gives

$$-a\,x^2+a\,f\,x-a\,b\,x+\cancel{f}\cancel{x^2}-f^2\,\cancel{x}+\cancel{b}\cancel{f}\,\cancel{x}=-b\,x^2+\cancel{b}\cancel{f}\,\cancel{x}+a\,b\,x-a\,b\cancel{f}+f\,\cancel{x^2}$$
$$-\cancel{x}\,f^2-a\,f\,x+a\,f^2,$$

or

$$x^2\,(-a+b)+x\,(2\,a\,f-2\,a\,b)=a\,f\,(f-b)$$

Dividing by $-(a-b)$ and then adding $\left[\frac{a\,(f-b)}{a-b}\right]^2$ to each side of the equation gives

$$x^2-2\,x\,\frac{a\,(f-b)}{a-b}+\left[\frac{a\,(f-b)}{a-b}\right]^2=\left[\frac{a\,(f-b)}{a-b}\right]^2-\frac{a\,f\,(f-b)}{a-b}$$

Extracting the square root and multiplying numerator and denominator of the last quantity by $(f-b)$ $(a-b)$ gives

$$x-\frac{a\,(f-b)}{a-b}=\pm\sqrt{\frac{a^2\,(f-b)^2}{(a-b^2)}-\frac{a^2 f\,(f-b)^2\,(a-b)}{a\,(f-b)(a-b)^2}}$$

The negative sign must be used to get a rational answer.

$$x=\frac{a\,(f-b)}{(a-b)}-\frac{a\,(f-b)}{(a-b)}\sqrt{1-\frac{f\,(a-b)}{a\,(f-b)}}$$

$$x=\frac{a\,(f-b)}{a-b}\left[1-\sqrt{\frac{af-a\,b-af+f\,b}{a\,(f-b)}}\right]$$

$$x=\frac{a\,(f-b)}{a-b}\left[1-\sqrt{\frac{b\,(f-a)}{a\,(f-b)}}\right]$$

Formula 2 may be derived in a similar manner, eliminating x and z instead of y and z.

5. More accurate results are secured in the earth overlap method by sending, approximately, equal currents through the fault during the tests made from the two ends. For this reason, equal bridge ratios m and n and batteries of equal elec-

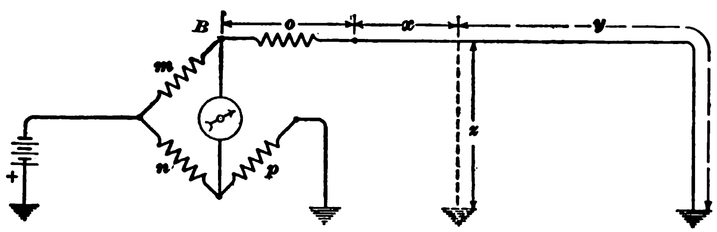


Fig. 2

tromotive forces should be used at each end and a suitable resistance o inserted in series with the lower resistance end so as to approximately equalize the resistance on each side of the fault. The arrangement, when making the test from the lower resistance end x, is shown in Fig. 2. When the measurement is made from the y end, this compensating resistance must be left in the circuit and the point B must be grounded, thereby leaving o in series with x, and $f+o$ must be substituted for f in the formulas given in Art. **4**.

6. If o is adjusted so that equal currents flow during the measurements from each end, the formulas reduce to

$$x=\tfrac{1}{2}(f-o) \qquad (1)$$

$$y=\tfrac{1}{2}(f+o) \qquad (2)$$

The zinc, or negative, terminal of the battery should be connected toward the line and the tests in the earth overlap method should be made alternately and as rapidly as possible from each end, so that pairs of readings may be secured while the fault undergoes as little change as possible.

When one end of a good line is grounded and its resistance measured, the result, called its *apparent resistance*, will be less than the true resistance of the conductor when perfectly insulated. Better results will be obtained in the earth overlap method if for f the apparent resistance of the wire measured under normal conditions, that is, free from faults, is used, rather than its true resistance, which is usually determined from a wire table. The shorter the line or the better its insulation, the less is the error due to using the true resistance.

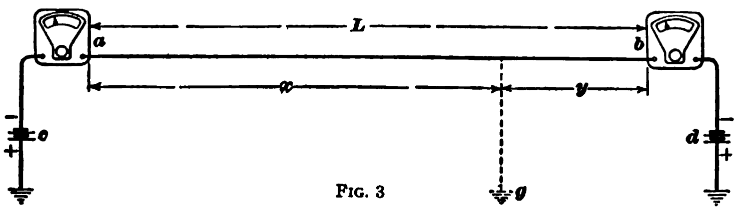


FIG. 3

7. Ammeters at Each End.—A good method for locating a ground where no good wire is available and where an ammeter or milliammeter and similar batteries are available for making simultaneous readings at each end is indicated in Fig. 3. At both ends connect between the line and ground similar ammeters a and b and similar batteries c and d of like voltage, like poles being connected to the ground. The batteries oppose each other and no current would flow if the line was perfectly insulated; but on account of the ground some current will flow through each ammeter. The ammeters at both ends are read, then both batteries are reversed and the ammeters again read. Let the average of the two readings at a be a amperes and the average of the two readings at b be b amperes, if L is total length of line, in miles, the distance to the ground g from end a is

$$x = \frac{b\,L}{a+b}, \qquad (1)$$

The distance, in miles, to the ground from end b is

$$y=\frac{aL}{a+b} \qquad (2)$$

Example.—A No. 9 B. W. G. iron line wire connecting two stations 25 miles apart was tested for a ground between the stations by connecting a milliammeter and an 80-volt battery at each end between the line and the ground, with the negative terminals of both batteries toward the line. The ammeter at end a read 300 milliamperes and that at end b 150 milliamperes. What is the distance to the ground from end a?

Solution.—Reducing the milliamperes to amperes, although not really necessary, and substituting in formula **1**, gives the distance from end a to the ground as

$$x=\frac{.15\times 25}{.3+.15}=8.33 \text{ mi.} \quad \text{Ans.}$$

TESTS FROM BOTH ENDS WITH A GOOD WIRE

8. Good Wire of Unknown Resistance or Length.—A ground on a wire of known resistance f or known length l may be located by tests made with a bridge from both ends by the use of a good wire of unknown resistance or length. Join the good and bad wires together at the distant end S and balance a bridge located at the end N and connected as shown in Fig.

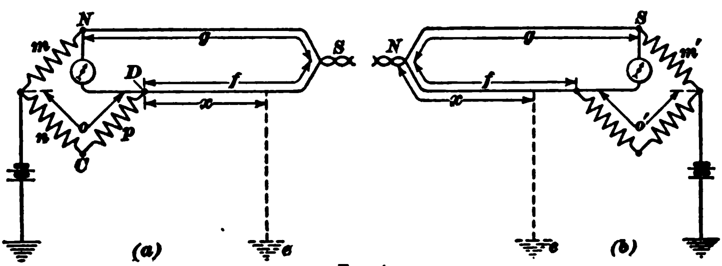


Fig. 4

4 (a), in which the battery has one terminal grounded, and the galvanometer has one terminal connected to junction D. Or the galvanometer may be connected to junction C, which is the usual Wheatstone bridge arrangement; and the arm p short-circuited, provided the arm n contains enough adjustable resistances. Or a slide-wire bridge may be used for the two arms m and $n+p$. Let f represent the resistance of the faulty

wire and g the unknown resistance of the good wire. Then $f+g=R$, in which R is the resistance of the loop formed of the two line wires. When the bridge is balanced and o represents $n+p$, the connections shown in (a) give,

$$\frac{m}{o}=\frac{R-x}{x}, \text{ or } \frac{m}{o}=\frac{g+f-x}{x}, \text{ or } g=\frac{x\,(m+o)-f\,o}{o}$$

Then with a bridge arranged at the other end in a similar manner, as shown in (b), and balanced,

$$\frac{m'}{o'}=\frac{g+x}{f-x}, \text{ or } g=\frac{f\,m'-x\,(m'+o')}{o'}$$

Equating the two values of g, thereby eliminating the wire of unknown resistance or length, and solving for x gives,

$$\frac{x\,(m+o)-f\,o}{o}=\frac{f\,m'-x\,(m'+o')}{o'}$$

or $x\,o'\,(m+o)-f\,o\,o'=f\,m'\,o-x\,o\,(m'+o')$, or $x\,[o'\,(m+o)+o\,(m'+o')]=f\,o\,o'+f\,m'\,o$; hence,

$$x=\frac{f\,o\,(m'+o')}{o'\,(m+o)+o\,(m'+o')} \qquad (1)$$

In this formula, the resistance f of the faulty wire must be known from some previous measurement or calculated from its known size, length, and material by the help of a wire table. As the resistance of a uniform wire is proportional to its length, if the wire is of the same size and material from N to S, and if d represents the distance from D to the ground e and L the distance between the two stations,

$$d=\frac{L\,o\,(m'+o')}{o'\,(m+o)+o\,(m'+o')} \qquad (2)$$

9. Slide-Wire Bridge and Good Wire of Unknown Resistance and Length.—When a slide-wire or other bridge where $m+o$ is always equal to $m'+o'$, is used in the place of a Wheatstone bridge in the preceding method, the formulas reduce to

$$x=\frac{f\,o}{o+o'} \qquad (1)$$

$$d=\frac{L\,o}{o+o'} \qquad (2)$$

EXAMPLE.—A test was made to locate a ground on a line wire connecting two stations 50 miles apart by slide-wire-bridge measurements from each end and using a good wire of unknown resistance or length that ran in a roundabout way between the two end stations. The slide wire was 1,000 millimeters in length. A balance was obtained at one end station N when the slide-wire pointer rested on the slide wire 720 millimeters from the junction of the good wire and the slide wire. A balance was secured at the other end station S when the slide-wire pointer was 640 millimeters from the junction of the good wire and slide wire. How far from station N is the ground?

SOLUTION.—In formula 2, o will represent the distance along the slide wire from its junction with the faulty wire to the slide-wire pointer that is connected to the battery. Hence, $o = 1{,}000 - 720 = 280$, and $o' = 1{,}000 - 640 = 360$. Substituting in formula 2 gives

$$d = \frac{50 \times 280}{280 + 360} = \frac{1{,}400}{64} = 21.9 \text{ mi. Ans.}$$

TEST FROM ONE END WITHOUT A GOOD WIRE

10. Blavier Test.—The Blavier method for locating a partial ground or an escape is about the only way where there is no available good wire and when the test must be made from

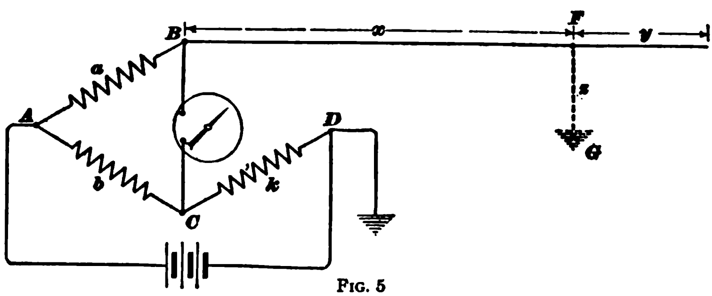


FIG. 5

one end only. However, this method is rather unreliable in practice, because, if the resistance of the partial ground changes between the two measurements, the result will be very unreliable, and moreover the normal, or total, resistance of the line must be known from some previous measurement, obtained from a wire table, or calculated from the length, size, and conductivity of the line wire. Let the total resistance of the line wire be f. First, measure the resistance of the line with the distant end open, as indicated in Fig. 5, and call the resistance so obtained b. Also, measure the resistance of the line with the distant end grounded, as shown in Fig. 6, and call this resistance c. Then, the resistance x to the partial ground from the testing station is given by the formula:

$$x = c - \sqrt{(b-c)\,(f-c)}$$

By dividing x by the resistance per unit length of the wire, known from some previous measurement, obtained from a wire table, or calculated by the length, size, and conductivity of the

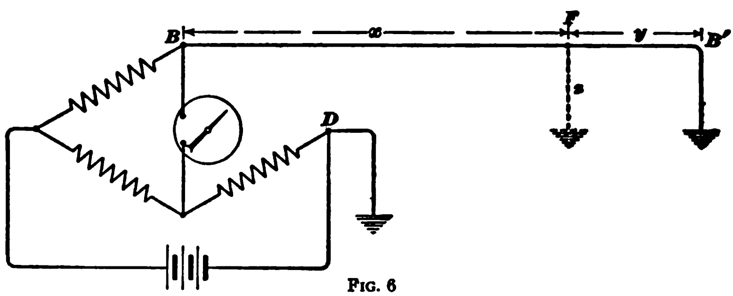


FIG. 6

line wire, the distance to the partial ground is obtained. If L is the length of a cable and f the total resistance of the bad wire to the distant end of the cable, the distance to the fault is $\frac{x\,L.}{f}$

11. The accuracy of the result obtained by this test depends on the resistance z of the fault remaining the same during both measurements. The farther the fault lies from the tested station, the more accurate will be the result; so the more reliable result will be that obtained by making the test from the end that is the farther from the fault. However, if two faults exist, the best result is obtained by making the test at the end the nearer to the one to be located. Where a series of observations is taken, the most accurate result is secured by using the lowest of all the readings taken with the distant end open and the lowest with the distant end grounded; but if the resistance of the fault is very unsteady the means of each series may be used.

NOTE.—The formula for the Blavier test is derived as follows: Let the resistance of the home end of the line to the fault F, where the partial ground occurs, be x ohms, the resistance from F to the distant end be y ohms, and the resistance of the fault be z ohms. Calling f the normal resistance of the whole line, $x+y=f$. When the partial ground is present but the distant end open, $x+z=b$. Finally, when the partial ground is present and the distant end grounded, y and z are in parallel with each other, but in series with x; hence,

$$x+\frac{yz}{y+z}=c$$

These three equations may be solved for x as follows: From the first equation $y=f-x$, and from the second $z=b-x$. Substitute these values of y and z for y and z in the third equation, giving

$$c=x+\frac{(f-x)(b-x)}{(f-x)+(b-x)}=x+\frac{bf-fx-bx+x^2}{f-2x+b}$$

Clearing this equation of fractions gives,

$$cf-2cx+bc=\cancel{fx}-2x^2+\cancel{bx}+bf-\cancel{fx}-\cancel{bx}+x^2$$

or

$$x^2-2cx=-bf-cf-bc$$

Complete the square of the first side by adding c^2 to each side,

$$x^2-2cx+c^2=bf-cf-bc+c^2=f(b-c)-c(b-c)=(b-c)(f-c)$$

Then $x-c=\pm\sqrt{(b-c)(f-c)}$, and the resistance from the testing station to the partial ground or escape is

$$x=c\pm\sqrt{(b-c)(f-c)}$$

Evidently, the minus sign $(-)$ must be used, because x cannot be greater than c.

12. Ayrton Test.—The Ayrton method is a modification of the Blavier, not so convenient as the latter, but suitable when the resistance f of the line is not known with sufficient accuracy for the Blavier method. Besides measuring the

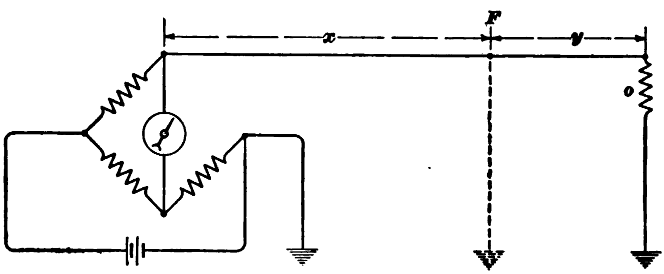


FIG. 7

resistance b of the line with the distant end open and the resistance c with the distant end grounded, it is necessary to measure the resistance d with the distant end grounded through a known resistance o, as shown in Fig. 7. Then the resistance x from the testing station to the ground at F is given by the formula

$$x=b-\sqrt{\frac{(b-d)\ (b-c)o}{b-c}} \qquad (1)$$

The resistance y from the fault to the distant end is given by the formula:

$$y=\frac{(x-c)\ (x-b)}{b-c} \qquad (2)$$

Furthermore, $$f=x+y \qquad (3)$$

Then the distance to the fault equals $\frac{xL}{f}$ in which L is the length of the cable. The resistance of the fault is equal to the term that is subtracted from b in formula **1**. This method can only be used occasionally, because the resistance of the fault is generally too variable while three measurements are being made to give reliable results.

LOOP TESTS WITH ONE OR MORE GOOD WIRES

13. Varley Loop Test.—Where there is one available good wire, the Varley loop method is probably the most convenient and best method for locating a ground or cross on a line. The distant ends of the good and bad wires are joined

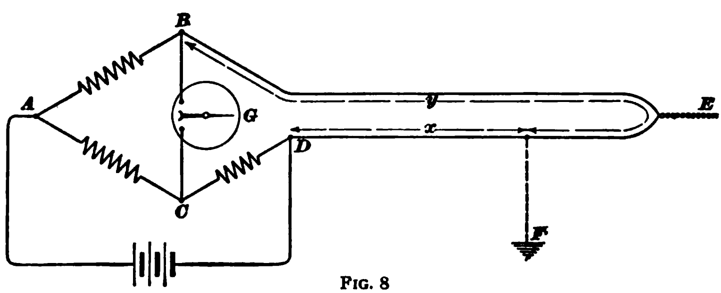


FIG. 8

together and the resistance of the loop so formed is measured with the Wheatstone bridge, if not already known from some previous measurement, by connecting as shown in Fig. 8. G is a reflecting galvanometer connected across the arms of a Wheatstone bridge in the ordinary manner; AB and AC are the ratio arms of the bridge, and CD is the rheostat or variable arm. DE is the faulty line, BE the good line, and F the location of the fault, assumed to be a ground in this case. The ends B and D of the loop are connected across the terminals of the bridge, so as to form the unknown resistance or fourth arm of the bridge. The battery is connected between A and D. Balance the bridge and let the resistance of the loop, found by working out the bridge proportion as usual, be R. Then connect one end of the battery to the ground, instead of to D, as

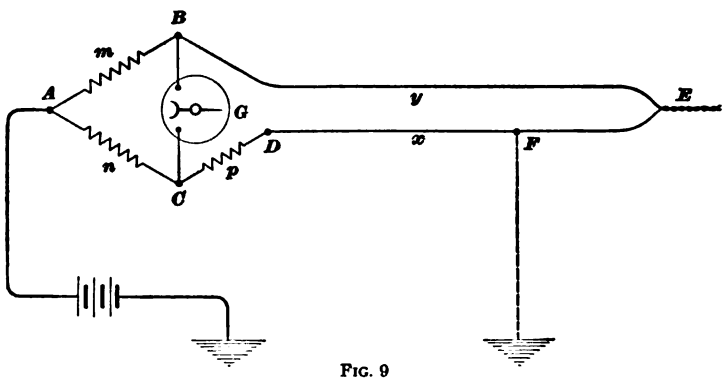


FIG. 9

shown in Fig. 9. Call y the resistance of the loop from B through E to F, x the resistance from D to F, and R, the total resistance of the loop, is equal to $x+y$. Then, when the bridge is balanced,

$$\frac{m}{n}=\frac{y}{p+x}=\frac{R-x}{p+x};\quad m\,p+m\,x=n\,R-n\,x;\quad m\,x+n\,x=n\,R-m\,p.$$

Hence, the resistance,

$$x=\frac{n\,R-m\,p}{m+n}$$

This is entirely independent of the resistance of the fault or of any earth currents that may exist. Having found x, and knowing the resistance of the wire per foot, the distance to the fault is readily calculated.

EXAMPLE.—A ground occurred on one conductor of a cable 10,000 feet long, composed of three No. 14 B. & S. gauge insulated copper conductors. At the distant end, the grounded conductor was joined to one good conductor. On testing, with the connections shown in Fig. 9, the bridge was balanced with the following resistances: $m=10$ ohms, $n=1{,}000$ ohms, and $p=4{,}642$ ohms. One good wire was used to complete the loop. Where is the ground, the resistance per thousand feet of the conductor being 2.521 ohms at the temperature of the test?

SOLUTION.— $R=2\times 10\times 2.521=50.42$ ohms, or R could have been actually measured by connecting the bridge as shown in Fig. 8 and balancing it. Then, the resistance

$$x=\frac{1{,}000\times 50.42-10\times 4{,}642}{1{,}000+10}=3.9604 \text{ ohms}$$

Distance from testing station is $\frac{3.9604}{2.521}\times 1{,}000=1{,}571$ ft. Ans.

14. Check-Method.—A check on the result of the last method may be obtained by reversing the connections of the good and bad wires with the bridge, the connections being otherwise as shown in Fig. 9. If m', n', and p' are now the resistance in the bridge arms required to give a balance, $\frac{m'}{n'}=\frac{x'}{p'+y'}$; solving for x' gives $\frac{m'}{n'}=\frac{x'}{p'+R-x'}$, $p'm'+m'R-m'x'=n'x'$, $p'm'+m'R=n'x'+m'x'$, $x'(n'+m')=m'(p'+R)$, or the resistance

$$x'=\frac{m'(p'+R)}{m'+n'}$$

The average of x obtained by the formula in the last article and this x' will give a more correct result than either one, if both have been measured under the same conditions and with equal care.

If x' is the result obtained by the formula just given and x the result obtained by the formula in Art. **13**, and two lead wires are used between the bridge and the line wires in making the Varley loop test, and s is the resistance of the lead wire in series with the bad wire, the corrected average resistance x'' of the bad wire to the fault is given by the formula:

$$x''=\frac{x+x'-2s}{2}$$

If the two lead wires are negligible in resistance, compared with the resistance along the bad wire to the fault, no corrections need be made for them.

15. Resistance of Loop Uniform.—If the loop whose resistance is R is uniform in resistance, the distance between stations or length of loop is L, and the ratio $\frac{m}{n}$ is made equal to 1 when making the second, or Varley, balance, then

$$1=\frac{R-x}{p+x}, \text{ or } x+p=R-x$$

or

$$x=\frac{R-p}{2} \qquad (1)$$

Multiplying each term by the number of feet in an ohm of the line wire gives $x \times$ feet per ohm = distance d to ground from testing station, and hence

$$d=\left(\frac{R-p}{2}\right)\times \text{feet per ohm of faulty wire} \qquad (2)$$

Dividing each term of $x=\frac{R}{2}-\frac{p}{2}$ by the resistance of the conductor per mile, which is $\frac{R}{2L}$, gives $\frac{x}{\frac{R}{2L}}=\frac{R}{\frac{R}{L}}-\frac{p}{\frac{R}{L}}$, but $\frac{x}{\text{res. per mile}}$ is the distance d to the ground from the testing end, hence

$$d=L\left(1-\frac{p}{R}\right) \qquad (3)$$

Furthermore, $L-d=\frac{pL}{R}$, but $\frac{L}{R}$ is the number of feet per ohm, hence the distance from the distant end to the ground, when the loop consists of wires of uniform resistance per unit length, is very simply obtained by multiplying the resistance p in the rheostat arm of the bridge for the Varley balance by the feet per ohm of the faulty line wire, or

$$L-d=p\times \text{feet per ohm} \qquad (4)$$

16. Large Good Wire.—If the good wire is larger, and hence lower in resistance, than the faulty wire and the fault is near the far end of the smaller wire, a balance may not be obtainable with the bad wire joined to the rheostat arm, as shown in Fig. 9. In such a case reverse the line-wire connections on the bridge and with $m = n$

$$x = \frac{R-p}{2}$$

The distance, in miles or in feet, to the ground from the testing station may be calculated by dividing the value found for x by the ohms per mile or per foot of the faulty wire.

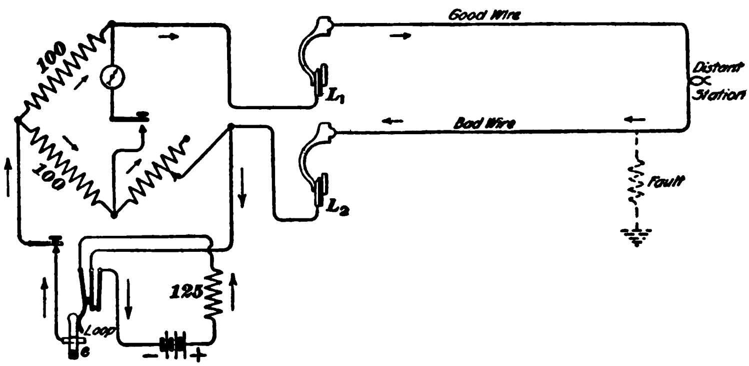


FIG. 10

17. For the first measurement in the Varley loop test made with the Western Union bridge, the connecting plug e is inserted in the loop jack, the wedge L_2 is inserted at the switchboard in a spring jack to which is connected a bad wire on which the fault is to be located, and wedge L_1 is inserted at the switchboard in a spring jack to which is connected a good wire running to the same distant station as the bad wire. With this arrangement, shown in Fig. 10, the bridge is balanced and the resistance R of the loop, formed by the good and bad wires, is determined.

To obtain the second balance in the Varley-loop test, transfer the connecting plug to either the positive or negative battery jack, say the positive jack $Vg+$; if the fault has a positive ground potential the negative-battery jack should be used and vice versa. This arrangement is shown in Fig. 11.

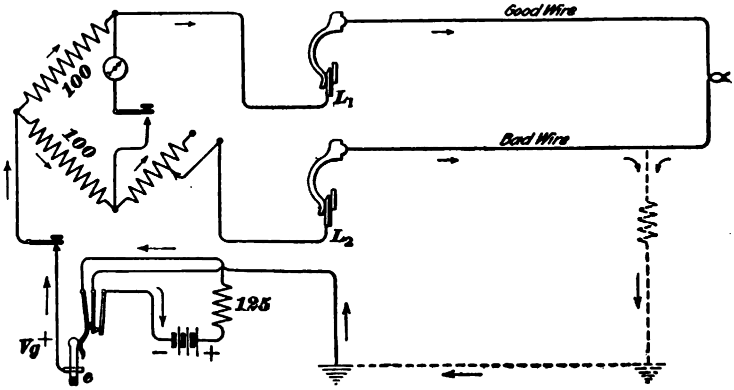


FIG. 11

18. High Resistance Faults.—When making bridge measurements, it sometimes occurs that the galvanometer is not affected by a change of 1 or more ohms in the rheostat arm. When this is due to high resistance at the fault, the difficulty may be eliminated by using a much higher testing voltage, taking care to protect the bridge by connecting a sufficiently high resistance in the battery circuit. With the Western

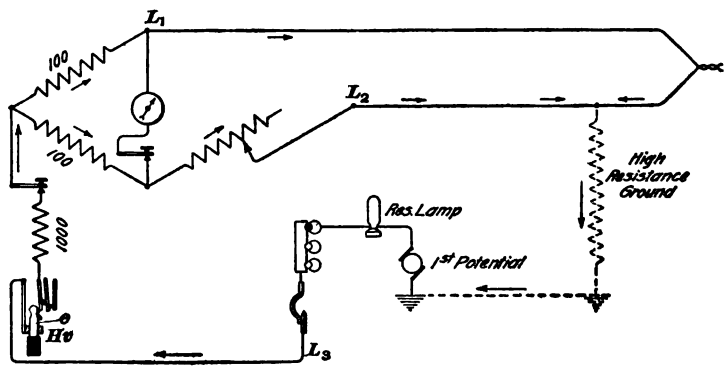


FIG. 12

Union bridge, this is readily done by inserting, as indicated in Fig. 12, the connecting plug *e* in the jack marked *Hv* on the jack-box. This disconnects the regular bridge battery and its 125-ohm protecting resistance and in its place puts a 1,000-ohm resistance between the bridge and the wedge, which is marked L_3 and which can now be inserted in a switchboard jack to which is connected a battery tap of about 60 volts.

In extreme cases, it is allowable to use up to 120 volts for this purpose, but no higher voltage should ever be used.

19. Corrections for Lead Wires.—For very accurate results, corrections must be made when lead wires are used between the bridge and the line wire in the Varley loop test. If both the lead wires are of the same size, length, and material, use one-half their combined resistance as the resistance of the lead wire in series with the faulty wire.

It is simplest to use lead wires of the same size and material as the faulty wire in all tests where lead wires must be used. In most loop tests the lengths of both lead wires must then be added to the length of the loop, which is equal to the length of the good wire plus that of the bad wire, and from the calculated distance to the fault from the testing end to subtract the length of the leading wire connected to the faulty wire.

20. If lead wires are different in size from the line wires, multiply the length of each lead wire by its rated resistance per 1,000 feet and divide by the rated resistance per 1,000 feet of the line wire. The values thus found represent equivalent length of line wire having a resistance equal to each lead wire. If the resistance of the lead wire is known, divide it by its rated resistance per foot (usually obtained from a table) to get the equivalent length of faulty wire having the same resistance.

If the separate resistance of two fixed lead wires is unknown but desired, join them together at the end and measure the loop resistance, which gives R. Then ground the end junction and apply the Varley or Murray loop test to get the resistance of one lead x. The other lead has, of course, a resistance y equal to the difference between R and x.

21. H. W. Fisher gives the following method for determining the resistance of the lead wire in series with the bad wire when both ends of this lead wire cannot be directly connected to and its resistance directly measured by the Wheatstone bridge. Let s be the resistance of the lead wire in series with the bad wire. Connect the bridge as in Fig. 9, and let p be the resistance in the arm CD, m the resistance in the arm AB, and n the resistance in the arm AC when the bridge is balanced. Completely reverse the position of the lead wires, with respect to both the bridge and the line wires; use the same ratio resistances m and n as before and let p' be the resistance required in the arm CD to again balance the bridge. Then join the distant ends of the lead wires and obtain their resistance S with the bridge in the usual manner. Then the resistance s of the lead wire in series with the bad wire is given by the formula:

$$s=\frac{S}{2}+\frac{m(p'-p)}{2(m+n)}$$

22. Total Resistance of Bad Wires.—By the Varley loop method, the resistance of the bad wire to the fault is obtained. If, in addition to this, the total resistance f of the faulty wire to the distant end of the cable can be determined correctly, the resistance x to the fault can be divided by this total resistance f, which gives a ratio that when multiplied by the length L of the cable or line gives the distance d to the fault; that is, the distance

$$d=\frac{xL}{f}$$

23. Total Resistance of Bad Wire When Only One Good and One Bad Wire Are Available.—The total resistance f of the bad wire to the distant end cannot be very accurately determined when only one good and one bad wire are available. When the good and bad wires are in the same layer in the cable and are both the same size, the total resistance of the bad wire may be taken as half the loop resistance R. If lead wires are used between the bridge and the line wires, their resistance S must be subtracted from the loop resistance and the result divided by 2 to get the total resistance f of the bad wire; that is,

$$f=\frac{R-S}{2}$$

24. If the good and the bad wires are of different but known lengths and sizes and both at the same temperature,

Let l = length of bad wire;
r = resistance per 1,000 feet of bad wire, according to a reliable wire table;
l' = length of good wire;
r' = resistance per 1,000 feet of good wire, according to same table;
R = resistance of loop, as measured by Wheatstone bridge in making first part of Varley loop test;
S = measured resistance of lead wires used.

Then the following formula gives, according to H. W. Fisher, the total resistance f of the bad wire:

$$f = \frac{l\,r\,(R\ S)}{(l\,r) + (l'\,r')} \qquad (1)$$

If the length or the size of the good wire is not known, but the length and the size of the bad wire are known, the resistance f of the latter can only be determined approximately by the use of a wire table; that is,

$$f = \frac{l\,r}{1{,}000}, \qquad (2)$$

in which r = resistance of bad wire per 1,000 feet;
l = total length.

25. Total Resistance of Bad Wire When One Good and Two Bad Wires are Available.—It frequently happens that there is available for a test only one good wire and two or more bad wires of the same size and length, as in a bad cable. In order to locate a fault under such conditions, especially if the Varley loop test is used, it is usually necessary to determine the resistance of the good wire and one bad wire to get the distance to the fault. Under such conditions, use the following method for determining their resistance: Let the resistance to the distant end of the cable of one good wire be u, of one bad wire v, and of a second bad wire w. First, measure the resistance of the good wire u in series with one bad wire v, and let this resistance be a ohms. Then, $a=u+v$. Second, measure the resistance of the good wire u in series with the other bad wire w, and let this resistance be b ohms. Then $b=u+w$. Third, measure the resistance of the good wire u in series with the two bad wires v and w in multiple and let this resistance be c. Then,

$$c=u+\frac{v\,w}{v+w}.$$

Solving these three equations gives the following formulas*

$$u=c-\sqrt{(a-c)(b-c)} \qquad (1)$$
$$v=a-c+\sqrt{(a-c)(b-c)} \qquad (2)$$
$$w=b-c+\sqrt{(a-c)(b-c)} \qquad (3)$$

Where a and b do not differ by more than 2 or 3 per cent. the following approximate and much simpler formulas may be used:

$$v=\frac{3\,a+b}{2}-2\,c \qquad (4)$$
$$w=\frac{3\,b+a}{2}-2\,c \qquad (5)$$

*These formulas may be derived as follows: The first measurement gives $u=a-v$, and the second, $u=b-w$; hence, $a-v=b-w$, or $v=a-b+w$. The third measurement gives $c=u+\frac{v\,w}{v+w}$. Substituting $b-w$ for u and $a-b+w$ for v in the last equation, gives

$$b-w+\frac{(a-b+w)w}{a-b+w+w}=c.$$

Solve this for w as follows:

$$a\,b-b^2+2\,b\,w-a\,w+b\,w-2\,w^2+a\,w-b\,w+w^2$$
$$=a\,c-b\,c+2\,c\,w;$$
$$-w^2+2\,b\,w-2\,c\,w=b^2-a\,b+a\,c-b\,c$$

Add $(c-b)^2$ to each side, and reverse all signs,

$$w^2+2\,w\,(c-b)+(c-b)^2=(c-b)^2-b^2+a\,b-a\,c+b\,c$$
$$(w+c-b)^2=a\,b-a\,c-b\,c+c^2$$

Extract the square root of each side,

$$w+c-b=\sqrt{a\,b-a\,c-b\,c+c^2};$$

or,

$$w=b-c+\sqrt{a\,b-a\,c-b\,c+c^2}$$

But, $a\,b-a\,c-b\,c+c^2=a\,(b-c)-c\,(b-c)=(b-c)\,(a-c)$

Hence, $w=b-c+\sqrt{(b-c)\,(a-c)}$

As given above, $v=a-b+w$;

hence,

$$v=a-b+b-c+\sqrt{(b-c)\,(a-c)}=a-c+\sqrt{(b-c)\,(a-c)}$$

Similarly,

$$u=a-v=a-a+c-\sqrt{(b-c)\,(a-c)}=c-\sqrt{(b-c)\,(a-c)}$$

26. With this method lead wires can be used, the total measured resistance of each loop being a, b, and c, but the same lead wires must be used throughout the tests. Having determined the resistance of the faulty line wires, a loop test can then be used to locate the fault.

This method is very satisfactory and can often be applied to advantage when all the wires of a cable become bad, provided that one good wire outside the cable is available. This method of finding the resistance of the bad wire cannot be applied with absolute certainty when the faults on the bad wires occur at different points, unless the resistances of the faults are high and the resistances of the faulty wires are comparatively low; in the latter case, this method gives quite accurate results, even though the faults are a considerable distance apart.

When a number of wires fail in a cable at the same time, it can generally be assumed that the faults are all located at the same point. However, if the trouble has been caused by lightning, this may not be true.

27. Total Resistance of Bad Wire When Two Good Wires Are Available.—The total resistance of the bad wire can be accurately determined and hence the distance to the fault accurately located when two good wires whose terminals are accessible to both ends of the faulty wire are available. It is not necessary that the two good wires have the same resistance, nor that they follow the same route as the faulty cable. All three wires can differ widely in resistance and not in any way affect the result, neither is it necessary that the lead wires between the Wheatstone bridge and the line wires be of the same resistance, but the resistance of these two lead wires must be measured. This method is given by H. W. Fisher. Let g and g' represent the resistances of the two good wires, and S the resistance of the two lead wires. First, have one good wire g and the bad wire b joined together at the distant end, measure their loop resistance, and let it be u ohms; then $u=b+g+S$; second, have the other good wire g' and the bad wire b joined together at the distant end, measure their loop resistance, and let it be v ohms; then $v=b+g'+S$; third, have the two good wires g and g' joined together at the distant end, measure their loop resistance, and let it be w ohms, then $w=g+g'+S$. The same lead wires are supposed to be used in each of these three measurements. Then,

$$b=\frac{u+v-w-S}{2} \qquad (1)$$

and

$$g=\frac{u+w-v-S}{2} \qquad (2)$$

The formula for g is given because this method may be used to determine the resistance of two of three wires, when lead wires are also used.

28. Murray Loop Test.—The Murray Loop test is quite similar to the Varley loop test. Under favorable and suitable conditions, the Varley loop test gives more correct results, but

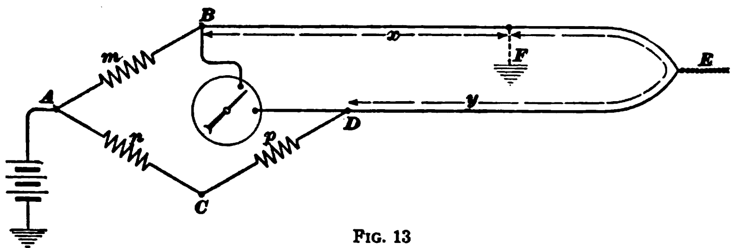


FIG. 13

the great simplicity of the Murray loop test recommends it, especially for underground cable work, where it is generally only necessary to locate the fault between manholes. First, have the distant ends of the available good and bad wires joined together. Then connect the loop so formed to the bridge, as shown, in Fig. 8, for the Varley loop test, and measure the resistance of the loop. Let this resistance be R. Evidently, $R=x+y$. Then connect the loop and battery as in Fig. 13, thus having really only two adjustable arms, because AC and CD form only one arm now. F is now the junction between the arms x and y. When the bridge is balanced,

$$\frac{m}{n+p}=\frac{x}{y}$$

But,

$$x+y=R$$

Solving these two equations for x, the resistance of the line wire to the fault, gives,

$$x=\frac{m R}{m+n+p}$$

EXAMPLE.—In order to locate a ground on one conductor in a cable, the Murray loop method was used. At the distant end of the cable, the bad wire was joined to a good wire and the resistance of the loop so formed was measured by the Wheatstone bridge and found to be 63.44 ohms. One end of the galvanometer was then disconnected from the junction C between the arms n and p, and was joined instead to the point D between the arm p and the good wire, and one terminal of the battery was grounded, as in Fig. 13. The bridge was then balanced and it was found that there were 1,000 ohms in the arm m, 1,000 in n, and 282 in p. Each conductor in the cable consisted of one No. 12 B. & S. gauge insulated copper wire, having a resistance of 1.586 ohms per 1,000 feet at the temperature of the test. What was the distance, in feet, from the testing station to the fault?

SOLUTION.—By substituting $R=63.44$ ohms, $m=1,000$, $n=1,000$, and $p=282$, in the formula, the resistance along the bad wire to the fault is $x=\frac{1,000\times 63.44}{1,000+1,000+282}=27.80$ ohms. Then, the distance to the fault from the testing station is

$$\frac{27.8\times 1,000}{1.586}=17,528 \text{ ft., or } 3.32 \text{ mi.} \quad \text{Ans.}$$

29. A test made by this method gives a result that is independent of the resistance at the fault. If the good and bad wires constitute a pair of wires in a cable or at least two wires of equal length, size, and material, x may be called the distance to the fault while twice the length L of the cable may be used for R. The formula may then be written,

$$\text{distance to fault}=\frac{2\,m\,L}{m+n+p} \qquad (1)$$

If the distance to the fault is desired in miles, L must be expressed in miles; if the distance is desired in feet, L must be expressed in feet. This formula is more accurate than the formula in the last article because errors due to differences of temperature and slight variations in size have less effect upon the calculated result.

When the good and the bad wires are of different sizes and lengths, this test and formula may be used, but for L in feet use

L' = (length of good wire, in feet, × its rated resistance per foot ÷ rated resistance per foot of bad wire) + length of bad wire, in feet. (2)

As the good and bad wires may not be true to gauge throughout and may differ in temperature the result is not as exact as when both wires are alike and in the same cable or on the same poles.

30. A check on the result obtained by the Murray loop test may be secured by reversing the connections of the good and bad wires with the bridge, obtaining another balance and result. If m', n', and p' represent the resistances in the arms for the second balance, if the tests have been correctly made, $m'(n'+p')$ should be equal to $m\,(n+p)$. The result obtained by this check-method is

$$x' = \frac{(n'+p')R}{m'+n'+p'} \qquad (1)$$

and the average of the two values x and x' which usually gives the best result is

$$x'' = \frac{x+x'}{2} \qquad (2)$$

31. For reliable results by the Murray loop test, the good wire should have an insulation resistance of at least ten times that of the bad wire. Some good wire should be selected and the insulation resistance of the good and the bad wires measured or compared by some suitable and convenient method to determine if this condition is fulfilled.

It is best to connect the good and the bad wires directly to the bridge, but if lead wires must be used, R in the formula for this test must be increased by the resistance of the two lead wires and the resistance of the lead wire in series with the bad wire must be later subtracted from the calculated resistance to the fault to get the correct result. If the leading wires are short and differ by one or two sizes only from the cable wires, the error introduced does not amount to more than a few feet, which is usually negligible, if the length of one of the two equal lead wires is added to the length L of the cable in the formula **1** of Art. **29**, and then this same length is subtracted from the final result.

32. Murray Loop Test With Slide-Wire Bridge.—A very simple, and sometimes a very convenient, way of locating a ground on a line wire consists in using a slide wire in place of the two adjustable arms of a Wheatstone bridge in the Mur-

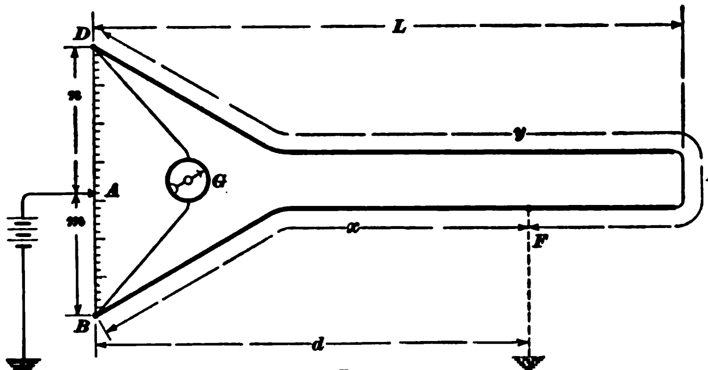


FIG. 14

ray loop method. In Fig. 14, BD represents a wire of uniform resistance stretched over a uniformly divided scale and F is a grounded point on the conductor BE that it is desired to locate. Then, if A is a point on the slide wire touching which produces no deflection of the galvanometer, $\frac{n}{m}=\frac{y}{x}$; adding 1 to each side of the equation, gives $\frac{n+m}{m}=\frac{y+x}{x}$; but $y+x=R$, then $\frac{n+m}{m}=\frac{R}{x}$; thence,

$$\text{resistance } x=\frac{mR}{n+m} \qquad (1)$$

in which x will be the resistance along the bad wire to the ground and R the resistance of the loop, which must be determined, if not already known, by another measurement or calculated by means of a wire table.

33. This method is especially useful, however, when both x and R are considered as distances in miles or feet. $\frac{R}{x}$ and $\frac{m}{n+m}$ are merely ratios. Moreover, if the two line wires are of the same size, length, and material, their resistances are proportional to their lengths; hence,

$$\frac{\text{resistance } R}{\text{resistance } x}=\frac{2\times\text{length } L}{\text{distance } d}$$

Consequently formula **1** may also be written,

$$\text{distance } d=\frac{2\,m\,L}{n+m},$$

in which L = length of one line wire, or length of a cable containing line wires;
d = distance from B to fault F.

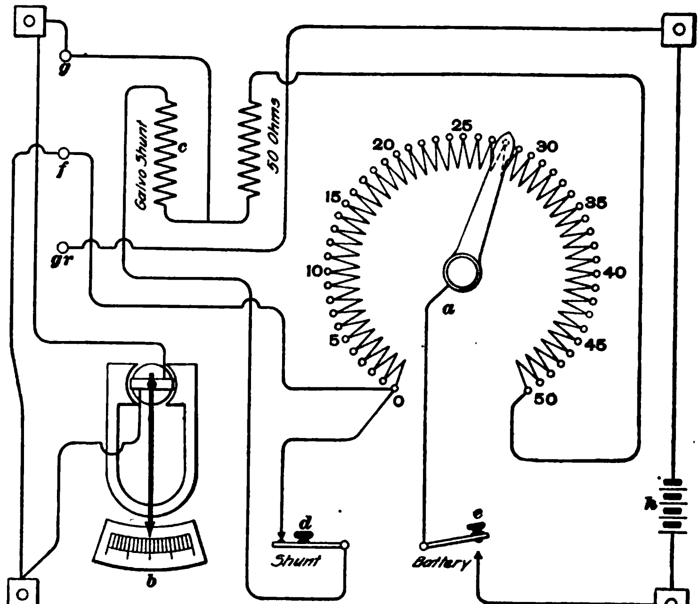
The length $2L$ will usually be twice the length of one line wire plus the length of any lead wires, preferably of the same size and material as the line wire that may be used to connect the two line wires to the points B, and D.

EXAMPLE.—A test was made by this method to locate a ground on a line of No. 19 B. & S. wire 3 miles long. The point of balance on the slide wire, which was divided into 1,000 equal divisions, was found to be 210 divisions from the end to which the bad wire was joined. How many miles is it to the ground?

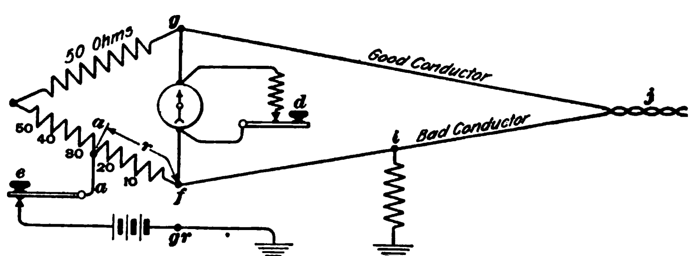
SOLUTION.—In this case, $m=210$, $n+m=1{,}000$, and $L=3$; hence,

$$x=\frac{2\,m\,L}{n+m}=\frac{2\times210\times3}{1{,}000}=1.26 \text{ mi., or 1 mi. and 1,373 ft.} \quad \text{Ans.}$$

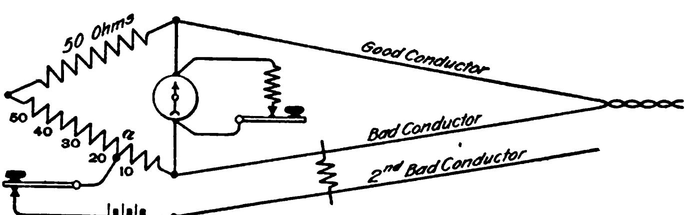
34. If all the conductors in a cable have become defective, but some are much more heavily grounded than others, the Murray loop test may still be used with fair success, provided that there is no disturbing difference of potential from an outside source between the two wires selected for the test. Even if all the conductors in a cable are heavily or equally grounded, the Murray loop test may be successfully applied if there is available a good aerial wire or conductor in another cable that can be joined to the faulty conductor at the distant end.



g
f
gr
Galvo Shunt
c
50 Ohms
25
20
30
15
35
10
40
a
5
45
50
0
b
d
Shunt
e
Battery
h
(a)



g
50 Ohms
Good Conductor
d
j
50
40
a
30
r
i
Bad Conductor
e
20
10
a
f
gr
(b)



50 Ohms
Good Conductor
50
40
30
a
20
10
Bad Conductor
2nd Bad Conductor
(c)

FIG. 15

35. Proportional Test Set.—For the use of linemen and others who have to locate grounds and crosses on cables, the engineer of equipment of the Western Union Telegraph Company has devised what he calls a proportional test set. In Fig. 15 (*a*) is shown the actual arrangement of the set, which is a simple bridge containing an adjustable rheostat *a*, having fifty 1-ohm units, a fixed resistance of 50 ohms, a D'Arsonval type of galvanometer *b*, having a small lever for use only for centering the galvanometer when necessary before making a test, a galvanometer shunt resistance *c* that shunts the galvanometer when the shunt key *d* is in its normal position, a battery key *e*, a battery *h*, and the necessary connections and binding posts, all placed in a box 7 inches by 9 inches by 5 inches. Pressing the key *e* closes the battery circuit and pressing the key *d* opens the shunt around the galvanometer.

36. When a ground is to be located upon a conductor, connect it to a binding post *f* and to another binding post *g* connect a good conductor of the same size and material, preferably a good wire running over the same route or in the same cable. The binding post *gr* should be grounded and the distant ends of the two wires connected together to form a loop. These connections are shown in a simplified manner in (*b*). The arm of the rheostat is moved around until no galvanometer deflection is produced when the battery key *e* is pressed. Then press both battery and galvanometer keys *e* and *d* and, if the galvanometer needle moves, readjust the arm *a* until the galvanometer shows the smallest or no deflection. Then the resistance from *g* through the rheostat to *a* is to the resistance from *a* through the other part of the rheostat to *f* as the resistance from the binding post *g* through the distant end *j* to *i* is to the resistance *i* to *f*. Or $\frac{\text{res. } (g \text{ to } a)}{\text{res. } (a \text{ to } f)} = \frac{\text{res. } (g\,j\,i)}{\text{res. } (i \text{ to } f)}$. Adding 1 to each side of this equation gives $\frac{\text{res.}(g \text{ to } a) + \text{res.}(a \text{ to } f)}{\text{res. } (a \text{ to } f)} = \frac{\text{res.}(g\,j\,i) + \text{res.}(i \text{ to } f)}{\text{res. } (i \text{ to } f)}$ or $\frac{\text{res.}(g\,a\,f)}{\text{res.}(a \text{ to } f)} = \frac{\text{res.}(g\,j\,i\,f)}{\text{res.}(i \text{ to } f)}$. But the resistance *g a f* is always 100 and the resistance *i* to *f* is the resistance from the testing station to the fault while the resistance $gjif$ is the resistance of the whole loop, hence $\frac{100}{\text{res. } (a \text{ to } f)} = \frac{\text{res. of loop}}{\text{res. to fault}}$ or res. to fault $= \frac{\text{res. of loop} \times \text{res. } (a \text{ to } f)}{100}$. But the value of the resistance a to f, which may be called r, is given by the position of the rheostat arm and it is read directly from the rheostat. Furthermore, if the wires are of uniform size and material, resistances are proportional to lengths and therefore the total length L of the loop may be substituted for its resistance and the distance d to the fault may be substituted for the resistance to the fault. Therefore the simple formula is obtained,

$$d = \frac{L\,r}{100}$$

If L is in feet, d will be given in feet. The total length L of the loop is equal to the sum of the lengths of the good and bad conductors. In the case of a cable pair, L is twice the length of one conductor.

37. For the location of a cross, the procedure is the same as for the location of a ground, except that instead of connecting the battery post *gr* to ground, it is connected to one end of the second bad wire, the other end of which is open. The connections for locating a cross are shown in Fig. 15 (*c*). The same formula is used for locating a cross as for locating a ground.

EXAMPLE.—When locating a cross upon a loop 2,200 feet long, the galvanometer showed the least deflection when the rheostat arm rested at the point 16. What is the distance to the cross from the testing station.

SOLUTION.—Substituting in the formula $d = \frac{L\,r}{100}$ gives $d = \frac{2{,}200 \times 16}{100}$ $= 352$ ft. to the cross.

EXAMPLE FOR PRACTICE

When locating a ground upon one conductor of a pair in a cable 800 feet long, the bridge was balanced when the rheostat arm pointed to 25. What is the distance to the ground? Ans. 400 ft.

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38. Murray Loop Test Requiring Two Good Wires. Where a good wire of the same size as the faulty conductor is not available, but where two good wires of any known or unknown size, length, and material, either inside or outside the cable, are available, the following modifications, of the Murray loop test, made by H. W. Fisher, may be used. It must be possible to connect together at the distant end the faulty conductor BE and the two good available wires i and j, as shown in Fig. 16. These conductors are connected together at E and to the bridge, as shown at (*a*) and the arms m and n are adjusted

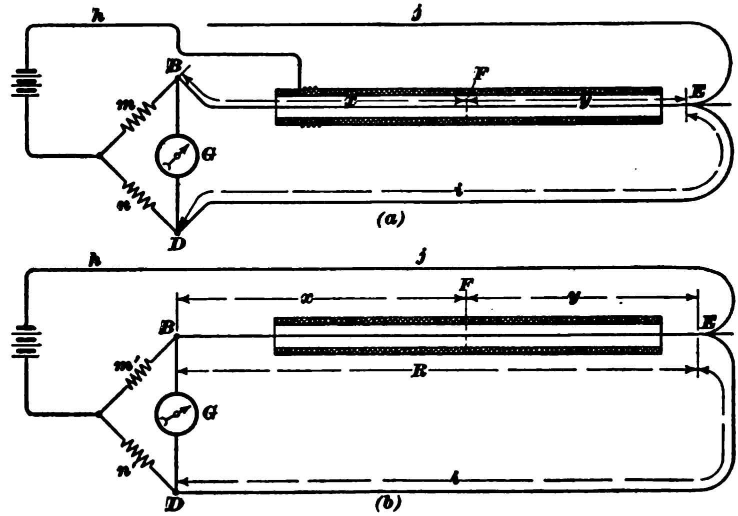

FIG. 16

until the galvanometer gives no deflection and their values recorded. The wire h running from the battery to the lead sheath of the cable is then connected to the conductor j as shown at (*b*), after which the bridge arms are adjusted until values m' and n' are obtained that again produce no deflection of the galvanometer. If L is the total length of the faulty conductor the resistance of which is R and d the length of the faulty wire to the fault, the resistance of which is x, then,

$$d = \frac{m(m'+n)'L}{m'(m+n)}$$

NOTE.—This formula may be derived as follows: The first balance gives $\frac{n}{m} = \frac{i+y}{x} = \frac{i+(R-x)}{x}$, or $i+(R-x) = \frac{n\,x}{m}$ and $i = \frac{n\,x}{m} - (R-x) = \frac{n\,x}{m} - R + x$

$=x\left(\frac{n}{m}+1\right)-R=x\left(\frac{n+m}{m}\right)-R$. The second balance gives $\frac{n'}{m'}=\frac{i}{x+y}=\frac{i}{R'}$, or $i=\frac{R\,n'}{m'}$. Equating these two values of i, gives $x\left(\frac{n+m}{m}\right)-R=\frac{R\,n'}{m'}$, or $x\left(\frac{n+m}{m}\right)=R\left(1+\frac{n'}{m'}\right)=R\left(\frac{m'+n'}{m'}\right)$, from which $x=\frac{R\,(m'+n')\,m}{m'\,(n+m)}$. As resistances of wires are proportional to lengths, then $d=\frac{L\,m\,(m'+n')}{m'\,(m+n)}$.

39. In the application of this method, the resistance of conductors i, j may be quite different without affecting the result, hence before the test is made, long enough lead wires may be used at either end for making the connections with the conductors i, j. Usually, the same values for m and m' can be used, thereby reducing the calculations. If the faulty wire cannot conveniently be connected to the Wheatstone bridge a wire of the same size and material as the cable conductor may be used to make the connections, then it will be necessary to add the length of this wire to the length of the bad wire or cable, using this total length for L in the formula, and then subtract the length of this lead wire from the calculated distance d to the fault.

EXAMPLE.—A cable 800 feet long was tested to locate a ground between one conductor and the sheath. A piece of wire, 10 feet long, of the same size and material as the cable conductor was used to connect the cable conductor to the bridge. Two good wires were available so that the method just explained was selected. With the connections shown in Fig. 16 (*a*), a balance was obtained when $m=100$ and $n=301.5$ ohms. The connections were then made as shown in (*b*) and a balance obtained when $m'=100$ and $n'=120.5$ ohms. What is the distance to the fault?

SOLUTION.—The length L of the conductor during the test was $10+800=810$ ft. Substituting the known values for the letters in the formula $d=\frac{m\,(m'+n')\,L}{m'\,(m+n)}$, gives

$$d=\frac{100\times(100+120.5)\times 810}{100\times(100+301.5)}=444.8\text{, or } 445 \text{ ft.}$$

From this must be subtracted the 10 ft. of connecting wire, giving as the distance to the fault from the home-office end of the cable 435 ft. Ans.

40. Different Sized Conductor Forming Faulty Line. When the faulty line wire consists of two different known sizes and lengths, make whatever tests and calculations are necessary to determine the distance d to the fault. Then let l and r be the length, in feet, and the rated resistance per foot, obtained from a table if necessary, of the first wire and l' and r', the length, in feet, and the rated resistance per foot of the second size wire. Then for L, the total length of the faulty wire, occurring in any formula, substitute the quantity

$$l+\frac{r'\,l'}{r} \qquad (1)$$

If d is the resulting calculated distance to the fault and it does not exceed the length l of the first-size wire, then d is the true distance to the fault. If the fault occurs on the second-size wire, that is beyond the junction of the two-sized wires, d is greater than l and the true distance d' to the fault is

$$d'=\frac{l+(d-l)r}{r'} \qquad (2)$$

EXAMPLE.—The test explained in Art. 9 was made to locate a ground upon a line consisting of 1,700 feet of a conductor having a resistance of 8 ohms per 1,000 feet from station A and 11,600 feet of a conductor having a resistance of 1.6 ohms per 1,000 feet ending at station B. When the bridge at station A is balanced the sliding contact rests at 233 divisions from the junction of the slide wire and the faulty wire. When the bridge at station B is balanced, the sliding contact rests at 267 divisions from the junction of the slide wire and the faulty line. What is the actual distance from station A to the fault?

SOLUTION.—The formula for calaculating the distance to the fault by this method is $d=\frac{L\,o}{o+o'}$. But as the faulty wire is not uniform in resistance per foot throughout its whole length, it is necessary to substitute for L in this formula, the value $l+\frac{r'\,l}{r}$, which equals $1{,}700+\frac{11{,}600\times 1.6}{8}$ $=4{,}020$ ft. Then $d=\frac{4{,}020\times 233}{233+267}=1{,}873$ ft., which is greater than 1,700 ft., the length of the size wire starting at station A. Hence, the true distance to the fault from station A is

$$d'=1{,}700+(1{,}873-1{,}700)\times\frac{8}{1.6}=1{,}700+865=2{,}565 \text{ ft.} \quad \text{Ans.}$$

41. Where several lengths of different sized conductors form one circuit, reduce each size to the equivalent length of one size having the same resistance. The size or cross-section or rated resistance and length of each conductor must be known. Multiply the length, in feet, of each conductor by its rated resistance per foot and divide the product by the rated resistance per foot of the size to which it is to be reduced.

EXAMPLE.—A line circuit is made up of 2,000 feet of No. 12 B. & S. G. hard-drawn copper wire having a resistance of 1.623 ohms per 1,000 feet. 2,500 feet of No. 19 B. & S. G. cable conductor having a resistance of 44 ohms per mile, and 1,200 feet of No. 14 B. & S. G. copper-clad line wire having a resistance of 6.6 ohms per 1,000 feet. (*a*) What is the total equivalent length of this line in terms of the No. 19 wire? (*b*) If a fault is determined by a loop-test formula to be 3,000 feet from the testing station, how would a man be directed to the fault?

SOLUTION.—(*a*) 2,000 ft. of No. 12 is equivalent to $\frac{2{,}000\times.001623}{\frac{44}{5280}}$ $=\frac{2{,}000\times.001623\times5{,}280}{44}=389.5$ ft. of No. 19. 1,200 ft. of No. 14 copper-clad wire is equivalent to $\frac{1{,}200\times.0066\times5{,}280}{44}=950.4$ ft. of No. 19. $389.5+2{,}500+950.4=3{,}839.9$ ft. of No. 19 wire. Ans.

(*b*) $3{,}000-2{,}500-389.5=110.5$ ft., which is the distance, in terms of No. 19 wire, from the junction of the No. 19 and No. 14 wires. This is equivalent to $(110.5\times\frac{44}{5{,}280})\div.0066=139.5$ ft. of No. 14. Hence, the fault is 139.5 ft. from the junction of the No. 19 and No. 14 along the No. 14 copper-clad wire. Ans.

42. Goodrum Slide-Wire Bridge Method.—One of the best and simplest loop methods for locating grounds and crosses where two good wires are available is that proposed by C. L. Goodrum. Theoretically, it is the same as the method explained in Art. 38, but a slide-wire bridge is used instead of a regular Wheatstone bridge, thereby simplifying the test. In Fig. 17, *BC* represents a slide wire, which may be a piece of No. 24 B. & S. German-silver or iron wire stretched between posts *BC* so as to be over a scale divided into exactly 1,000 equal divisions, preferably millimeters. The smoother and more uniform the diameter and material of the wire *BC*, the more accurate will be the results. This method may be used to determine the distance *x* to a fault at *F*, which may be either a ground on wire *2* or a cross between wires *1* and *2*.

Have all the wires joined together at the distant end, except in the case of a cross, when the wire *1* with which wire *2* is crossed may be preferably left open at the distant end, and at the testing end join *B* to *2*, *C* to *3*, and the battery to *4*; the dotted line connection is not now made. *G* represents

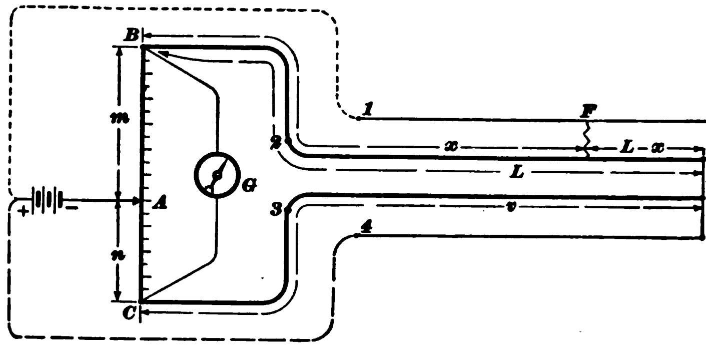

FIG. 17

a galvanometer or a sufficiently sensitive millivoltmeter connected from *B* to *C*. Adjust the pointer along the slide wire until a point *A* is found where *G* gives no deflection. Then,

$$\frac{L}{v}=\frac{m}{n},$$

in which L = length of cable;
v = length of wire *3*;
m = distance BA, that is, scale reading from end B to point of balance A;
n = distance AC, that is, length $BC-m$.

The connecting wires from *B* to *2* and from *C* to *3* should be sufficiently short or large in diameter or both, so that their resistance may be neglected.

If line *2* is crossed at *F* with line *1*, connect the positive terminal of the battery to this wire *1*, as represented by the light dotted line instead of to line *4*, as represented by the dash line and have this line *1* opened at the distant end. If line *2* is grounded at *F*, connect the positive terminal of the battery to ground instead of to line *1*. In either case, the procedure is as follows: Again, balance the bridge and let m' be the new reading on the slide-wire scale from B to the new point of balance. Then,

$$\frac{x}{L-x+v}=\frac{m'}{n'}$$

Solving these equations for the distance x to the fault gives

$$x=\frac{m'L}{m}$$

43. Although two good wires *3* and *4* are required, they may be of any reasonable size, material, or length, and they may be wires inside or outside the cable. The distance x to the ground or cross is merely a certain ratio $\frac{m'}{m}$ of the total length L of the cable and this distance is independent of the

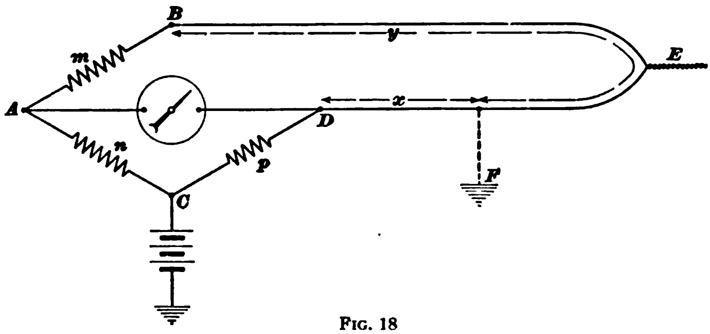

FIG. 18

length of the faulty or good wires. The only requisite necessary for extreme accuracy is that the faulty wire *2* shall twist in the same uniform manner throughout the entire length of the cable. If it starts as an inside wire, it must continue as such. Most loop tests not only assume this to be the case, but also assume that the good and faulty wires are of exactly the same length, which is not true when one is an inside wire and the other an outside wire in a cable, because the latter twists around the inner wires and is therefore somewhat longer than any wire inside of it. This method requires only two balances and only one connection has to be changed. An apparatus, called the *lineman's faultfinder*, has been placed on the market for locating faults by practically this method.

44. Allen Loop Test.—Allen's modification of the Murray loop test gives a very simple and quick method of testing where the resistance of the loop is not already known. The loop BED is connected to the bridge, as shown in Fig. 18, and a balance obtained. Then,

$$\frac{m+y}{n}=\frac{x}{p}$$

Now, reverse the connections of the loop with the bridge, joining the bad wire to B and the good wire to D. Obtain a new balance on the bridge, then

$$\frac{m'+x}{n'}=\frac{y}{p'}$$

Solving these two equations for x gives the following formula:

$$x=\frac{p\,(m\,n'+p'\,m')}{n\,n'-p\,p'}$$

This formula simplifies when m, m', n, and n' are multiples of 10, as they usually are in practice. A measurement made by the Allen loop test is independent of the resistance of the fault.

45. For the location of grounds, some form of loop test is usually superior to all others. When the leakage along the lines is great, the loop tests may be seriously vitiated thereby, in common with other methods. The next best method is the earth overlap, which is more suitable than the Blavier method for a fault that has a varying resistance or much polarization. As the earth overlap method requires tests from both ends of the line, it is not always applicable, in which case the best alternative method is the Blavier, and under certain conditions the Ayrton method.

OTHER METHODS OF LOCATING GROUNDS

46. Receiver Method—The following method is said, by A. B. Dungan, who has used it successfully, to be very simple and reliable for locating grounds on aerial cable conductors, provided that the cable is free from dead grounds against other cables and guy wires. In Fig. 19 is shown the necessary connections consisting of a lead-covered cable with its sheath connected to one side of a 110-volt lighting circuit; the conductor or conductors that are grounded at some point *F*, are connected through a suitable resistance, such as five 110-volt 16-candlepower lamps in parallel, to the other side of the 110-volt lighting circuit; either direct or alternating current may be used. If a portion of the cable is water soaked or the cable is injured so that one or more conductors are more or less grounded on the lead sheath, some current will pass from the conductors at the fault to the sheath through which

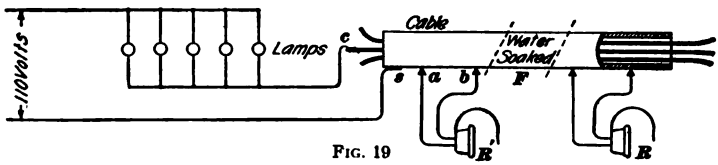

FIG. 19

it returns to the office. If an ordinary head-telephone receiver, wound to a very low resistance, about 5 ohms, has its two terminals touched to two points *a* and *b*, as far apart as convenient on the lead sheath of the cable at any place between the exchange and the point *F* a noticeable click will be heard in the receiver at the moment its circuit is closed, due to a part of the current passing through it. If the same connection is made beyond the point *F* no sound whatever will be heard in the receiver. The points *a* and *b* should be kept the same distance apart for all comparative tests. In this way, the most inexperienced lineman is said to be able to locate such a ground in a cable within a few inches.

47. Stabler Test With Millivoltmeter.—When all the conductors in a cable are so badly grounded as to preclude the application of any loop test, H. B. Stabler says the following simple test, which resembles the preceding, has been successfully used to locate a ground on conductors in lead-covered aerial cables. The test can only be made when the lead sheaths are comparatively well insulated from the ground, or if heavily grounded, provided that it is only at some certain known point or points.

In Fig. 20, let *MN* represent an aerial lead-covered cable, whose sheaths and supporting wire are in contact only with the dry wood of cable boxes, poles, and cross-arms and hence normally insulated fairly well from the ground. A battery or other suitable course of direct current is connected between the ground and the one or more conductors that have become grounded on the lead sheath at some point *F*. By applying the terminals of a galvanometer or millivoltmeter to two points *a* and *b* a few feet apart on the lead sheath of the cable between *F* and *M*, the presence and direction of the current in the cable sheath will be indicated by the deflection of the needle. By repeating the tests at other points along the cable, the point *F* where the current first reaches the sheath

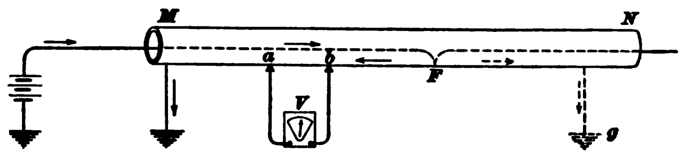

FIG. 20

may be located, for there will be no current flowing in the cable sheath beyond the point *F*.

48. If the cable sheath is already grounded at two or more points, the test may still be made. For, if the sheath is also grounded at *g*, the point *F* can be located, not by the absence of a deflection beyond it, but by deflections in opposite directions on each side of *F*.

This method fails where there is a high resistance in the cross between the conductors and the sheath, as a large enough current cannot then be conveniently obtained in the sheath to give suitable deflections. The amount of current required, is not, however, very large. For instance, with a cable sheath whose resistance is .1 ohm per 1,000 feet, the difference of potential between two points on its surface 4 feet apart will be .1 millivolt when carrying a current of .25 ampere. In a central-energy telephone system, such a current may often be fed from the central office through cable conductors to the desired point, in order to save the party making the test the trouble of transporting a suitable battery to the end of the aerial cable. This method will fail when the cable sheath is grounded at points on each side of *F* if there already exists a difference of potential between these points due to the leaking of current from external wires to the cable sheath.

49. Exploring Coil Method.—In underground telephone cables, a ground may be located by passing an alternating current through the grounded circuit and then carrying a large exploring coil, in series with which is connected a receiver, along the street directly over the cable at fault. The alternating current will induce current in the exploring coil, even though a few feet away from the cable, which will produce a sound in the receiver. When the grounded point is passed, the noise will cease, which shows that the coil has been carried beyond the grounded point. Where this method can be properly applied, faults may be located with considerable accuracy. An effective exploring coil for locating faults in underground cables can be made of a bicycle-wheel rim with the groove filled with fine insulated wire, and the ends connected to a receiver.

50. An exploring coil that has proved successful may be made of 500 turns of No. 18 B. & S. G. insulated copper wire wound in a coil 2 feet in diameter and connected to a 100-ohm receiver. A .1-ampere, 60-cycle, alternating current gave a sound in the telephone receiver when this exploring coil was 5 feet away from the faulty wire. Maximum sensitiveness is obtained when the impedance of the receiver is equal to the impedance of the exploring coil. To locate faults in concealed house wiring, a coil 6 to 8 inches in diameter, wound with No. 30 B. & S. or smaller wire to a resistance of 75 to 125 ohms will answer the purpose.

The exploring coil method can be used to locate a ground when there is more than one and when loop tests are useless. The sound in the receiver will decrease at the first ground and cease at the last ground.

51. The exploring coil can often be used in conjunction with a bridge measurement. An approximate location should be made by means of a bridge test and the exact location then found with the exploring coil. Often with small cables, 50 pair or less, it is possible to remove short-circuits and grounds due to lightning without opening the cable by bending the cable back and forth several times at the point where the test has located the fault. If the fault is in the nature of a small weld between wires or between one wire and the sheath due to a

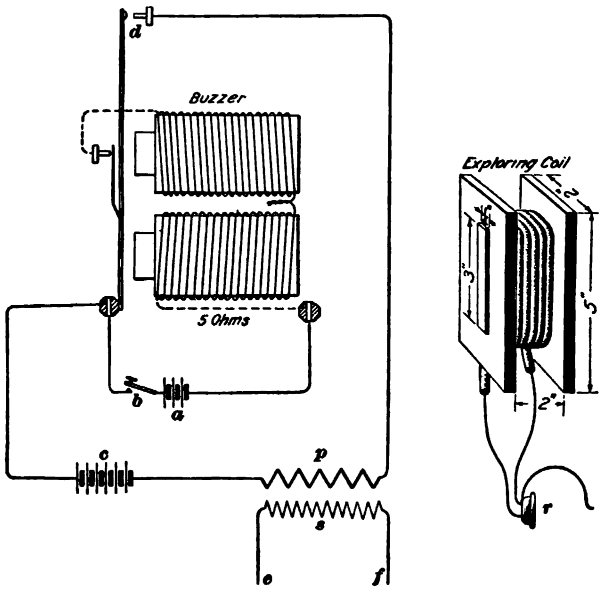

FIG. 21

lightning discharge, the bending of the cable will break the weld and clear the fault.

52. Aerial-Cable Tone Tester.—Where the exploring coil can be held close to and moved along the cable, it is even more serviceable for locating trouble than on underground cables. It is also very useful for locating trouble in the house wiring of telephone, electric-light, and power systems. In Fig. 21 is shown a home-made testing set that has proved very satisfactory for locating crossed pairs and grounded conductors. It is not so satisfactory for locating a short-circuit between two conductors of one pair, for, on account of the wires being twisted around each other, the outgoing current counteracts the effect of the return current on the exploring coil.

The battery *a* simply keeps the 5-ohm buzzer in operation when the switch *b* is closed. A battery *c* containing any desirable number of dry cells has its circuit, which includes the primary *p* of a repeating, or induction, coil, interrupted by an extension of the buzzer armature at *d*. The terminals *e* and *f* of the secondary winding *s* form the tone-test binding posts from which alternating current is fed to the circuit in trouble. The exploring coil, the dimensions of which are shown, consists of 80 ohms of No. 32 B. & S. G. copper-wire wound on an iron core 3 in.$\times\frac{1}{4}$ in.$\times2\frac{3}{4}$ in. The coil is connected to an 80-ohm head-receiver *r*.

53. To locate a cross between two cable pairs, open both pairs at the cable box, connect binding post *e*, Fig. 21, to both wires of one pair and binding post *f* to both wires of the other pair. Then go along the aerial cable with the exploring coil close to the sheath and the receiver to the ear. A noise will be heard until the cross is passed. When the usual sound ceases or changes very much, a fault is passed. When the sound ceases but can be heard again by going back a foot or more, the trouble is there. Sometimes by placing the coil on the sheath where the loudest tone is produced, and tracing the tone to a point where it can be lost and again heard in the space of an inch, the fault can be very accurately located.

To locate a ground connect post *e* to the bad wire and post *f* to the sheath and proceed along the cable with the exploring coil. If the wire being tested is grounded at more than one point the device will indicate the first ground nearest the office; this one should be first cleared and so on until all grounds are removed. If there are several grounded or crossed wires in a cable, only one should be tested and cleared at a time.

54. To locate a wet spot in a cable, connect both wires of several bad pairs to one post and both wires of several other bad pairs to the other posts. Sometimes better results are obtained by grounding one set on the lead sheath. In almost all tests better results are secured by connecting the lead sheath thoroughly to the ground every few hundred feet. Where a common return system is used for the open wires beyond a cable, the vibrating device must be connected at the end of the cable between the common return, which should be grounded, and the faulty wire; the faulty cable wires must be open at the office end. The wires in such a cable, other than the ones under test, will take up the tone-test current, but the fault will be found at a point where the sound in the receiver diminishes very perceptibly.

The spiral winding of a pair, especially an outside pair, will cause the tone to rise and fall at regular intervals of about 8 to 11 inches, but by moving the coil spirally along the cable, in cases where it is necessary, the tone can be kept more constant. While it may not be necessary on systems that do not use the ground as a return circuit, nevertheless it is best in all cases to remove the fuses in the cable box and to otherwise clear the line or lines under test of all outside connections. This is particularly necessary on telephone circuits having party-line telephones whose bells are connected to ground.

55. In locating faults in cables, the first test on the cable should be made before it leaves the building to make sure that the apparatus is properly connected and working in good order, and furthermore the trouble may be inside the building. The second test should be made where the circuit changes from underground to overhead cable. If the sound is still heard the trouble is further out. Then a test should be made at some pole about one-half the distance to the end; if the sound is still heard, the next test should be made half way between this point and the end and so on until the sound is no longer heard. The trouble should thus be located in a span between two poles. A cable car must then be used to ride over the cable, frequent stops being made for a test. Where the trouble has been passed, the sound in the receiver will cease or be very appreciably reduced, then by going back slowly the trouble can usually be very closely located. Sometimes the sagging caused by the weight of the cable car and passenger, or the heat caused by the testing current clears a fault, which, especially in the case of a short circuit is very likely to return.

The detector coil made by the Electric Specialty Manufacturing Company is shown in Fig. 22. This well-designed coil has two iron pole pieces *a* and *b* shaped to fit an ordinary lead-covered cable. The same company uses a clockwork device in series with the line circuit to open and close the line circuit at regular intervals, thereby producing an unmistakable tone when testing where induction from foreign circuits interferes when only the usual testing current is used. It is said to be particularly useful when testing for trouble due to moisture.

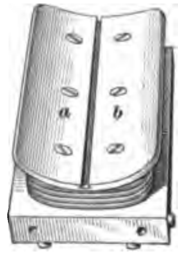

FIG. 22

56. Compass Method of Locating Grounds.—Another method used by power companies for locating a ground on a cable is to pass a current that changes its direction about once in 3 seconds through the cable and placing a compass over the cable to be tested at each manhole in succession. The compass needle will slowly vibrate from one side to the other as the current changes direction, until the manhole beyond the ground is reached. The ground is thus between the last two manholes and that portion of the cable is withdrawn for repairs. A special machine made by the General Electric Company for this test consists of a motor that drives a commutator at such a speed that a direct current is reversed once in 3 seconds.

This method will not apply if the alternating or pulsating current passes through the two wires constituting a pair in series, because the return current will neutralize the effect produced by the outgoing current. By passing a current through only one wire or through the two wires of a pair in multiple this method can still be used for the location of faults.

57. Location of Ground by Voltmeter.—The distance to a ground on a line can be determined only approximately by means of a voltmeter and then only when the resistance at the ground is negligible compared with the resistance of the bad wire from the testing end to the ground. To estimate the distance to the ground, connect the voltmeter across the terminals of a suitable battery (usually a few dry cells will answer this purpose), and call the reading d. Then connect the same battery and voltmeter in series with the line to be tested and the ground, thus forming a circuit through the battery, voltmeter, line, and ground. Let the voltmeter reading be d'. Then the resistance of the grounded circuit (less the resistance of the voltmeter) is given by the formula $R = r\left(\frac{d}{d'} - 1\right)$, in which r is the resistance of the voltmeter. This is the same formula used in determining the insulation resistance of a line. The resistance R includes the resistance of the line, earth, and ground contacts.

LOCATING CROSSES

GENERAL METHODS

58. Where the two crossed wires run parallel and have the same resistance per mile, it is a rather simple matter to locate a cross. Where such is not the case, the resistance of each wire per mile must often be considered. The loop methods given for locating grounds can generally be used also for locating crosses, in which case one of the crossed wires is used instead of the ground. In case there are two crosses between the same conductors, the bridge methods locate the cross between the two faults; in such cases open the cable or conductor at the point indicated and test both ways for the real location of the crosses.

RESISTANCE AT CROSS NEGLIGIBLE

59. To Determine Resistance of Cross.—When trying to locate a cross, it is first necessary to determine if the resistance at the cross is negligible. This may be done as follows: Connect the lines with a Wheatstone bridge, as shown in Fig. 23. so as to measure the resistance from B to D through the cross F; call this a. Then, $x+y=a$. Now have the wires connected together at the nearest station beyond the cross and again measure the resistance; call this b. If b is only a little less than a, the resistance of the cross is probably negligible, but not necessarily perfectly so. For if the cross is

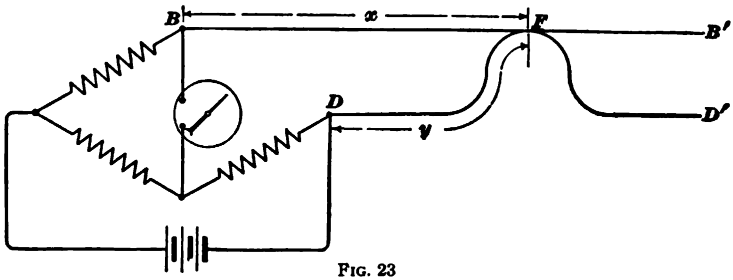

FIG. 23

near the testing station and the resistance of the line wires to the next station where the lines are intentionally connected together is very high, the second measurement b may be but little less than the first measurement a, in spite of the fact that the resistance of the cross is not perfectly negligible.

60. Cross Between Two Wires of Same Size and Material.—If the resistance of the cross is negligible, and if the two wires are of the same size and material and run along parallel the whole distance from the testing station to the cross, the distance d to the fault, in miles, is given by the following formula:

$$d=\frac{a}{2s}$$

in which s = resistance per mile along one wire;
a = resistance of loop through cross.

61. Resistance of Two Line Wires per Unit Length Not Equal.—If the wires are still parallel with each other, but the resistance of one is w ohms per mile and the other v ohms per mile, the formula becomes,

$$d=\frac{a}{w+v}$$

RESISTANCE OF CROSS NOT NEGLIGIBLE BUT CONSTANT

62. Varley Loop Method.—To locate a cross, when the resistance of the cross is not negligible but is constant, first insulate the distant ends of the two crossed wires. Then con-

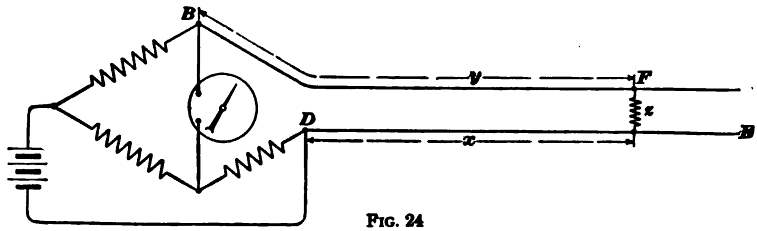

FIG. 24

nect as shown in Fig. 24, and measure the resistance from D to B through the cross at F. If there is any appreciable difference in the resistance of the two line wires the higher resistance wire should be connected to B. Let the resistance of the cross be z ohms, and the resistance found by balancing the bridge be R ohms; then,

$$R=x+y+z$$

If the galvanometer deflection remains zero for a few seconds, it is fair to assume that the resistance of the fault is constant.

63. Ground either wire, say $D\,E$, anywhere beyond the cross, as at G, and connect as shown in Fig. 25. The negative terminal of the battery should be grounded if the distant

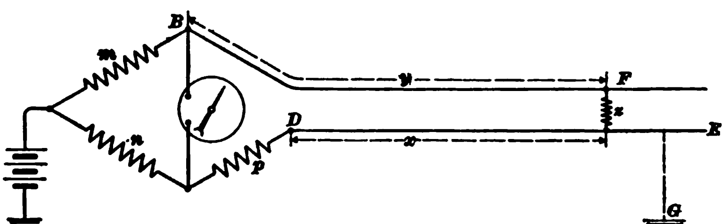

FIG. 25

ground G has a negative potential and vice versa. When the bridge is again balanced,

$$\frac{m}{n}=\frac{y+z}{p+x}$$

From these equations, the following formula is obtained:

$$x=\frac{nR-mp}{m+n},$$

which is exactly the same as the formula for locating a ground by the Varley loop method.

Then, dividing x by the resistance of the wire DE per unit length, gives the distance from D to the fault along the wire DE. The resistance of the cross z eliminates and the method is accurate, provided that the resistance z has remained the same during both measurements. The Murray loop method can also be used for the location of crosses.

64. Varley Loop Method With Equal Balance Arms. When the balance arms m and n are made equal in the Varley loop method and R is the resistance of the loop, the formula for x in the last article reduces to $x=\frac{R-p}{2}$, from which is obtained

$$p=R-2x \qquad (1)$$

But R is the total resistance of the loop and for a pair of wires $x=y$, hence $2x$ is the resistance of both wires to the fault from the distant station, and $R-2x$ is the resistance of both wires from the fault to the distant end; therefore, the resistance p in the rheostat arm gives the resistance of both wires from the fault to the distant end without any calculation whatever. When $m=n$, this rheostat reading, divided by 2, gives the resistance of one wire from the fault to the distant end and this multiplied by the number of feet per ohm of the wire gives the distance d from the fault to the distant end, in feet, that is

$$d=\frac{p}{2}\times\text{feet per ohm} \qquad (2)$$

If the gauge of the wire is known, the number of feet per ohm can be readily obtained from a table, and if much used, this value for three or four of the common sizes of wire is easy to remember.

65. Fault on Multiple-Connected Telephone Cable. The formula just given for the distance from the fault to the farther end of a cable is very useful for locating faults where a pair of wires is tapped into a number of different terminals, as shown in Fig. 26. Suppose there is a fault at *z* and that the test is made from the exchange. The helper connects the two wires together at the distant end *c* if the fault is a ground on either wire of the pair, the bridge being connected as shown in Fig. 9; or he connects one wire to the ground if the fault is a cross between the two wires, the bridge being connected as shown in Fig. 25. Then, with $m = n$, the bridge is balanced and the distance *d*, calculated from formula **2**, Art. **64**, gives

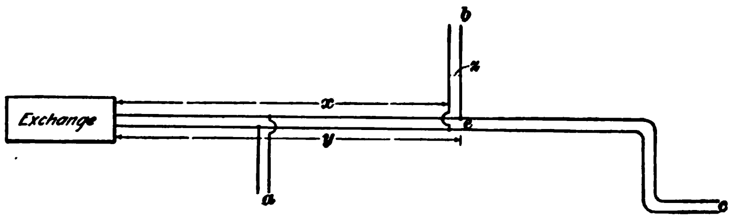

FIG. 26

the distance back from the helper at *c* to the apparent location of the fault. If the distance from *c* to *e* is known and agrees fairly well with the distance calculated from the test, the fault is either at *e* or somewhere in the branch *b*, as at *z*. If the calculated distance is less than the distance *c e*, the fault is between *e* and *c*; if greater, it is on the exchange side of *e*. The wires at *c* are then opened and insulated, the test is repeated with the proper connections made by the helper at *b*. If necessary to locate the fault, the test can be repeated for terminal *a*.

66. Metallic Varley Method.—The following method of locating crosses, frequently called the metallic-Varley test, requires a good wire in addition to the two wires that are crossed. It will give more accurate results, especially in wet weather, than the Varley method with an earth circuit, and therefore should be used in preference to the regular Varley method, when the three wires required are available. Errors due to leakage are almost eliminated. By this method a good wire is connected to one of the crossed wires at the first convenient point or station beyond the cross and is joined to the bridge as shown in Fig. 27; one of the crossed wires is now open at both ends.

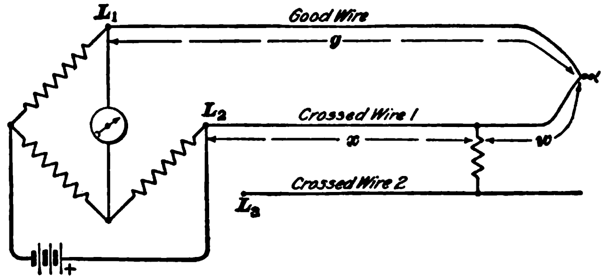

FIG. 27

67. With the Western Union bridge, this is done by connecting the home end of the good wire through a jack to a wedge connected to the bridge at L_1 and the home end of the crossed wire *1* through a jack to another wedge connected to the bridge at L_2, and placing a connecting peg in the loop jack in the jack-box very much as shown in Fig. 10. If other wires are also crossed with the two mentioned, they are left open

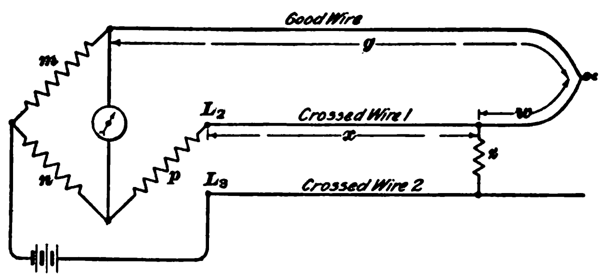

FIG. 28

at both ends. Balancing the bridge, with the connections shown in Fig. 27, gives the resistance R of the loop formed of one good and one crossed wire. Then,

$$R = g + w + x$$

Now connect the positive terminal of the battery to the home end L_3 of the crossed wire *2*, as shown in Fig. 28, instead of to

L_2, as shown in the previous figure. In the Western Union bridge this is done by simply connecting wedge L_3 through a jack to the crossed wire *2* and transferring the connecting plug to a jack marked *Mv* on the jack-box.

Balancing the bridge for this arrangement gives $\frac{m}{n}=\frac{g+w}{p+x}$. Solving the two equations for x so as to eliminate $g+w$, gives $g+w=R-x$ and $\frac{m\,p+m\,x}{n}=g+w$, hence, $R-x=\frac{m\,p+m\,x}{n}$, $m\,x+n\,x=R\,n-m\,p$, or

$$x=\frac{R\,n-m\,p}{m+n} \qquad (1)$$

If, as in the Western Union bridge $n=m$,

$$x=\frac{R-p}{2} \qquad (2)$$

For locating a high-resistance cross, about 120 volts with a protecting resistance of about 1,000 ohms in the battery circuit, may be used.

68. Method Requiring Three Measurements.—To locate crosses by making three measurements, first measure, as explained in Art. **63**, the resistance from B to D through the cross, the resistance of which may be called z ohms, con-

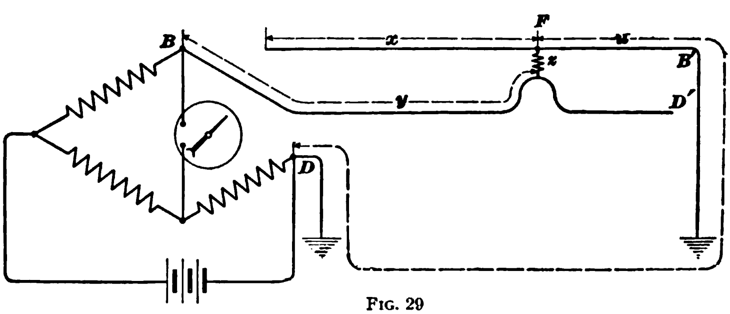

FIG. 29

necting the bridge as shown in Fig. 24 with the distant ends of the two crossed wires open. Let the resistance so measured be a; then, $x+z+y=a$. Now measure the resistance through

y, z, and u, by connecting the bridge as shown in Fig. 29. Let this resistance be c; then, $y+z+u=c$. Finally, measure the resistance of the line $B\ B'$, as shown in Fig. 30, by having the distant end B' grounded, and the ends $H\ D'$ open. Let this resistance be b; then, $x+u=b$.

This order of making the measurements is preferable because the two measurements involving the resistance of the cross are

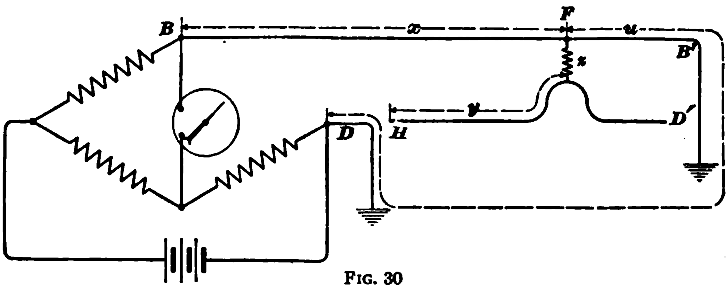

FIG. 30

made immediately one after another, thus giving less opportunity for the cross to change in resistance as may be the case if the third measurement is made between the other two. Subtracting the second equation from the sum of the first and third equations and then solving for the resistance x from the testing station to the fault gives the following formula:

$$x=\frac{a+b-c}{2}$$

Dividing x by the resistance of the wire x per mile gives the distance, in miles, to the cross F. It will be noticed that the resistance of the cross z eliminates, so that if z remained constant during the second and third measurements, the formula is accurate and independent of the value of z.

RESISTANCE OF CROSS NEITHER NEGLIGIBLE NOR CONSTANT

69. A method will now be given in which the resistance of the cross is eliminated, whether constant or variable, and the test requires, moreover, only two resistance measurements. However, the ordinary bridge connections have to be slightly modified, which is an objection.

First, connect up as shown in Fig. 30 and measure the resistance of the line $B\ B'$, including the ground return path. Let this be a; then, $x+u=a$. Then connect the bridges as shown in Fig. 31, using only two arms p and n of the bridge; the third arm m, being on open circuit, is not used. The galvanometer, instead of being connected to the end of the arm m, is connected to the end of the wire y. Thus, $B\ F$ forms the third arm and $F\ B'\ C$ the fourth arm of the bridge. The resistance of the cross z and that portion y of the line $D\ D'$ is included in the

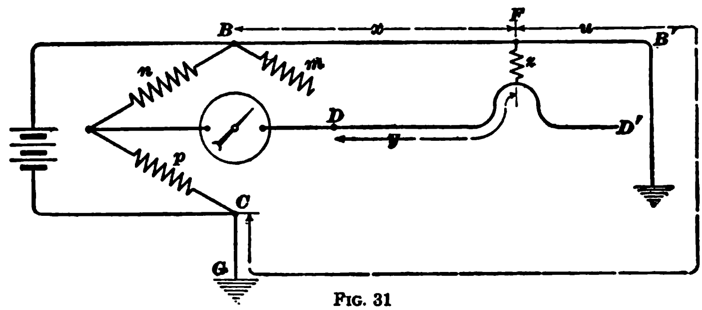

FIG. 31

bridge or galvanometer circuit, and, therefore, this resistance z and y will not enter into the result for the same reason that the resistance of the galvanometer never does in measurements made with the Wheatstone bridge method. Hence, the resistance of the cross does not enter into the measurement, and, furthermore, the final formula is entirely independent of this resistance whether it is constant or not. The resistance u, from F through B' and back through the ground to G, forms the fourth arm of the bridge. From the well-known principle of the bridge, after adjusting it until there is no deflection, $\frac{n}{p}=\frac{x}{u}$. Solving these equations for x, the following formula for the resistance along the wire $B\,B'$ to the cross is obtained:

$$x=\frac{n\,a}{p+n} \qquad (1)$$

Finally, by dividing x by the resistance of the line $B\ B'$ per mile, the distance, in miles, from B to the cross F is found.

If more convenient to do so, the end B of the wire may be joined to the end of the arm m. In this case, x in the second equation must be changed to $m+x$ and the following formula for x is obtained:

$$x=\frac{n\,a-p\,m}{p+n} \qquad (2)$$

70. To locate a cross between two wires of equal size by means of a slide-wire bridge, connect as shown in Fig. 32. A good wire is necessary in addition to the two crossed wires, and it is connected to either of the crossed wires at some point—beyond the cross. The home end of the crossed wire, to which the good wire is connected, is joined to the bridge at g; and one terminal of the galvanometer is connected to the

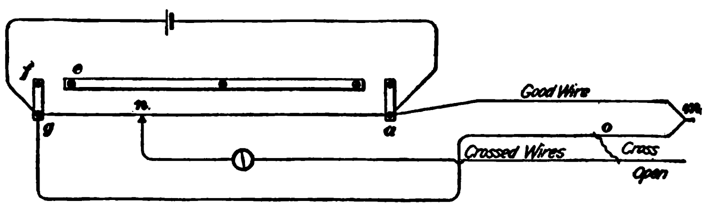

FIG. 32

other crossed wire, which must be open at the distant end. Then find a point n on the slide wire that produces no deflection of the galvanometer. Then the

$$\text{distance } g\,o = \text{distance } g\,o\,m\,a \times \frac{\text{length } g\,n}{\text{length } g\,a}$$

For the distance $g\,o\,m\,a$, twice the length of one line wire or twice the length of a cable being tested may be used. This result is independent of the resistance of the fault, even if it varies during the test. This is practically the Murray loop test made with a slide-wire bridge.

71. One Wire in Use.—The method of locating crosses about to be described may be used to determine the resistance of one wire or the distance to a cross between that wire and another wire while the latter is in regular use as a telegraph line. The result is not, however, independent of the resistance of the cross. By this method, low-resistance crosses and grounds may be located and if a balance can be secured while the fault exists, swinging crosses and grounds may be approximately located.

The connections for this test are shown in Fig. 33, in which $B\,C$ represents a slide-wire bridge; R, a known resistance; G, a sensitive galvanometer with its usual shunt r and short-

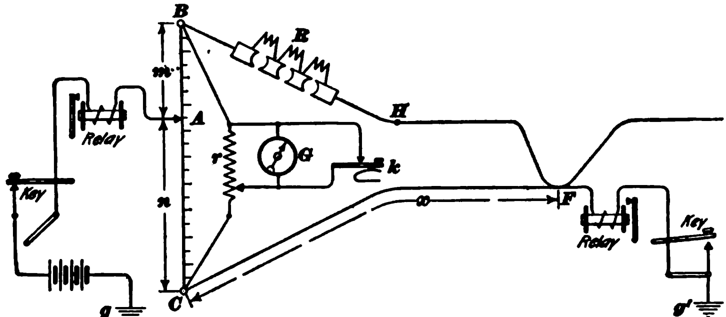

FIG. 33

circuiting key k; $C\,F\,g'$, the wire in use; and $H\,F$, the line wire, which is crossed at F with the other line wire and is open beyond the cross.

72. To make the test, set the slide about midway along the slide wire $B\,C$, short-circuit or remove all the resistance at R, open the galvanometer short-circuit key k, and adjust the position of A along the slide wire until the galvanometer returns to its normal position of rest. The telegraph relays may be in service all the time the test is made, although the test is more readily made with this relay circuit permanently closed. Remove or open the galvanometer shunt, and readjust n if necessary, until the galvanometer gives no deflection and note the lengths m and n. Then remove the plugs from R, that is, insert the resistance R between B and the crossed wire $H\,F$; move the pointer A until the bridge is balanced again in the same manner as before and note the lengths m' and n'. The resistance x of the working wire from C to the cross F may then be calculated by the formula,

$$x = \frac{n\,n'\,R}{(m'-m)\,(m+n)}$$

$m + n$ is the total length of the slide wire and is usually 1,000 or 100. The resistance used at R should be enough to make the two points of balance quite different. The greater the resistance of $C\ F$, that is, the greater the distance to the cross, the greater must be R.

NOTE.—This formula is derived as follows: The first balance gives $\frac{m}{n} = \frac{B\ H\ F}{x}$; the second balance gives $\frac{m'}{n'} = \frac{R+B\ H\ F}{x}$. Solving both equations for $B\ H\ F$ and equating their values, gives $B\ H\ F = \frac{m\ x}{n}$ and $B\ H\ F = \frac{m'\ x}{n'} - R$, or $\frac{m\ x}{n} = \frac{m'\ x}{n'} - R$; solving for x, gives $\frac{m'\ x}{n'} - \frac{m\ x}{n} = R$, $x\left(\frac{m'}{n'} - \frac{m}{n}\right) = R$, $x\left(\frac{m'\ n - n'\ m}{n'\ n}\right) = R$, $x = \frac{n'\ n\ R}{m'\ n - n'\ m}$. But $n' = n+m-m'$, then $\frac{n'\ n\ R}{m'\ n - m\ (n+m-m')} = \frac{n'\ n\ R}{m'\ n - n\ m - m^2 + m\ m'}, = \frac{n'\ n\ R}{m'\ (n+m) - m\ (n+m)} = \frac{n'\ n\ R}{(m'-m)\ (n+m)}$

EXAMPLE.—A wire having a resistance of 13.3 ohms per mile was tested for a cross with another wire. The first balance, when there was no resistance at R, gave the distance $A\ B = 490$ divisions. When a resistance of 50 ohms was inserted at R, the point of balance gave $A\ B = 580$ divisions. The slide wire was 1,000 divisions long. What is the distance, in miles, to the cross?

SOLUTION.—From the first balance, $m = 490$ and $n = 1{,}000 - 490 = 510$; from the second balance, $m' = 580$ and $n' = 1{,}000 - 580 = 420$; furthermore, $m+n = 1{,}000$. Substituting these values in the formula, gives

$$x = \frac{510 \times 420 \times 50}{(580-490) \times 1{,}000} = 119 \text{ ohms}$$

The distance to the fault is therefore $119 \div 13.3 = 8.9$ mi. Ans.

TESTING OF CIRCUITS
(PART 3)

TESTING

ROUGH TESTS

TESTS WITH MAGNETO GENERATOR AND BELL

1. It is frequently necessary to make rough tests to show whether circuits are continuous or broken, whether crossed, grounded, or properly insulated. These tests do not require accurate measurements, they being merely for the purpose of determining the existence of a certain condition without the necessity for measuring accurately the extent to which that condition exists. While much of this Section applies to the testing of telephone circuits and lines, the same principles are involved in testing telegraph circuits and lines, except that telegraph lines usually have a ground return instead of a pair of wires with no ground return and that a telegraph key and an ordinary, or box, relay will be used as a testing set instead of a telephone receiver, buzzer, or magneto set.

2. Magneto Testing Set.—A very common and useful form of testing instrument is that consisting of a magneto generator and polarized ringer, together with some simple form of telephone, all mounted compactly in a box provided with a strap for convenience in carrying. The polarized bell is usually connected in series with the generator, which is preferably provided with an automatic shunt. The circuits of one form of magneto testing set are shown in Fig. 1, in which the polarized bell *R* is connected in series with the generator *G* when the switch *S* is in contact with the center button. When the switch is thrown to the left, the bell is cut out of circuit and the generator only is connected across the line terminals, this condition being advantageous when it is necessary to signal a distant station over a line that may be partly grounded or crossed. When the switch is thrown to the right, the magneto telephone *T* is connected across the circuit, and may be used either as a transmitter or a receiver in communicating with another party on the line.

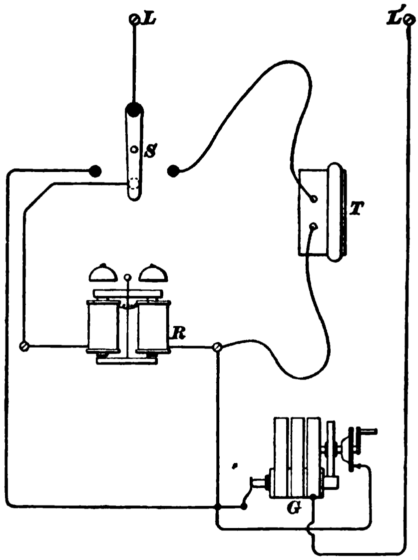

FIG. 1

When the generator is at rest and the switch is thrown to the right, the telephone receiver *T* alone is connected in the circuit between the binding posts, the magneto generator being shunted out of circuit by the automatic shunting device. If, however, the generator should be operated while the switch is in this position, the current from it will pass through the telephone and to line, thus producing a buzz in the telephone receiver.

3. Continuity Tests.—When testing wires for continuity, the terminals of the magneto set should be connected to the terminals of the wire and the generator operated, the switch of the testing set being thrown so as to include the bell and generator in series. A ringing of the bell will usually indicate that the circuit is continuous. This is a sure test on short lines, but should be used with caution on long lines and cables, because it may be that the capacity of the line wires themselves will be sufficient to allow enough current to flow through the bell to operate it, even though the line or lines are open at some distant point.

4. **Testing for Crosses.**—When testing a line for crosses, either with the earth or with other conductors, one terminal of the magneto set should be connected to the line under test, both ends of which are insulated from the ground and from other conductors. The other terminal of the magneto set should be connected successively with the earth and with any other conductors between which and the wire under test a cross is suspected. A ringing of the bell will, under these conditions, indicate that a cross exists between the wire under test and the ground or the other wires, as the case may be, and the strength with which the bell rings and also the pull of the generator in turning will indicate in some measure the extent of this cross.

An experienced lineman can often tell with considerable accuracy the approximate location of a cross on a line by the sound produced by the bell or by the pull of the generator crank when the generator alone is thrown on the circuit. Here, again, however, as in the case of continuity tests, the ringing of the bell is not a sure indication that a cross exists, if the line under test is a very long one. The insulation may be perfect and yet a sufficient current may pass to and from the line, through the bell, to cause it to ring, these currents, of course, being due to the static capacity of the line itself.

5. When testing very long lines or comparatively short cable lines, the magneto set must be used with caution and intelligence, on account of the capacity effects referred to. For short circuits in local testing, however, the results may be relied on as being accurate. Ordinary magneto testing sets are commonly wound in such a manner that the generator will ring its own bell through a resistance of about 10,000 to 15,000 ohms, although some are wound and constructed to ring very lightly through 50,000 ohms. They may be constructed to ring only through about 10,000 ohms or through as much as 125,000 ohms. One that will ring its own bell through 25,000 ohms is probably best adapted for

all-around testing work. A very good generator, when rapidly rotated, will commence to ring its bell through about .1 microfarad, and an ordinary generator through about .3 microfarad; each will ring stronger as the capacity is increased.

TESTING OUT CIRCUITS OF INSTRUMENTS

6. When a case of trouble arises in a telephone instrument, for example, a careful inspection of the instrument will usually reveal about what the nature of the fault is. For

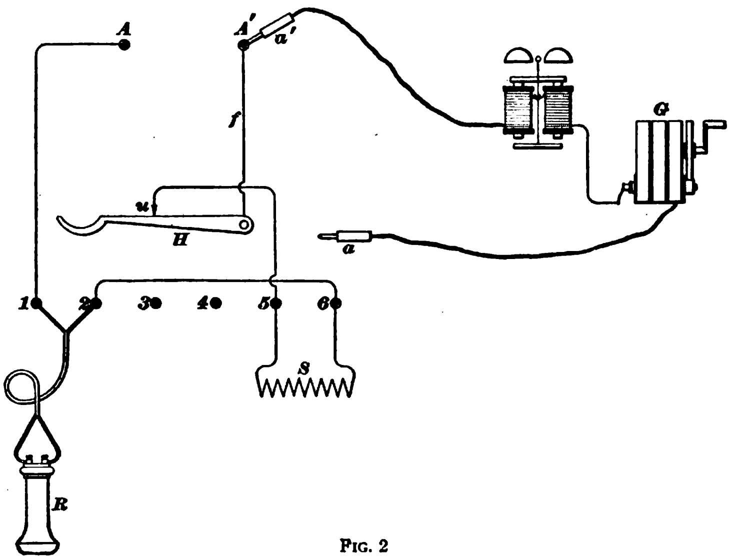

FIG. 2

instance, if in the ordinary instrument, it is found that the instrument will both receive and transmit signals to the distant station, but refuses to either receive or transmit speech, the inspector will at once conclude that the signaling apparatus and circuits are all right, and that the fault is somewhere in the talking apparatus or circuits. Furthermore, from the fact that the instrument will not receive speech, he will know that the fault is not in the primary circuit because that circuit has nothing whatever to do with the receiving properties of the instrument. This will mean that something is wrong with the secondary circuit, and will probably indicate that this circuit is open at some point. A test to find out at what point this break occurs may be made as indicated in Fig. 2, where only the secondary circuit of an ordinary local-battery telephone is shown.

7. In Fig. 2, *1*, *2*, *3*, *4*, *5*, and *6* are the binding posts at the bottom of the magneto box, and S is the secondary of the induction coil. At the right of this figure is shown the testing set, consisting in this case of a magneto-bell and generator. A receiver and battery might be substituted for this, the test being performed in exactly the same manner. At a and a' are shown two convenient testing terminals, forming the ends of the testing circuit. The line wires should be disconnected from the telephone at the binding posts A and A'. The terminal a' should be touched to one of the binding posts A', and for convenience it may be inserted in the binding post in place of the line wire. The terminal a should then be touched to the opposite binding post A, when a failure of the polarized bell of the testing set to ring when the generator G is operated will show that the secondary circuit is open at some point.

8. The test to locate this point is made as follows: The terminal a', Fig. 2, is left fastened in the binding post A' and the magneto generator is kept turning, preferably by another party, while the terminal a is applied successively to all the wires in the parts forming the secondary circuit of the telephone. It should first be applied to the wire f, a ringing of the bell indicating that the circuit so far was unbroken. It should then be applied to the hook lever H, then to the upper contact u, and so on, point by point until the secondary circuit has been traced out. If, for instance, when the hook is up, the bell fails to ring while the terminal a is applied to the upper contact u, but rings when the terminal a is applied to the hook H, it clearly indicates that the circuit is open between the hook H and the upper contact u; this contact should therefore be carefully inspected and repaired.

If the circuit is complete as far as the binding post *5*, but the bell fails to ring when the terminal is applied to the binding post *6*, the secondary coil is open; if an inspection of the exterior circuits leading to the coil fails to show the difficulty, the coil should be removed and another substituted. In this manner, any circuit in a telephone may be readily tested out, and the

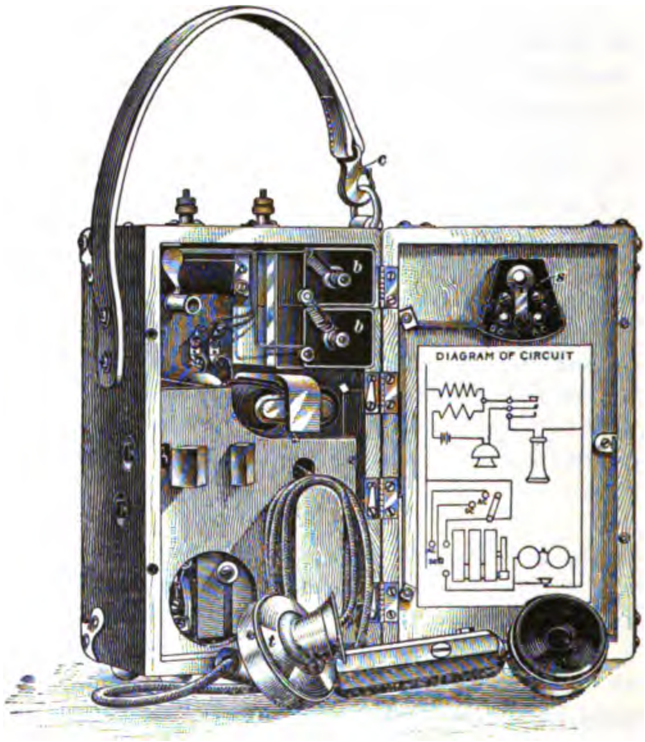

FIG. 3

fault located, after which the repair is usually a very simple matter.

9. Telephone Testing Set.—In many forms of testing sets, microphone transmitters and batteries for operating them are also included, although the addition of this extra apparatus usually adds considerably to the weight of the testing set. A portable telephone testing set is shown in Fig. 3. It contains a standard three- or four-bar generator, a 1,000-ohm bell, and other telephone devices. The receiver and transmitter are secured to one handle, the granular-carbon transmitter *t* being provided with a metal mouthpiece that prevents the breaking of the same. In the handle of the *microtelephone*, as it is termed, is a push button that, when closed, connects the batteries in the transmitter circuit. This prevents the exhaustion of the batteries when not actually in use for talking purposes. The door of the testing set may be closed when the microtelephone is outside.

10. When the full voltage of the generator is desired for ringing on a line, the bell can be cut out of the circuit by means of a push button. The generator is provided with collecting devices by means of which either alternating or direct pulsating currents may be obtained; a switch *s* through which the desired current may be obtained is placed on the inside of the cover.

The box has a strap with a snap catch *c*, by means of which the box may be easily suspended from a cross-arm or any convenient support. The door is opened by a push button and held closed by an automatic catch. The set is very solidly made, the corners of the box being protected with brass. All terminals are provided with thumb-nut binding posts, for tightening or loosening which no screwdriver is required. These terminals are put in readily accessible positions and the batteries *b* may be easily removed without disturbing the rest of the apparatus. A diagram of the wiring of the set is shown on the inside cover of the box.

TESTS WITH VOLTMETER OR CURRENT-DETECTOR GALVANOMETER

11. In order to test for grounds, crosses, or open circuits on long lines or on cables, without the liability to error that is likely to arise when testing with a magneto set, a cheap form of galvanometer for detecting currents, a voltmeter, or millivoltmeter may be used. When testing for grounds or crosses, the millivoltmeter, or galvanometer, should be connected in series with several cells of battery, and one terminal of the circuit applied to the wire under test, it being carefully insulated at both ends from the earth and from other wires, while the other terminal of the millivoltmeter, or galvanometer, and batteries should be connected to the ground and to adjoining wires successively. A sudden deflection of the needle may take place whenever the circuit is first closed, due to the rush of current that is necessary to charge the wire. If the insulation is good, the needle will soon return to zero; but if a leak exists from a line to ground or to the other wire with which it is being tested, the needle will remain permanently deflected.

12. Tests for insulation can be made with considerable accuracy by this method if a battery consisting of about fifty cells is used, but if a very high insulation resistance must be measured with more accuracy, more reliable methods should be used.

When testing for continuity, the distant end of the line should be grounded or connected with another wire, known to be good, and the voltmeter, or galvanometer, and battery applied, either between the wire under test and ground or between the wire under test and the good wire. In this case, a permanent deflection of the needle will denote that the wire is continuous; while if the needle returns to zero, it is an indication of a broken wire.

TESTS WITH TELEPHONE RECEIVER

13. The importance of the telephone receiver as a testing instrument is greatly underrated. A good telephone receiver is one of the most sensitive detectors of current known, and if connected in series with a battery, it may be used for rough tests in many cases with greater facility than the magneto testing set or the detector galvanometer.

The ordinary watch-case receiver with a head-band for holding it to the ear of the user, together with one or two small-sized cells of dry battery, form a testing set that, for local work, is unsurpassed and may be used when testing out cables for grounds or broken wires. If the set is to be portable, the batteries should be small enough to be carried in the coat pocket of the user; and if two cells are used, they may be bound together, side by side, by string or by a wrapping of ordinary adhesive tape. One terminal of the battery is connected to one terminal of the head-receiver, while to the remaining terminals may be connected flexible cords provided with terminals adapted to make contact with the various parts of the circuit that it is desired to test. This arrangement, while being capable of detecting the most feeble currents, has the further advantage of being light and of allowing the complete freedom of both hands of the user.

14. Grounds and Crosses.—When using the receiver for making rough tests for grounds or crosses on conductors in a lead-covered cable, one terminal of the testing circuit, including the receiver and battery, should be connected with the sheath of the cable, while the other terminal should be connected with the wire under test, which should be free from other wires at each end. All the other wires in the cable should be bunched together at the near end of the cable and connected with the sheath. The wires at the distant end of the cable must be carefully separated from one another and from the sheath, so that there is no possibility of a cross existing between them at that end. A click will be heard on closing the circuit with the wire under test, whether or not the wire is grounded, this being due to the fact that a small amount of current will flow into the wire even if it is properly insulated.

15. If the wire is grounded, the flow of current will continue as long as the terminal is applied to the wire; but if the wire is well insulated, the flow will cease as soon as the wire has received its full charge. In order, therefore, to guard against misleading results, the terminal of the testing set should be held against the wire several seconds, then the connection should be broken and quickly remade; if no sound is heard at the instant the connection is again made, the insulation is good; while a continuance of the clicks each time the circuit is remade will indicate that the wire is grounded. The loudness of the click depends on the sensitiveness of the telephone used, the number and voltage of the cells used, the electrostatic capacity of the conductor, the resistance of the insulation, and the interval of time between the break and make. Under ordinary conditions with a telephone cable from 1,000 feet to a few miles in length, 1 second between a break and the next make, and a battery of 1 volt, no click usually means at least 50 megohms resistance between the conductor and the ground. This number increases about in proportion to the increase in electromotive force used.

16. For Continuity.—When testing for continuity with the receiver, all the wires should be bunched together at the distant end of the cable and connected with one terminal of the test battery by a separate wire leading to the end of the cable where the test is to be made. The other terminal of this battery should be connected to one terminal of the receiver, the other terminal of which may be applied to the separate wires at the near end of the cable, all the wires at this end being carefully separated from one another. A continuation of the clicks, on tapping, will, in this case, indicate that the wire being tested is continuous, while the cessation, after a few taps, will indicate that it is broken. It is probably better, when making this test, to use an ordinary vibrating bell or buzzer instead of a receiver, for then, if the wire is only partly ruptured so as to offer a very high resistance, it will not allow enough current to pass to ring the bell, while it would allow enough to pass to produce a decided click in the receiver.

CABLE TESTING

NUMBERING OF CABLE CONDUCTORS

17. Twisted-pair cable conductors are numbered from 1 up; the odd number represents the first conductor of a pair and the even number its mate. As a result of a custom established when ground circuits were used in telephone practice, the odd-numbered conductor is called *the line* and the even-numbered conductor *the test*. If a cable splicer connects his telephone or test set with a certain conductor, to communicate with another splicer similarly associated with the other end of the conductor, he is said to *meet* the other splicer on the conductor. For example, if the splicer connects his telephone with conductor No. 1, using the earth as a return, and his assistant at the other end of the cable tries each conductor with his testing set until he finds No. 1 and communicates with the splicer on it, he is said to meet the splicer on No. 1; and as No. 1 is an odd-numbered conductor, he meets the splicer on the line of No. 1 pair. On communication being thus established, the helper will be directed to meet the splicer on the test, and on receipt of this instruction, he will connect his test set with conductor No. 2. When a telephone man thus connects his test set with a conductor for the purpose of communication, he is said *to go on the conductor*. When he connects his test set with both the line and test of a pair of conductors, and thus talks over a metallic circuit, he is said *to go metallic*.

18. The same conductor should have all its terminals, both in the central office and outside of it, numbered the same; for which purpose a test is necessary whenever a new cable is installed, whenever a defective section is replaced by a new cable, and whenever a system is changed from open wire to cable, or from aerial circuits to underground cable. The nature of the test and the method of making it depends on the conditions to be met.

IDENTIFYING WIRES IN CABLES

19. It is frequently necessary, when a certain wire has been picked out at one end of a cable, to identify that same wire at the other end in order that connection may be made with it. In order to do this, the wire desired should be grounded at one end, and also carefully insulated from all the other wires. At the other end, the wires should be separated from one another and be free from the ground. A circuit containing a battery and a receiver, galvanometer, voltmeter, or ordinary vibrating bell or buzzer or a telegraph relay and key should then have one of its terminals grounded, while the other terminal should be applied successively to the various wires in the end of the cable. A continuation of the clicks in the receiver, a permanent deflection of the galvanometer, or voltmeter, a ringing of the vibrating bell or the closing of the relay will indicate when the wire desired has been touched.

20. Using a Buzzer.—A bell or buzzer can be used for testing in two ways. Either the battery can be connected to one end of the wire to be found and a search made at the other end with a grounded buzzer, or the battery with the buzzer in series is connected to one end and a search made at the other end with a receiver. In this latter case, when the proper wire is touched, the sound of the buzzer at the other end is heard in the receiver. The advantage of using the buzzer lies in the fact that the receiver of the talking set can be permanently connected to the talking wire, which is not the case when only receivers are used.

21. Battery-Receiver Test.—The ability to talk over a pair of wires is not a sure test of their continuity because it is often possible to talk over a wire with one end open. A battery in series with a receiver is claimed to be reliable because a closed circuit is necessary before a battery current can flow; however, this method is open to the objection that a click may be produced when the circuit is first closed even when open at the distant end. While several methods are employed for testing twisted-pair cables after they are spliced, the following battery-receiver method is considered the most practicable by some cable testers.

22. The office end is formed up and numbered first. The man in the office connects his receiver across wires 1 and 2 and connects one end of a feeler wire, or *third leg* as it is termed, to wire 1. He then touches the other end of the feeler wire to ground and waits for the man on the pole to find him, which he does by grounding one terminal of a battery, connecting the other terminal to a receiver and with a wire attached to the other terminal of his receiver he runs over the insulated ends of the wires until he gets a click in his receiver, which occurs when he touches wire 1 or 2. He connects his receiver only across the pair of wires 1 and 2 so found and one terminal of his battery to wire 2. The two men now have a complete metallic circuit consisting of wires 1 and 2 for talking. When he is ready, the pole man tells the office man to touch wire 3 with his feeler, the other end of which is connected to wire 1. As soon as the man on the pole finds this wire 3 by touching his feeler to it (the other end of this feeler is connected through the battery to wire 2), both men get a decided click in their receivers. A code of signals can be arranged to save talking; thus three clicks may mean all right. Then the office man goes on the next wire with his feeler and so on until all the wires are tested. If a wire is bad, the pole man can tell the office man and they can skip the bad wire until the last; if it cannot then be found, an extra pair can be substituted for it. It is useless to try to talk with the office-feeling wire on the wire picked up, as the office receiver is then shunted. This is said to be a very fast method of working and can be used on working cables where a common battery is not used.

23. Combined Common-Return and Metallic Circuits.—If some of the telephone subscribers have a ground or common-return circuit, the ground or common-return circuit terminates at the cable pole; from there through the cable to the office the circuits are complete metallic. When testing a working cable on such a system, ground the outside end of all the switchboard-cable wires used in this way, disconnect them from the cable to be tested and disconnect the grounded-cable wires at the pole from the ground. Find a pair of wires not in use and proceed to test in the way described in the preceding article, except that the office man must have the battery, as going through the cable with the battery at the pole would throw the drops at the office.

24. Identifying Without Cutting.—It is frequently desirable to identify a wire at some intermediate portion of a cable without cutting the wire. This may be done by removing the sheath, or the outer coating, if the cable has no sheath, and loosening up the wires so that each one may be touched. The tests explained in Arts. **19** and **20** may then be made by using, as a terminal to the testing circuit, a needle that will readily pierce the insulation and make contact with the conductor within. This method will save much trouble in the testing of switchboard cables, where it is often necessary to lead off branch wires from intermediate points of certain wires in the cable.

When testing a working cable on a central-energy system, ground one side of the receiver and use a needle or a penknife to push through the insulation on the wires in the cable, which has been previously opened. On good working lines, a click will be heard and when the operator answers, ask for the drop number and tag the wire with the proper cable-line number. Lay aside all the dead pairs as found. After picking out all the working pairs, test the dead pairs, as explained in Arts. **21** and **22**.

25. It is desirable to have the two ends of a telephone cable connected to the terminal heads or frames and numbered in a similar manner. One end of the cable is first connected, usually the office end, and then the conductors are tested out in order to connect and number them in a similar manner at the distant end. The first thing to do is to test out a pair that may be used for communication during the rest of the test. A common method of locating this talking pair is to have the man at the distant end *M*, Fig. 4 (*a*), connect his head-receiver between one conductor and the lead sheath, all conductors at that end being preferably fanned out and at least insulated from the conductor that is being tested. The man at the office end *O* then connects one terminal of his head-receiver to the sheath, and the other terminal to two or three dry cells *B*, while with the free end *d* he touches all the conductor terminals, one at a time, until both men get a decided click in their receivers, which indicates to them that the wire to which the pole man *M* has his receiver connected has been found by the office man *O*.

The other wire *2* of this pair can be readily found, and, if necessary, tested in a similar manner. The connections shown at both ends of Fig. 4 (*b*) are then made, and the pair *1-2* used to talk over. The pole man *M* then connects his terminal *e* to any wire whose location and number he desires, and the office man *O* feels for this wire by touching, with *d*, all his terminals until a loud hum indicates to both of them that the desired wire has been picked up by the office man *O*.

26. The buzzer makes and breaks the circuit containing the primary winding *p* of an induction coil, thereby inducing

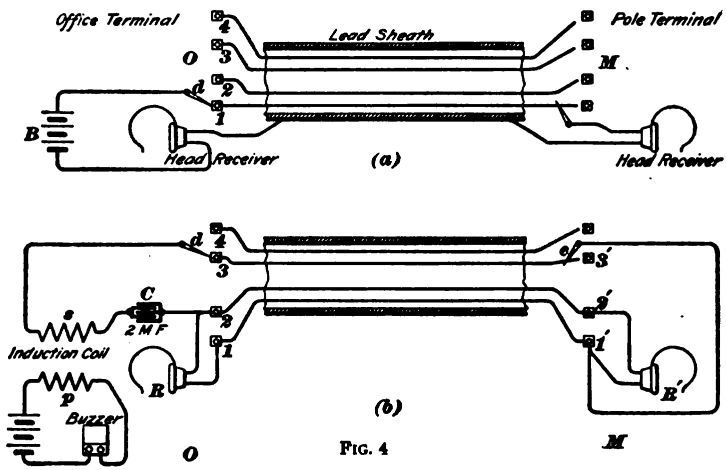

FIG. 4

an alternating electromotive force in the secondary winding *s*. This may, at all times, produce a slight hum in the receivers due to the slight charging and discharging of the 2-microfarad condenser *C*, but the hum will be very much louder when the circuit of *s* is completed through a conductor. The current arriving at *2* divides about equally through *2*–*R*–*1*–*1'* and *2*–*2'*–*R'*–*1'*, reuniting at *1'* and returning through *e*–*3*–*d*–*s*. The office man *O* then removes his needle *d* from the conductor just found and tells the pole man *M* its number, so that the latter can connect it to the terminal of the same number at his end.

Should the loud hum be also obtained when the office man *O* touches his needle to *4*, while the pole man *M* keeps his needle against *3′*, conductors *3* and *4* are probably crossed, and if the loud hum should be obtained when the office man *O* touches the sheath, the conductor touching *e* is probably grounded. In this way, each conductor may be tested for a cross or ground. This test is very similar to that explained in Arts. **21** and **22**, except that a buzzer, induction coil, and condenser are required in addition to a battery, and the source of current is placed at the office end instead of at the pole terminal. When testing cables while in use on central-energy systems, the source of current should be at the office end in any case. As the charging and discharging of an open cable line, especially a long one, may cause a click or a hum in a receiver, many prefer to use a buzzer in place of a receiver for such tests.

27. When a new cable is placed in position, the pairs are taken at random and connected to the main distributing board in regular order. An assistant is then sent to the distant office or terminal with a test set consisting of a buzzer and talking outfit. The cable splicer then connects two dry cells and a buzzer to the line of the first pair, or, what is the same thing, on conductor 1, the other side of his test set being grounded on the lead sheath, or otherwise, and instructs his assistant at the other office to meet him on the conductor. The assistant having reached the far office, connects one side of his buzzer to ground and, with a wire attached to its other side, touches each conductor in succession. When the proper conductor is reached, a circuit will be formed along it to the other office, thence through the first buzzer and battery to ground, and the buzzers at both ends will sound. The two men then talk to each other over this conductor with their test boxes, and the splicer then directs his assistant to meet him on the test. This having been done in the same manner, the assistant enters this pair into the positions to be occupied by conductors 1 and 2. He then proceeds to find the next pair in the same manner.

This is illustrated in Fig. 5, where *a*, *b*, *c*, *d*, etc. represent conductors in a cable running between the two central offices *F* and F'. At the office F is the buzzer T and battery connected to the conductor d, while at the office F' the wire connected to the buzzer T' will be seen to be just about to touch the conductor d at x. If the two buzzers do not work well in series, short-circuit the vibrating contact on either, as represented by the dotted line on T'. When contact with d is made, a circuit will be formed over the conductor d through the two test boxes and through the earth as a return. From this diagram, it will be seen that if the conductors at F have been arranged according to a certain order, their other ends at F' can be arranged in the same manner when tested out in this way.

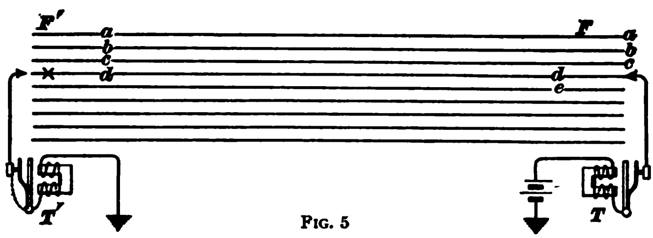

FIG. 5

28. When the conductors have been all tested out, the two men, starting from the first, go metallic on every pair. In making these tests, one conductor that has been tested out is set aside for a talking wire, and should the assistant fail to meet the splicer on any given conductor, owing to its being in trouble, he is always able to communicate the fact over the talking circuit, thus saving unnecessary delay. The cable having been thus tested out and its conductors entered properly on the rack in the two offices, is ready for service.

29. Cables With Split Branches.—When testing out cables having branches, the method employed is necessarily different. Some claim that the testing should be done from the branch terminals instead of from the central office, because the conductors are located at the branches. Suppose that in Fig. 6 A represents the central-office end of a 200-conductor cable, and B its main terminal. Suppose that at the branch terminal C conductors *1–50* are to appear, and at branch terminal *D* conductors *51–100* are to end, the remainder being carried through to *B*. When making the splice at *C'*, fifty conductors are taken at random and a **Y** splice is made. When making the splice at *D'*, fifty more conductors are selected at random, the cable splicer being sure not to get any of the first fifty, as those have already been turned aside, as it were. This work having been done, the conductors are entered into the terminal boxes at *C*, *D*, and *B* in the proper order.

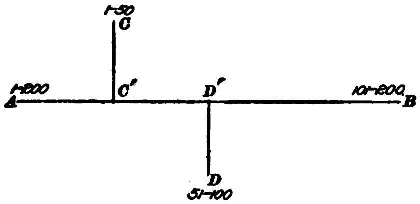

Fig. 6

As the conductors appearing at *C* have been given the numbers *1–50* they must take the first twenty-five pair of terminals on the terminal rack; therefore, this test must be made from the cable box *C*. The cable splicer goes on the line of pair *1* with his buzzer and battery, and the assistant at the exchange finds it on the rack and connects it to spring *1*; the test of this pair is then found in the same manner. When all fifty conductors have been located and properly entered on the rack, the splicer and his helper talk metallic on each pair, which finishes the test.

The cable splicer then goes to cable box *D*, goes in with the buzzer and battery on the line of twenty-six pair, or conductor 51, and his assistant meets him at the exchange. The test wire is then found, and the pair entered on the rack. This process is continued until all these conductors have been located and entered on the rack. The same process is then repeated from the terminal *B*. The conductors having been all entered on the main distributing rack and soldered to the arrester springs, the cable is ready for service.

30. Another way used by cable splicers is as follows: At the office, bunch wires *1–50* and test from *C'* before splicing into the branch *C*. At the office, ground the bunched wires and at *C'* ground one terminal of a battery, connect the other terminal to a receiver, and with the other terminal of the receiver connected to a feeler run over all the wires. On fifty wires, a click should be heard and no click on the rest; after picking out the fifty, remove the ground at the office end and touch one of the fifty. If no click is heard, they are all clear; if a click is heard, separate all the wires at the office end and test for the grounded wires with a battery and receiver, a click being heard on the grounded wires for which a spare pair should be substituted. The wires in branch *C* can be spliced at *C′* at random to the fifty pair picked out at *C′* and then tested and numbered to correspond with the office end after the splice is completed. The wires *51–100* are picked out, spliced, and tested in the same manner at *D′*.

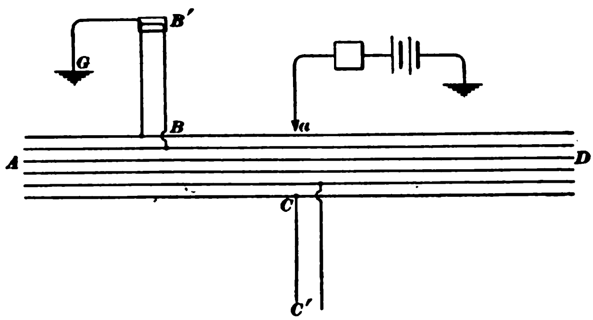

FIG. 7

31. Cables With Bridged Branches.—It is necessary to test out cables on which branches are bridged in a somewhat different manner than that employed in the case of split branches. In the case of split branches, if the start is made at the branch nearest the central office, the conductors can always be selected at random, as there is no danger of making two splices on the same pair. With a bridging cable, however, it is different, and as all conductors pass the entire length of the cable, care must be taken, after the first branch has been spliced, not to include in any subsequent branch any of the conductors included in the first splice.

32. Referring to the case shown in Fig. 7, suppose that the first splice is made at *B*, the pairs having been selected at random. The cable splicer then goes to the cable box B', straps all the conductors together and grounds them. He then goes to the point C where the second splice is to be made and with one terminal of his buzzer and battery connected with the ground he goes over the conductors with the other terminal. If he touches any of the conductors that have been bridged at B, he will get a closed circuit and his buzzer will sound; all other wires will test open. He selects a sufficient number of conductors that test open and splices them. Should there be more than two branches on the cable, he straps all conductors

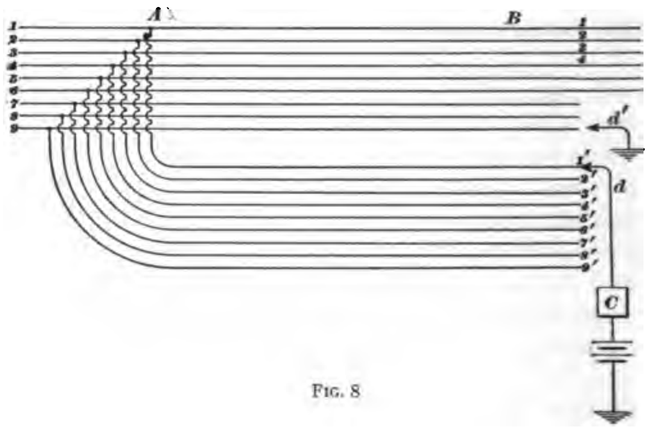

FIG. 8

to a ground at C', goes to the place of the third splice, and proceeds as before. The testing out, for the purpose of entering the conductors properly on the main rack and in the cable box, is made from the cable boxes toward the central office in the manner already described, the ground connections previously made being first removed. Some prefer a receiver for this test in place of the buzzer, and claim that the office end of the cable should be connected up first and all testing done from there.

33. Replacing Cable.—It often happens that a section of cable must be replaced because it goes bad through age or from injury. The work of replacing bad sections must be done on cables that contain a number of working wires, and it therefore becomes necessary to carry it on with as little interruption to the service as possible. Indeed, defective sections can be replaced, if the work is done properly, without any interruption to the service whatever. In Fig. 8, let *1*, *2*, *3*, *4*, etc. represent conductors in a cable that has become defective between the points *A* and *B*. A new section of cable, whose conductors are indicated by the numbers *1'*, *2'*, *3'*, etc., is pulled through a spare duct between the points *A* and *B*, which are always manholes in the case of underground cables. In the manhole *A*, the new section is spliced to the old by using the bridging splice. In this way, each conductor is opened only for an instant. Before making this splice, care must be taken to open the end of the new cable in the manhole *B* and spread the conductors to prevent the occurrence of short circuits and crosses.

This splice having been made, the splicer goes to the manhole *B*. If the assignment of the conductor is to remain unchanged after the new section has been cut into service, the conductor in the new cable that has been spliced to conductor *1* in manhole *A* must also be spliced to conductor *1* in manhole *B*, and so on. To insure this, a battery and buzzer *C* is connected by a wire *d* to conductor *1'*, the other side of the battery being grounded. The conductors of the old cable are then touched in succession with a grounded needle *d'* until the buzzer is heard, which is an indication that conductor *1* has been found. Conductor *1'* is then spliced to conductor *1*, and the process continued until all have been spliced. The conductors of the cable between *A* and *B* are then cut, and sleeves are wiped on at *A* and *B* in the usual manner. Some prefer a receiver and battery in place of the buzzer and battery.

TESTING CABLES WITHOUT A HELPER

34. First Method.—Usually two men, a tester and a helper, are required to test out and properly connect the wires in a twisted-pair cable to the cable terminals. By the arrangement shown in Fig. 9, one man can do this without assistance. After forming up one end, the cable tester grounds wire *1* and then connects together *2* and *3*, *4* and *5*, *6* and *7*, and *8* and *9*, leaving the last wire, *10* in this case, open. This is shown at the *A* end of the cable. He then goes to the other end *B*, separates the ends of all the wires there, so as to have each one insulated and open, and tests for the grounded wire. When found, he knows it to be conductor *1* and the wire twisted with it he knows to be conductor *2*. Then, connecting one terminal of his testing set to wire *2* instead of to the ground wire as in the preceding test, he tests with the other terminal of his testing set for conductor *3*, which is connected to conductor *2* through the jumper he put on at the other end. Conductor *4* is the wire twisted with conductor *3*. He then tests for conductor *5*, and so on until the cable is finished. He knows the last wire because it tests open and also because it is the only wire left. It is evident that a cable of any number of pairs may be tested in this way. If the tester comes across some wire, besides the last one, that is also open, possibly broken inside the cable, no more wires can be tested without assistance, or at least without another trip to the *A* end of the cable. However, this will not often happen.

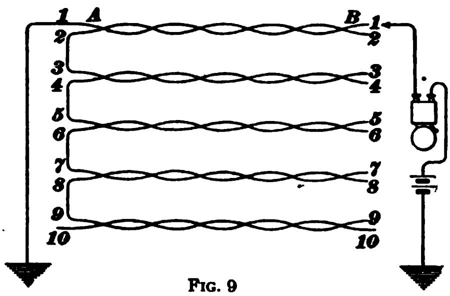

FIG. 9

35. Second Method.—The method about to be given is said to be better than the preceding because if any of the conductors are open the others may still be tested and the last conductor may be picked up at any time and tested the same as any other. It has, however, two disadvantages, namely: (*a*) if the battery fails for any reason, it is at the other end, which may be some distance from the tester or at a place inconvenient to reach for repair or replacement; (*b*) when the end is formed and the battery connected, a cross between the first and last wires (numbers *1* and *12* in Fig. 10) will run down the battery; if number *1* is grounded, the same thing results.

36. The connections for this method of testing cable conductors without a helper are shown in Fig. 10. One end *c* of the cable is formed and the even and odd conductors are connected together, as shown on the formed end, starting *2* to *3*, *4* to *5*, as in the preceding method. Here is shown a 6-pair cable. The battery is connected to conductors *1* and *12*. The side of the battery connected to wire *12* is also grounded or connected to the lead cable sheath. Now at the other end of the cable, connect the buzzer to ground and with a feeler on

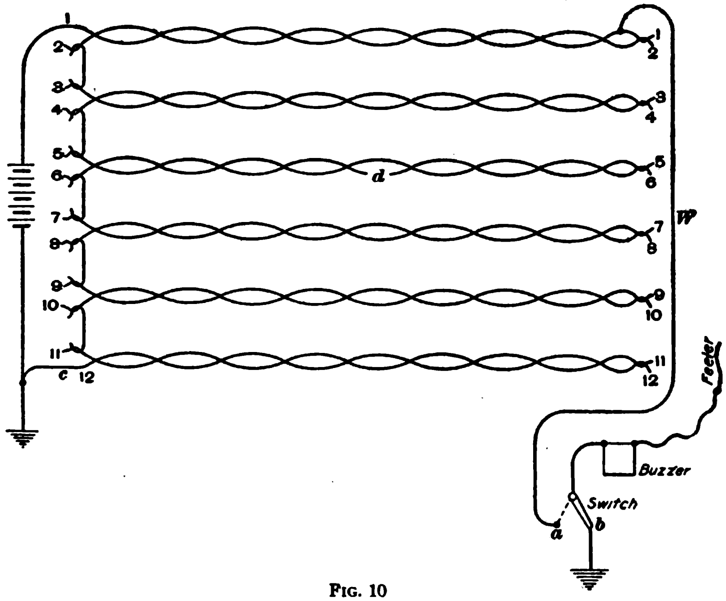

Fig. 10

the other side of the buzzer feel for wire *1* and tag it. Its mate is wire *2*. Connect wires *1* and *2* together.

Now interpose the two-way switch as shown, connecting point *b* to ground, point *a* to wire *1*, and the lever to the buzzer. Leave the feeler connected to buzzer as before. Turn the switch to point *a* and feel again. The wire picked up is the last wire *12*, because wires *3* to *12* are open at end *W*. Turn the switch to point *b*, pick out *3*, and connect wire *3* to wire *4*. In the same manner, pick up and connect the remaining pairs.

Suppose that wire *5* has been picked up and connected to its mate *6* and that an attempt is made to pick up wire *7*, but no buzz is heard; wire *6* or *7* is therefore open at some point *d*. Turn the switch to point *a* and pick up wire *12*. Connect wires *12* and *11* together, feel again and pick up wire *10*. Connect *9* to its mate *10*, similarly test and connect together wires *7* and *8*. Thus it will be seen that all conductors may be tested in the manner given, unless there should be two or more open wires, in which case the pairs between the breaks could not be tested without a trip to the other terminal of the cable.

ELECTROLYSIS OF CABLE SHEATHS

GENERAL REMARKS

37. Electrolysis means here the eating away of cable sheaths, underground pipes, rails, or other grounded or buried conductors by stray currents from street railway or other circuits. Currents due to electric-railway or other systems carrying large currents, and using earth returns are likely, in choosing their path back to the power station, to select the sheaths of underground cables, or of any other metallic bodies that offer paths of lower resistance than the circuit intended for them. This phenomena in general may be illustrated by means of Fig. 11. In this, the return current at the remote end of the trolley line enters the earth from the rails *R* and meeting with a line of water pipe *W*, which forms a route to the power house, selects this conductor as the return circuit. After a time, this line of pipe may come in proximity to the line of telephone cables *C* whose lead sheaths form a still better return path. The current will then follow this new-found conductor to some point where a more direct route is again found, and the current will emerge from the cable sheaths and enter the new conductor.

38. Danger Points.—Except in a few cases, the current in flowing from one kind of a conductor to another will be compelled to pass through the earth, and it is at the points where the current emerges from the conductor and enters the moist earth that electrolytic action occurs and injures the conductor. Thus, in Fig. 11, the danger point on the cable sheath *C* will be that at which the current leaves the sheath in order to pass back to the earth and rails, no damage being likely to occur at the point where the current enters the sheath.

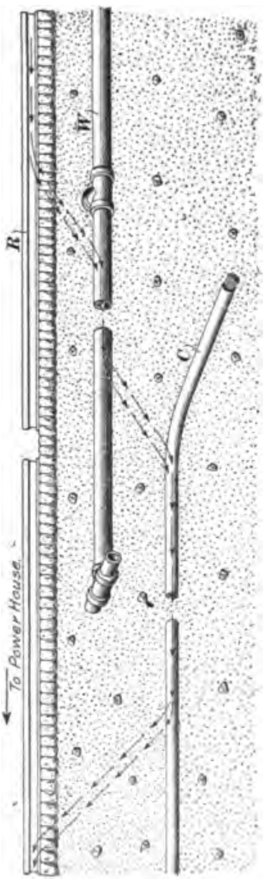

FIG. 11

39. Under certain conditions, the chemical actions produced where the current leaves a pipe causes no eating away of the metal pipe. This may be due to the fact that the energy expended per unit area of the pipe surface may not be great enough to decompose the salts in the damp earth. Electrolytic action may also take place for a while and then cease, owing to the character of the earth around the pipe having become changed by the decomposition of the salts contained therein and rendered incapable of acting longer as an electrolyte. Underground conductors may also become corroded by the simple chemical action of the salts in the earth. The only sure way of determining this point is to bury a similar-sized piece of exactly the same metal insulated from, but alongside, the metal that becomes pitted for about 6 months. At the end of that time the difference in the effect on the insulated and uninsulated similar pieces of metal should be noted by weighing or by observation. The relative effects of corrosion from the two sources can thus be determined.

40. Lead is eaten away nearly twice as rapidly as tin, over twice as rapidly as zinc, over three times as rapidly as copper or iron, and over twelve times as rapidly as aluminum. Underground lead sheaths are, under similar conditions, eaten away very much more rapidly than iron pipe. Wrought-iron pipe is eaten much more rapidly than cast iron, probably due to the impurities, which form a kind of scale on the cast-iron pipe and protect it.

The use of conduits of highly insulated material, such as vitrified clay, goes a great way toward preventing the effects of electrolysis, but it is found necessary to use other means of protection for the cables. Especially is this true in all forms of conduit where no attempt is made to insulate the cable sheaths from the surrounding earth.

LOCATING DANGER POINTS

41. Ordinary Method.—The method of procedure in each case, in order to locate the danger points on a cable, is usually to measure the difference of potential, with a voltmeter, or preferably with a millivoltmeter, between the cable sheath and the surrounding conductors, such as water pipes or the rails of electric railways, at frequent intervals along the cable line. A convenient method of taking these measurements is shown in Fig. 12. Two brass rods of $\frac{3}{8}$-inch stock, about 10 feet long, should be provided. They should each be made in two parts so as to be easily taken apart and put together again, and one should have a conical steel tip for making contact with the earth and other conductors, while the other should be provided with a wedge-shaped tip sufficiently sharpened to make a good contact with the cable and yet not so sharp as to injure it.

The construction of these rods is shown in Fig. 13. On opening the manhole, the rods should be connected with the voltmeter by means of wires of suitable lengths, and the rod with the wedge-shaped tip should be touched to the cable, while the other one is successively touched to the earth, the duct, whatever pipes there may be in the hole, and to whatever other grounded conductors there may be in the vicinity.

Readings of the voltmeter should be taken at frequent intervals along the cable line, and the results recorded in some such form as that shown in Table I.

42. By means of such a table made out for the entire

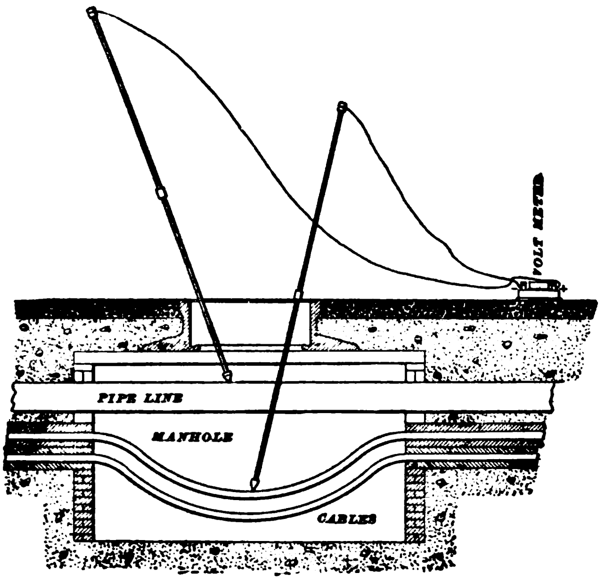

FIG. 12

length of the cable line the danger points may be readily picked out. As long as the cable sheath is negative to all the

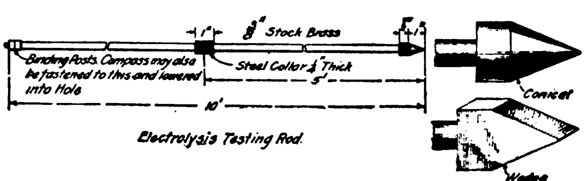

FIG. 13

surrounding conductors it is in no danger from electrolysis, for this indicates that the current is flowing from the surrounding conductors to the sheath. If, however, a point is found where the cable sheath is positive to the surrounding conductors, the current is flowing from the cable to the other conductors through the ground at that point. The maximum positive point on the cable should be determined, and a heavy copper bond should be run from this point to the water pipe, or other conductor, to which the readings indicate the current to be flowing. The record given in Table I will show that the maximum danger point in this case was at 1st Avenue and

TABLE I

RESULTS OF VOLTMETER TESTS

Location of Manholes	Reading from Cable				
	To Earth Volts	To Water Volts	To Gas Volts	To Duct Volt	To Track Volts
1st Ave. and A St.	−.2	−1.2	−1.0	−.1	−4.0
1st Ave., bet. A and B Sts. .	−.3	−1.2	−1.0	−.1	−4.2
1st Ave. and B St.	−.3	−1.2	−1.0	−.05	−4.3
1st Ave. and C St.	−.3	− .9	+ .2	−.05	−3.8
1st Ave. and D St.	−.4	−1.0	+ .4	−.05	−3.2
1st Ave., bet. D and E Sts. .	−.4	−1.0	+ .3	−.05	−3.0

D Street, and a bond would therefore be required from the cable at that point to the gas pipe.

43. Herrick's Method.—The following method is recommended by A. B. Herrick as being much more reliable for determining the potential between a pipe or sheath and the adjacent earth than the older method of using a millivoltmeter:

An insulated pointed rod *a*, Fig. 14, is driven through the soil until the point comes in contact with the pipe. A second insulated rod *b* is driven in so that its point will come close to the pipe but will not touch it. Both rods are insulated and protected by running them through a piece of iron pipe lined with insulating material, as, for example, a piece of lined conduit such as is used for wiring buildings. The earth-potential point is covered with cadmium so that there will not be a local electromotive force set up, which will disturb the difference of potential due to the earth currents. Also, the electromotive force existing between the pipe and the test point is measured not by means of a voltmeter, which would

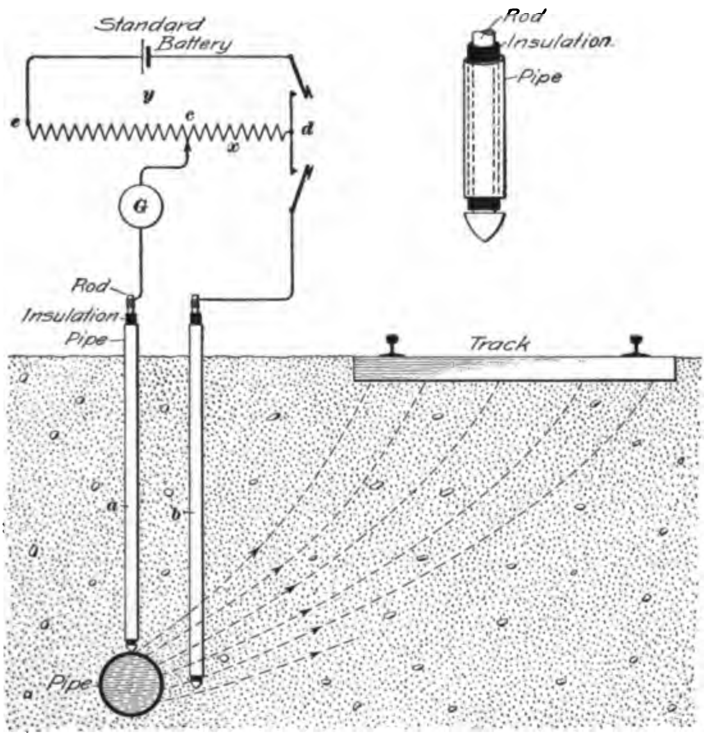

Fig. 14

disturb the normal current flowing between the pipe and ground, but by balancing the unknown electromotive force against a known electromotive force from a standard battery. The resistance *c d* is adjusted until the galvanometer *G* indicates zero current, and the electromotive force between the pipe and ground then bears the same relation to the known electromotive force of the standard battery that resistance x between c and d bears to the total resistance y included between e and d;

or
$$E_1 = E\frac{x}{y},$$

in which E_1 = electromotive force between pipe and ground;
E = electromotive force of standard battery;
x = resistance $c\ d$;
y = total resistance $d\ e$.

It is not necessary to know the values of x and y, in ohms, if the ratio of their resistances is known. Resistance y can be in the form of a slide-wire bridge or a bare high-resistance wire wound on a cylinder and provided with a sliding contact and scale, so that the divisions read off for any position of the contact will be proportional to the resistance x.

EXAMPLE.—A test was made, as shown in Fig. 14, with a battery giving 5 volts and a sliding-contact resistance divided into 100 equal parts. When the galvanometer gave no deflection, resistance x was represented by 30 divisions on the scale. What was the electromotive force between the pipe and ground?

SOLUTION.—In the formula $E_1 = E\frac{x}{y}$, because the resistances are proportional to the lengths of wire,

$$\frac{x}{y} = \frac{30}{100} \text{ and } E_1 = 5 \times \frac{30}{100} = 1.5 \text{ volts. Ans.}$$

44. Voltmeter for Electrolysis Testing.—For electrolysis work, the voltmeter should have a range of about 0 to 15 on one scale and 0 to 150 volts on the other and have a sensibility of about 2,500 ohms per volt. The voltmeter terminals should be plainly marked so that it may be known absolutely which way the current flows through the instrument to deflect the needle in a certain direction. An instrument with zero in the center of the scale is preferable, for often, in cases of poorly bonded rails and intermittent service, the needle will fluctuate first on one and then on the other side of the zero.

It is very desirable to have an extra binding post on the voltmeter, and arranged so that it may be used as a millivoltmeter to determine the direction and relative or approximate amount of current in a heavy bond without cutting the bond.

This is accomplished by taking the drop over a few feet of the bond and if its resistance is known or can be determined in any way, the current through it can then be calculated.

PREVENTION OF ELECTROLYSIS

45. A large system of piping forms a conducting network of very low resistance in parallel with the track, hence it is very difficult to prevent part of the current from leaving the track. However, if proper steps are taken, the bad effects of electrolysis can be largely avoided; the following are the main points that experience has shown should be observed:

1. The trolly wire should be made the positive side of the system.

2. The track should be thoroughly bonded and the bonds maintained in good condition.

3. Any metallic connections that may exist between piping or lead-cable systems and the track should be located and removed.

4. Return feeders should be run from the station and connected to those pipes or cables that carry the greater part of the current. Thus, the current in the pipes or cables will be "drained" off without passing from the pipes or cables to the ground.

5. Where service pipes, cables, or underground conductors pass under tracks or through other regions where they are exposed to electrolytic action, they can often be protected by being covered with glazed tile or by being placed in a trough filled with asphalt.

6. If, in any part of a system, the rail return carries an excessive current, return feeders should be run so as to relieve the rail of part of the current and prevent an excessive fall of potential along the rail. The greater the fall of potential in the rails, the greater is the tendency for the current to pass off to neighboring pipes.

46. The remedy given in 3 is important. Very often accidental connections exist between the rails and pipe or cable so that the current can pass directly to the piping or cable system. This is specially the case where pipes or cables run across iron bridges that also carry railway tracks. Before attempting to drain off the current from a piping system, it is needless to say that all metallic connections between track and pipe or cable sheath must be removed. Where pipes or cables pass across iron bridges, the best plan is to insulate them from the bridge, or if this is impossible, insulate them by the insertion of insulating joints at either end of the bridge.

Remedy 4 is very commonly practiced and gives good results if properly applied. The return feeders should be attached to the pipes or cable sheaths that carry the most current and, as a rule, the current so returned to the power house will not be more than 5 or 6 per cent. of the total railway current; if it exceeds this amount, it is probable that there is a metallic connection somewhere between the track and pipes.

Service pipes, crossing under street-car tracks, are particularly subject to electrolytic action and when they are being laid or repaired it costs but little to cover them with tile or to run them in a box as explained in 5.

47. A voltmeter reading between a cable sheath and the earth at the bottom of a manhole is safe, but readings to a water hydrant or gas main may be very misleading, while readings to a car track will often be very fluctuating and of little value, as the influence of rail potential may not extend more than a few feet from the rail in dry weather.

A difference of potential may be found between the earth at the bottom and top of the manhole and wet weather may change the readings considerably.

48. Under increasing railway-load conditions, a bond that was sufficient when installed, may require several more similar-sized bonds to help it. Also the sheath of a cable may have to be assisted with No. 00 or No. 0000 bare copper wire drawn in the same duct with the cable for blocks where a small cable sheath connects two localities having a considerable difference of potential. If a sheath is only $\frac{1}{10}$ volt positive to the surrounding earth, steps should be taken to lower the sheath potential. Generally, it is a mistake to bond a cable sheath to a rail as a poor bond from one rail to another anywhere on the road to the power house may raise the potential of the sheath above the rail and earth. Even with welded rails, if the traffic is heavy, the fall of potential along the rail may be greater than that along the earth. Some advise bonding together all cables in each manhole and grounding them.

In cases where the cables do not go near the power house, the rail may be the only connection that is available for a bond. If a good low-resistance connection to earth could be obtained, it would be ideal, but even many 1½-inch iron ground pipes driven into the ground in the bottom of a manhole will not carry the 50, 100, or more amperes that may be required to drop the potential to a safe point.

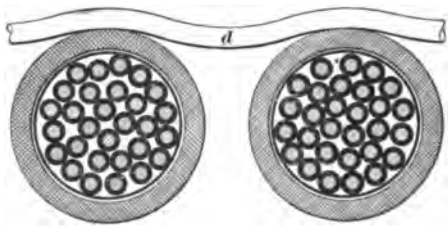

Fig. 15

49. Method of Bonding to Cable Sheaths.—Where bonds are used, all the cables in the manhole should be bonded together. The wire used for bonds is generally No. 8 B. & S. gauge bare copper tinned. Fig. 15 illustrates a way of soldering bonds to lead sheaths. The surfaces of all the sheaths are scraped clean of mud, of which they are nearly always covered. In doing this work, an old file will be found useful, but great care must be taken not to cut away too much of the sheath. The end of the bond wire *d* is then heated in a portable furnace and placed on the bright surface of the sheath and solder applied. A soldering iron is then used to heat the sheath to the required temperature. The surface of the next sheath is then cleaned in turn, and the bond wire bent down and soldered to it.

Where cables are placed on racks close together, they are bonded together with strips of sheet copper tinned by cleaning and drawing them through a pot of molten solder. A strand of three, tinned, copper wires may be used as well. A large soldering iron should be used, as wiping them to the sheaths is not necessary and is more liable to injure the sheath.

50. If the bond wire runs to a gas pipe, it may be soldered as in Fig. 16, in which *a* is a piece of sheet copper, which is

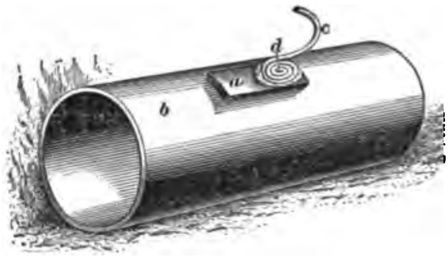

FIG. 16

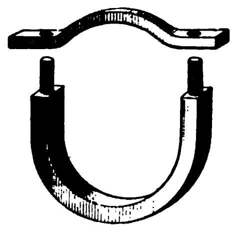

FIG. 17

soldered to the surface of the pipe *b* that has been previously brightened and tinned. The bond wire *c* is then coiled as at *d* and soldered to the copper plate.

51. It is almost impossible to solder to a water pipe on account of the water rapidly conducting the heat away from the pipe itself. Where it is necessary to bond to a water pipe, a yoke, shown in Fig. 17, may be made of strap iron and securely clamped in place on the water pipe, the surface of which has been previously brightened. The whole should then be given a heavy coating of asphaltum, to prevent corrosion.

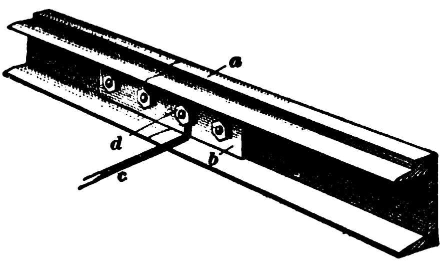

FIG. 18

The method of bonding to a rail is shown in Fig. 18, which needs no explanation, except to say that the contact surfaces must be clean and bright when the bond is made.

ELECTRICAL EXAMINATION OF GROUND POTENTIALS

52. By means of the line wires, an electrical examination of the territory through which the cables extend may be made in a very rapid and simple manner. If a wire at each station is grounded the difference of potential between the ground at

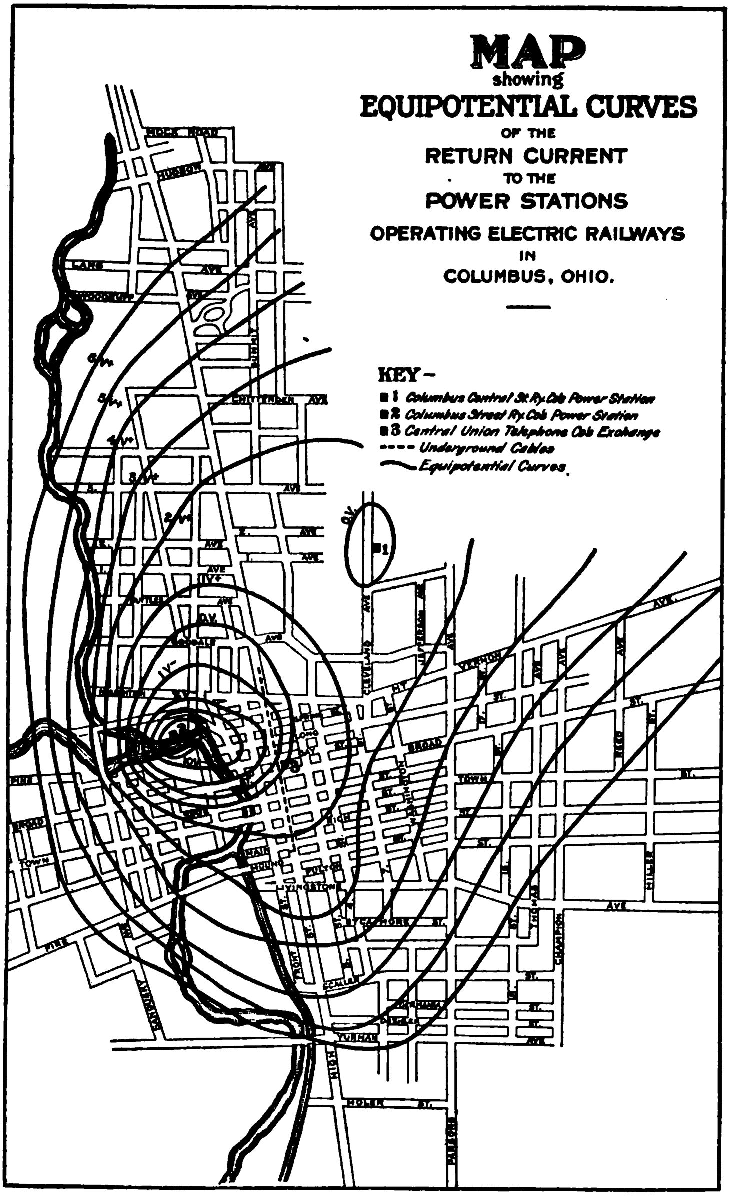
MAP
showing
EQUIPOTENTIAL CURVES
OF THE
RETURN CURRENT
TO THE
POWER STATIONS
OPERATING ELECTRIC RAILWAYS
IN
COLUMBUS, OHIO.
KEY –
1 Columbus Central St. Ry. Co's Power Station
2 Columbus Street Ry. Co's Power Station
3 Central Union Telephone Co's Exchange
Underground Cables
Equipotential Curves.

FIG. 19

the central office and at the substation may be obtained by inserting a plug, connected through a voltmeter to ground, into the office jack. A complete map of the territory, which will show the difference of potential at nearly every point to which the line wires extend, may be obtained by sending successively to station after station, one inspector who calls up the central office and notifies the inspector there to take the voltmeter reading, and then momentarily grounds one of the line wires.

53. From the data thus secured, a plot may be made on the map of the town, similar to Fig. 19, by joining together with a line all the points having approximately the same voltage. *1* and *2* are power stations and *3* a telephone exchange. A series of contour lines are shown in this figure, placed at intervals of 1 volt difference of potential. Points on any one of these equal potential lines will have little or no difference of potential, while points on a line that crosses one of these equal potential lines will have more or less difference of potential. Cables, therefore, that are parallel to the equal potential lines will not be subject to damage by electrolysis, while those that intersect them will be. While such an investigation does not entirely eliminate the desirability of voltmeter readings directly between the cable sheaths and the ground, it largely reduces the amount of time required to make the latter examination. It indicates invariably where such measurements should be made. As already stated, injurious action only arises where the current leaves the cable sheath through a moist contact. The object is to prevent absolutely such a departure of the current, for no matter how slightly a pipe or cable may be electropositive to the ground, it is an invariable indication of possible damage.

TO REDUCE ELECTROLYSIS

54. Two methods to reduce or eliminate electrolysis are as follows: Wherever an electropositive point on the cable sheath is found, the return conducting system of the railway should be reenforced in such a manner as to prevent current going into, and then leaving, the cable sheath. This may be accomplished by improving the bonding of the railway tracks or by introducing additional feed-wires into the railway return system or by providing an extra wire, which is attached by a large sleeve of ample area to the cable sheath and thus convey the current away without allowing it to first pass into moist earth.

The other method consists in providing at a danger point, a very large ground plate, which may be cheaply and efficiently provided by placing in a hole a ton or two of coke and upon this a load of old iron, such as worn-out car wheels, old rails, chips from machine shops, etc. The cable sleeve should be connected to the ground plate by copper wire of good size.

A large sleeve should be used to make the best possible metallic contact with the cable sheath that it is desired to protect, either by soldering the sleeve to the cable sheath, or by securing metallic continuity by the use of some flexible amalgam that is manufactured for making bonds with rails and similar purposes. The connection to the ground plate may be made in a manner similar to that with the lead sheath. It is well, however, where soldered joint connections are made, and especially to the ground plate, to paint the soldered joint thoroughly with some good waterproof paint, in order to resist electrolytic action between the two kinds of metal at the joint.

55. As the copper wire is of much lower resistance than the surrounding ground, the current will usually follow the wire to the ground plate and thus the flow of electricity into the ground from the cable sheath and the resulting electrolytic action is reduced. Of course, there will be more or less electrolytic action at the ground plate, but this plate is so large that it will resist corrosive action for a long time, and moreover, it is cheaper to replace this ground plate, if necessary, then to have the cable sheath damaged by electrolysis. A good ground plate is also usually cheaper than to provide a copper return cable or wire of sufficient size to carry the stray current back to the power station.

56. As street-railway companies frequently change their roads, number of cars, and arrangement of their conducting system, a remedy once installed must not be relied on for too long a time. It is well, at least once a year, to make an electrolytic survey of the entire area in which the underground cables are located, in order to determine where the danger points, if any, exist, and to decide on the best methods for protection, to ascertain the efficiency of the methods that have been previously installed, and to make sure that all cables are sufficiently protected from electrolysis. The lead sheaths of cables should be connected to other conductors or to a good ground only where proper tests have indicated that it will be beneficial; the promiscuous bonding of cables with the hope that it will be beneficial may increase the injurious effects.

LINE TESTING WITH VOLTMETER AND AMMETER

57. Western Union Voltmeter Arrangement.—Where Western Union wire chiefs are responsible for line conditions, they should be supplied, as shown in Fig. 20, with an instrument *a* mounted on a swinging arm so that its pointer can be seen from any position in front of the switchboard and a jack-box *b*. Both are mounted on a backboard that can be fastened to ordinary telegraph switchboards, one such outfit for every two sections of a fifty-wire switchboard. The instrument *a* may be used either as a voltmeter or milliammeter, and has a scale reading from zero in the center to 200 scale divisions on either side. The side to which the needle deflects depends on the direction of the current through the instrument. When used as a voltmeter the instrument has a resistance of 20,000 ohms and may be used to measure potential differences from 0 to 200 volts. When used as a milliammeter, it has a resistance less than 1 ohm and measures currents from 0 to 200 milliamperes.

58. The voltmeter reading bears the same proportion to the total voltage of the battery as the voltmeter resistance does to the total resistance. For instance, if the battery gives a voltmeter reading of 100 and the voltmeter shows a reading of 50 when connected in series with the same battery and a line, the current through the voltmeter has been halved, because the voltmeter reading is proportional to the current through it, and consequently the total resistance is twice as great as that of the voltmeter alone, hence the line resistance is 20,000 ohms. Similarly, if the battery voltage is 150 and the voltmeter reads 50 when in series with the same battery and a line, the total resistance is three times as great and the line insulation resistance must be $3 \times 20{,}000 - 20{,}000 = 40{,}000$ ohms.

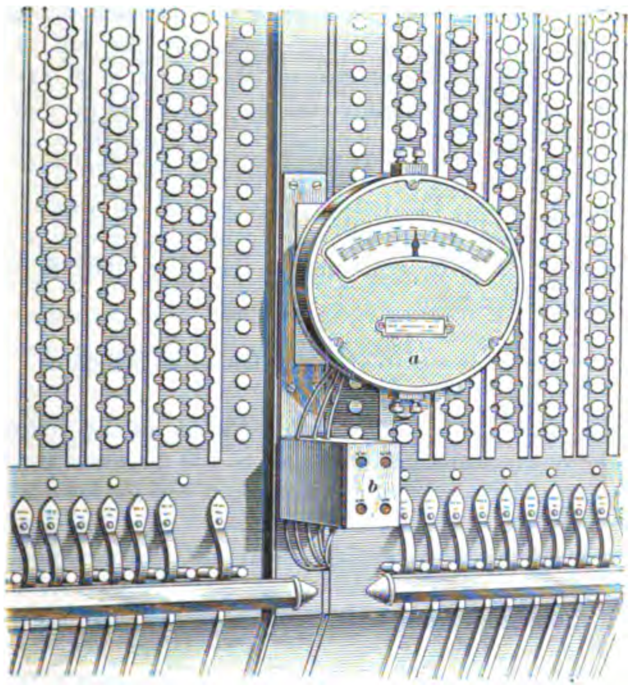

Fig. 20

If r is the voltmeter resistance; d, the reading of the voltmeter when connected directly across the battery; and d_1, the voltmeter reading when it is connected in series with the same battery and a line, or other circuit whose resistance is desired, the resistance R to be determined is

$$R = \left(\frac{d}{d_1} - 1\right) r$$

One terminal of the voltmeter-battery circuit is grounded for line to ground insulation tests. For measuring insulation resistance, and high conductor resistances, this is a quick and fairly accurate method, much superior to estimating the resistance by feeling the pull on the armature of a relay, which has been considerably used by telegraph wire chiefs.

59. The Western Union Telegraph Company has prepared for the use of its wire chiefs a number of convenient tables for testing purposes. One table, calculated by the aid of the formula just given and based upon the use of a 20,000-ohm voltmeter, gives the insulation resistances directly in ohms for each 5-volt reading of the voltmeter from 5 to 100 volts and for testing battery voltages of 100, 140, 160, 165, 170, 175, 180, 185, and 200 volts. For instance, the insulation resistance of a line when tested with a 180-volt battery and giving a voltmeter reading of 20 is, according to the table, 160,000 ohms, which is calculated from

$$R=\left(\frac{d}{d_1}-1\right)r=\left(\frac{180}{20}-1\right)\times 20{,}000=160{,}000 \text{ ohms}$$

Another table gives the maximum reading of the voltmeter allowable for an insulation resistance of 100 megohms per mile for the testing-battery voltages just given and for lines 25, 50, 75, 100, 150, 200, 250, 300, and 400 miles long. Specifications supplied with the tables explain them and give directions for their use in making insulation tests. Such tables save much time and trouble for those who make frequent tests of this kind.

60. External Electromotive Force Present.—It frequently occurs that there are sources of small electromotive forces in the line, caused by electrolytic action and produced where the line is in contact with foliage of trees or other damp objects. The errors thus caused may be eliminated, or at least much reduced, by taking two voltmeter readings, one with the positive battery terminal and the other with the negative battery terminal toward the line being tested, and using the average of the two readings for d_1 in the formula.

Errors due to stray currents from direct-current street railway, power, or lighting circuits may also be eliminated, or at least reduced, by taking direct and reverse readings as just explained. Their variable character is usually very troublesome and it may be necessary to use the average of a number of direct and reverse readings. By allowing the voltmeter to remain in the circuit for several minutes without any battery or dynamo, some idea may be obtained of how much the foreign potential, if large enough to give a reading, is varying.

61. Metallic Leakage.—To distinguish leakage between two wires from that between a wire and ground, the former is termed **metallic leakage.** Metallic leakage is determined in exactly the same manner as leakage to earth, except that the voltmeter and battery are connected in series between the two wires. It is advisable in this case also to take reverse battery readings and where voltmeter insulation tests, metallic or to ground, are frequently made on a number of lines, the battery and voltmeter should be connected to reversing keys for convenience and speed of manipulation.

EXAMPLE.—The battery voltage is 121, the voltmeter resistance 20,000 ohms, length of line 20.1 miles, average voltmeter reading between two line wires 9.1. What is the insulation resistance per mile between the two wires?

SOLUTION.—Substituting in the formula $R=\left(\frac{d}{d_1}-1\right)r$, gives

$$R=\left(\frac{121}{9.1}-1\right)\times 20{,}000=12.3\times 20{,}000=246{,}000 \text{ ohms for } 20.1 \text{ mi.}$$

Hence, the insulation resistance per mile is $24{,}600\times 20.1=4{,}944{,}600$ ohms per mi., or 4.94 megohms per mi.

62. Extra Resistances in Circuit.—It sometimes occurs that there is a cable between the office and the open wire whose insulation condition only is desired and there may be protective resistance in the battery circuit. In this case, first determine if the insulation resistance of the office connections and cable conductors is satisfactory; it should be so high as to give no steady reading or at least a negligible reading. In the case of cable circuits, the kick of the voltmeter needle upon closing the circuit, due to capacity, should not be mistaken for the steady leakage reading. If the resistance of the cable conductor and of the protective resistance is not known, it may be measured and subtracted from the calculated insulation resistance to get the insulation resistance only. Usually the protective and cable-conductor resistances can be neglected unless the insulation is very low.

EXAMPLE.—A cable 12 miles long has a conductor resistance of 50 ohms per mile of single wire to ground, and there is a protective resistance of 800 ohms in the office circuit. If the dynamo voltage is 121, the voltmeter resistance 20,000 ohms, the length of a single conductor on the bare line 20 miles, the average voltmeter reading between one conductor and ground, including the same dynamo 11, and the insulation of the office leads and cable conductors so high as to be negligible: (a) What is the insulation resistance per mile of the open wire? (b) Is the correction for line and protective resistances worth making in this case?

SOLUTION.—(a) Substituting in the formula $R=\left(\frac{d}{d'}-1\right)r$, gives $R=\left(\frac{121}{11}-1\right)\times 20{,}000=200{,}000$ ohms. The protective and cable-conductor resistances $=800+12\times 50=1{,}400$ ohms. $200{,}000-1{,}400=198{,}600$ ohms. $198{,}600\times 20=3{,}972{,}000$ ohms per mi. Ans.

(b) If this correction was not made the insulation resistance per mile would be calculated as follows: 200,000 ohms $\times$ 20 = 4,000,000 ohms. The difference is $4{,}000{,}000-3{,}972{,}000=28{,}000$ ohms; or $28{,}000 \div 3{,}972{,}000=.007$, or .7 per cent. which is negligible; therefore, the correction need not be made. Ans.

63. Milliammeter.—When the deflection of this voltmeter connected in series with a battery and a line exceeds 75 per cent. of the voltage across the battery terminals, more accurate results can be secured by using the milliammeter winding of the instrument. Thus, if the full battery voltage is 200 and the voltmeter, when in series with the battery and line, gives a deflection exceeding 150, the milliammeter should be used to determine the resistance of the circuit. On account of the low resistance of the milliammeter, it usually adds negligible resistance to a line circuit.

To determine a resistance with the milliammeter, the simple application of Ohm's law is all that is required. Measure, if not already known, the voltage E applied to the circuit with the voltmeter, then measure the current I flowing in the circuit by connecting the battery, milliammeter, and line in series, then by Ohm's law the resistance of the circuit is equal to $\frac{E}{I}$. The reading, being in milliamperes, must be divided by 1,000 to get amperes. Thus, if a battery, whose voltage is 200, sends 150 milliamperes through a certain line circuit, the resistance of the circuit is $200 \div \frac{150}{1000} = 1{,}333$ ohms.

64. The connections of the instrument for the various tests are made by the insertion of a plug in one of four jacks mounted in the jack-box below the instrument, and the connection with the line to be tested is made by means of a flexible conductor terminating in a switchboard wedge that may be inserted in the ordinary line spring jacks.

The instrument and jack-box connections are shown in Fig. 21. $V-$ and $V+$ are the upper two spring jacks and A and Vg the lower two spring jacks in the jack-box. The terminals b, c, d, e, f, j, k, and l are inside the jack-box. Inserting the connecting plug a in the jack A, pushes springs *1* and *2* into contact with each other and spring *3* is connected through the metallic plug with the metal body *4* of the jack. When plug a is in jack A the circuit may be traced from the line side of the wedge through f – *4* – plug – *3* – j – milliammeter winding h and its shunt i – terminal n – l – *2* – *1* – e to marked side of wedge, which would usually connect through the regular line battery to ground.

When a plug is inserted in jack $V+$ the circuit may be traced from g through the positive dynamo – lamp – c – p – k – voltmeter winding o – j – q – f – line side of wedge.

The marked side of the wedge is open at spring *1*. Thus the positive dynamo is connected between the line and ground with the voltmeter in the circuit. By inserting a plug in jack $V-$, the negative dynamo and voltmeter are connected between ground g' and the line. By inserting a plug in jack Vg, the voltmeter winding o is connected between the line side of the wedge and the ground g'', the marked side of the wedge being open at spring *1*.

65. Line Tests.—The following directions for making tests on lines by the use of this instrument and jack-box are abstracted from those prepared in the office of the engineer

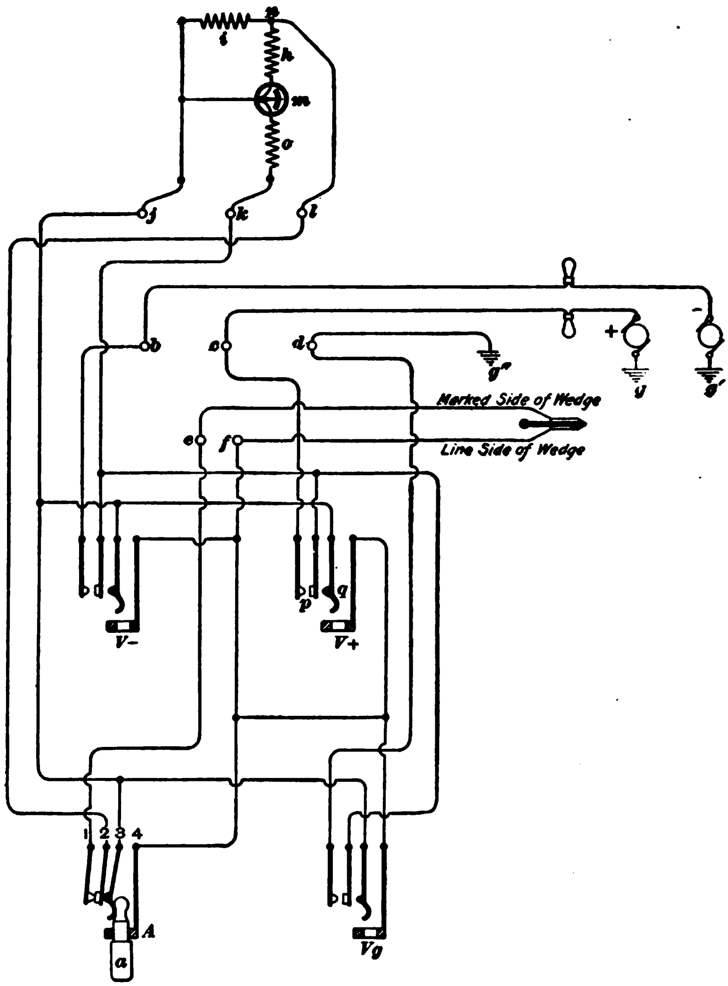

Fig. 21

of equipment of the Western Union Telegraph Company.

The first test to be made is to determine whether the line is well insulated from the ground and other conductors. For this purpose the line is opened at the distant end of the section to be tested and the wedge is inserted in the switchboard spring jack of the wire to be tested with the marked side of the wedge outwards and therefore connected with the working battery, while the unmarked side connects with the line. This circuit is shown in Fig. 22. Any other wires that might be crossed with the wire to be tested should be connected either to the battery or ground. If they are working telegraph lines, this is provided for by the regular working battery and it is unnecessary to disturb them, but if such wires are out of service they should be grounded while making tests. The connecting plug is then inserted in jack *Vg*, jack *V+*, and jack *V−* and the reading of the voltmeter observed each time.

66. The inserting of the connecting plug in jack *Vg* will show if there is a foreign current flowing in the line and its

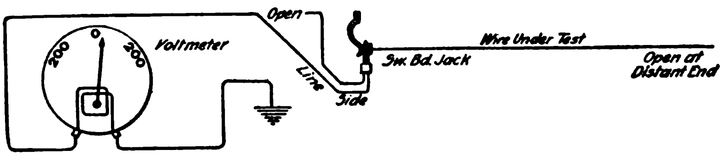

FIG. 22

direction. If the voltage is positive, the voltmeter needle will deflect to the left; if negative, the deflection will be to the right. There are several things that may cause such a voltage. The working battery may not have been disconnected at the other end, the wire may be crossed with a working circuit, or it may be leaky or grounded at a point where considerable ground potential exists. The first condition is generally easy to detect on account of the high and steady deflection of the voltmeter.

The second condition, a cross with a working circuit, will cause the voltmeter needle to move rapidly in response to the Morse signals and the working circuit can generally be located readily by observing the pointer while the working dynamo or battery is removed in turn from each wire likely to be mixed up with the one being tested, for the needle will come to rest, although not necessarily at zero, as soon as the working circuit, with which it is crossed, is opened. However, if the working circuit is not in use at the time this test is made, the voltmeter needle might be steadily deflected or even remain at zero, in which case the cross would not be detected until tests are made with the plug in jacks $V+$ and $V-$. The third condition, a deflection due to ground potential, is most commonly noticed on wet days and generally produces a rather slowly varying reading of only a few volts.

67. The test with the plug in jack $V+$ is made with the wire still open at the distant end and with the connecting plug transferred from jack Vg to jack $V+$. This circuit is shown in Fig. 23. The regular switchboard working battery remains disconnected as before because special connections to the second-potential dynamo, or battery, of 140 to 180 volts are always used with this voltmeter arrangement. A deflection is almost certain to be produced because the line is not likely to

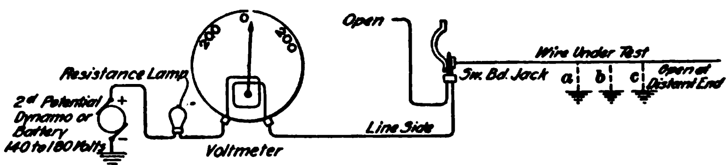

FIG. 23

be perfectly insulated and there will be leakage paths, as indicated at a, b, and c. If the leakage is slight, as in the case of a good wire in clear weather, the voltmeter will indicate only a few volts. The greater the leakage or the lower the resistance of a ground fault, the greater will be the voltmeter deflection; a solid ground or cross with a grounded wire, will produce a reading almost equal to the voltage of the testing battery.

68. The distinction between a cross and a ground is usually made without difficulty. A cross with a working wire will be detected generally by the first test; if not, it will show up in either this test or the following one by giving a high reading on the voltmeter, probably much in excess of the testing voltage. A cross with a grounded wire will give the same results as a ground, but as the wire chief knows which wires he has grounded for the test, he will open such wires one by one, watching the voltmeter to see whether any change occurs; the needle will drop much lower as soon as the ground is removed from the crossed wire, but if the fault on the wire under test is a ground no change will be produced in the deflection.

69. After noting the voltmeter reading given in the previous test with the wire still open at the distant end, the connecting plug is transferred from the $V+$ to $V-$ jack; the connections are the same as in Fig. 23, except that the dynamo potential has been reversed. The voltmeter deflection will be reversed. Usually the deflections obtained with this negative potential will not differ greatly from those obtained when the positive potential was used. It is necessary to take both readings, however, because the leakage may be at a point where considerable earth potential exists, or there may be a cross

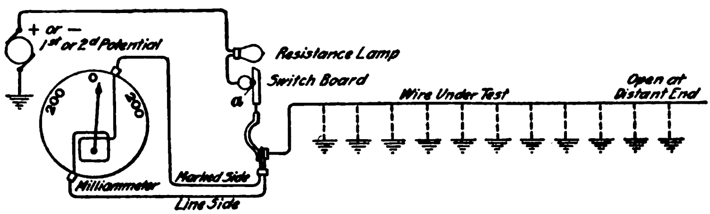

FIG. 24

with another wire having some potential and either of these potentials might be such as to oppose or assist the testing battery, thus giving a much lower or higher voltmeter reading than would be the case if these potentials were absent. Reversing the testing battery shows up such faults, for one deflection is decreased below normal as much as the other is increased above it. These deflections obtained with + and − potentials will vary widely with the weather conditions.

70. Milliammeter Tests.—To make a test with the milliammeter, the connecting plug is inserted in jack A, Fig. 21, which gives the circuit shown in Fig. 24. The regular switchboard working potential is used and the milliammeter is simply looped in the regular circuit. Usually the plug a should be so placed as to give the second potential. In these tests, the milliammeter readings are used to make comparisons between various wires rather than for the calculations of resistances by Ohm's law. The tests so far described are to show whether the line is reasonably well insulated from the ground and other conductors and the only remaining test is to determine whether it is open. This is done by having the distant end grounded; if the wire is continuous the milliammeter deflection will increase, the increase depending on the resistance of the line circuit. If the voltmeter is used, the reading will be nearly as high as the voltage of the testing battery. If the line is open, the grounding of its distant end will not affect either a voltmeter or milliammeter reading.

By inserting the wedge, to which the milliammeter is connected with the marked side outwards in a spring jack of the line under observation and on the line side of any other wedge or wedges already in the jack, the current and its polarity may be readily determined. By inserting the connecting plug in the *Vg* jack, the other connections remaining the same, the voltage and polarity of the distant battery may be determined. The voltmeter reading will be less than the voltage directly around the battery by the fall of potential (current times resistance) through the line wire and leakage paths.

71. Test for Ground.—If a milliammeter is connected in a line circuit at the home station, it will give a reading as soon as the circuit is closed. Unless the line is dead-grounded at some point between the terminal and the testing point, the wire chief can actually determine by the action of the pointer, the result of an open or ground test made at his direction at any station on the circuit.

As an illustration, suppose that a certain line has a resistance of 15 ohms per mile with 12 stations 5 miles apart having 150-ohm relays, and receiving a normal working current of 70 milliamperes from equal-voltage batteries at each end. If an operator reports having lost or being unable to raise some one or more offices on the circuit, the wire chief will connect his milliammeter in the circuit. If he gets a normal reading when his battery is in circuit and a zero reading when his milliammeter is directly grounded, that is with the battery cut out; this indicates a line grounded at about its ohmic center.

72. If the reading was 46 milliamperes with the home battery in circuit and zero with the milliammeter directly grounded and 70 milliamperes is the normal current, it indicates a line grounded approximately midway between the ohmic center and the distant terminal. For the resistance of one-half the line may be taken as 1—then the resistance of one-half the distant half plus the resistance of the near half of the line is $1\frac{1}{2}=\frac{3}{2}$ as the relative resistance of the line between the home office and the ground. Then the home battery will only produce two-thirds of the normal current in the home end of the line; that is, two-thirds of 70 = 46 milliamperes.

Similarly, a reading of 140 milliamperes will indicate a ground at about one-fourth the ohmic length of the line from the home station.

When two unequal batteries are used at terminal stations, say 180 and 100 volts, then the ground that gives a normal current reading will be on the side of the ohmic center toward the lower voltage battery. A ground at such a point is sometimes called a no-voltage ground because its potential is the same as that of the ground, and a ground at that point will allow both terminal batteries to furnish their normal currents. If the milliammeter gives a reading less than normal when connected in series with the home battery and line and zero when the milliammeter is grounded, the circuit is grounded beyond the no-voltage point, the probable location being indicated by the reading.

73. Test for Open Circuit.—If a line is very poorly insulated; that is, it has a large escaping current, and a test for an open circuit is made by having the stations ground the wire in turn, no change in current strength will indicate that the station where the line is grounded is beyond the open circuit, but a change in current strength will indicate that the station where the line is grounded is on the home side of the open circuit.

74. Test for a Cross.—When using a milliammeter to locate a cross there is very little or no danger of making an error on account of a leaking current, as when the test is made with an ordinary relay; for a change in current strength, however slight, is visible on the milliammeter, as each station in turn is asked to open the circuit. When the station on the home side of the cross is opened, there is a larger decrease in current than when stations beyond the cross are opened.

DIFFERENTIAL MILLIAMMETER TESTS ON MULTIPLEX SETS

75. Differential Milliammeters.—The Postal-Telegraph Company began using differentially wound Weston milliammeters about 1913 for measuring the current in and balancing multiplex sets. They are connected at the split in multiplex sets, so that one coil of the differential milliammeter is in the line and the other coil in the artificial-line side of the set. By means of these instruments, which are very sensitive, a practically perfect ohmic and static balance can be secured.

76. Ohmic Balance of Multiplex.—With the distant multiplex set grounded, the artificial-line rheostat is adjusted until the differential-milliammeter pointer indicates zero, which is in the middle of the scale. With the negative potential connected to the line at the distant end, note the reading. Then connect equal negative potential at the home station to the line; if the pointer moves toward zero, decrease the rheostat resistance; if the pointer moves away from zero, increase the rheostat resistance, in each case until the pointer is unaffected by reversing the potential polarities. Make similar tests with positive potentials, increasing rheostat resistance if the pointer moves toward zero and decreasing rheostat resistance if the pointer moves away from zero, in each case until the pointer is unaffected by reversals.

77. Static Balance.—With the distant multiplex set grounded and the condenser retardation resistances cut out at the home station, to obtain a static balance proceed as follows:

If, upon closing the home key, thereby sending negative current toward the line the pointer kicks to the right, decrease the capacity until the minimum kick of the pointer is observed. Then adjust the retardation resistances until the pointer is unaffected by reversing the potential polarities.

With negative potential to line at the distant station and the condenser retardation resistances at the home station cut out, proceed as follows: If, upon closing the home key, thereby sending negative current toward the line, the pointer kicks away from zero, increase the capacity; if the pointer kicks toward zero until the minimum kick of pointer is observed, decrease the capacity. Then adjust the retardation resistances until the pointer is unaffected by reversals.

78. Measuring Current.—To measure the current received from the line, ground the home set and open the artificial line. To measure the outgoing current have the distant set grounded, and open the home artificial line.

If the distant set is supposed to be grounded, but the ground coil open, the balancing rheostat resistance will be abnormally high. By adjusting the rheostat the milliammeter pointer can be brought to zero if the line is grounded, but it cannot be brought to zero if the line is open.

To locate an open coil in series with the home battery or generator proceed as follows: Open the artificial line and have the distant set grounded. If the pointer moves to zero when the key that puts the negative potential to line is closed, the negative-battery coil is open; if the pointer moves to zero when the same key is open, thereby putting positive potential to line, the positive-battery coil is open.

PRINTING AND MESSENGER-CALL SYSTEMS

PRINTING TELEGRAPH SYSTEMS

EARLY SYSTEMS

1. Telegraph systems that record the transmitted signals in plain Roman letters upon a moving tape or a sheet of paper are called **printing telegraphs.** Such systems have been used since about 1856, for the problem of automatically recording telegraph messages in Roman type is one that has fascinated inventors almost from the days of Morse. On account of constant improvements, however, there are more of these systems than it is practical to describe. Royal E. House invented a type-printing telegraph that was in successful operation in this country in competition with the Morse and Bain systems prior to 1857. The systems that are used in the large cities for reporting stock quotations, race-track news, etc., are commonly known as *stock-ticker systems*.

The Phelps printing telegraph was used on several main-line circuits by the Western Union Telegraph Company. The Murray page-printing telegraph system was used for a time by the Postal Telegraph-Cable Company in America and somewhat in England. The Barclay page-printing telegraph system has been used in America by the Western Union Telegraph Company.

2. Hughes and Baudot Systems.—One of the earliest printing systems, which has also met with permanent success and by means of which a large proportion of telegraph work in Europe and nearly the whole of that between England and Europe has been done, is the Hughes type-printing system. It produces a clearly-printed tape message ready for delivery; it therefore eliminates transcription errors and increases the speed, as compared with Morse working, by about 25 per cent. Furthermore, it can be duplexed.

What is considered, in Europe, a better and faster method is that of Emile Baudot, a Frenchman. It admits of the transmission of a much larger number of messages over a wire than the Hughes and is more flexible, inasmuch as the various channels that it provides can be divided among an equal number of way stations. The systems of Baudot and Professor Rowland employ an arrangement for dividing the use of the line among several operators, so that it resembles in this respect the Delany synchronous multiplex system. The Baudot system is extensively used in France and has been introduced in England.

3. Creed System.—Creed has developed a system resembling the Murray page-printing system, but he uses the Wheatstone alphabet and transmitter. At the receiving end a perforated Wheatstone tape is reproduced by a punching machine, which, controlled by reverse currents from the transmitter and using compressed air as a motive power, perforates from one up to eight receiver tapes at about 150 words a minute. This tape is then passed through an automatic typewriter—adapted to the Wheatstone tape—which prints the message on a long tape that is cut up and pasted on the regular telegraph blank. In both the Murray and Creed systems, which have been used in England, the received slip can be inserted in a second transmitter and the message thereby repeated to another town, an advantage in the transmission of news. As the Hughes, Baudot, and Creed systems are used very little, if at all, in America, a description of their rather complicated mechanism will not be given.

PRINCIPLE OF PRINTING TELEGRAPH SYSTEMS

4. Most printing telegraphs depend on the synchronous rotation of the transmitting and receiving mechanism, but the methods used for accomplishing this vary considerably. They may be described, roughly, as two toothed wheels, synchronously propelled by clockwork or otherwise, placed one at the transmitting and one at the receiving station. These wheels contain as many teeth as there are characters, there being one character on the face of each tooth. In circuit with the magnet controlling these wheels is a key, the pressing down of which will not only stop the rotation of each wheel, but will also cause an electromagnet to press the tape upon which the characters are to be printed against the tooth that stops opposite it.

When the two wheels start to rotate, similar letters upon the two wheels must occupy exactly similar positions; that is, if the letter A is opposite a certain point at the transmitting station, the letter A must be opposite a similar point at the receiving station. Then, if the operator stops the wheel at his station when the letter he wishes to transmit comes into a certain position, that same letter will be opposite the tape in the receiving machine, so that if the tape is pressed against it when the wheel stops, the character will be printed. When the key is released, the wheels will immediately start to rotate again and the paper tape will also be moved along by clockwork or otherwise. In this way any character can be printed in succession at the will of the transmitting operator.

5. A number of receiving stations may sometimes be connected in series in the same line circuit. It is necessary to make all the wheels rotate synchronously, which would not be an easy matter merely with clockwork. To obtain the synchronous rotation of the type wheels, usually a step-by-step mechanism, controlled by the transmitting apparatus, is used. This may be done by sending into the line one brief current every time each character of the transmitting wheel passes a certain point, each one of these brief currents causing a properly arranged electromagnet in the receiving instruments either to release a clock-driven wheel one tooth at a time or to push the wheel around one tooth each time. Furthermore, it is usually necessary to have a correcting device that will bring all receiving wheels absolutely to the starting point, no matter what their position may be at the instant the correcting device operates. It may operate about every third revolution of the receiving wheels.

STOCK-TICKER SYSTEMS

6. Stock-ticker telegraphs may be divided into the single-wire single-wheel, the single-wire double-wheel, and the two-wire double-wheel systems.

In the **single-wire single-wheel system,** there is only one line wire, and all the characters, both letters and figures, are placed in succession on the periphery of one printing wheel. While this is theoretically the simplest method, it is not so fast as the others, and is not used as extensively.

In the **single-wire double-wheel system,** there is one line wire and two printing wheels alongside each other, one usually for letters and another for figures and other characters. The two wheels usually rotate together, but the paper tape is pressed up against only one at a time.

In the **two-wire double-wheel system,** there are two line wires and two printing wheels. The two printing wheels are alongside each other and have the characters on their periphery, as in the preceding system, but in this case a separate wire is used to shift a pad from one to the other type wheel as required. One wire governs the rotation of the printing wheels and causes the pad to be pressed against the type wheel opposite which an electromagnet connected in the other line wire has moved it.

PAGE-PRINTING TELEGRAPH SYSTEMS

MURRAY PAGE-PRINTING TELEGRAPH

7. Two page-printing telegraph systems that use a perforated transmitting tape are the Murray and the Barclay. The received records in each system are finally printed on the ordinary telegraph blanks. The Barclay system, which has been used commercially on lines of the Western Union Telegraph Company, has a maximum speed of about 100 words a minute on the circuit between New York and Chicago. The circuit can be duplexed, giving about double the above capacity.

8. Transmitting Arrangement.—Mr. Murray uses a special alphabet, perforating the transmitting tape with a keyboard perforator, having a separate movable lever for each character. Each character occupies an unvarying linear space on the tape and consists of five perforated and unperforated subdivisions of such space. The difference in the number and succession of these subdivisions or perforations imparts the designating characteristics. There are no spaces between successive letters or characters. Either makes and breaks or reversals can be used in transmitting. It is to this fundamental fact—all letters of the same length—that the success of the system is due. Each letter occupies $\frac{1}{8}$ inch on the transmitting tape, and a similar length on the receiving tape. The result is that a comparatively simple transmitting-tape perforator worked by an ordinary typewriter keyboard is rendered possible. In connection with the ordinary typewriter keyboard, there is a group of ten punches, one punching magnet, and one spacing magnet that controls a motor-driven escapement.

9. Receiving Apparatus.—At the receiving station there is an electromagnetic perforating device that accurately reproduces the transmitting tape by producing corresponding perforations and spaces. This receiving perforated tape passes from the receiving perforator into the typewriter-operating device. This typewriter-operating device consists of five

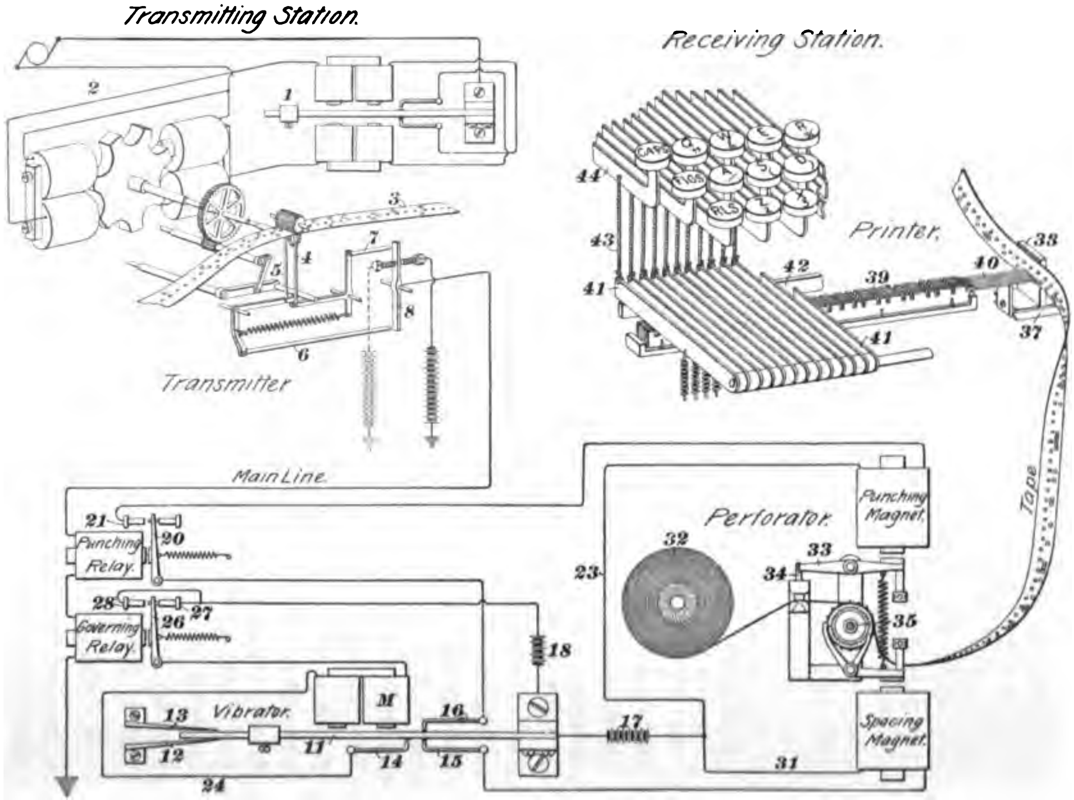
Transmitting Station.
Receiving Station.
Transmitter
Printer.
Main Line.
Perforator.
Punching Magnet.
Spacing Magnet.
Tape
Punching Relay.
Governing Relay.
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Fig. 1

longitudinally reciprocating bars or combs *39*, Fig. 1, presenting five pointed terminals *40*, to a perforated plate or die *38*. The perforated tape passes between the surface of the perforated plate and the pointed terminals of the bars; the pointed terminals of these bars register respectively with the five holes in the die. The tape is moved along between the die and the pointed ends of the bars step by step, the length of a letter or character at each step being, say, $\frac{1}{2}$ inch. When perforations in the tape coincide with the pointed ends of the bars and corresponding perforations in the plate or die, and the plate is moved toward the pointed ends of the bars, the bars may be separated into two groups: one group is moved longitudinally, corresponding with the unperforated subdivisions of the tape; the other group projects through the perforations in the tape and in the die and is unmoved. Lying over the five bars or combs at right angles thereto are a series of thin metal strips *41*; each strip is mechanically connected with its individual key lever on the typewriter. The upper surface of the five bars first described are notched arbitrarily. These notches are caused to be alined below any one of the strips under the control of the perforated tape and die; when any one of the strips drops into a groove, a motor-driven cam engages it and produces a movement of the typewriter lever. The movement of the die and paper tape and of the typewriter-key lever is produced by motor-driven cams. It will be seen that this mechanism will operate not only a typewriter, but any keyboard machine, such as a typesetting machine. The perforated receiving tape is, therefore, available for setting type automatically.

10. The Diagram.—In the diagram shown in Fig. 1, the apparatus at the transmitting station is connected by a single main line with the apparatus at the receiving station. The vibrating reed *1* at the transmitting station is in a local circuit with an electromagnetic motor *2*. The reed makes and breaks its own circuit, and is substantially like the well-known La Cour phonic-wheel device used in the Delany and other multiplex systems. The prickers *4* and *5*, familiar features in the Wheatstone transmitter, are located as usual in line with the advancing lines of perforations in the transmitting tape *3*; *6* and *7* are reciprocating rods engaging respectively with opposite ends of the centrally pivoted pole-changing switch arm *8*. The parts shown are all essential parts of the well-known Wheatstone transmitter, which is here used practically without alteration, except that the prickers *4* and *5* are arranged to move or reciprocate together instead of alternately, thereby enabling any multiple of a single impulse to be transmitted. The ordinary arrangement of the Wheatstone transmitter can only transmit unit signals or odd-number multiples thereof; it can transmit a dot or a dash equal to three or five dots, but cannot transmit a dash equal to two or four dots. Mr. Murray, to avoid this difficulty, arranges the prickers to reciprocate together instead of alternately. There is thus obtainable transmitted impulses or dashes equal to one, two, three, four, or five dots, with corresponding spaces.

11. When transmitting, the number of impulses thrown upon the main line is minimized by producing the impulses locally at the receiving station and using only sufficient main-line impulses to determine the action of the perforator at the receiving station. At the receiving station there is, therefore, a main-line relay to determine the action of the punching magnet, and a governing relay that operates to maintain unison between the main-line impulses as they arrive and the corresponding impulses in the local circuit. These local uniform impulses are created by a vibrating reed *11*, operated by an electromagnet *M*. The circuit of this magnet extends from the local battery *18* through the reed *11* – contact point *14* – wire *24* – magnet *M* – armature *26* of governing relay – points *27* or *28* to the battery. The precise operation of the governing relay will be described presently.

12. The receiving perforator is composed of a punching magnet and a spacing magnet. The punching magnet operates a spring-retracted pivoted armature bar *33*, mechanically connected with the punch *34*, reciprocating through a guide block engaging the tape upon the surface of a suitable die, over which the tape passes. The tape is fed along by a star wheel located on a motor-driven shaft *35*, and upon this shaft is an anchor escapement under control of the spacing magnet. The vibrating reed *11* alternately makes and breaks the local circuit of the spacing magnet; this circuit extends from battery *17* to reed *11* – contact spring *15* – spacing magnet and wire *31* to the battery *17*. The punching magnet is in a local circuit with a contact point *16* operated by the vibrating reed *11* and controlled by the contact points of the punching relay, so that while the reed is continually generating local circuit impulses, these impulses are effective to operate the punching magnet at only such times as the punching relay is closed upon its front contact *21*. This local circuit passes from the battery *17* through reed *11* – contact point *16* – armature *20* – contact *21* – punching magnet – wire *23*, to the battery. It will thus be seen that the reed *11* is continually making and breaking two circuits alternately; first, that of the spacing magnet, which is a continuous operation; and second, that of the punching magnet, which is an intermittent operation, rendered so by the action of the punching relay.

13. The punching relay and the governing relay may be neutral relays responsive to makes and breaks or they may be polarized relays responsive to reversals of current; in only the latter case, however, will the battery that is shown dotted at the transmitter be used. As the reed *11* vibrates, the electric impulses in the spacing-magnet circuit permit a steady progressive movement of the tape. Upon the arrival of an impulse of current from the transmitting station, the contact points *20* and *21* of the punching relay are held closed for one, two, three, four, or five times the time interval of one dot length. While this relay circuit-breaker is closed, the punch *34* operates to perforate the tape as many times successively as permitted by the time length or duration of the transmitted impulse upon the main line. Mr. Murray has thus avoided the necessity of transmitting over the main line all impulses necessary to produce spacing, and all but a fractional part of the impulses necessary to produce the perforations. It is of vital importance, however, to preserve unison between the arriving transmitted impulses in the main line and the local punching and spacing impulses at the receiving station.

14. Maintaining Unison.—The governing relay operates a circuit-breaker *26*, moving between two fixed contacts *27* and *28* electrically connected to the same circuit terminal, so that the moving contact in going from one to the other operates to open the circuit during its time of transit only. This break in the local-vibrator circuit takes place at the beginning and end of each main-line signal, and as the main-line signals arrive at a uniform rate and are of unit or multiple-unit duration, the governing relay operates its break point at uniform unit intervals or multiples of these intervals.

15. In the same circuit in which this break point operates, there is also the break point *14* of the motor magnet *M*, which works on the familiar buzzer, or vibrating bell, principle. There are thus two break points in the same circuit. If they open and close together, full vibratory impulses flow through the magnet *M*. If, on the other hand, the rate of vibration of the reed tends to accelerate, or the rate of the arriving current signals tends to lag, the two breaks occur more or less alternately, and, consequently, less current gets through—the impulses are clipped—and the rate of vibration of the reed is reduced. In practice, the receiving vibrator is set to go 1 or 2 per cent. faster than the rate of the arriving signals, and then the governing action of the two interfering break points in the same circuit results in the establishment of a steady balance between the accelerating tendency of the reed and the retarding tendency of the arriving main-line signals. By this arrangement, the necessity for sending correcting impulses over the main line to secure synchronism is avoided, the correcting impulses being obtained locally with the cooperation of the main-line signals themselves.

16. It is to be understood that movable weights are present upon each reed, that of the transmitting station and that of the receiving station, and by varying the position of the weight upon the reed, the rate of vibration and the rate of transmission may be changed. It is necessary, in order to maintain unison, to have a considerable range of variation in the speed of the reed at the receiving station, such variation in speed to be attained in response to variation in the length of current impulses of uniform strength.

17. Constrained Vibration of Reed.—To assist in securing the desired rate of vibration, there is placed at or near the free end and upon the opposite sides of the reed, resilient stops, shown at *12* and *13*. These springs receive the reed on each side with a cushioning effect and impart an initial return movement. In explanation of this result it should be stated that the rate of vibration of a reed varies with its length, mass, and the distribution of such mass; increase of current in the magnet *M* circuit increases the amplitude of vibration without varying the rate of vibration beyond a practically negligible amount due to a slight electromagnetic damping effect. Rigid limiting stops have not proved satisfactory. By the use of resilient stops, the movement of the reed is rendered smooth and uniform; it is freed from the interference due to an impact with a rigid stop, which jars and disturbs the normal rate of vibration; and its rate may be varied by varying the length of the current impulses.

18. Shape of Punch.—The shape of the punch for perforating the receiving tape is quite important. The punch shown in Fig. 2 has the best shape.

Fig. 2

19. Murray Alphabet.—Murray, by using multiple units of current and space (that is, by using several different time intervals instead of only one), has not found it necessary to use reversals. The Murray alphabet is shown in Fig. 3. It will be seen that the uniform time for each letter is divided into five equal units or subdivisions, one or more of these five subdivisions being a current impulse, so that current impulses or spaces of one, two, three, four, or five units' duration are secured. Thirty-two possible combinations are obtained in this manner, and by using two of these letter signals as prefixes to the others for capitals, figures, and lower-case letters, about 87 characters may be transmitted. Makes and breaks or reversals may be used, therefore, adapting the system for use in quadruplex trans-

TABLE OF ALPHABETS

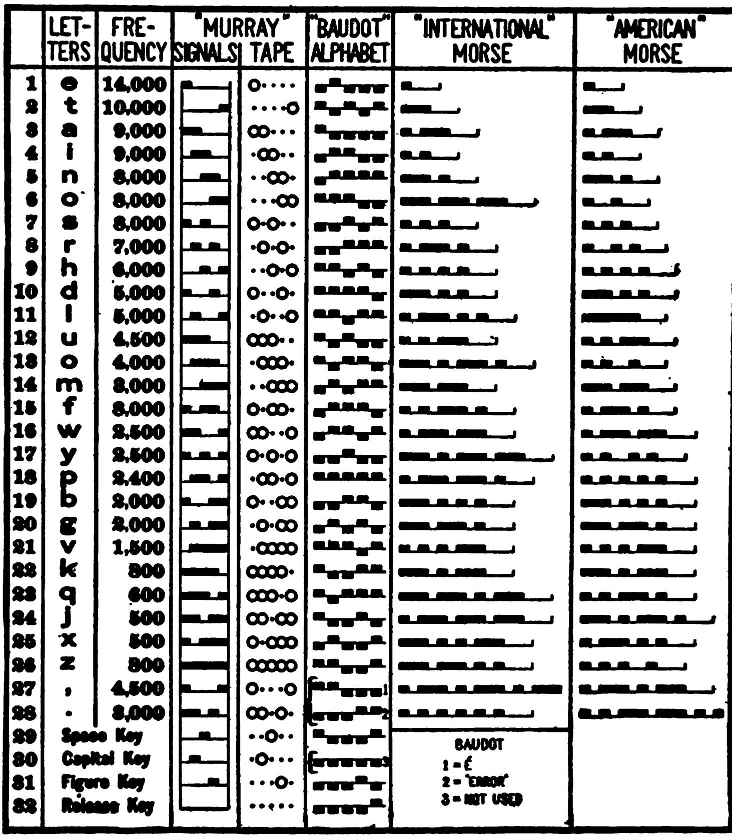


FIG. 8

mission, a use not practicable with an alphabet using both makes and breaks and reversals as in Baudot's alphabet.

The alphabet, however, is only available for machine telegraphy, as it is practically impossible to observe five different time intervals with sufficient accuracy in manual transmission. No space is required between letters in the Murray alphabet, whereas in the Morse a three-unit space follows each letter. An examination of Fig. 3 will show that the maximum number of impulses required is three for the letter y, and the average number reckoned according to the frequency of the letters is 1.25 impulses per letter as against 2.59 for International Morse and 5 for the Baudot alphabet, in addition to the necessary correcting impulses to secure or maintain synchronism. Murray has the shortest alphabet possible to be constructed from reliable

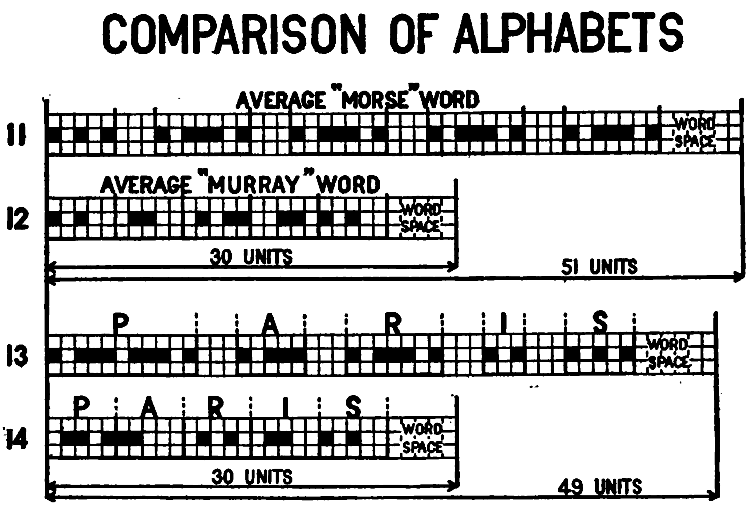


FIG. 4

signaling material, and by combining it with machine transmission, the entire time of the line is used in the most advantageous manner.

20. Comparison of Alphabets.—Fig. 4 shows that the Murray word is shorter than the Morse in the ratio of 30 to 51, or 41.18 per cent. This is borne out by the comparison made with the word Paris on lines *13* and *14*; in this case the Murray alphabet is shorter than the Morse in the ratio of 30 to 49, or 38.78 per cent. Practically, the two alphabets are in the ratio of 3 to 5. Hence, using the same number and length of current impulses in each case, a speed of 100 words a minute with the Murray alphabet will not be more than about 60 words a minute in Morse.

The saving in the Murray alphabet lies chiefly in the fact that there is no space between the letters. Indeed, signals in adjoining letters not unfrequently coalesce, as in the case of the letters P and A in the word Paris, where one current impulse is actually shared by the two letters, and five letters are transmitted by 7 impulses, whereas in the Morse representation of the same word no less than 14 impulses are required.

21. Speed.—Tests have been made of the capacity of the Murray page-printing system, both on loops of varying lengths and on circuits between cities. The following speeds were calculated on the basis of five letters to the word and a word space equal to one letter; that is, the receiving tape fed through the perforator in 1 minute was measured to find the number of letters it contained, and this number was divided by 6. In April and May, 1900, a series of tests were made between New York and Chicago. Working direct from Chicago to New York via Meadville without a repeater, a distance of 1,050 miles by the route of the wire, the best speed attained was 77 words a minute. Working with a repeater at Meadville, 102 words a minute were easily attained. The wire used was copper, 208 pounds and 4.5 ohms per mile. Duplex working was readily secured.

22. Exhaustive tests of the system were made from October 17 to November 3, 1900, between Boston and New York. Two hundred ordinary commercial messages were transmitted, averaging 10.8 words in the paid portion of each message. Following the usual practice of counting single figures as words, they averaged about the usual rate of 30 words per message; but, counting figures as single letters, and counting all letters by measuring the transmitting tape and dividing by 6, the average was about 26 words per message. These 200 messages were perforated in Wheatstone tape. A column press despatch from the New York Herald, containing 5,988 letters and 1,261 words, or an average of 4.75 letters per word, was also prepared in Wheatstone tape. This press despatch and the 200 commercial messages were transmitted from Boston to New York day after day at speeds varying from 60 to 96 words per minute. It was found that the apparatus worked with great accuracy, the whole 200 messages frequently coming through without error. At other times occasional errors occurred, owing to swinging wires and other familiar line troubles common to all telegraph systems.

23. The length of the Postal Telegraph-Cable Company's lines from New York to Boston is about 290 miles, and the lines include from 20 to 30 miles of cable. Over this comparatively short line the system did not require any readjustment for weather, which varied during the tests from clear and cold to dense fog and rain all the way between the two cities. Duplex working was perfect.

This system, working at the 60-word rate, has a capacity of 140 messages per hour. Cutting this down to 120 messages per hour to allow for corrections and delays, and working duplex there is an output of 240 messages per hour, or 50 per cent. more than the Morse quadruplex can achieve.

BARCLAY PRINTING TELEGRAPH SYSTEM

24. A page printing telegraph system was invented by C. L. Buckingham and extensively tried and experimented with by the Western Union Telegraph Company. Mr. Barclay, electrical engineer for the same company, made many improvements to it and it might be considered almost a new system. By some, it is called the Buckingham-Barclay page printing telegraph system and by others the Barclay printing telegraph system; the latter designation is used here for the sake of brevity.

25. In the Barclay printing telegraph system, the message is first punched in a paper tape by a perforator controlled by a typewriter universal keyboard. By depressing a key, a corresponding series of punches cut clean round holes in the paper tape. The various combinations of holes together with the proper spacing and feeding of the tape are brought about by selective arrangements that constitute the distinguishing feature of the perforating system.

The perforated tape is fed through a pole-changing transmitter, the same as is used in the Wheatstone system, producing in the line long or short negative impulses, called ***marking impulses***, and long or short positive impulses, called ***spacing impulses***.

26. Arrangement of Dots and Dashes.—Six impulses are used for each character to be printed and they are arranged in different combinations on the punched tape, which renders possible the selection of 56 characters on the printer wheel in addition to the space, paper feed, type shift, type-shift release, resetting, and carriage-release movements. Three of the electric impulses are marking impulses and three are spacing impulses. By variations in the length and arrangement of these impulses, all the printing, spacing, and other magnets are controlled.

A specimen of the perforated tape representing letters a, b, and c is shown in Fig. 5, (*a*) and the corresponding signals as

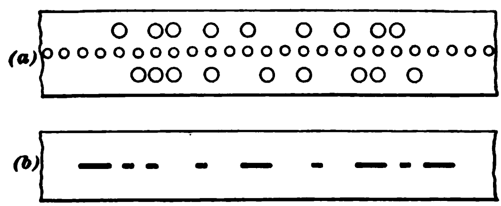


FIG. 5

they would be received on a tape is shown in (*b*). The center row of holes is used only for feeding the tape through the perforating and transmitting instruments. The upper and lower holes control the movements of the pole-changing transmitter so as to produce in the line the correct signaling impulses, which are constantly changing both in direction and duration. Two holes, one above the other, represents a dot; for two dots, vertical lines through the centers of the two pairs of vertical holes will be $\frac{1}{10}$ inch apart horizontally; for a dash, the top hole is $\frac{1}{10}$ inch horizontally ahead of the lower hole.

27. Barclay Alphabet.—The 32 different characters used in the Barclay alphabet consist, as shown in Fig. 6, of three marking and two spacing impulses of either long or short duration and a final long spacing impulse. A dash, or long, impulse is three times the length of a dot, or short, impulse and a long spacing impulse is three times the length of a short spacing impulse. The space between words, groups of figures, etc., is made by punching three dots in the tape, the resulting combination of impulses merely causes the printer to feed the paper tape the desired amount and the final long spacing impulse that follows the three dots, as well as every other character,

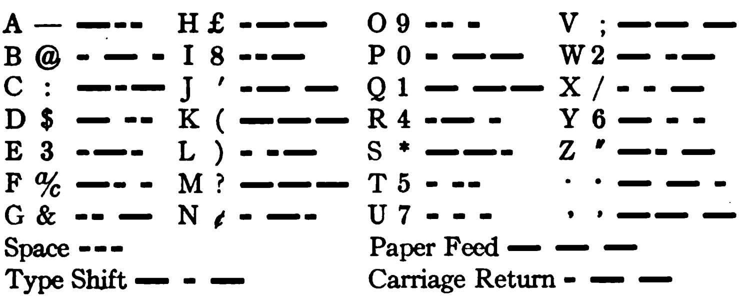


FIG. 6

finds a path open to it through the spacing magnet, the energizing of which operates the spacing attachment of the printer, thereby leaving a blank space upon the paper.

28. Receiver.—The receiving apparatus contains in the main line but one instrument, a differentially wound polarized relay. When used for duplex work, there is also, of course, the transmitting pole changer and artificial line. The duplex system is balanced like any ordinary polar duplex. The front and back stops of the polar relay control local circuits containing relays that, in turn, control a set of magnets possessing peculiarly constructed levers through one or more of which a path is built up to any desired character magnet of the typewriter.

The number of possible combinations in the positions of these circuit-creating levers has been found amply sufficient to provide local-current paths for each individual character in a standard typewriter, as well as for the additional magnets required for spacing, shifting the carriage, and other requirements.

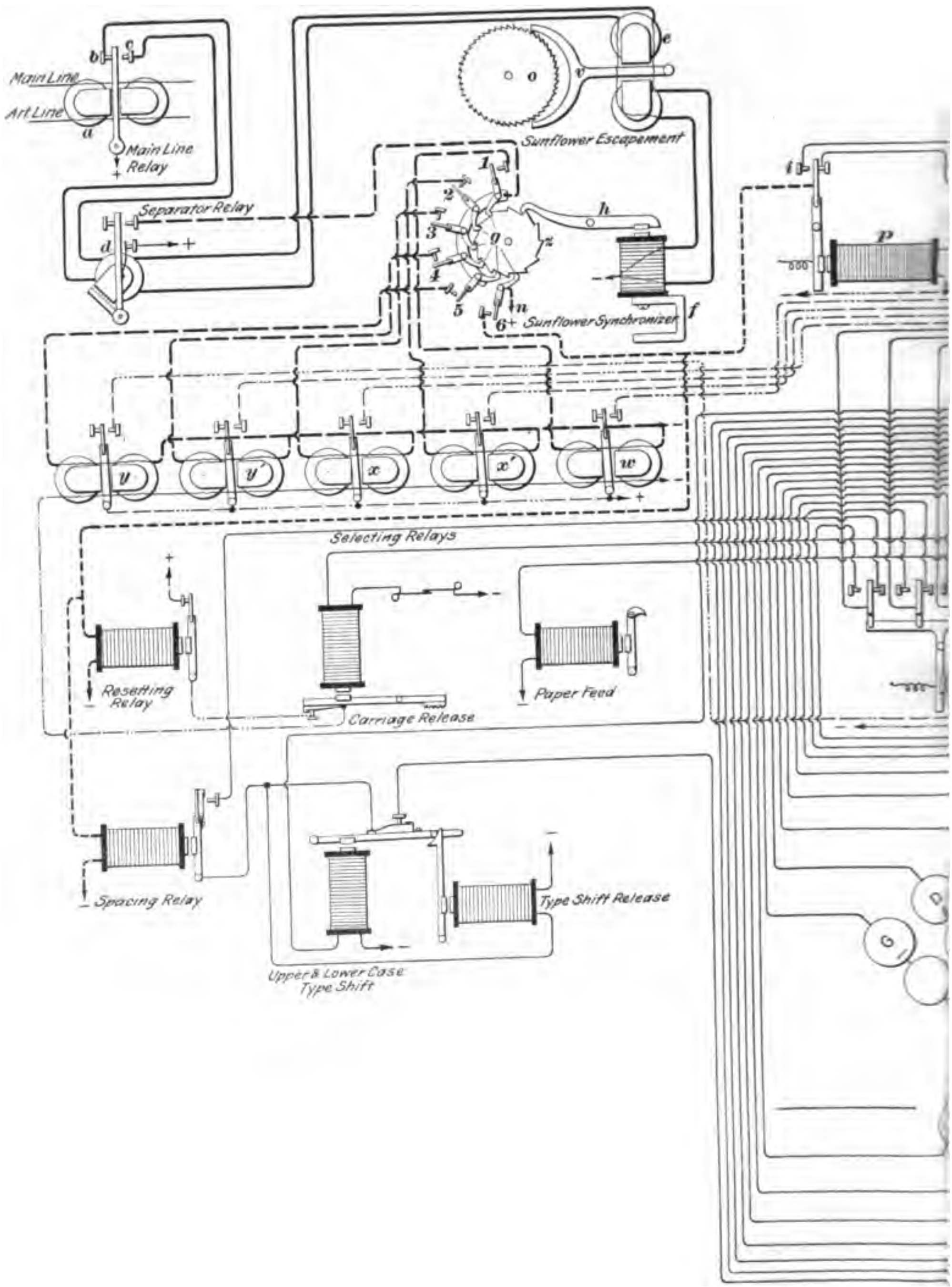
29. Typewriter.—The typewriter has an electromagnet in a local circuit for operating each character lever. For this purpose an ordinary Blickensderfer electric typewriter is used with such parts eliminated as are not required. The typewriter wheel has, in two rows on its periphery, all the 56 characters required for printing, any one of which is brought into position by rotating the wheel the proper amount and in addition by giving it, for half the characters, a motion along its axis. The moving of the wheel and the striking of the final blow that prints the character is effected by power from a shaft driven through the agency of a clutch by a constantly rotating motor within the casing.

The 28 magnets for controlling the 28 typewriter levers are located in the base of the machine. When an armature is attracted, the corresponding character lever is depressed in the same manner as a key lever on any typewriter would be depressed and this movement results in printing either one of two particular characters that it alone represents. As to which character is printed depends on whether the type-shift magnet has been energized. The type-shift magnet moves the type wheel along its axis so that the second character on the wheel is printed when the printing blow is struck.

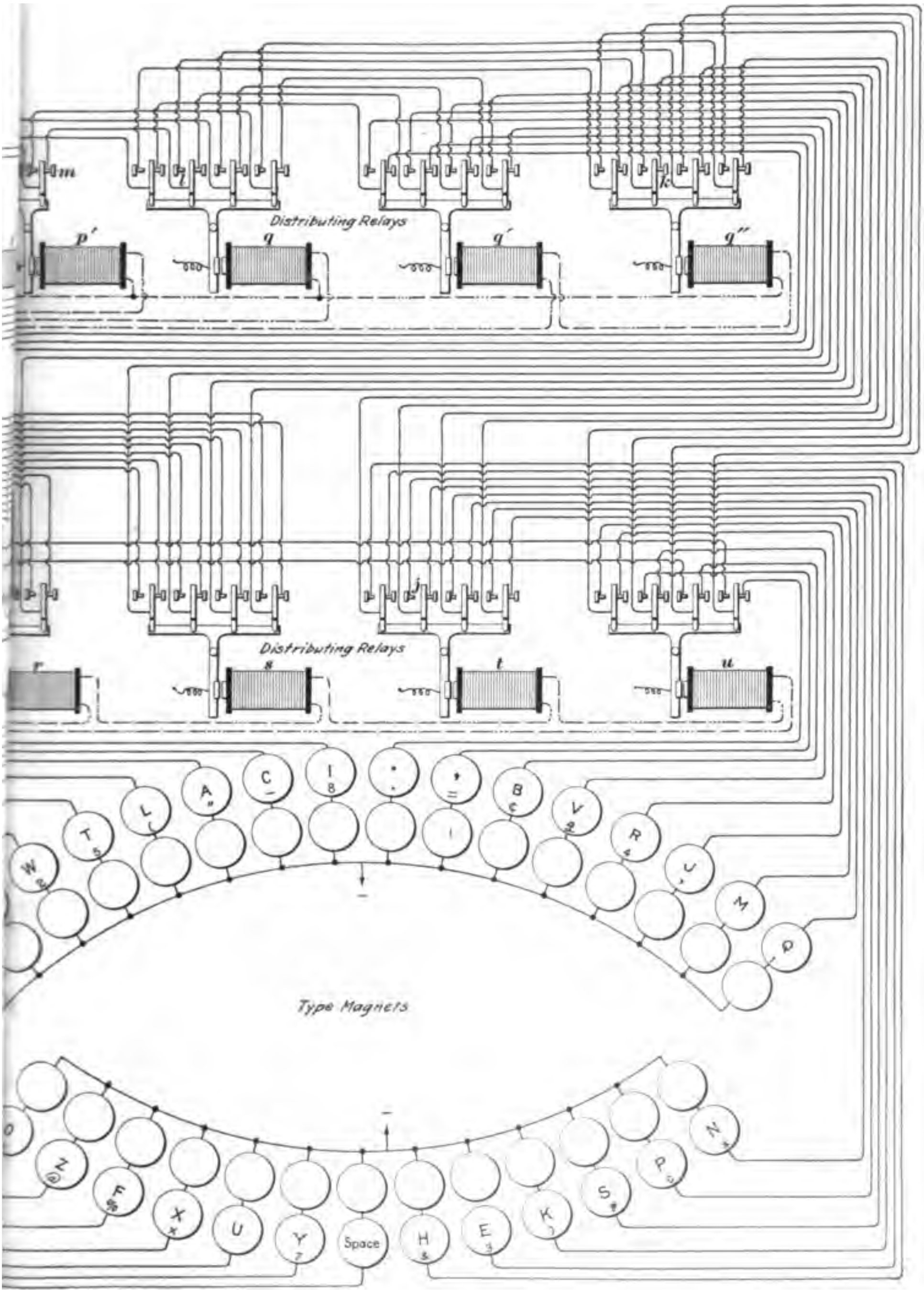
The entire operation of the typewriter is accomplished by means of relays and magnets in local circuits, hence the typewriter is not only immune from weather and other extraneous influences but may be permanently adjusted and requires practically no further attention.

RECEIVER

30. Receiving Circuits.—In Fig. 7 is shown the main line and local circuits of the receiving apparatus. The differentially wound polar relay *a* is connected in the line circuit and, for duplex working, in the artificial line also. Its front and back contacts *b* and *c* control alternately two local circuits


Main Line
Art Line
Main Line Relay
Separator Relay
Sunflower Escapement
Sunflower Synchronizer
Selecting Relays
Resetting Relay
Carriage Release
Paper Feed
Spacing Relay
Type Shift Release
Upper & Lower Case Type Shift

Fi



m
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Distributing Relays
p′
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Distributing Relays
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Type Magnets
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I
B
V
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M
Q
D
Z
F
X
U
Y
Space
H
E
K
S
P
N

containing the separator relay *d*, the escapement magnet *e* controlling the escapement of a device called a *sunflower*, and the sunflower synchronizer magnet *f*. The sunflower is the master selector and one of the most important devices in the system, as it distributes current impulses to the local circuits in the same order in which the main-line impulses are received by the polar relay. As each separate combination of long and short impulses is received a path is constructed to a different magnet that controls the character to be printed.

31. Principle Involved.—The essential principle involved in the receiver consists in the use of strong local currents in a number of local circuits which are selected and closed according to the combination of current impulses and spaces received from the line. This does not mean that an ordinary permanently arranged local circuit, a different one for each magnet, is merely closed temporarily by contact points in the usual way, but that the circuit must be actually built up for each character out of a network of short wires and relay contacts, differently arranged for each character, and included in the apparatus for this purpose only. In fact, circuit building is one of the most prominent features in the Barclay system, a circuit must be built up for each character to be printed and then dismantled immediately after the character is printed in order that the apparatus may be in its normal condition ready to build up another circuit for another character.

32. Sunflower.—The sunflower, so called on account of its circular shape and partial resemblance to that flower, possesses six small levers *g*, which close contacts *1* to *6*. The first five, when closed are connected successively with the five selecting relays *y*, *y′*, *x*, *x′* and *w*.

A ratchet wheel *o* and the sunflower escapement *v* are concentrically placed directly above the small-lever contacts *g*, instead of to one side as indicated in this figure for the sake of clearness. The ratchet wheels *z* and *o* are made to rotate in synchronism with the arriving impulses by passing the impulses through the escapement magnet *e*, which rocks the escapement lever *v*, and through the synchronizer magnet *f* which controls the pawl *h*. The levers *1* to *6* are successively moved to one side by the ratchet wheel *z*. The escapement lever *v* controls the speed of rotation of the ratchet wheel *z*, which moves with the toothed wheel *o*.

OPERATION

33. The main-line polar relay *a* is very sensitive and responds to all incoming line impulses, whether long or short. The separator relay *d* is, however, very sluggish in action and will respond only to long impulses in either direction, that is to long marking or long spacing impulses, but will not respond to any short impulses. Now the sunflower rotates regularly so that as each impulse arrives one of the levers is forced to touch its contact, and if a long impulse arrives when such a contact is closed, a path will be closed from the positive terminal of the dynamo through the contact *d* of the sluggish relay and one sunflower-lever contact to a corresponding selecting relay. As the six lever contacts close successively in direct step with the arrival of the six main-line impulses, any one or more, as desired, of the selecting relays may be energized by merely causing a dash to arrive in the same relative position, as to order of rotation, that the sunflower lever controlling such relay occupies. For instance, if the first and third selecting relays are to be closed, dashes, or long impulses must be received on the first and third periods of the six used in making up the various characters; dots, or short impulses fill in the remaining periods out of the first five; the last impulse is always a long one, but the sixth lever has no connection with the sluggish separator relay and merely causes the printing of the character after it has been selected and also the restoring of the local circuits to their normal positions. None of the other selecting relays will be operated because the sluggish separator relay did not close its circuit at the instant that the corresponding sunflower levers were made to touch their contacts by the regular rotation of the ratchet wheel.

34. For example take the letter A which has but one long impulse, ignoring the sixth which is always a long one. As this is the first of the six, the first sunflower lever catches the long impulse and causes the first selecting relay *w* to close, which in turn closes a circuit through the winding of the distributing relay *p*, which throws its lever to the left. There being but one long pulse no other distributing relay is affected and a circuit is complete from the + dynamo terminal *n* through the sunflower lever *6*, contact *i* and right-hand contacts of the levers on the distributing-relays *p'*, *q*, *q'* and *r*, to the magnet for lever A and then back to the negative pole of terminal of the dynamo, thereby energizing the magnet that causes the printing of the letter A.

If three long pulses in rotation are transmitted (— — —), which is the combination for the letter k, the first, third, and fifth levers of the sunflower will catch and cause the closing of the three corresponding selecting relays *w*, *x*, *y*, which in turn close the distributing relays *p*, *q*, *r*, *s*, *t*, *u* (*r*, *s*, *u* have, however, no effect on the path for letter k). Upon the completion of the final long sixth impulse a path to the letter k magnet is closed. This circuit may be traced from the positive terminal *n* of the dynamo through *6* – *i* – *m* – *l* – *k* – *j* – letter-*k* magnet – negative terminal of dynamo.

After each character is sent, current also flows from *n* through the coils of the resetting relay, which closes a circuit through a restoring winding on all selecting relays, thus restoring all the selecting relays, and the opening of the local circuits of these relays causes all the distributing relays to return to their normal positions, thereby restoring all circuits to their normal positions, so as to be ready for the next combination.

35. The space between words is made by merely transmitting over the line three dots or short spaces, which together with the two intervening spaces operates five times the main-line relay only and produces one cycle or complete rotation of the sunflower, but no motion of the sluggish separator relay, which responds only to long impulses, and consequently no selecting relays are closed. Under these conditions the typewriter carrier simply moves along the required distance without any printing being done.

For the letter X, the second, fourth, and fifth impulses are long, levers *2*, *4*, and *5* close the selecting relays x', y', and y, which in turn close the distributing relays p', q', q'', r, s, t, and u, thereby building up a circuit from n through levers of $p - p' - q - q' - s$ to magnet x.

36. Correcting Errors.—When an error occurs, due to a swing or other source of interruption to the line circuit, the correction is usually made on one of the Morse circuits when such is available, so as to not break in on the regular incoming matter. If the mutilation is too great to be fixed up neatly a service message is sent requesting a repetition of the entire message.

37. Speed.—The capacity of the circuit with the Barclay system is about 90 to 100 messages an hour each way, when not interrupted by wire or other trouble. When there is no interruption of any kind 100 words may be sent a minute in each direction on a line 1,000 miles in length with a repeater midway. The Barclay printer, which has been extensively used by the Western Union Telegraph Company, is claimed to possess marked advantages over preceding printing telegraph systems and for a time supplanted quite largely the Wheatstone automatic system in America. Others claim that the Wheatstone system, on account of its greater rapidity, reliability, accuracy, and economy of operation is still preferable.

WRIGHT PRINTER

38. The **Wright printer system,** due to John E. Wright, has a typewriter transmitter with a standard keyboard which may be operated at typewriter speed. The depression of a key selects a combination of positive and negative current impulses, which select a corresponding character at the receiving typewriter that prints the message in page form on a message blank. The transmitter also produces a copy of the outgoing message in page form. At the receiving end there is a polar relay that, in response to the combination of current impulses received from the line, controls the movement of a type wheel. This wheel revolves about its axis, moves along its axis, and perpendicularly to its axis across the message blank for the selection and printing of the various characters. These motions are reversible. The blanks are fed to the receiving printer by an attendant who watches the printed messages for errors. The disposition of the characters on the periphery of the wheel is such that an average of 3½ line-current impulses is required to print a letter. About 40 words a minute in each direction is said to be the speed of this system on lines up to 300 miles in length.

MESSENGER-CALL SYSTEMS

CIRCUITS AND CALL BOXES

PRINCIPAL FEATURES

39. In all large cities there are companies having the necessary line circuits and devices that enable a subscriber to notify them that a messenger is desired at once. The subscriber, by turning the crank on a small *call box* placed in his office, causes a certain special signal or number to be sent to the central office, thereby notifying the central office exactly what subscriber is calling. While the majority of call boxes are made merely to call for a messenger, there are some that enable the subscriber to notify the central office whether a messenger, doctor, policeman, fire department, or other service is desired. Furthermore, all types of call boxes may be fitted with a return signal whereby the subscriber is notified by the ringing of a bell or by some other signal that his call has been properly received. The telephone has been adapted by some district telegraph companies. A telephone specially connected is installed in each subscriber's office to enable the subscriber to call up the central office and make his wants known. However, the central office cannot usually call up the subscriber nor can one subscriber be furnished with connection to any other subscriber. In other words, there is no provision or intention whatever to enter the telephone-exchange business.

40. Call boxes are made in an almost infinite number of different ways and for various purposes. However, they are invariably connected in series in a circuit that does not normally use the ground as a return conductor. Morse ink or embossing registers are invariably used at the central office to record the calls sent in by the subscribers, and, in addition, a bell or gong is generally used to notify the central-office attendant that a call is coming in.

41. Diagram of Connections.—A diagram of connections used in the district telegraph service is shown in Fig. 8, in which the central office and four subscribers' call boxes *A*, *B*, *C*, and *D* are included. At the central office, the line circuit normally includes the key *k*, battery *B*, and relay *R*. If call box No. 42 is properly operated, the line circuit, which is normally closed, will be opened four times, and after a proper interval two times, thus causing the armature of the relay to close, on its back stop, a circuit containing a local battery *LB*, a Morse ink or embossing register *E*, and a gong *S* four and two times. Thus a record of the signal 42 is made on the register *E* and at the same time an audible signal is made by means of the single-stroke gong or bell *S*. If return-call boxes are used on this circuit at the subscribers' station, the attendant presses the key *k* immediately after receiving the signal, thus sending a current from the return-call battery *T* over the line to the box that has been operated, where a momentary connection to earth affords a return circuit. The batteries *LB* and *T* usually consist of Leclanché cells, and *B* of some form of closed-circuit cells, such as gravity, Gordon, Edison, or storage cells, or a converter or motor dynamo may be used. *A* and *D* represent ordinary single-call boxes, *B* and *C* return-signal boxes, *B*, as indicated, having five distinct calls.

42. The mechanism at *D* consists of a gear-wheel *e*, having a spiral spring that is wound up whenever the crank *f* is turned in the act of calling for a messenger. When the crank is

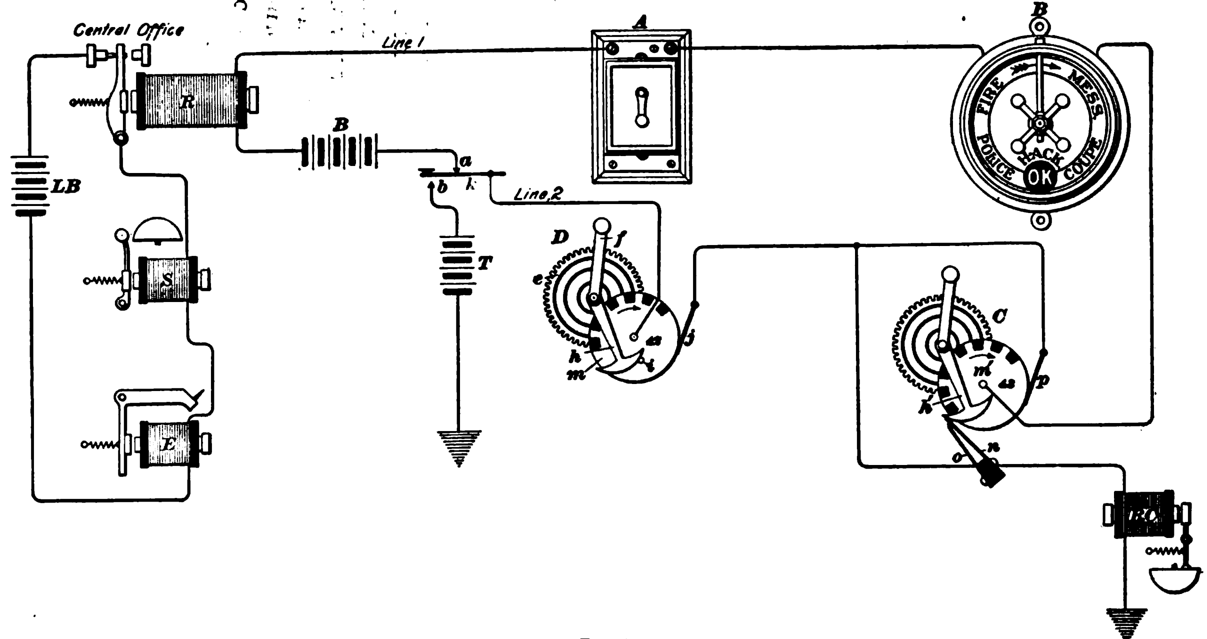

Central Office
Line 1
A
B
FIRE
MESS.
POLICE
HACK
COUPE
OK
R
B
a
b
k
Line 2
LB
S
E
T
D
f
e
h
m
j
C
m
k
p
o
n
P.O.

Fig. 8

released, it returns to its normal position. When the handle *f* is turned, the stop *h* moves out of the path of the pin *i* and the spring propels the mechanism, causing the break wheel *m* to make one revolution in the direction of the arrow; the lever *h* coming in the path of the pin *i* stops the wheel at exactly the same place every time. As the wheel revolves, the circuit between the wheel and the brush *j* is broken every time an insulated segment on the periphery of the wheel comes under the brush. Thus at station *D*, the circuit is broken four times, and then two times, causing the signal 42 to be sent into the central office.

43. Multiple-Call Box.—In a call box such as shown at *B*, by means of which several different calls may be made, the circuit would be interrupted, after the box number would have been sent in, once for a messenger, twice for a coupe, three times for a hack, etc. Upon the periphery of the break wheel there would be, besides those necessary for sending in the box number, such additional insulated segments as are required for the various calls.

44. Return-Call Box.—At *C* in Fig. 8 is shown the mechanism of a return-call box. It has two springs *o* and *n* that are normally insulated from each other, and also from the break wheel *m'*. The break wheel when released makes two complete revolutions. Upon making the second revolution, the arm *h'* comes into such a position as to press the two springs *n* and *o* together, for a short time only, however. If, while these two springs are in contact, the attendant depresses the key *k*, a current from the return-call battery *T* will pass out over line *2*, through the springs *o* and *n* and the magnet *RC* of the return-call bell, and return through the ground. It is necessary with this type of box for the attendant to depress the return-call key as soon as the whole signal is received, otherwise he cannot give the return signal. Return-call boxes may be manual or automatic. In one form of the manual return-call box, the subscriber, after calling, must press his finger on a knob, or push button, in order that the office may signal back.

This is done by causing a little ball to tap against a glass disk, thus informing the subscriber that his call has been received.

45. Automatic Return-Call Boxes.—Box *B* in Fig. 8 is an automatic return-call signal box made by the Viaduct Manufacturing Company. When the subscriber calls, the *OK* disappears and when the office signals back, the *OK* drops into view, signifying that the call has been received. The return-call magnet has a resistance of about 13 ohms and the normal current due to the battery *B* is not sufficient to operate it.

46. The **Field and Fireman** return-call box made by the Western Electric Company has provision for sending in as many as eleven different calls. When primary batteries are used with this call box, the arrangement is generally as shown in Fig. 9 (*a*). In (*b*) is given a general view of the exterior of the box. At *C* enough of the box mechanism is shown to show the method of giving the return signal. Normally, the gravity battery *B*, containing about 14 cells, sends enough current through the circuit to keep the relay energized; and the magnet *Rs*, which gives the return signal, is short-circuited by the connection between the spring *b* and the piece *a*. When a call is made by moving the lever *f*, the piece *a* is moved so that the spring *b* is separated from *a*, thus opening the short circuit around *Rs*, and, furthermore, the hook *c* catches at *d* and holds the circuit open between *a* and *b*. The magnet *Rs* is then directly in the line circuit. While the box is in this condition, just after a call has been completed, the attendant presses a special push-button key *K*, which connects *e* to the line at *n*, and *i* to the other line at *o*. This connects the battery *F* of about twelve Leclanché cells and the large spark coil *I* between *n* and *o*. On account of the high inductance of the coil *I*, almost all of the rapidly increasing initial current from *F* will pass over the line, momentarily energize the return-signal magnet *Rs*, cause its armature to release *a*, the hammer attached to which strikes the gong, and the circuit around *Rs* is closed at *b*. The current is only on a moment while the key *K* is depressed.

47. Many boxes have a provision for temporarily or permanently grounding the circuit in case of a break somewhere in the circuit. By also grounding both sides at the

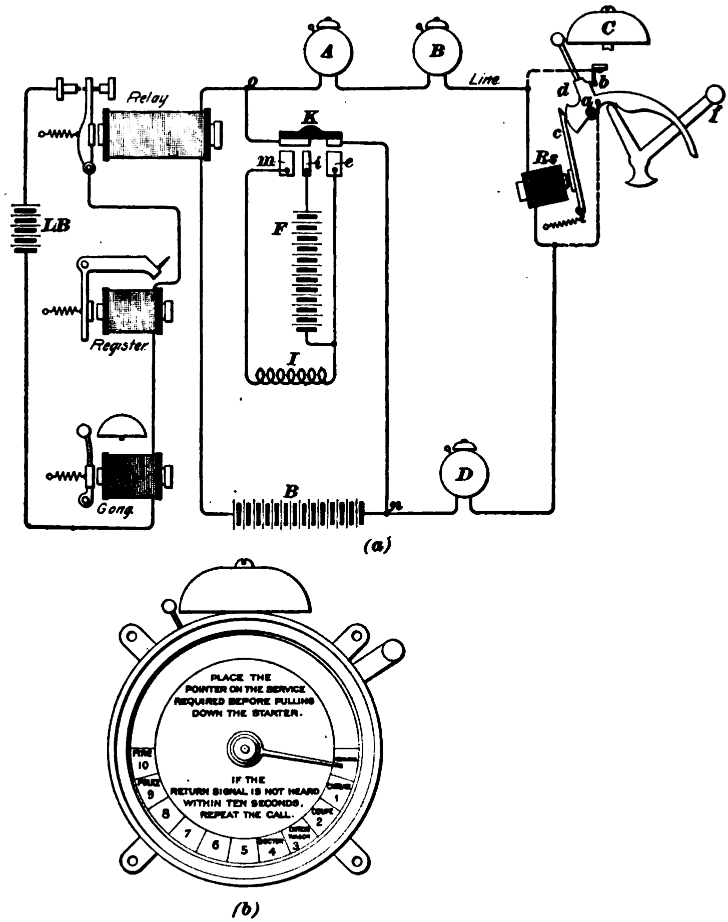


Fig. 9

central office, all boxes are still in working condition, but with a ground return, instead of a complete metallic circuit. With metallic circuits, which are the ones generally used, one accidental ground on a circuit does not interfere with the operation of the system. In the case of two grounds on the same circuit, only the call boxes between the two grounds are rendered useless until one or both grounds are removed. It is customary to make regular tests at the central office of every call box about once an hour, in order that grounds and breaks may be detected and removed. It is further customary to have extra relays at the central office that may be instantly cut in the circuit in place of the regular relays, in case any of the latter fail to work. All possible precautions are taken to keep all circuits always in working order.

Switchboards resembling those in telegraph offices are used for connecting the central-office relays, batteries, and test instruments with the various circuits. Although as many as 100 call boxes may be operated in one circuit, it is not customary to connect over 50 in the same circuit; with such a large number there is so much more danger of signals from more than one box being sent in at the same time. In district telegraph systems, usually no provision is made to avoid the interference of one signal with another. In case it happens and the attendant is unable to recognize one or both signals, there is no remedy, and one or both subscribers must repeat their calls. In case the subscriber has a return-call box, he will know from the absence of a return signal, that he should repeat his call.

M'CULLOH SYSTEM USING BATTERIES

48. Ordinarily, a break in the line might result either in the cutting out of all call-box stations beyond the break or in making the entire circuit inoperative until the break is located and repaired. To avoid this defect, the arrangement shown in Fig. 10 was devised by C. F. McCulloh. The boxes have ground connections that are normally open, but the ground connections are closed temporarily when the boxes are operated, and the ground at the central office may be connected to the circuit at any time by the attendant. The boxes are provided with a device for simultaneously making and breaking connections with the main line and with the ground, so that while the line is intact, the current returns over the line wire, but in the event of a break, the return is through the ground. Nothing short of two simultaneous breaks, one on each side of the station, can throw a box out of communication with the central office and even then the other stations on the same circuit are not affected.

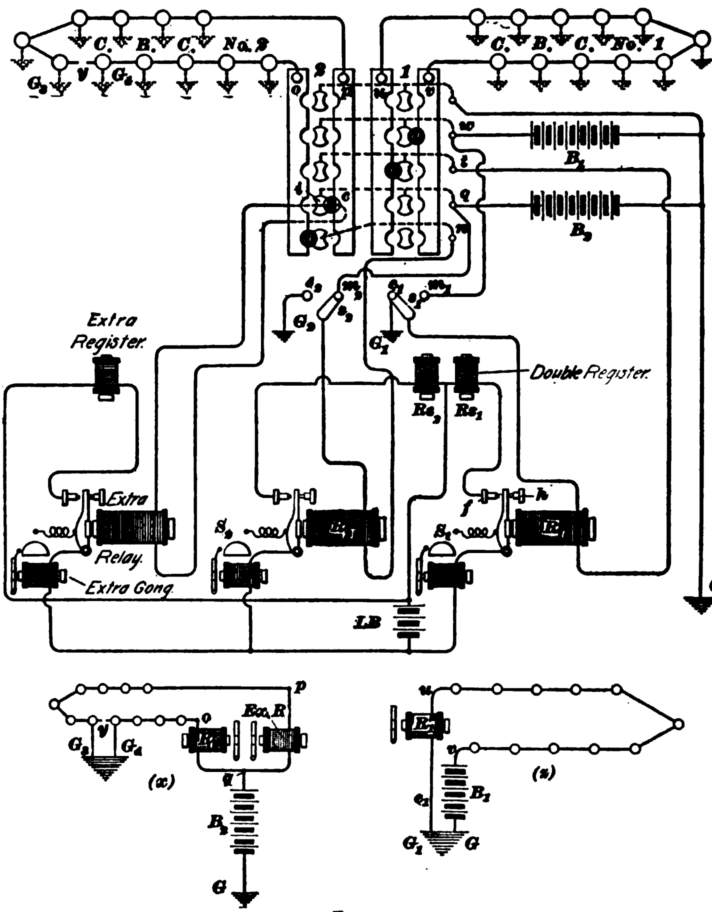


FIG. 10

49. Operation.—Ordinarily, common pin plugs would be placed in the hols *a*, *b*, *c*, and *d*, and the switches s_1 and s_2 would be turned to the left so as to connect with the two grounded buttons e_1 and e_2, as shown here for the call-box circuit No. 1

(*C. B. C., No. 1*). The current may be traced from G_1 through $e_1 - s_1 - R_1 - t - b - u$ - call-box circuit No. $1 - v - a - w - B_1 - G$ back to G_1. This is shown in the small detached diagram (z), which is lettered the same as the other part of the figure. The central office is immediately notified if a break occurs on a circuit, because the current through the relay in that circuit will cease and hence the gong will ring once.

In case there is a break somewhere, as at y on the No. 2 circuit, the switch s_2 should be turned to the right in contact with the button m_2. A split wedge, containing an extra relay in circuit with it, should be inserted in the hole c, as indicated. This will make two outgoing parallel circuits worked with the same battery B_2 and a ground return whenever a call box on this circuit is operated. This is clearly shown in the detached small diagram (x), in which the circuit is lettered the same as in the other part of the figure. One circuit may be traced from the battery B_2 through $q - i$ - extra relay $- c - p$ - call-box circuit No. 2 - ground, as at G_3, at some box from which a signal is being sent and back through the ground to G and the battery B_2. The other circuit from the battery B_2 passes through $q - m_2 - s_2 - R_2 - n - d - o$ - call-box circuit No. 2 to a ground, as at G_4, at some box from which a signal is being sent and back through the ground to G and the battery B_2. Thus stations on both sides of the break can signal the central office.

50. Breaks and Grounds on Line.—The central office is notified immediately a break or ground occurs on an otherwise good circuit. For, suppose a break occurs on circuit No. 1, and that the wire on the side of the break connected to v becomes grounded. When the break occurs, all current will be cut from the relay R_1, the gong S_1 will sound, and the register Rs_1 start. The attendant recognizes that the one side is open and can test to determine whether the other side is grounded or open by inserting in the hole a a split wedge, containing in circuit with it an extra relay.

If the No. 1 circuit is grounded on the v side of the open circuit, the extra relay will be energized; if open, it will not be energized. If the side connected to *u* [see diagram (*z*)] becomes grounded and the other side opens, there will be no current in either R_1 or in the extra relay, because now no current flows from B_1 in either side of the No. 1 circuit. In this case, the register Rs_1 and the extra register will run until stopped. In case of an open circuit and the registers start, the local circuit should be transferred from the back stop *f* to the front stop *h* of the relay to stop the register and also in order that the gong will sound when the break is repaired and the relay is again energized.

51. Double-pen ink registers are commonly used in district telegraph offices. The one local battery *LB* supplies current for the three local circuits. A good form of open-circuit cell, storage batteries, or converters may be used at *LB*. Batteries B_1 and B_2 should be closed-circuit cells, storage batteries, or converters. Whenever storage batteries or generators are used, resistances and fuses to limit the current to a safe strength should be connected in each circuit.

M'CULLOH SYSTEM USING DYNAMOS

52. The connections of the McCulloh system, as used in Denver, where dynamos are used, replacing 175 gravity and Leclanché cells, is shown in Fig. 11 (*a*). The momentary grounding of each call box when operated made it necessary to place the 400-ohm relay that controls the register recording the call on the same end of the circuit with the generator. On this account the arrangement shown here was made to enable the operator to at once detect a ground, heavy escape, or break in the circuit. There is a 400-ohm relay that controls the register on the dynamo end and a 150-ohm relay that controls a vibrating bell on the ground end of each circuit. Both the register and vibrating bell are normally connected to the back contact stops of their respective relays, enough current being used to keep both the relays closed. However, the local contact stops of the relays are so connected that either the front or back stop may readily be used as the occasion demands.

53. There are fourteen circuits in the Denver system; the current for all of them is supplied by a motor dynamo giving

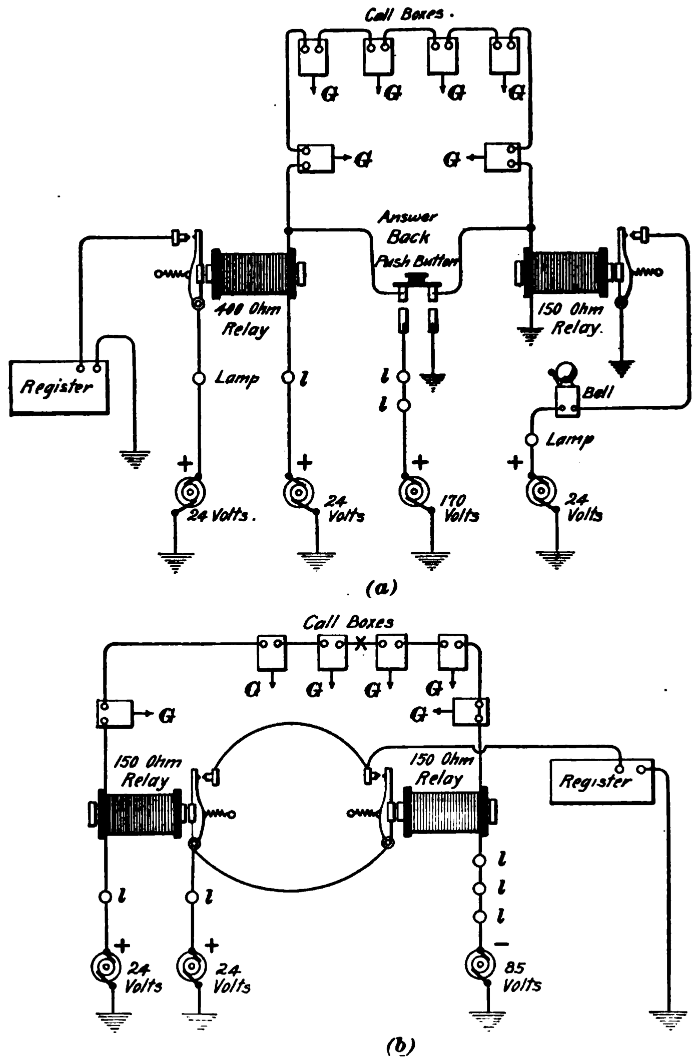


FIG. 11

24 volts, the positive brush being connected toward the line. The current is reduced by means of resistance lamps to such a

strength that it will not magnetize the 13-ohm coil of the answer-back signal magnet in the subscriber's box sufficiently to cause the *OK* in the box *B* in Fig. 8, to drop into view.

The answer-back push button when pressed down grounds the end of the circuit just outside of the 150-ohm relay, and at the same time connects 170 volts positive to the other end of the line just outside the 400-ohm relay. Enough current is thus forced through the circuit containing the 13-ohm coil of the answer-back signal in the call box to release the catch and drop the *OK* into view.

54. In case of a ground, escape, or opening of a circuit, the current being cut off from the 150-ohm relay causes the relay to open, thereby closing the local circuit and ringing the bell. The operator at once switches the circuit to a set of so-called McCulloh relays, as shown in (*b*), so that no call will be lost, unless more than one break or ground occurs at the same time on the same circuit. A break is represented in this figure by the cross on the line wire. One of the relays being connected to the 24-volt positive dynamo, the other had to be connected to the 85-volt negative dynamo, no smaller negative voltage being available, and opposite polarities being desirable, so that the two relays will close when a break on the circuit is repaired. The operation of either relay will work the register. The switchboard, which is a collection of small spring jacks, having fourteen jacks for each circuit, was made expressly for these circuits, and is so wired that changes may be rapidly made from the regular relays to McCulloh sets, making it almost impossible for a call to be lost.

AMERICAN DISTRICT AND WESTERN UNION SYSTEMS

55. To keep the call-box circuit in working condition in spite of a break or ground on the line is the object of the arrangement shown in Fig. 12, which is used by both the American District and Western Union Telegraph Companies. The call-box circuit is brought to the main switchboard *q* from which, the circuit is extended to the office apparatus shown below it.

With the switches in the position shown, one opening anywhere in the call-box circuit will cause both relays *TE* and *BA* to release their armatures and thus start the register and buzzer. A single ground will short-circuit relay *TE*, thereby operating the buzzer until it is noticed by the attendant, who can put the entire circuit in working condition by turning down the switch *s*. This connects in parallel both sides of the call-box circuit to the accidental fault, the dynamo being put between the ground and each side. If the fault is a ground, its removal will start the register and buzzer, while the operation of a call box on either side of it will send in its signal. If the fault is an open circuit, switch *m* is turned to the left and *n* to the right,

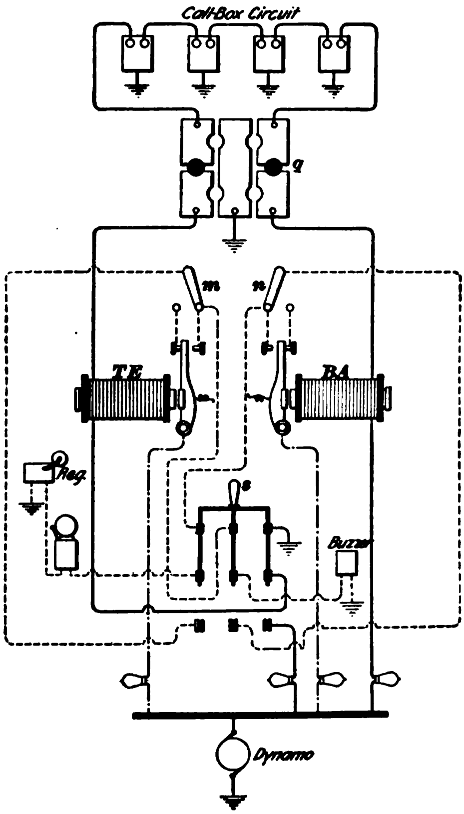


Fig. 12

then the closing of the break will start the register and buzzer. By grounding the circuit through an emergency fuse on each side of the break, only those call boxes between the two emergency grounds will be rendered useless.

M'CULLOH AND BAUER SIGNAL BOXES

56. To keep the call-box circuit in a usable condition in spite of an open circuit or a ground and without requiring the attention of the operator is the object of the McCulloh and Bauer signal boxes, which are so constructed as to open mechanically and also ground the circuit while producing its own signal. Thus, should a metallic circuit be either opened or grounded at one point only, every call box in the circuit can still turn in a signal without any action on the part of the office attendant. The McCulloh signal boxes are used by both the American District and Western Union Telegraph Companies.

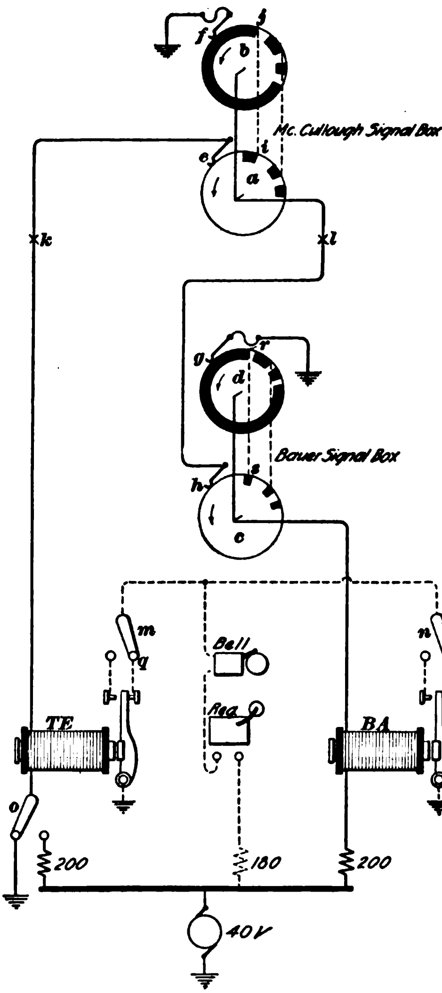


FIG. 13

57. McCulloh Box.—The McCulloh and Bauer signal boxes and their connections are shown in Fig. 13. The McCulloh box consists of the ordinary simple break wheel *a* mounted on the same shaft with a grounding wheel *b*. The break wheel *a* has the signal 12 cut into the brass wheel and this space filled with insulating material, so as to break the circuit as the cutaway portions pass under the brush *e*. The brass wheel *b* has enough of its periphery cut away and filled with insulating material to leave projecting brass teeth corresponding to the signal 12. These two wheels are fixed on the same shaft in such a relation to the brushes *e* and *f* that as soon as the brush *e* reaches the end of a signal, as at *i*, the brush *f* will reach the beginning of the corresponding signal at *j*. Thus the circuit is opened by the signal on wheel *a* and then grounded by the corresponding signal on wheel *b*. The opening of the circuit with the switches in the positions shown, causes both relays *BA* and *TE* to release their armatures and operate the register and bell.

58. If there is a ground at some point *k* between the McCulloh box and the tailing relay *TE*, the attendant turns switch *m* to the left, or switch *o* to the right, if there are other call boxes between *k* and relay *TE*, and the opening of the circuit by the wheel *a* will still send the signal to relay *BA*. The grounding of the circuit by the operation of the wheel *b* will work the relay *BA* even if the circuit happens to be open at some point *k*. If the circuit is either open or grounded at some point *l* between this box and relay *BA*, the relay *TE* will be deprived of current, hence it will release its armature and the bell and register will run until noticed by the attendant who can put the entire circuit in working condition by turning the switch *o* to the right. If the fault is an open circuit, the switches *m* and *n* are turned to the left; in case of a ground, they are left where shown. In either case, the closing of the break or the removal of the ground will cause the bell to ring.

59. An objection to the arrangement of segments in the McCulloh box is due to the fact that the tail-end relay is open for one period while brush *e* passes over an insulated gap in the wheel *a* to the point *i*, and also for the following period while the circuit is grounded as brush *f* passes over the metal tooth *j*. Thus, for instance for signal 5, the bell and register will operate continuously instead of giving five separate rings. If, however, this McCulloh box is used in the circuit shown in Fig. 12, the register will record the signals properly because it is now controlled only by relay *BA*, but the buzzer, which is now controlled by relay *TE*, will sound continuously.

60. Bauer Box.—To overcome these objections to the McCulloh box, the Bauer box has teeth of one-half the length. When the brush *h* passes over the first half of the gap *s* both relays release their armatures and the register would print a dash of one-half the length due to a similar signal from a McCulloh box, if it were not that the circuit is grounded by wheel *d* when brush *h* is in the middle of the break *s*; thus the relay *BA* attracts its armature and would open the register circuit at contact *p*, but the register circuit is kept closed at *q* as long as the brush *h* rests on tooth *s*. Thus the register circuit is kept closed the usual length of time.

61. The circuit shown in Fig. 13 has the advantage that the central-office wiring is simplified by the omission of the six-point knife switch and the buzzer circuit, and only three, instead of four, dynamo leads with lamps, or resistances, are required. Furthermore, if a ground wire is broken at a McCulloh box, the fact is not likely to be immediately discovered if the attendant is busy on another circuit at the time the defective box is pulled, because the buzz and the ringing of the bell when the McCulloh box is operated in the circuit shown in Fig. 12 will coincide and the continual buzz will be absent. But the tape will show no irregularity and if the attendant does not detect the irregularity of this particular signal from the defective box the broken ground wire will be overlooked.

62. With the Bauer box, the permanent record printed on the tape, in case of a defective ground wire, will be only half dashes, which are little better than dots. As the attendant will notice that box 12, for instance, sent in only half dashes, he will make a note of it, and at his earliest convenience will call up box 12 on the telephone and ask that another signal be sent for a test. The attendant then noticing that the signal comes in on both relays at once, but only in half dashes on the tape, notifies the trouble hunter that the ground wire at box 12 is defective. If, however, the half-dash signals come in on the tail-end relay *TE* only, the circuit is evidently not opened by the operation of the box as usual, but the tail-end relay is cut-out by the ground-wheel signals; hence, the wires running into box 12 are crossed and he notifies the lineman that box 12 is on a crossed-out loop.

POSTAL TELEGRAPH-CABLE CO. SYSTEMS

63. Dynamo Metallic Circuit.—In Fig. 14 is shown the dynamo, metallic-circuit, messenger-call system as arranged by the Postal Telegraph-Cable Company. As usual, the call boxes are arranged in a series circuit, but between about every two call boxes there is a fuse block connected between the line and ground, without a fuse however. In case of emergency, as when the line becomes broken on the side of the emergency fuse block away from the exchange, a ½-ampere enclosed fuse can be quickly slipped into position, thus enabling at least those call boxes on the exchange side of the break to remain in working order. There is a 1-ampere fuse in each wire running to each call box and a ½-ampere fuse and 10-mil mica arrester in each side of the circuit at the main office.

64. The outside circuit terminates in a normally open pin jack *e*, into which may be inserted the double-conductor plug at one end of the double-conductor cord *f*, the wedge at the other end being suitable for insertion in either of the spring jacks *g*. The movable portions of these jacks *g* are connected together, and the stationary portions to normally closed pin jacks *h* into either of which may be inserted the plug *i* that is connected through a flexible cord to a test call box *j*. This arrangement is used to determine whether any line is in working condition. The circuit then passes through call-circuit relays *k* and *l*. One side then passes through a 200-ohm coil to the 40-volt dynamo *o* and the other side is usually grounded through the switch *m*.

65. Should there be an accidental ground, or a break, and one or two grounds put on purposely by means of one or two emergency fuses one on each side of a break, by turning the switch *m* to the left, each side is supplied from the 40-volt dynamo through a 200-ohm coil. Thus calls may still be sent into the office from boxes on the office side of an accidental or

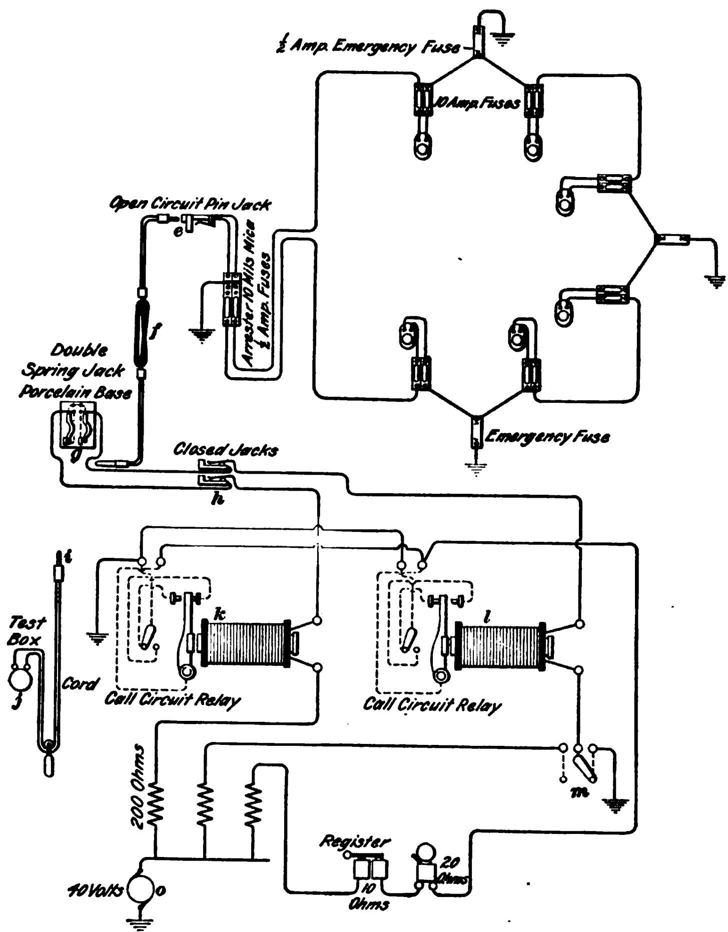


FIG. 14

purposely made ground and an open circuit may put none or only a few boxes out of use. The relays *k* and *l* are each provided with a switch whereby the 10-ohm register and 20-ohm bell may be operated on either the front or back stop of either relay. The relay contacts are connected in parallel so that either relay will control the register and bell.

66. Battery Metallic Circuit.—A similar system to that just explained but operated by primary batteries is shown in

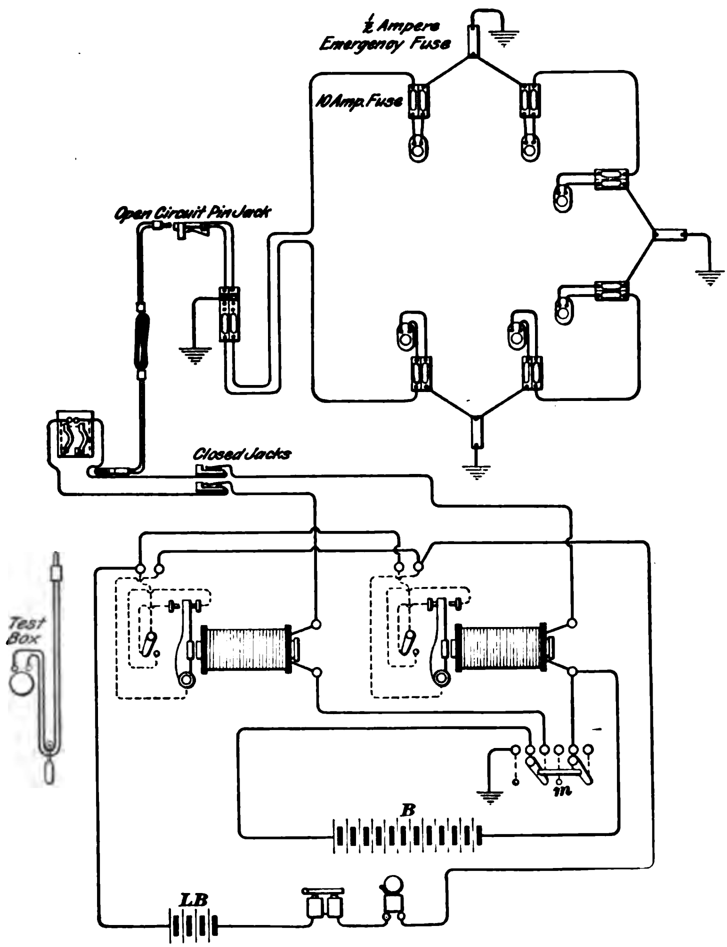


FIG. 15

Fig. 15. When the switch *m* is turned to the right, which is its normal position, the main-line battery *B* is in series with the two sides of the line circuit; when *m* is turned to the left, each

side of the line circuit is connected together and through the battery *B* to the ground, so that call boxes on either side of the circuit having a ground on the side away from the office may still be worked. The local battery *LB* operates the register and bell. No further explanation seems necessary as the circuit

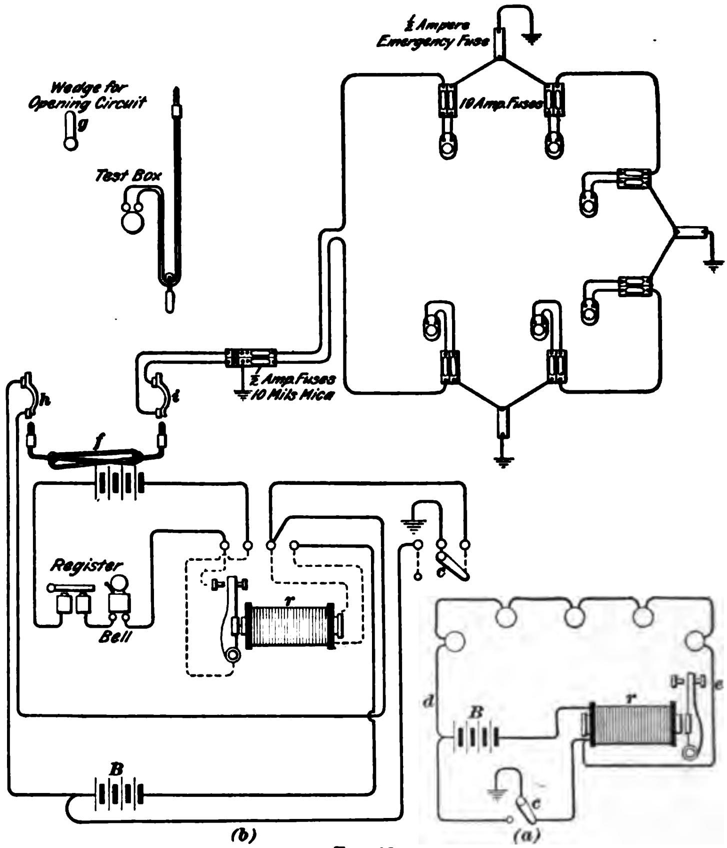


FIG. 16

operates the same as the dynamo, metallic-circuit, messenger-call system.

67. Battery System for Small Stations.—A similar messenger-call system, but suitable for small stations is shown in Fig. 16 (*b*). A simplified circuit is shown in (*a*). Ordinarily, the switch *c* rests in a central position and all call boxes, the battery *B*, and the relay *r* are connected in a simple series circuit. For testing purposes and for operating more or less of the circuit when there is a break, cross, or two or more grounds on the line, the switch *c* may be turned to the right or left. Suppose there is a break in the line on the *d* side of the center of the circuit, then the side containing the largest number of boxes, that is the *e* side, can be kept in working order by turning the switch *c* to the left and inserting an emergency fuse in a ground circuit between the break and the nearest box toward the *e* side of the circuit. The usual test call box connected through a flexible cord to a plug is also provided.

When the cord *f*, view (*b*), connects the two jacks *h* and *i* together, either side of the circuit may be held open for testing purposes or for the operation of a part of the circuit by inserting the insulating wedge *g* on either side of the wedge in either jack *h* or *i*.

68. One Register for Several Circuits.—In Fig. 17* is shown an arrangement used by the Postal Telegraph-Cable Company whereby one register may be made to serve a number of circuits; thus there is a considerable reduction in the cost over the arrangement having a register in each circuit and little or no impairment of the service because each circuit is in use such a small part of the time. With the *c* switches in the position shown, current passes from the 40-volt dynamo through a 600-ohm resistance coil, an *a* relay, one pin and one spring jack, another pin jack, one *b* relay, and *c* switch to ground, the six relays and three switches shown being thus arranged in three sets. If the *c* switches are thrown to the left, the circuits are split, thereby putting each relay and a 600-ohm coil in a separate tap from the main dynamo lead. The local circuits of each two relays are connected in parallel between the ground and one 10-ohm bell, each bell having a 10-ohm annunciator coil in series with it; the three annunciator circuits are then joined together and pass as one circuit through the one 10-ohm register and one 180-ohm resistance coil to the 40-volt-dynamo lead.

*This and the next two diagrams were given in the Telegraph Age.

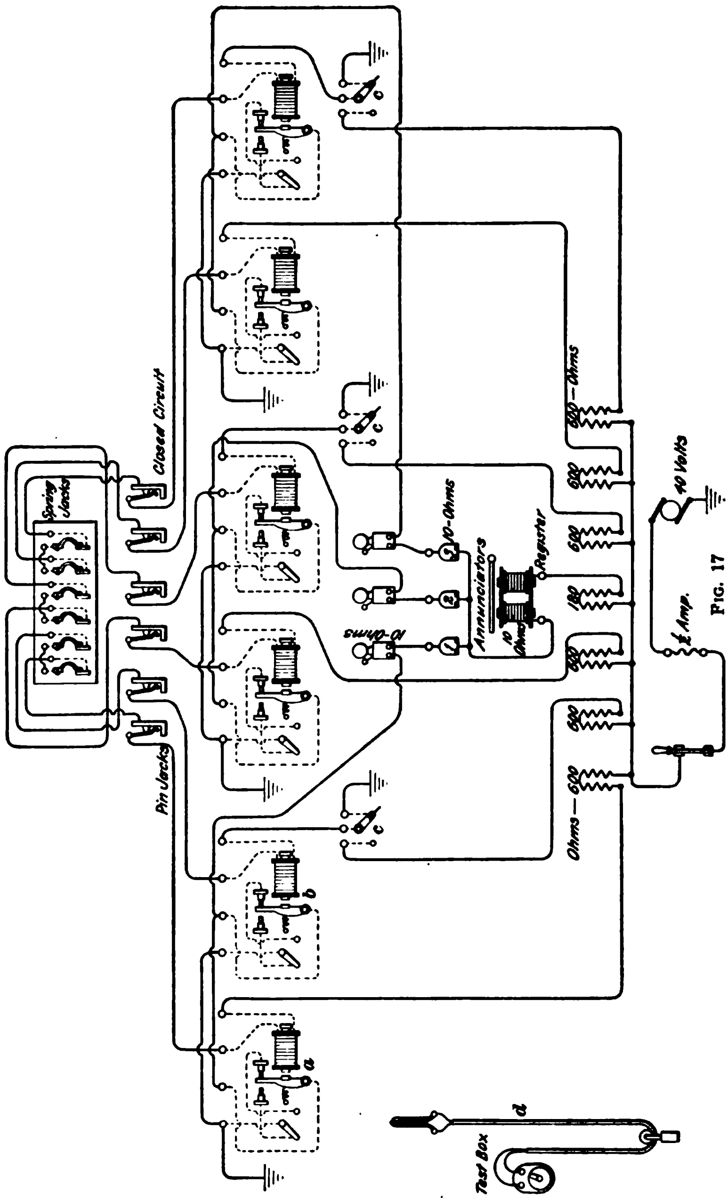

Closed Circuit
Spring Jacks
Pin Jacks
10-Ohms
10-Ohms
Annunciators
Register
10 Ohms
600-Ohms
600
600
180
600
600
Ohms—600
40 Volts
¼ Amp.
Test Box
a
b
c
d

FIG. 17

A call coming in over any line will ring one of the bells and operate the annunciator in that circuit and also the one register. The line circuits are connected at the spring jacks, while the test-box cord-circuit *d* may be connected through any pin jack for testing any line or circuit. By connecting one bell in the register circuit, it will ring when any call box is pulled and as many bells can be saved as registers are saved by the arrangement shown.

69. In Fig. 18 is shown another district telegraph circuit used by the Postal Telegraph-Cable Company. The line circuit containing the call boxes *1*, *2*, *3*, *4*, *5*, and *6* terminates in a plug jack *i*, while the office circuit terminates in spring jacks *j*; the two are connected together by a flexible cord terminating in a plug *p* and two single wedges *w* or one double wedge. The closed-circuit jacks *k* may be used for testing the circuit by the office attendant. Fuse blocks *a*, *b*, and *c* are connected to the circuit between each pair of call boxes; they are normally disconnected from the ground, but the fuses may be readily inserted and thus a permanent ground put on the circuit between any two boxes and the fuse protects the circuit each way from the ground. The call boxes are the ordinary break-circuit or break-wheel variety that simply break the circuit the number of times required to produce the signal for that particular box.

At the office each line wire passes through a relay *BA* or *TE*; with the ground switch *GS* turned to the right, one end of the circuit is grounded and the other end connected through a dynamo *d* to ground. Thus all the call boxes, two relays, and a dynamo are normally in series.

70. Normally, all circuits are closed, the switch *GS* turned to the right, and the local switches *m* and *n* turned to the left. When a call box is pulled, the circuit is broken a definite number of times and the armatures of both relays *BA* and *TE* fall to their back stops; each relay thus opens and closes the register-bell circuit and thus the proper number of signals due to breaks only are recorded on the tape and sounded by the bell. If the line circuit should become grounded at some point accidentally, the tailing relay *TE*, being deprived of current by having the circuit on each side of it grounded, will release its armature and start the bell and register. In such a case, the switch *GS* will be turned to the left, thereby connecting in parallel both sides of the circuit from the accidental ground. Under this

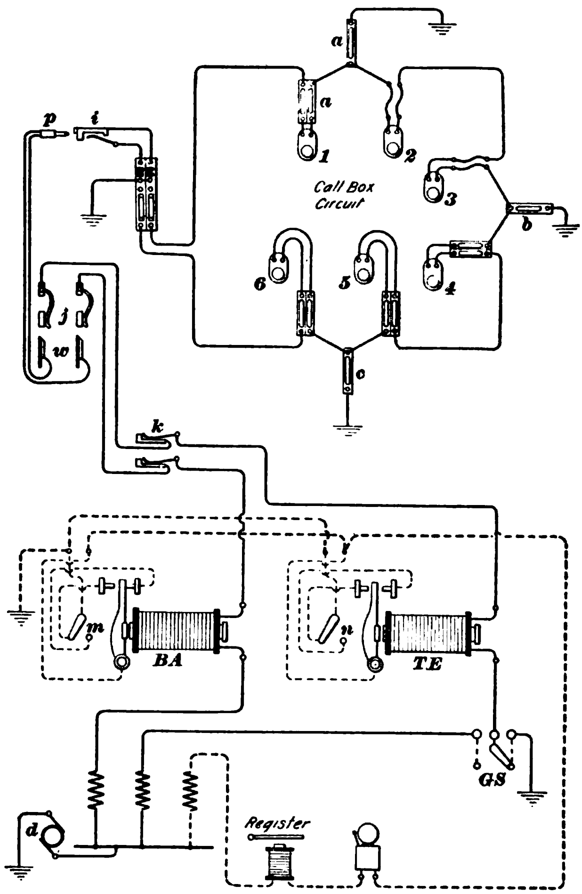


Fig. 18

arrangement, there will be practically two separate call-box circuits, each relay recording only the signals from such boxes as are located on its side of the accidental ground. An open circuit renders the circuit useless; in this case, the switches *m* and *n* will be turned to the right and as soon as a troubleman repairs the break or grounds the circuit on each side of it, the relays will pull their armatures and start the bell and register, which will notify the attendant that the circuit is again in a useful condition.

71. Alternating-Current Messenger-Call Circuit. It is usually more economical to obtain current from an incandescent-lighting circuit than from batteries or through a motor-generator set in places where the telegraph company has no power plant of its own; but generally in such places the lighting circuits are supplied with alternating current only. During 1909, the Postal Telegraph-Cable Company displaced many hundred gravity cells by using the alternating-current, metallic-circuit, messenger-call system shown in Fig. 19, (*a*) for large stations and in (*b*) for small stations. All current for operating the relays, registers, and bells is taken from a 110-volt alternating-current circuit.

The 10-ohm register, 10-ohm bell, a 600-ohm coil, and the relay contacts are connected in a circuit through a double-pole switch *c* directly across the 110-volt, alternating-current circuit. The primary winding of the transformer is connected across the same circuit while the secondary winding is connected in series with the line relays, line and call boxes.

72. The relays *a* and *b*, circuit (*a*), are ordinarily connected in series, one in each side of the line, and their contacts are in multiple so that both, operating in unison, or either one alone (for instance, if the line is open somewhere) control the local register and bells. An alternating current, if not too low in frequency, will operate relays, sounders, and other non-polarized instruments. Of course, the impedance of such instruments is greater for alternating than for direct current. With careful adjustment of the relays, the results obtained are said to be equal to those secured with direct current. The transformer is wound so as to produce a voltage in the secondary one-fifth of that in the primary, or about 22 volts.

By moving the switch *d* to the left, one terminal of the transformer secondary is grounded while from the other terminal current flows through both relays and the two sides of the

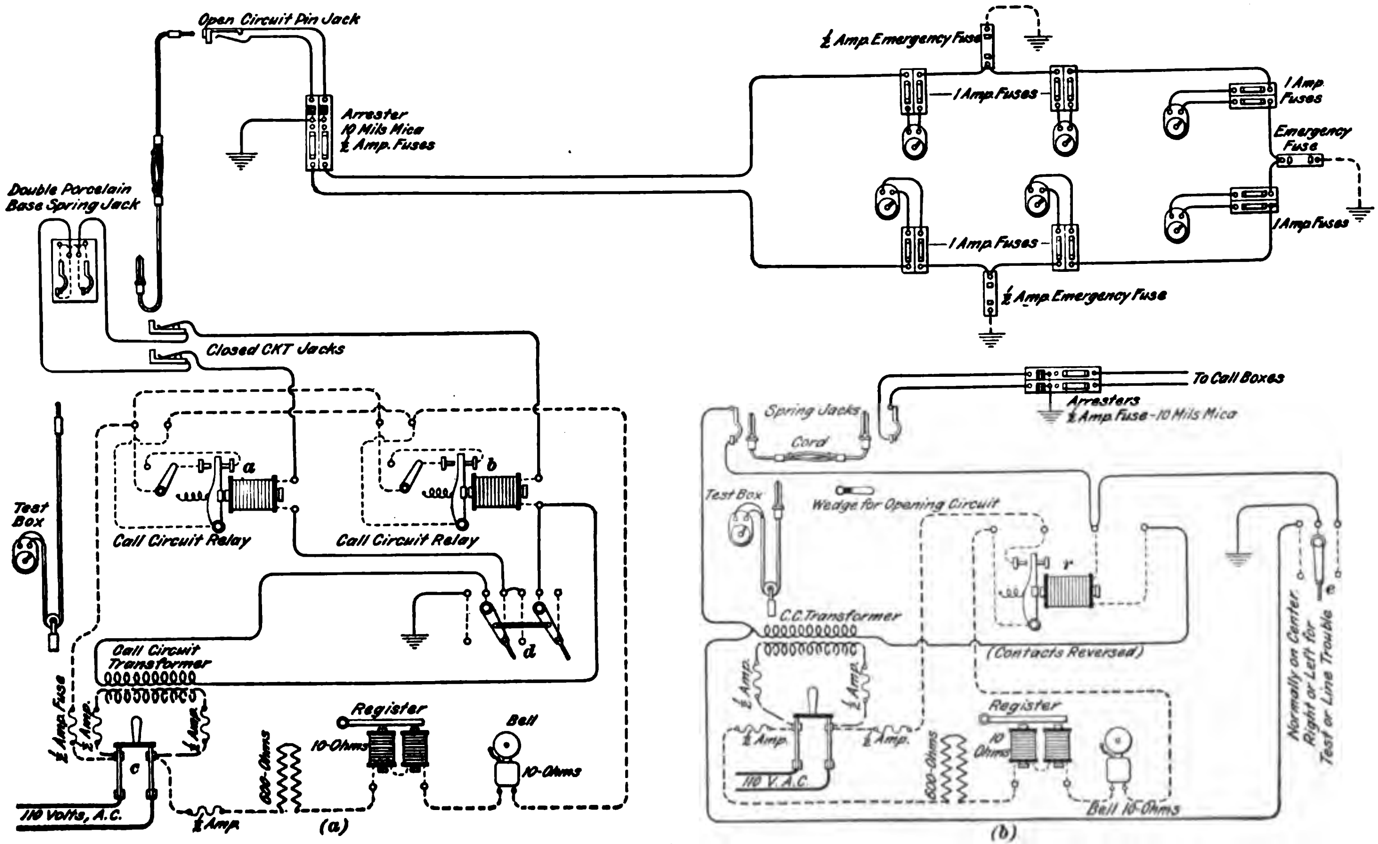

Open Circuit Pin Jack
Arrester
10 Mils Mica
½ Amp. Fuses
Double Porcelain Base Spring Jack
Closed CKT Jacks
Test Box
Call Circuit Relay
Call Circuit Relay
a
b
d
c
Call Circuit Transformer
½ Amp. Fuse
½ Amp.
½ Amp.
Register
10-Ohms
600-Ohms
Bell
10-Ohms
110 Volts, A.C.
½ Amp.
(a)
½ Amp. Emergency Fuse
1 Amp. Fuses
1 Amp. Fuses
Emergency Fuse
1 Amp. Fuses
1 Amp. Fuses
½ Amp. Emergency Fuse
To Call Boxes
Arresters
½ Amp. Fuse-10 Mils Mica
Spring Jacks
Cord
Test Box
Wedge for Opening Circuit
r
C.C. Transformer
(Contacts Reversed)
Normally on Center.
Right or Left for
Test or Line Trouble
e
½ Amp.
½ Amp.
½ Amp.
½ Amp.
110 V. A.C.
600-Ohms
Register
10 Ohms
Bell 10-Ohms
(b)

FIG. 19

line which are now in parallel, to a ground somewhere on the line. For use in case of line trouble, emergency fuse blocks are connected between the line and ground between nearly all call boxes, so that a ½-ampere enclosed fuse can be quickly inserted in one or more of these fuse blocks and all or at least many of the call boxes kept in usable condition.

73. The fuses in the call-box stations are 1 ampere, while those in the main station are ½ ampere, hence the main station fuses, which are the most accessible for replacement, will usually melt first and usually prevent the others from melting. The emergency fuses, between the line and ground are ½ ampere in capacity. The station circuit is provided with all necessary jacks, flexible cords, and test call box for the proper connection and testing of the circuit.

74. In Fig. 19 (*b*), the switch *e* normally rests in its center position, as shown; when turned to the right or left for testing or in case of line trouble, current flows from the transformer secondary through the relay *r*, in either position of the switch, and back through the line or through one side only of the line and back through some ground on the line. The abbreviation *ckt* is extensively used by telegraph operators in place of the word circuit.

TELEPHONE IN DISTRICT TELEGRAPH SYSTEM

75. The telephone is coming more and more into use every day in district telegraph, police, fire-alarm, and railroad systems. In Fig. 20 is shown an arrangement introduced by the Viaduct Manufacturing Company for the use of the telephone in the district-telegraph service. The circles in the line circuits represent subscribers' stations. The connections at one subscriber's station are shown in full at the left. Besides the usual strap switchboard, relays, registers, gongs, and batteries at the central office, there is also a spring jack in each loop circuit and a few telephones connected, as shown at the right side of the figure, to wedges or plugs *w*, and a number of plugs connected in pairs, as at *Q*. Normally, there is no wedge in the jack and the telephone receiver rests on the regular telephone hook switch.

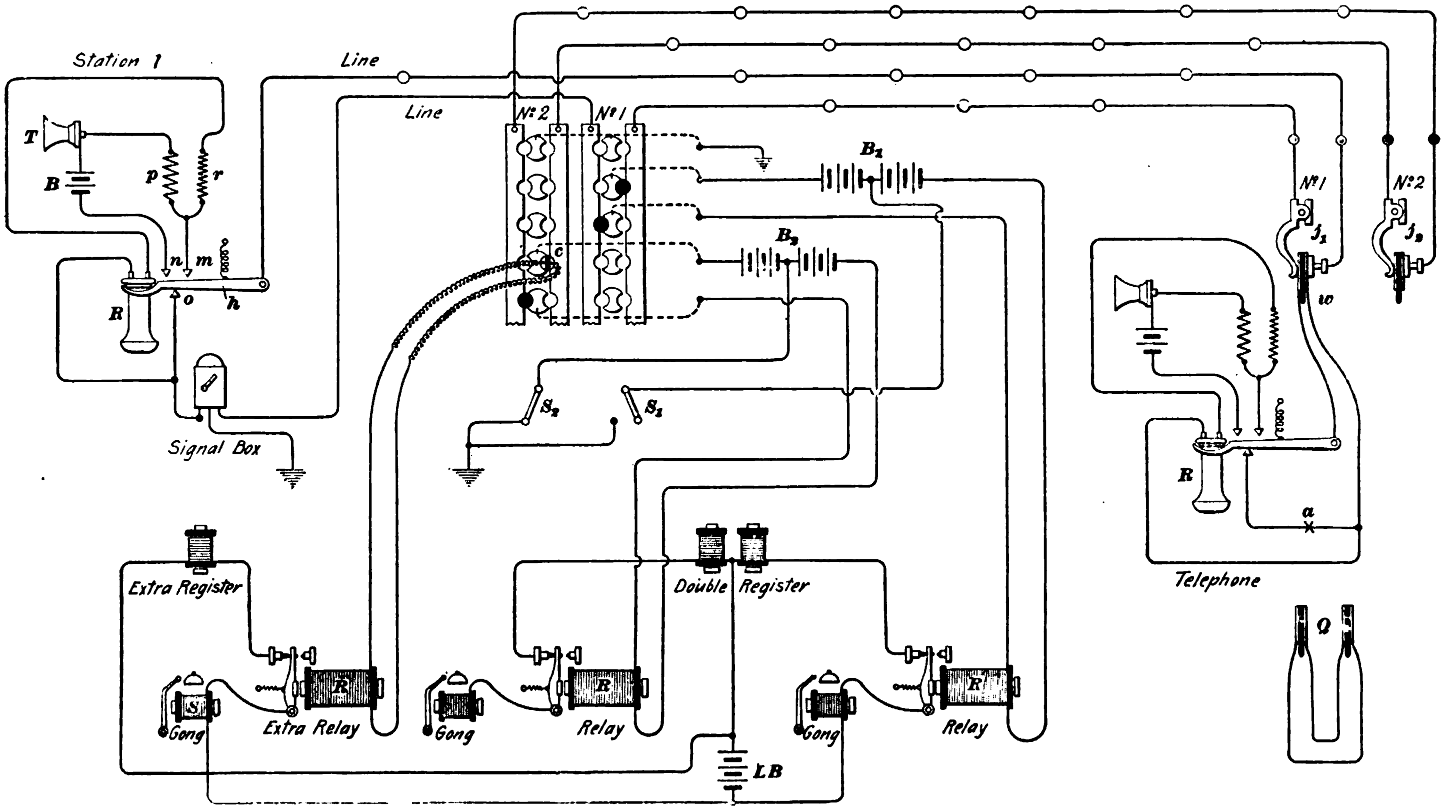

Station 1
Line
Line
T
B
p
r
n
m
h
o
R
Signal Box
No. 2
No. 1
c
B_1
B_2
S_2
S_1
No. 1
No. 2
j_1
j_2
w
R
a
Telephone
Q
Extra Register
Gong
S
R
Extra Relay
Gong
R
Relay
Double Register
Gong
R
Relay
LB

Fig. 20

When the line is in its normal position, any subscriber can call up the central office by turning the handle of an ordinary single-call signal box in the usual manner. As soon as the call is received on the register in the No. 1 circuit, for instance, the operator inserts a double wedge *w*, to which a telephone is connected, into the jack j_1. Both subscriber and operator put their receivers to their ears and can then communicate with each other. The subscriber makes his wants known and the operator attends to them. When the telephone receiver is removed from the hook, the lever *h* makes contact with *m* and *n* and parts from *o*. This closes a local circuit containing the battery *B*, the telephone transmitter *T*, and the primary winding *p* of an induction coil. It also connects the telephone receiver and the secondary winding *r* of the induction coil in series in the line circuit.

76. No method is here shown by which the central office can call up a subscriber. If this is done, it requires either an answering battery and key of some kind at *a* and a gong at the signal box or a magneto generator at *a* and a magneto, or polarized, bell at the subscriber's station. It is not absolutely necessary, or advisable in some cases, to use a hook switch in the telephone at the central office. The telephone-transmitter circuit may be closed permanently during the busy part of the day and the receiver and secondary winding of the induction coil permanently connected to the two sides of the wedge *w*. Plugs connected together as at *Q* may be used, by inserting each in a different jack, to interchange the grouping of the call-box circuits. A simple telephone switchboard could be used in place of the jacks and plug circuits shown here.

77. Signaling in Case of a Fault.—Suppose there is an open circuit, or ground, at some point on the No. 2 circuit. By turning the switch S_2 to the left and inserting a split plug, connected to an extra relay, in the switchboard at *c*, subscribers on both sides of the trouble can still signal the exchange. This will put half the battery B_2 and a relay in circuit with each portion of the circuit. A signaling box, that makes connection alternately with one line and the ground when operated, must be used at each station. B_1 and B_2 are main-line, closed-circuit batteries; all the other batteries usually consist of Leclanché cells. When this arrangement is equipped to send in fire-alarms, a so-called *slow-motion fire-alarm box* will be used. The mechanism of such a box is constructed so that the signals follow one another slowly, thus allowing the gongs to strike slowly. Fire-alarm boxes usually repeat the number of the box three to five times.

78. The American District Telegraph Company in New York City introduced on some of its circuits a compact signal and telephone instrument. The telephones worked upon a common-battery system, there being no battery for the telephone transmitter at the subscriber's station, all batteries being located at the central office. On each box were two push buttons, one on each side of the instrument, for connecting either side of the line to the ground. By pushing one or the other of these buttons in case of an open circuit on the loop, communication may still be maintained with the central office.

SUBMARINE TELEGRAPHY

INSTRUMENTS USED IN SUBMARINE TELEGRAPHY

INTRODUCTION

1. In submarine-cable telegraphy, the double-current system—a current in one direction to indicate a dot, and a current in the opposite direction to indicate a dash—is invariably used. Cablegrams are now transmitted both by hand and by automatic transmitters. The hand key *K*, Fig. 1, consists of two long spring levers, or keys, *a* and *b*, one being operated by the index finger and the other by the second finger of the right hand. One lever *b* is connected to the cable conductor or apparatus and the other *a* is connected to the ground *G*. The two levers normally press against the strip *z*, which is connected to the zinc pole of the battery; the under strip *c* is connected with the copper pole of the battery. When the lever *b* is pressed down, it leaves the strip *z* and touches the strip *c*; the circuit may then be traced from the ground *G* through lever *a* – strip *z* – negative pole of battery *B* – battery – strip *c* – lever *b* – to cable conductor or apparatus. Thus the copper, or positive, pole is connected toward the cable and the zinc or negative pole to earth; hence, a positive current flows toward the cable. When the other lever *a* is pressed down, a negative current will flow toward the cable. When both keys are pressing against the strip *z*, the line is connected directly to earth. This is a good feature, for it allows the cable to discharge wholly or partially whenever, in making a space between two succeeding signals, both keys touch the top strip at the same time. The rate of signaling is not over 20 to 30 words a minute where this key is used, because its manipulation is not so simple as that of the ordinary key used on land lines in the United States.

2. In order to avoid the danger of injuring the insulating material of a submarine cable, an electromotive force exceeding 40 or 50 volts is seldom, if ever, used. For this reason, and

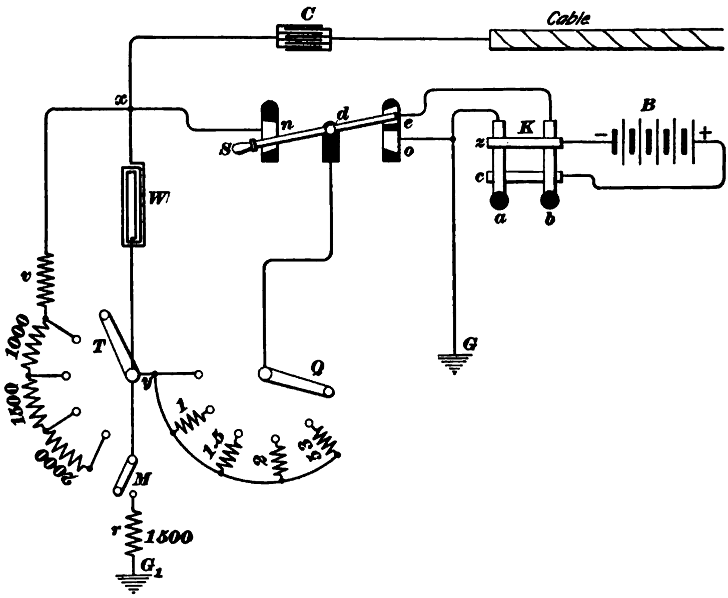
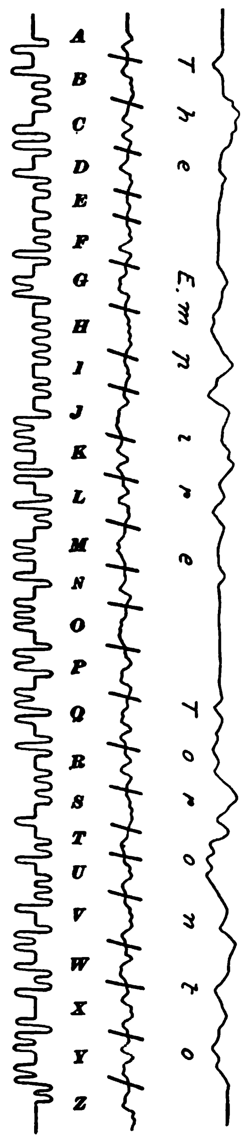


FIG. 1

also on account of the large distributed electrostatic capacity of a long submarine cable, the current at the receiving end is very small, usually too small to operate any kind of electromagnetic relay; consequently, a more delicate receiving apparatus is necessary. As it requires some time, after the closing of the key at the transmitting end, for the current at the receiving end to acquire an appreciable strength, the smaller the current that can be detected by the receiving instrument, the higher can be the speed of signaling.



(a) (b) (c)

FIG. 2

3. Cable Alphabet.—In submarine telegraphy, the letters of the alphabet, figures, and other characters are formed by prearranged combinations of positive and negative currents that cause corresponding right and left movements of the recording end of the siphon. The letter *a* consists of one positive and one negative impulse, thus producing, to one facing the tape as it comes from under the siphon of the receiving instrument, one movement of the siphon to the left and one to the right; *b* consists of one negative and three positive impulses, producing one movement of the siphon to the right and three to the left; and so on. On the paper tape these signals appear as being above or below the zero line that the siphon, when at rest, traces along the center of the tape. There is necessarily no return of the siphon to its zero line every time between impulses. In the case of impulses of opposite polarity, the siphon will usually cross the zero position or line, but in the case of several impulses of the same polarity, the curve will merely fall back a little and move a little farther away each time from the zero line.

4. The continental code is used on all submarine cables. If this alphabet is deliberately sent over a very short cable, it will be traced by a siphon recorder about as shown in Fig. 2 (*a*). If the letters are sent continuously one after another, the actual record made by the siphon recorder connected to a long submarine cable is shown in (*b*). View (*c*), which is an accurate reproduction of a portion of a message actually transmitted over a transatlantic cable with the accompanying translation, will more clearly convey the character of the recorder signals. The message is translated and written down by the operator as the tape glides along in front of him.

RECEIVERS

EARLY DEVICES

5. At first reflecting galvanometers were used for receiving devices, the signals being read by the right and left deflections of the spot of light, a movement in one direction indicating a dot and a movement in the opposite direction a dash. One man observed the deflections and told them to another, who wrote the message upon paper.

The two kinds of receivers commonly employed in 1909, were the siphon recorder and the Brown, or drum, cable relay. The siphon recorder, the principle of which was invented by Lord Kelvin in 1867, inks the message as received on a moving band of paper. The drum cable relay, by means of an electric contact-making device, brings in a fresh source of energy from a local battery, so that the electric signaling impulses are multiplied many times over in strength and are thus enabled to do many useful things besides inking the message, such as working signaling keys to retransmit the message to another line or to guide the levers of an automatic punching machine when perforating a tape with the message. The siphon recorder requires constant attention while the drum relay does not. In cable systems not duplexed, the receiving instrument is connected in the circuit at *W*, Fig. 1.

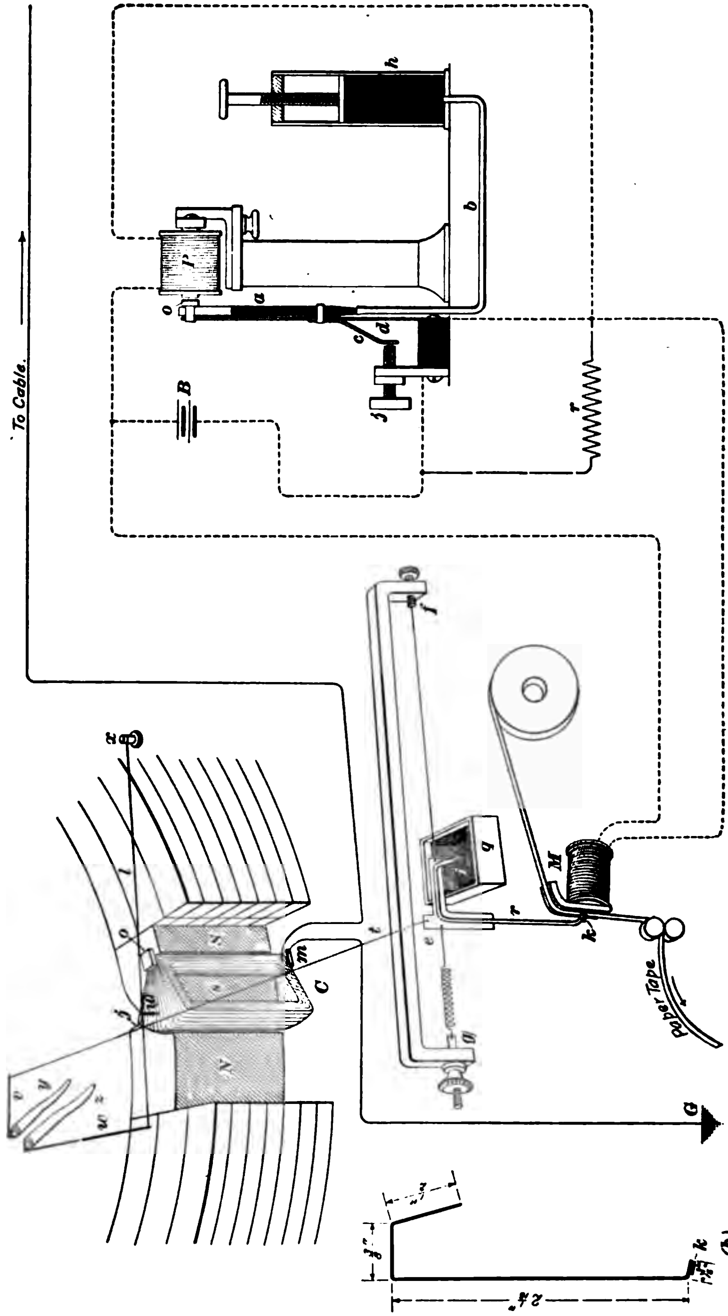
KELVIN SIPHON RECORDER

6. The **Kelvin,** or as it was formerly called the **Thomson, siphon recorder** consists of a coil of wire suspended by a fiber between the poles of a magnet. The current passes through this coil and causes it to swing in one direction or the reverse, according to the direction of the current. This coil is attached to a glass siphon by a thread, thereby moving the recording end of the siphon across a paper tape as the latter moves along uniformly under the siphon. The upper end of this siphon dips into a vessel containing ink, and the lower end spurts the ink upon the paper that is drawn past the end of the siphon. The ink is charged positively, while the plate over which the paper passes is given a negative charge. Consequently, the ink is splashed upon the paper in a very fine stream of dots and a record is thus obtained of the movements of the coil.

7. The electrostatic machine used for charging the ink was called the **mouse mill.** At times the moisture in the atmosphere was sufficient to seriously interfere with the electrostatic charging devices, for which reason recorders that do not depend on the attraction of a positive charge for a negative charge of electricity to cause the ink to flow, but on a mechanical vibration of the siphon tube, are much preferable.

CUTTRISS SIPHON RECORDER

8. The principle of the **Cuttriss siphon recorder** is shown in Fig. 3. In this recorder, a powerful, compound, permanent magnet maintains a strong field in the space between the poles N and S, which are made up of a number of separate permanent magnets. The pole piece s is curved outwardly at the end facing the pole N and the pole N is cut away, or hollowed out, to correspond, thus forming one convex and one concave cylindrical surface about $o\,m$ as an axis. A narrow space is left between these two cylindrical surfaces on N and s and there is also an opening, or slot, between S and s from the front to a point slightly beyond the central line, in order that the coil C of fine wire may be put in place. The pole piece s extends through the coil C and one vertical side of the coil is free to revolve in the strong field between N and s about the vertical side $o\,m$ as an axis.



(a)

FIG. 3

The movable galvanometer coil *C* is very delicately pivoted and supported by means of jewel bearings at *m* and *o*, and above the coil is a plate or piece of iron (not shown in the figure) so disposed that, by attracting a small iron pin fastened to the coil, it reduces the pressure and, therefore, the friction at the bearings and causes the coil to seem to float in the magnetic field.

9. Glass Siphon and Support.—The fine glass siphon, which has an outside diameter of $\frac{1}{64}$ to $\frac{1}{100}$ inch, is shown in Fig. 3 (*b*), the actual dimensions of one form being given. On the lower end of the siphon is fastened a small piece of iron *k* about $\frac{1}{8}$ inch long. This siphon *k i*, view (*a*), is fastened by wax or paraffin to a delicate holder *e* that is attached to the fine wire *g f*. By means of the screws *g* and *f*, between which the wire is stretched, not only can the right tension be given to the wire but also the right torsion for the siphon holder. To the top of the siphon holder *e* is fastened one end of a fine thread *t*, the other end being fastened to one end of a delicate spring *v*. At right angles to this thread is another thread *l* that is fastened rigidly at *x* to an adjusting screw and at the other end to a delicate spring *w*. The *tension fingers* *y* and *z*, as they are called, press with sufficient force ordinarily to hold them in place against the top of the plate upon which the device is mounted. They may be independently adjusted and made to exert whatever stress is required upon their respective threads. The thread *l* passes through a slot or fork in a projecting piece *u* that is fastened to and moves with the coil *C*; the other thread *t* is fastened to the thread *l* at the point *j* where they cross each other.

10. When the coil is deflected in the direction of the hands of a watch, it moves the thread *l*; this pulls on the thread *t*, and the spring *v* takes up the slack in the thread *t*. This causes the lower end *k* of the siphon to move toward the reader. The tendency of the torsion in the wire *g f* is to oppose the pull of the thread *t* and to move the lower end of the siphon away from the reader. When no current flows through the coil *C*, these threads, wires, and springs are in equilibrium and keep the end *k* of the siphon in its middle, or zero, position.

The higher leg of the siphon dips into a small trough *i* of specially prepared ink. Between its lower end and the pole of the electromagnet *M*, there is uniformly drawn by a suitable motor a continuous tape of white paper along the middle of which, when the siphon is at rest, is traced a fine ink line, which may be called the *zero line*. The force tending to deflect the coil helps one or the other of the two forces that were previously in equilibrium and consequently the end *k* of the siphon is moved across the paper tape; the direction in which the siphon moves depends on the direction of the current through the coil *C*.

11. Vibration of Siphon.—The siphon is made to vibrate to and from the paper, in order to avoid the friction between the end of the siphon and the paper tape, which would impede the movement of the delicately suspended coil. Thus, the siphon traces a dotted instead of an absolutely continuous line. This is necessary because otherwise the ink is liable to gather upon the end of the siphon in globular form, and either blur the record or cause it to stop recording. The ink well also is adjustable, and may be readily lowered in order that it may be removed.

12. Magnetic Vibrator.—The apparatus shown in Fig. 3 and used with the Cuttriss recorder to make the siphon vibrate may be called a **magnetic vibrator.** It consists of an arrangement of apparatus that will send pulsatory currents through the electromagnet *M*, the frequency of these pulsations being so regulated as to correspond with the natural rate of vibration of the siphon. Almost every vibrating body has a particular rate of vibration, depending on its length and various other conditions, at which it will vibrate most easily and freely. For instance, a tuning fork or reed of a certain length and having a certain pitch will vibrate readily at a certain rate, but it cannot be made to vibrate uniformly nor continuously at any other rate without the expenditure of considerable more energy.

A glass tube *a* fastened to a spring or reed *d* has its lower end connected by a rubber tube with a cylinder *h* containing mercury. By means of a piston, the mercury can be forced to any desired height in the tube *a*, and thus the natural rate of vibration of the tube and spring may be varied as required. When a new glass siphon is adjusted on the apparatus, it is

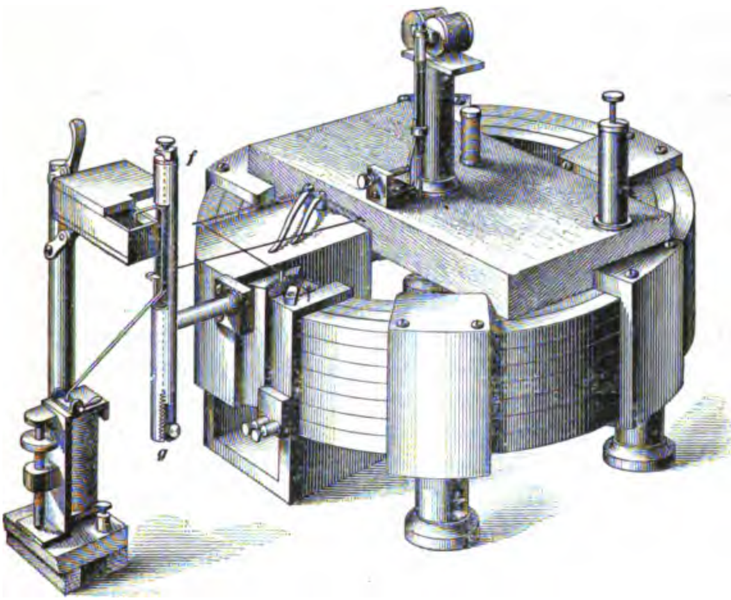


FIG. 4

frequently necessary to change the natural rate of vibration of the spring *d* and the glass tube *a* to correspond to the natural rate of vibration of the new siphon.

13. When the contact spring *c* attached to *d* bears against the screw *j*, the circuit containing the battery *B* and electromagnet *P* is closed and the magnet is energized. It then attracts the armature *o* fastened to the tube *a* and opens the circuit between *c* and *j*. The very high non-inductive resistance *r* that is connected between *c* and *j* neutralizes, or at least reduces, the sparking when the circuit is broken between *c* and *j*; but its resistance is so high that it does not allow enough current to flow through *P* to cause the latter to attract or to hold its armature *o*. Consequently, the armature is released, the circuit again closed between *c* and *j*, and the magnet *P* again energized. Thus *a* is kept vibrating uniformly and continuously, the principle being exactly the same as that used in buzzers and vibrating bells, and the circuit between *c* and *j* is thus opened and closed many times a second.

The opening and closing of the circuit containing the battery *B* and magnet *M* between *c* and *j* causes a rapidly pulsating current to flow from the battery *B* through the electromagnet *M*, causing it in turn alternately to attract and release the small piece of iron *k* fastened to the lower end of the glass siphon. Evidently the electromagnet *M* will have its circuit made and broken at the same rate as that of the electromagnet *P*.

14. Adjustments of Electromagnet.—The electromagnet *M* has an adjustable pole face constituting a table on which the paper rests as it passes beneath the recording point. As it is sometimes difficult to grind the recording end of the siphon so that its end will be exactly parallel with the face of the magnet, the pole piece of the magnet is made adjustable so that it may be turned until its face is parallel with the recording end of the siphon. The entire magnet *M* is supported so that it may be raised or lowered by means of an adjustable screw.

The general appearance of the Cuttriss recorder is shown in Fig. 4. It is practically the same as the figure already described, except that the wire *f g* that supports the siphon holder is vertical in this figure instead of horizontal, and the siphon is necessarily shaped a little different to suit this construction.

MUIRHEAD RECORDERS

15. Muirhead's hybrid siphon recorder has the usual permanent magnets but in addition is provided with a winding of insulated copper wire around the magnets, the wire ends being brought to terminal binding posts. By sending a current through this winding at intervals, the permanent magnets may be restored to their original strength.

Muirhead's gold-wire recorder has, in place of the silk fiber attached to the siphon, a fine gold wire and there are two silver contact pins arranged so that the motion of the gold wire causes it to rub against one or the other silver stop. This rubbing contact enables the recorder to be used as a cable relay as well as a siphon recorder.

BROWN CABLE RELAY

16. The **Brown, or drum, cable relay**, shown in Fig. 5, resembles the siphon recorder so far as the suspended coil and connecting fibers are concerned, but in place of the siphon tube

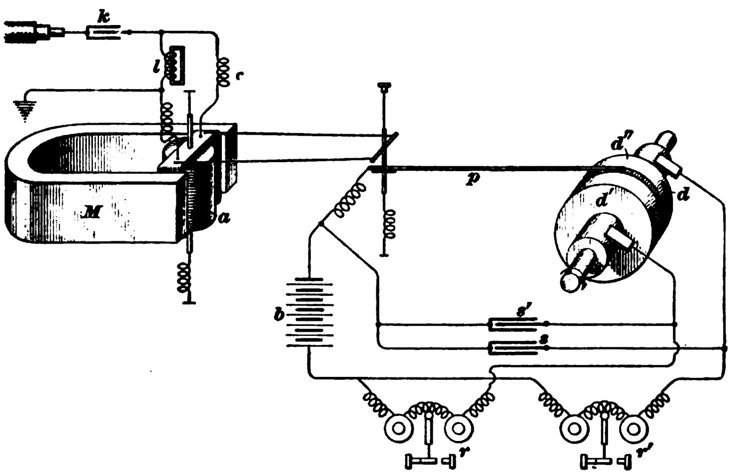


FIG. 5

a relay contact arm is provided. The end of this arm *p* is arranged to press upon the surface of a revolving drum *d*. The cylindrical surface of the drum is divided into three parts—a central insulated part, upon which the end of the contact arm normally rests when no signals are being received, and portions *d'* and *d''*, made of gold or silver, one on each side of the central insulated one. These outer metal surfaces are included in the circuit of a local battery *b* and two polar relays *r* and *r'*. When the relay arm *p* is deflected to one side or the other, upon the receipt of a signal, it slides, or skates, into contact with one or or the other of the outer portions of the drum, and thus closes the circuit of the battery through one or the other of the polarized relays. This polarized relay in turn controls a sounder or a key that retransmits the signal into a second cable.

17. To overcome the electrical resistance that is found to exist when the contact between the relay pointer and the revolving drum is first made and to allow a large current to pass promptly, condensers s and s' are connected so as to bridge the contact. These condensers are very important to the proper working of the relay, as without their aid very little current indeed could be obtained in the local circuit in time to do useful work.

The cable relay M is a very delicate instrument and mechanical effects had to be produced by means of energy four-millionths of that required to produce 1 candlepower in an ordinary 16-candlepower carbon-filament lamp. The operation of the relay is claimed to be quite automatic, reliable, and requires no operator to watch it. At k is shown the series condenser and at l the shunt inductance. By the rotation of the drum, the friction between the arm and the surface of the drum to the side movement of the arm is very greatly reduced so that the arm may be moved by the extremely feeble forces received at the end of the cable.

18. Earth currents, if allowed to flow through the suspended coil a, would produce deflections that would interfere with the proper working of the relay. The magnetic shunt l, which is always connected in parallel with the receiver coil, allows most of the earth currents to pass around the receiver coil, but sometimes the earth currents are strong enough to appreciably affect the receiver coil, and so, to make sure of it, the *unshunted*, *series*, or *Varley*, *condenser* k, as it is variously termed, is included in the system. The non-inductive resistance c, which is in series with the coil a, often has a condenser in parallel with it; this condenser is called a *shunted condenser*. The series condenser, unfortunately, charges up under a series of signaling impulses of the same polarity, and for this reason causes a wandering of the electric zero of the signals.

The effect of the wandering zero, due to the series condenser, can be cured, because the wandering, unlike that of the earth currents, depend on the signals themselves. The relay produces signals in its local circuit precisely the same as the signals that are sent through the cable to work it, and that are at the same time causing the shifting of the zero line. Current is, therefore, taken from the local circuit and passed through an electric retarding device, which is called the *local correction circuit*, consisting of a series of inductances and shunting resistances. This local circuit is adjusted until the current at the receiving end rises exactly as there is a drop in the received signaling current through the series condenser.

The correction current is passed through a separate winding on the suspended coil *a*, which is not, however, shown in the figure, and an effect is produced on the coil exactly opposite to that produced on the main winding by the variable zero itself; that is, two variable zeros of equal strength but of opposite directions are superimposed in the suspended coil, and thus neutralize each other; the variable zero of the signals themselves is thus eliminated. This local correction is a very important part of this relay adjustment and cannot very well be dispensed with. Mr. Brown states that 230 to 240 letters a minute were sent with this system each way over a cable through which the normal rate with a siphon recorder was 170 letters each way.

TRANSMITTERS

PLAIN AND CURB AUTOMATIC TRANSMITTERS

19. Sending messages by hand is open to two objections, according to S. G. Brown from whose lecture before the Royal Institution the following is abstracted: One of these is want of speed, the other, want of accurate spacing of letters. A good operator can send at the rate of about 140 letters per minute, but as most cables are capable of being worked at greater speeds, automatic, or machine, transmission has become universal.

An automatic transmitter does the work of a sending operator. For automatic transmission, the operator, by means of a hand perforator, punches the message as combinations of holes in a paper ribbon, which is then fed through the automatic transmitter. A common form of automatic transmitter has its mechanism, which is arranged to feed the perforated ribbon over the ends of a pair of blunt needles, driven by a spring or electric motor. It resembles the Wheatstone automatic telegraph transmitter in principle, at least. The needles are kept constantly moving up against and away from the moving ribbon. If a hole in the paper is fed over a needle, that particular needle will move a little way through the hole. When there is no hole in the paper ribbon opposite a needle, the latter moves up against the paper and no further movement can take place. Attached to the two needles are contact levers that connect the cable with one or the other terminal of the sending battery only when the corresponding needle passes through a hole in the ribbon.

20. The sending levers do one of two things: they join the cable to the earth or they disconnect it from the earth and connect it to a terminal of the battery. At the end of each signal the cable is automatically connected to the earth. Every time a needle passes through a hole in the ribbon, two things occur; an impulse is sent into the cable and the cable is then grounded. These two portions of the signal are adjustable relatively to one another; when the best relationship has been found it is maintained at that adjustment. The object of grounding the cable after the battery contact is to allow the cable to discharge and thus be clear for the next signal. Automatic transmitters of this character are called **plain automatics,** and are very extensively used.

21. The **curb automatic transmitter** was designed to sharpen the signaling impulse, thereby making more distinct signals, and to increase the speed. This was done by reversing the battery connection to the cable at the termination of each battery period. The reverse battery voltage helped to neutralize the charge already in the cable, and thus discharge the cable more quickly than by simply earthing it, as in the plain automatic. Unfortunately the use of the curb results in a greater voltage stress on the sending end of the cable, for the reason that the reverse voltage of the curb is added to the voltage already in the cable and ready to discharge, and the rapid reversal of current resulting from the application of the curb is liable to cause a so-called jar disturbance on the duplex balance. For these reasons curb automatics were given up about 1909.

22. The accuracy and speed of the working is greatly improved by the use of automatic transmitters, for by this mechanism is obtained the utmost uniformity of signal with a speed and tirelessness unattainable by hand. By the use of the automatic transmitters, a speed of 40 or 50 words a minute may be reached on transatlantic cables. The Cuttriss, Willmot, and Muirhead automatic transmitters are used by the various cable companies. The Cuttriss is used in the United States.

CUTTRISS AUTOMATIC TRANSMITTER

23. The principle of the **Cuttriss automatic transmitter,** whereby the positive and the negative impulses that are sent to the line or cable are controlled, may be explained by means of the diagram of connections shown in Fig. 6. *C*, *D*, *E*, *F*, and *B* show the ordinary arrangement of a cable key and the main battery. *G* and *H* are electromagnets, normally on open circuit, for operating the levers *C* and *D*. The *trailers* *o* and *p*, under which a punched paper tape is drawn, are necessarily light and delicate. In order to keep their contacts in good condition by preventing the occurrence of sparks at *m* and *n*, the circuit is broken at *h* by means of the spring bar *j* and a cam *i* before the trailers open the circuit at *m* or *n*. The sparking is thus confined to the single contact at *h*, which may be made of substantial form and easily renewed and repaired. The spark may also be reduced by the use of a high non-inductive resistance *r*, which forms a shunt around the contact points.

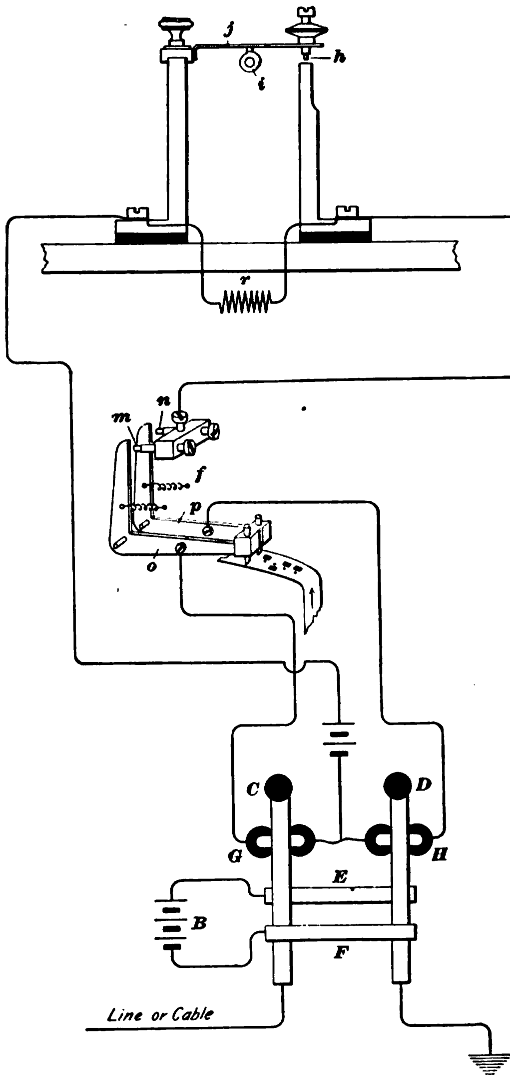


FIG. 6

24. A view of the Cuttriss transmitter is shown in Fig. 7, which is lettered the same as Fig. 6. On the shaft of an electric motor there is a worm-thread, or cam *v*, that engages with a wheel *W* that is provided with projecting pins in such a manner that every revolution of the shaft causes the wheel *W* to revolve

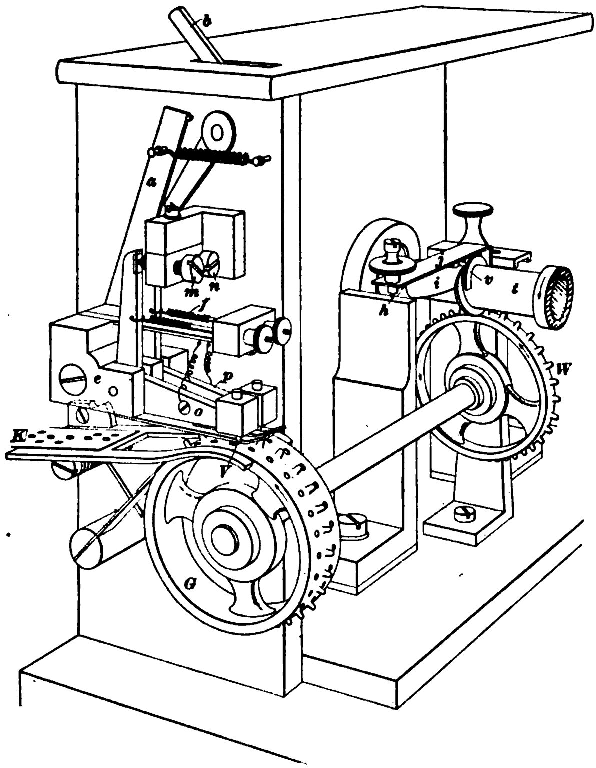


FIG. 7

through a space of one tooth. This wheel remains stationary, however, during a portion of the period of each revolution.

On the same shaft with the wheel *W*, but outside the case of the instrument, is fixed another wheel *G*; this also is provided with a like number of projecting pins but also has indentations on each side of each pin. The trailers *o* and *p* are right-angled metallic levers, pivoted side by side in an insulating block *e*, and having in their ends pins with points beveled on the under side, as shown, and lying directly over the lines of perforations in the wheel *G*.

Several springs keep the paper tape that runs over the wheel *G* pressed against the surface of the wheel, and furnish guides through which the pins on the ends of the trailers may readily move up and down, but cannot move sidewise out of line of the holes. Each trailer has a spiral spring *f*, which tends to make the pin enter the indentations on the surface of the wheel *G*.

25. The paper tape *K* is made with a central line of equidistant perforations. It is prepared for the transmitter by a suitable perforating machine that makes two lines of perforations on opposite sides of the central lines of perforations. The Wheatstone perforator may be used by merely replacing certain round punches with square punches. The side on which the perforations are made depends on the direction or polarity of the impulses that they are designed to transmit, but every perforation is exactly in line with one of the central perforations. The pins in the wheel *G* enter the perforations in the center line of the tape and so draw along the tape when the wheel rotates.

26. Action of Transmitter.—When the motor that revolves the shaft *t* continuously and uniformly is started, both wheels *W* and *G* are rotated intermittently, the period of rest being timed to occur when the pins on the lower ends of the trailers are opposite, that is, in line with the pins projecting from the surface of the wheel *G*. If there is no perforation in the paper, the pins are prevented from dropping down, but whenever a perforation comes under one of the pins, it passes through the paper and causes its lever to make contact with *m* or *n*. On the shaft *t* is fixed a sleeve *i* having a raised portion that serves as a cam to raise the bar *j*, thus causing *j* to open the circuit at *h* (see Fig. 6), while the wheel *G* and the tape are at rest, and prior to the time when either trailer, if it is in contact with its back stop, can be separated therefrom by the advance of the tape. The opening of the circuit, therefore, always precedes the separation of the trailers from their contacts.

27. The sleeve *i* is quite long in the direction of the axis of the shaft *t*. The edge of the projection on the surface of the sleeve, which raises the bar *j*, is oblique to the axis of the shaft, while the other edge of the sleeve, which allows the bar *j* to drop down again and close the circuit, is straight or parallel to the axis. By adjusting the bar *j* bodily at right angles to the axis of the shaft, the period of engagement between a lug on the under side of the bar *j* and the projection on the sleeve may be varied, according as the lug on the under side of the bar *j* passes over a narrower or wider part of the projection on the sleeve. Furthermore, the sleeve may be turned around on the shaft and fastened in any position desired.

28. As the magnets *G* and *H*, Fig. 6, are only energized when the circuit is closed at *h*, the cable is connected directly to the ground at all times, except when the circuit is closed by the bar *j*. The circuit may be closed at the contact *h* at a time that is adjustable within limits during each revolution of the motor shaft, and then opened at *h* after an interval of time during which the tape wheel and trailers are absolutely at rest. Moreover this interval of time during which the tape wheel and trailers are at rest may be varied by means of a speed governor on the electric motor that drives the transmitter, and thus the relative lengths of the impulses and of the intervening spaces, during which the cable is directly grounded, and the speed of transmission may be varied to suit the requirements of working at any time or through any cable.

The tape may be stopped without stopping the motor, by moving the handle *b* to the right, thus forcing the lever *a* to the left and raising both trailers and the springs that press the paper against the wheel away from the wheel. The forked spring, on which the paper tape *K* is resting in the figure, then lifts the tape above and free from the pins on the wheel *G*.

In connection with the electric motor, there is a speed regulator and indicator that is not shown. By means of the regulator, the speed may be adjusted as desired, and the divisions on a graduated dial will indicate the number of turns of the shaft per unit of time, and, hence, the average number of letters being sent per minute, or the rate of transmission.

29. The Muirhead automatic transmitter draws, by means a motor, a perforated slip past two small pointed rods, which engage in the dot or dash holes in the previously prepared slip. As these rods pass through the holes a circuit is closed through local sounders or relays operated by a 7-volt battery. The sounders or relays control the connections between the battery, cable, and earth. As the tongue of one side is attracted, positive current is sent to the cable; as the tongue of the other side is attracted, negative current is sent to the cable.

EARTH CURRENTS

30. The operation of submarine cables is interfered with by earth currents more than are land lines. This is due to the differences of potential at the two ends of a long cable, which cause a more or less steady flow of current, if means are not taken to prevent it. During electric or magnetic storms, temporary currents are induced in a long cable that are sometimes very troublesome, because the delicate instruments used on submarine cables are very readily affected by them. Such disturbances, however, are very uncertain both in intensity and time of occurrence. It is a well-known fact that the flow of a steady current can be prevented by the introduction of a condenser in the circuit; hence, steady earth currents are avoided in cables by the use of a condenser somewhere in the circuit between the ground and the cable. While a constant difference of potential between the two ends of the cable will charge such a condenser, there will be no steady flow of current through the cable of receiving instruments after the condenser is fully charged.

31. Elimination of Earth Currents.—The electromotive force due to the earth is fairly constant and seldom changes direction, while the direction of the electromotive force due to the transmitting battery is being constantly changed by the operation of the transmitting keys; hence, the earth potential alternately helps and opposes the battery potential. This may be obviated in two ways. A condenser may be inserted in the circuit between the cable and the ground connection, and the potential of the battery increased until the potential due to the earth is insignificant compared with it. This will evidently make the component of the signaling currents due to the earth potential negligible in comparison with the component due to the transmitting battery. In order that the charging and discharging currents may not now be too large, they can easily be reduced in volume by decreasing the capacity of the condensers (as *C* in Figs. 1 and 8). Thus one way is to diminish the capacity of the condensers and to then increase the electromotive force of the battery until the disturbing effects of the earth currents are eliminated. This is the method adopted in practice.

32. When a condenser is inserted in series with the cable, the combined capacity will be less than that of either the condenser or the cable alone, because the capacity of condensers joined in series follows a law exactly similar to that for resistances joined in parallel. Hence, to give the same charging current, a higher voltage battery will be required with condensers than without. However, the potential of the batteries must not be increased too much, for there is danger of injuring the insulation of the cables. Fifty volts is about the highest electromotive force that can be safely used. Low internal-resistance batteries, such as Fuller bichromate and storage batteries, having an electromotive force from 30 to 40 volts, are commonly used on submarine cables.

On transatlantic cables, the capacity of the condenser used for minimizing the disturbing effects of earth currents is about 50 microfarads.

33. The second way to eliminate earth currents is to determine at each end, by measurement or experimental trials, the intensity and direction of the potential between the ground and the cable conductor, due to the earth, and then to insert a battery of this potential in the ground wire so as to oppose it. An objection to this method is the fact that the battery potential will be constant, while the earth potential will vary more or less.

SUBMARINE TELEGRAPH SYSTEMS

SIMPLEX CABLE SYSTEM

SIMPLEX CABLE CONNECTIONS

34. Submarine cables are worked both simplex and duplex. When sending on a simplex cable system, the cable is connected through a condenser, switches, ordinary cable key, and the battery to the ground. When receiving, the cable key and battery are switched out and the siphon recorder connected in their place. A condenser is connected in series with the receiving instrument because this arrangement increases the sharpness of the signals.

35. Position of Switches for Transmitting.—When cables are worked simplex, they are often connected as shown in Fig. 1. Ordinarily, when transmitting, the switches will be placed in the positions shown. In this position of the switches, the transmitting key K, battery B, and condenser C are connected directly in series between the cable and ground G; all the current is then utilized to charge the condenser and cable. The condenser C is used to eliminate earth currents and to increase the speed of signaling.

36. To Record Signals Sent From Home Office.—If it is desirable to record the signals being sent from the home office to see whether they are being properly transmitted or to preserve a record for future reference, the switches Q, T, and M are closed. The resistance r is usually as high as the resistance of the cable itself. When the two switches Q and M only are closed, there are two paths for the current that comes from the battery B; one is by way of $d - Q - y - M$ to the ground G_1; the other by way of $d - n - x - C$ and cable, to the ground at the distant station. Hence, if x

and y have any difference of potential, some current will flow through W. This current may be increased by turning Q so as to increase the resistance between d and y, because this increases the difference of potential between x and y; or, it may be looked at in this way: The greater the resistance from d through Q to y, the greater will be the portion of the current flowing from d through $n - x - W - y$, and the smaller will be the portion flowing through the parallel path $d - Q - y$. The current through W may be decreased by closing the switch T. The more T is turned so as to increase the resistance from x to y, through $x - v - T$, which forms a shunt circuit around the coil W, the larger will be the portion of the current through W, and the smaller the portion through $x - v - T - y$. By adjusting the switches Q and T, the proper current may be obtained through W.

37. Position of Switches for Receiving.—To receive, the switch S is raised, causing the rear end of the lever to touch the segment o before the front of the lever leaves the segment n. This is very necessary because it allows the cable to discharge to earth through $n - d - o - G$, instead of through the coil W, as it would do if the switch lever left n before touching o. When the handle of the lever is up as high as it will go, contact between d and n is broken. The current from the cable then divides at x, part passing through W and the rest through v and T to y, where the currents reunite and pass through $Q - d - o$ to the ground G. When receiving, it is evidently immaterial whether M is closed or open.

DUPLEX CABLE SYSTEMS

RESISTANCE-BRIDGE DUPLEX SYSTEM

38. When submarine cables are duplexed, the bridge method is generally used; one arrangement is shown in Fig. 8. Adjustable resistances M, N, and S form two arms of the bridge and the cable and the artificial cable form the other two arms. The artificial cable corresponds to the artificial line in the bridge duplex telegraph system.

There are usually from 1,000 to 3,000 ohms in each of the boxes M and N, while S contains about forty $\frac{1}{4}$-ohm coils;

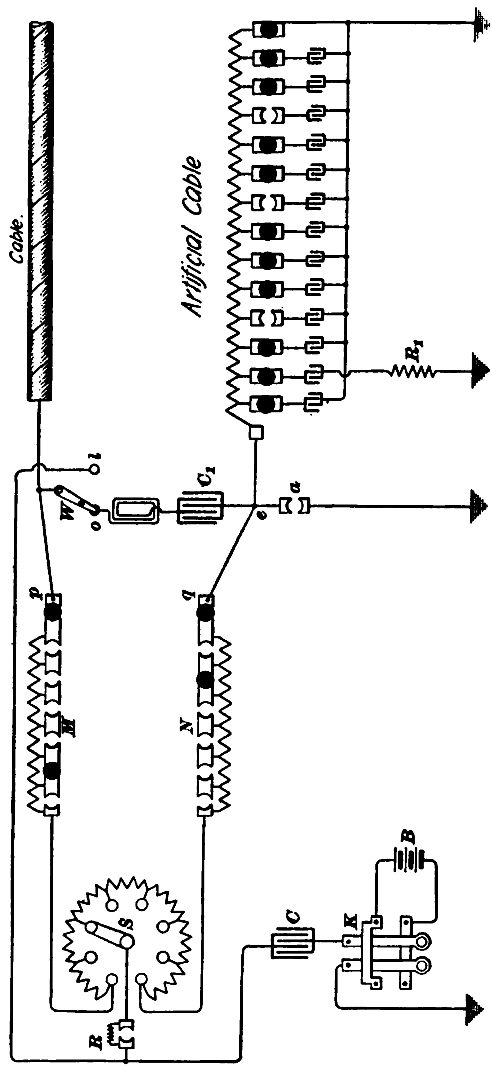


Fig. 8

C and C_1 are condensers of about 50 microfarads each. The condenser C is used to diminish the trouble due to earth currents and the other condenser C_1 is used to make the signals sharper. A 10-ohm resistance coil R may or may not be connected in the transmitting circuit.

When one of the levers of the key K is depressed, one pole of the battery is connected to the condenser C, causing the latter to be charged. This will send charging currents that divide in such a manner through the arms of the bridge that there is no difference of potential between the points e and W; hence, the receiving instrument connected between the condenser, C_1 and the point o is not affected by the operation of the home key K.

39. In cable duplex systems of this type, the relation between the various arms of the bridge when the set is balanced is expressed by the proportion; resistance of arm M is to resistance of arm N as the square root of the resistance of cable per microfarad is to the square root of the resistance of artificial cable per microfarad. The resistance per microfarad means the total resistance, in ohms, divided by the total capacity, in microfarads, of the part mentioned.

EXAMPLE.—A submarine cable has a capacity of 920 microfarads and a resistance of 5,000 ohms. It is duplexed by the method just described, there being 2,500 ohms in the bridge arm joined to the cable and 2,400 ohms in the bridge arm joined to the artificial cable. If the resistance of the artificial cable is 4,800 ohms, what should be its total capacity?

SOLUTION.—The resistance 2,500 : the resistance $2{,}400 = \sqrt{\frac{5000}{920}} : \sqrt{x}$.

Then
$$\sqrt{x} = \frac{2{,}400 \times \sqrt{\frac{5000}{920}}}{2{,}500}$$

or
$$x = \frac{2{,}400^2 \times \frac{5000}{920}}{2{,}500^2} = \frac{24^2 \times 500}{25^2 \times 92} = 5.008, \text{ or } 5$$

Then $5 = \frac{4{,}800}{y}$ or $y = 4{,}800 \div 5 = 960$ microfarads. Ans.

40. The **Stearns artificial cable,** as the arrangement of the artificial cable shown in Fig. 8 is called, consists of a large number of condensers and resistance coils put up in boxes. The coils and condensers are joined to terminals on the outside of the boxes, so that they may be connected together and to the ground in the way that will best resemble the real cable both in resistance and capacity. By connecting a condenser to the ground through a high resistance R_1, the discharge from that portion of the cable is retarded. Hence, the charge and discharge of the artificial cable may be accelerated or retarded to correspond to that of the real cable by connecting proper resistances between the ground and condensers at proper points in the artificial cable. Connecting resistances between the ground and condensers in the home end of the artificial cable will delay the discharge of the home end, and connecting resistances between the ground and condensers in other parts of the artificial cable will delay the discharge from those parts of the artificial cable. The more condensers that are connected to the artificial cable, the longer will it take to charge and discharge.

41. Changing From Duplex to Simplex.—When it is desired, as is often the case, to work the cable simplex, a plug is inserted at *a*, and the plugs at *p* and *q* are removed. When receiving, the switch *W* remains on contact button *o*, but when transmitting, it is shifted to the contact button *l*.

MUIRHEAD CABLE DUPLEX

42. In the **Muirhead cable duplex,** shown in Fig. 9, the condensers C and C_1 are used in place of the resistances M and N shown in Fig. 8. A condenser C_2 is also connected in the bridge circuit *e f*. For the present suppose C_3 and R to be entirely disconnected. The condensers C and C_1 act in the same way as the resistances in a Wheatstone bridge. When connection is made at K with one pole or the other of the battery B, the condensers C and C_1, the cable, and the artificial cable are charged. A charge is given to the condenser at the distant station corresponding to C_2. But if the charge of C is to the charge of C_1 as the charge of the cable is to the charge of the artificial cable, there will be no charge given to C_2, because there is no difference of potential between the two points *e* and *f* to which the receiving circuit, containing W and C_2, is connected, and consequently the receiving instrument W

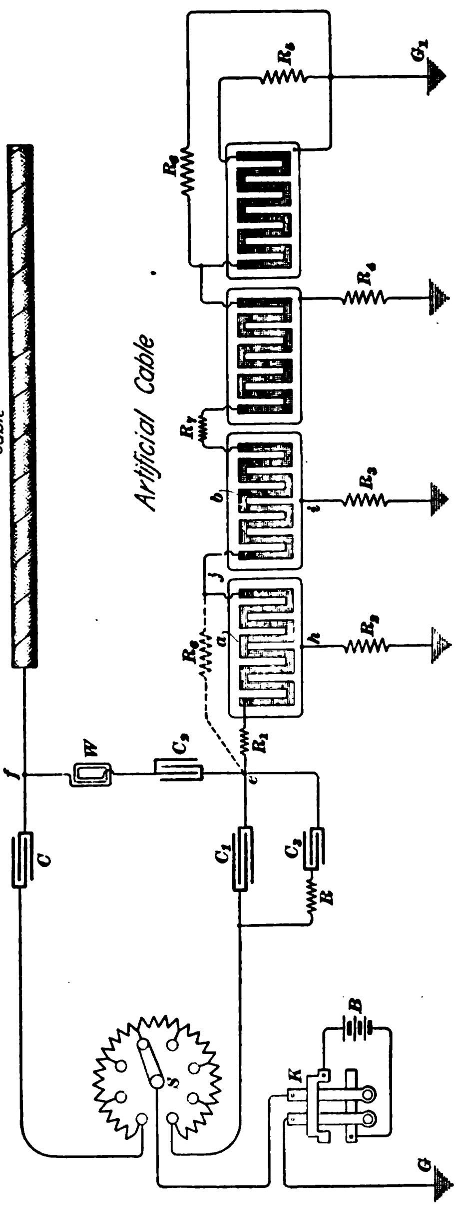


FIG. 9

is not affected. The condensers and cable may evidently be charged in either direction by means of the key *K*.

43. Muirhead Double-Block System.—As it is practically impossible to construct or build a number of large condensers, even out of exactly the same material, so that the rates of absorption of each will be the same, a supplementary condenser C_3, Fig. 9, and an adjustable resistance *R* are often connected, as shown, in parallel with the condenser C_1. The resistance *R* is usually non-inductive, but there may also be included an inductive resistance so arranged that, by sliding a V-shaped iron bar in and out of the coil, its inductance may be varied. The condenser C_3, which is adjustable by steps of .01 microfarad, has usually a maximum capacity of 5 microfarads. The resistance *R* usually contains from 1,000 to 100,000 ohms; *S* is an adjustable rheostat of low resistance, containing about forty ¼-ohm coils and sometimes one or two 10-ohm coils. The receiving instrument at *W* is usually a siphon recorder. The arrangement of the artificial cable, condensers, and resistances shown in this figure is known as the **Muirhead double-block system.** Mr. Muirhead gave the following values as those required for balancing one of the Mackey-Bennett cables: *C* and C_1 120 microfarads, C_3 .15 microfarad, and R_3 100,000 ohms.

44. In the Muirhead cable duplex, the relation between the various arms of the bridge when the set is balanced is expressed by the proportion: capacity of arm *C* is to capacity of arm C_1 as the square root of the resistance of the artificial cable per microfarad is to the square root of the resistance of the cable per microfarad. It will be noticed that the condenser arms do not follow the same proportion as the resistance arms of a Wheatstone bridge; this is due to the fact that the impedance of a condenser increases as its capacity decreases.

45. The **Muirhead artificial cable,** shown in Fig. 9, consists of a very large number of sections, only four of which are shown. Each section consists of a thin sheet of insulating material, such as paraffined paper, on one side of which is placed a plain rectangular sheet of tin-foil, and on the other side a piece of tin-foil *a* of about the same outside dimensions, but cut as shown, so as to form a long zigzag conductor. These are piled up, but are separated from one another by more sheets of paraffined paper. The rectangular tin-foil sheets in one pile are connected together, and the zigzag sheets are connected in series, so as to form one long conductor. By means of the terminals on the outside of the box to which the two ends of the zigzag conducting strips in each pile are connected, the zigzag strips in each pile as a whole may be joined to any other pile in any manner required. The strips are generally joined directly in series, but sometimes a resistance, as shown at R_7, is included. Enough of these zigzag strips of tin-foil are used to give a resistance equal to that of the real cable. The tin-foil being extremely thin and cut into quite narrow strips ($\frac{2}{5}$ to $\frac{3}{8}$ inch in width), has quite an appreciable resistance, and it is evident that sufficient resistance can be obtained by using enough sections. The sheets of tin-foil and insulating material can be pressed and packed very closely together; nevertheless, so many are required that the boxes containing them often measure several feet in each direction.

46. Terminals are also brought to the outside of the box from the rectangular sheets of tin-foil that are on the opposite sides of the insulation to the zigzag sheets. Some of these are joined together and to the ground, and some are connected through resistances, as at R_2, R_3, R_4, to the ground. As R_1 represents the resistance of the land line from the cable station to the cable itself, it does not usually amount to very much. At the end of the cable, the zigzag sheets are connected through the resistance R_5 to the ground G_1. In order to represent the small amount of leakage that there may be in the real cable, a high resistance R_8 may be connected between one of the zigzag sheets and the ground. In some cases, a resistance R_6 is connected between the point *e* and some point *j* in the artificial cable. This resistance, which is generally 80,000 ohms, or more, represents the leakage paths from the land lines and the first part of the cable. Thus the artificial cable may be made to resemble the real cable by having the same resistance, due to the zigzag sheets joined in series; the same capacity, due to the proximity of the zigzag sheets to the grounded rectangular sheets of tin-foil; and the same amount of leakage, due to the high resistances that are connected between the zigzag sheets of tin-foil and the ground.

It is especially necessary to make the home ends of the real and artificial cable resemble each other very closely; and for this reason the home end of the artificial cable is subdivided into smaller sections than the remaining portion in order to permit a closer adjustment of these resistances and capacities.

47. The resistances in an artificial cable may have about the following values: R_2, 175 ohms; R_3, 1,400 ohms; R_1, 40 ohms; R_5, 175 ohms; R_8 and R_6, 90,000 or more ohms, or is infinite, that is, disconnected. In some cases a resistance of about 500 ohms is placed in each arm between the condenser C and the point f, and between C_1 and e.

On one of the cables of the United States Cable Company, the following are the capacities and resistances used at one time at Nova Scotia: C, 41 microfarads; C_1, 40 microfarads; C_2, 41 microfarads; C_3, .28 microfarad; R_1, 29 ohms; R_5, 860 ohms; R_6, 90,000 ohms; R, R_2, R_3, R_4, and R_7, 0 ohms; R_8, infinite, that is, disconnected.

The condensers C and C_1 are 50 microfarads each, and C_2, 30 microfarads in the duplex arrangement used in connection with the Coney Island cable of the Commercial Cable Company between New York and Nova Scotia. This cable has a total resistance of 13,700 ohms, a capacity of 231.4 microfarads at 75° F., and a length of 880.6 nautical miles. The condensers C and C_1 upon the same company's No. 3 Atlantic cable between Nova Scotia and Waterville, Ireland, are each 80 microfarads capacity. This cable has a total resistance of 4,895 ohms, a capacity of 914 microfarads at 75° F., and a length of 2,164 nautical miles.

48. Balancing Cable.—In effecting a balance of such a system as shown in Fig. 9, the artificial cable is first of all made equal in resistance, capacity, and leakage to the real cable; the condensers C, C_1, and C_3 are then inserted and their capacities and the resistance of S adjusted to give a close balance. Then a slight increase is made in the capacity of C_3—say by 1 microfarad—and by trials the right amount of resistance required in the various rheostats is ascertained. If the artificial cables discharge too rapidly, more resistance must be inserted between the ground and the condenser plates. Too sharp a signal will indicate that the near end of the artificial cable is not properly adjusted; a faint signal, that the far end is not properly adjusted. When the home receiving instrument is not affected by the operation of the home key, the adjustment is correct. The artificial cable seldom needs adjustment more than twice a year and the bridge arrangement by means of the resistance S and condenser C_3, seldom oftener than once a day.

49. The receiving end of a cable terminating at Newfoundland is arranged in about the following manner: The capacity of the cable is 785 microfarads and its resistance 5,354 ohms. The capacity and resistance of the artificial cable is approximately the same as that of the cable. In Fig. 9, the block condensers C and C_1 and the receiving condenser C_2 have each a capacity of 80 microfarads, there being no condenser C_3 or resistance R. The receiving condenser C_2 is shunted by a resistance of 800 ohms. Connected between points f and e is another circuit in parallel with the receiver circuit; this parallel circuit contains a large coil having a resistance of 33 ohms and an inductance of 30 henrys in series with a non-inductive resistance of 100 ohms. The receiving instrument W has a resistance of 420 ohms. As a result of this arrangement, the first result of a sudden increase in potential across the points f e is to produce quickly a rapidly-rising current through the receiving instrument and condenser. The condenser capacity and the choking influence of the large inductance in the circuit parallel to the receiver assist each other in this matter. The discharge from the large inductance through the resistance in parallel with the condenser tends to maintain a current through the receiver after the potential across f e starts to decrease. Thus, a signal is started sharply and maintained long enough to do its work.

BROWN MAGNETIC BRIDGE DUPLEX

50. The Brown magnetic (or inductance) bridge has been in use on long ocean cables since about 1900 in all parts of the world because it materially increases the speed of operating submarine cables. The Western Union bridge quadruplex is its first application to aerial-line telegraphy, though it had previously been used with underground cables in England and Germany.

The principal features of the Brown magnetic bridge and receiving instruments are shown at the left-hand end of Fig. 10. Suppose that there is an outgoing signaling current, as indicated by the arrow *a*. The two 15-ohm coils are wound on one complete magnetic circuit, instead of two separate straight cores,

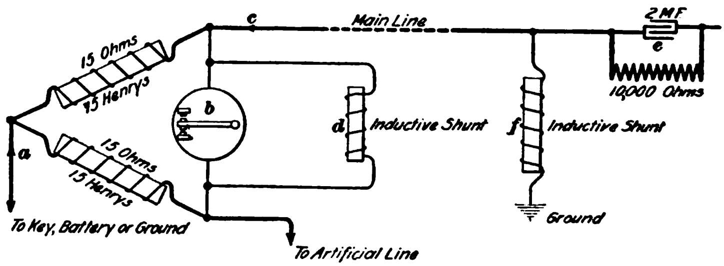


FIG. 10

as here shown simply for clearness. The bridge being exactly balanced, both in resistance and inductance, there will be no inductive reactance to the outgoing current in the arms of the bridge because equal currents circulate around the same core in opposite directions. The resistance in each arm is 15 ohms instead of 1,000 to 3,000 ohms as in the bridge duplex shown in Fig. 8. Even in the Stearns differential relay duplex used on land lines there is a resistance of not less than 100 ohms in this part of the circuit.

Any resistance at all at the entrance to the line impedes the speed and clearness of signaling. The more easily the current can pass into the line, the sooner and more distinctly does it reach the other end. The only limit to the speed of charging the line is the necessity for inserting sufficient resistance to safeguard the sending contacts from destructive sparking, especially on underground and submarine cables.

51. The first part of an incoming signal current *c* cannot pass the inductance of 15 henrys in the upper arm of the bridge, because the inductance greatly impedes this rapidly increasing current. This first, or rapidly increasing, part of the current is therefore diverted through the receiving relay *b*. It is the first part of the arriving current that has the most work to do in starting the moving part of the receiving device, which will be hereafter termed the relay and should therefore be the stronger part. As the rate of increase of the arriving current diminishes, the inductance impedes the current less and allows a larger proportion of it to flow through the upper arm of the bridge to earth. The inductance coil *d* shunting the receiving instrument *b* has exactly the same relative effect upon the current coming from the cable into the receiving-instrument circuit. After once being started, the small current that is left to flow through the receiving instrument can readily hold it closed; thus the receiving instrument is not choked or clogged with more current than it requires.

The signals that pass through the receiving instrument are sometimes termed *tadpole signals* bceause they have a large head and a small body. As the rate of change of the current diminishes, the receiving instrument is not only nearly short-circuited by the 15-ohm coil, but the tendency of the inductances to keep the current through them from diminishing in strength causes them practically to suck up the remainder of the signaling current from the line, thereby leaving the cable more or less clear for the next signal. Duplex working is said to be less troublesome with the magnetic coils than with condensers in the bridge arms.

52. The Brown magnetic bridge has very much the same effect on the receiving instrument as the older shunted condenser *e* without the trouble it produces in duplex working. A very advantageous feature of the magnetic bridge is its low resistance combined with its high inductance. The magnetic bridge must be used at both ends of a line or not at all and it is necessary, in order to secure the best results, to adjust the resistance and inductance to suit the particular line to which it is applied.

53. Brown Bridge and Shunt Inductances.—For ocean cables, the Brown magnetic bridge is a very large device, weighing about 300 pounds and is built like a transformer with a practically closed magnetic circuit of transformer sheet iron. The inductance in each arm of the bridge is adjustable to a fine degree, as well as the resistance, so that a very close magnetic and resistance balance can be obtained.

The Brown shunt *d*, Fig. 10, for ocean cables is also a very large device, weighing from 200 to 300 pounds and built up like a transformer with a closed magnetic circuit of sheet iron, having a resistance of a few ohms and an inductance up to 20 or 40 henrys. It may also be used as a leak from the cable to earth, as shown at *f*, around the receiving instrument for simplex working. The condenser *e* and its shunt and the inductance coil *f* are not used, except in the manner explained, in the Brown magnetic bridge duplex system.

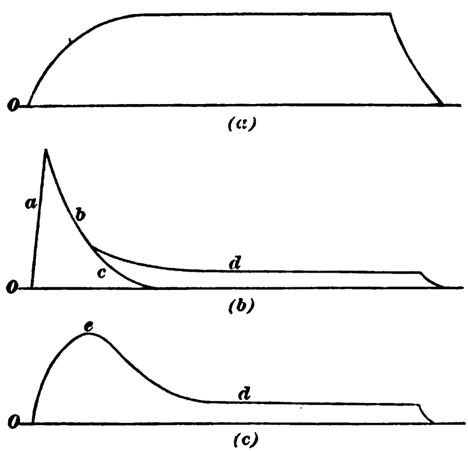


FIG. 11

54. Received Currents.—The current curves shown in Fig. 11 indicate clearly the effect of the bridge, shunt, and a shunted condenser and are the results of observations made with an oscillograph, which is an instrument for determining the shape of varying current curves.

Curve (*a*) shows an ordinary Morse dash as it passes through a relay at the receiving end of a comparatively short line. The curve *a b c* in (*b*) shows the same signal passing through a condenser; it rises almost instantly to full strength, then decreases a little less rapidly to zero, producing practically a short dot only on a receiving relay. The high resistance shunt around the condenser at *e*, Fig. 10, allows a little current to leak around the condenser, giving the curve *a*, *b*, *d* in Fig. 11 (*b*). The peak *a b* throws over the relay tongue and *d* holds it over. This is an ideal current for working a relay, provided there is sufficient current at *d* to neutralize inductive interference from other lines.

The curve (*c*) shows the shape of a dash signal after it has passed through the shunted condenser and the receiving relay. The inductance of the relay rounds the sharp condenser peak, as shown at *e*. With a magnetic bridge and shunt, the signal in the line remains more or less like curve (*a*), and it is through the relay only that the signal takes the form of curve (*c*). Inductive interference from other lines produces less disturbance with the magnetic bridge and magnetic shunt than with the shunted condenser.

If the sending speed is 200 letters a minute and the average number of elements, or impulses, per letter is 3.7, then there are 740 alternations, or 370 cycles per minute, or 6.2 cycles per second.

GOTT'S SIGNALING METHOD

55. A method for signaling through submarine cables so that an ordinary telegraph key may be used for sending, and a relay or sounder for receiving a message has been devised by John Gott, engineer for the Commercial Cable Company in England. The purpose of the invention is to apply the International Morse code to the transmission of messages through submarine cables, in place of the older methods, whereby uniformity of working with land lines and other connections may be established. In Gott's invention every dot or dash is formed by a reverse current so that in no case during transmission do current impulses of the same polarity follow one another. At the receiving end of the cable, these reverse currents are transformed so that the alphabet is produced in Morse characters in the same manner as though received through a short land line.

56. Diagram of Connections.—By making a diagram of the connection, as applied to a duplex cable, in the way that will now be described, good practice may be secured in sketching circuits and the diagram better understood. In a duplex-cable system, such as shown in Fig. 9, the point *S* is called the apex of the bridge. In one of Gott's arrangements the apex is connected to the lever of a specially connected but otherwise an ordinary land-line telegraph key. The lower front contact is joined to the lever of a polarized relay, the two contacts of which are connected to opposite terminals of the signaling battery and a binding post at the middle of this battery is grounded; these relay connections will then be about as shown for the pole changer *P C*, Fig. 12. The lower back contact of the key, which is insulated and not connected to the key frame, as on land-line keys, is joined to the coils of the polarized relay; the other end of the coils is grounded.

57. Operation of Gott's Arrangement.—When the telegraph key is open, the battery circuit is open at the lower front contact of the key and the apex is connected through the lever, the back contact of the telegraph key and the relay coils to the ground. Suppose that the polarized relay lever rests against the stop connected to the negative terminal of the battery and that the key is then closed. A momentary current will flow from the ground through half of the signaling battery - relay contact - relay lever - front contact of key - key lever - apex of bridge duplex to the line and artificial line, thereby charging the home side of the condensers in the arms of the bridge negatively. At the receiving end this charging current will move the siphon of a recorder, or the lever of a sensitive polar relay in a certain direction, say to the left.

When the telegraph key is opened at the end of a dot or dash, a negative charge from the condensers will pass through the key lever - back contact of key - relay coils to the ground, causing the relay lever to move over against the stop connected to the positive terminal of the battery. At the receiving end, the siphon of the recorder, or the lever of the sensitive polar relay will move to a center position. When the key is again closed at the end of a space, in order to start another dot or dash, the current will flow from the ground through the other half of the battery – other stop of polar relay – lever of polar relay – front lower contact of key – key lever to the apex of the bridge, thereby charging the condensers positively instead of negatively, as when the last dot or dash was started. When the key is again released to terminate this dot or dash and to start a space, the lever touches the back contact and a positive charge from the condensers passes through the relay coils, causing the relay lever to be moved to the opposite stop so that when the key is again closed the condensers are charged negatively. Thus each time the telegraph key is depressed to start a dot or a dash, the cable condensers receive a charge exactly opposite in character to the charge that was received when the preceding dot or dash was started. Thus, each dot or dash is made by a current of opposite polarity to the preceding dot or dash and the spaces are due to the discharge of the condenser between dot or dash signals. Each space is also made by a discharge of opposite polarity. Thus, currents of opposite polarity always follow one another.

58. Receiving End of Gott's Arrangement.—At the receiving end, the siphon recorder, or a sensitive polar relay, is connected in the usual manner across the bridge arms. The siphon of a recorder tends to return to a central position when the current ceases to flow through the recorder coil. Similarly the lever of a sensitive polar relay may be arranged, by the use of very fine springs, to return to an intermediate position between two contacts when current ceases to pass through the relay coils. The siphon is arranged to pull a lever from one contact to another as it moves to the right or left according to the polarity of the arriving impulse. This lever, or the lever of the polar relay, is connected through a sounder to a battery, the other terminal of which is connected to contact stops on each side of the lever or to both the front and the back stops of the polar relay. The Brown cable relay can be used nicely for this purpose.

59. An impulse starting a dot or dash moves the lever against a battery stop, causing the sounder to move downwards and make a click. Before this impulse ceases, the distant key is released and the dot or dash is terminated at the sending end, while at the receiving end the bridge terminals, across which the recorder or relay winding is connected, tend to return to the condition of no potential difference. The siphon or relay lever tends to return to the neutral position in which the sounder-battery circuit is open, thereby not interfering with, even if not assisting in, the production of a space in the usual manner by the ceasing of current through the sounder. The next reversed charge at the starting of the next dot or dash by the sender reverses the current impulse through the recorder or relay coils, causing the lever to be moved against the opposite stop whose polarity is the same, however, as that of the other stop, and the sounder is again energized and its armature moved downwards for making the next dot or dash. It should be remembered that cables do not charge and discharge instantly, on account of which it is not difficult to send by an automatic machine or even by hand, through most cables faster than the cable can completely charge or discharge.

The lever of a relay having its coils connected in a land line may be used in place of the telegraph key for repeating signals from the land line through a cable. Furthermore, the rocking lever of a Wheatstone transmitter may take the place of the key lever, the two upper contacts only of the Wheatstone transmitter being used.

60. Modification of Gott System.—A modification of the Gott system makes use of an induction coil or transformer at the transmitter. Instead of being directly grounded, the middle point of the signaling battery is connected through the primary winding of a transformer to the ground, the secondary winding and relay coils are connected in series, and the back contact of the telegraph key is directly grounded. This modified system possesses the same essential features as the original but the currents through the relay coils are induced in the transformer by the charge and discharge impulses; while in the former system they passed directly from the cable through the relay coils. Each change in direction of the current between the ground and the cable apex causes a change in direction of the current through the transformer windings and relay coils.

DUPLEX FOR A MIXED OVERHEAD AND CABLE LINE

61. The arrangement shown in Fig. 12 is that used in some countries for automatic duplex systems over a circuit consisting of both land lines and underground, or short submarine, cable. *PC* represents a transmitting key or device, often the Wheatstone automatic transmitter; *PR*, a differentially wound receiving device, often the polar relay of the

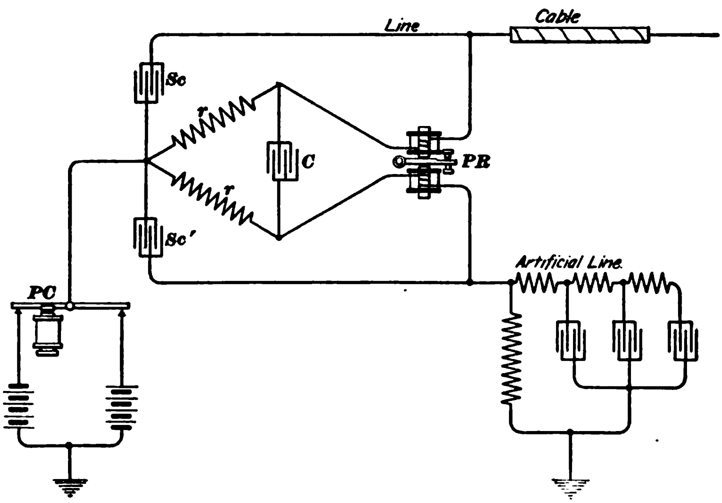


FIG. 12

Wheatstone automatic recorder; *Sc* and *Sc'*, so-called signaling condensers; and *C*, another condenser connected across the polar relay and the ends of the adjustable resistances *r*. This is really a differential polar duplex. When the transmitter opens the circuit, the discharge from the condenser *C* tends to neutralize the extra current due to the inductance of the relay coils. The condensers *Sc* and *Sc'* shunt the discharging current from the cable and artificial line past the coils of the relay *PR*. Preece and Sivewright state that these signaling condensers have a disadvantageous effect upon the received signals, but that this may be compensated by using a condenser of larger capacity at *C*. They further state that the attainable speed on two circuits was doubled by adding the signaling condenser compensation illustrated in this figure. The speed on one circuit was increased from an average of 60 to 120 words per minute by using the connections shown with the Wheatstone automatic transmitters and receivers.

TRANSMISSION THROUGH CABLES

62. A cable seems to impede the high-frequency signals more than the low. By connecting a condenser in series with the cable, the tendency of the condenser is to take a larger charge from the low-frequency signals, hence the condenser and cable together will more or less correct one another and distortion of signals be reduced. The series-condenser does, however, absorb some of the high-frequency signals, hence it increases the attenuation of all signals although it diminishes distortion. By **distortion** in a telegraph or telephone cable is meant the change in shape that a current wave suffers as it goes from the sending to the receiving end. By **attenuation** is meant the decrease of the amplitude of the current wave as it goes from the sending to the receiving end. The amplitude of a current wave is not only smaller, but its shape is also different at the receiving end than at the sending end, and hence the current suffers distortion as well as attenuation.

63. A condenser in series with the cable not only distorts some frequencies more than others, but it also alters the phase relation between the current and applied electromotive force, more for some frequencies than for others. A series-condenser introduced to reduce distortion, further increases the lead of the current over the electromotive force and hence reduces the effective power acting through the cable. By **effective power** at any given instant is meant the product of the values of current and voltage at that given instant at some one point. This effective, or true power has its maximum value only when the current and voltage are in phase, for when they are not in phase, the current is not a maximum when the voltage is a maximum.

By abolishing the sending condenser and replacing the receiving condenser by a magnetic shunt (inductive resistance, such as Brown's) placed across the suspended coil of the siphon recorder or relay, the speed and accuracy of signaling were materially increased in 1898. Where a cable relay is used, the series condenser is usually retained, so as to insure the effectual stopping of earth currents, but the condenser is made large. A shunt inductance has a similar time action on the incoming current to that of a series-condenser, but with this improvement, it helps to reduce the phase distortion between current and voltage, rather than increase it, as is the case with a condenser.

64. It has also been found that adding a condenser as an additional shunt, increases the size of the signals on the recorder and renders them more distinct. The reason for this is said to be that for the highest frequency used in cable signaling the shunts of inductance and capacity, when properly proportioned, act as a shunt of infinite resistance. For frequencies much below this, it is as if there was no condenser at all; for frequencies much above this, it is as if there was no inductance.

To reduce still further the harmful effects of phase displacement, series-inductances have been introduced at the ends of cables, particularly at the sending end. By placing an inductance coil of low resistance in series with the battery, at the apex of the duplex bridge, not only has the speed of signaling been increased, but the effect of what is known as jar on the duplex balance has also been greatly reduced.

65. Duplexing a cable reduces the speed of simplex, or of working one way only, by some 20 per cent., but the total carrying capacity of the cable, irrespective of direction, is raised about 70 per cent., and the duplex is for this reason valuable, and repays the trouble in maintaining the balance.

A bridge containing inductance in the two arms is said to be better than one containing capacity because the former gives, in practice, higher speeds than any other.

If 40 volts is applied to a cable duplex, the two currents dividing between the cable and artificial cable must not vary more than will produce $\frac{1}{200}$ volt across the receiver circuit; hence, a variation of 0 to 40 volts at one key must not produce a variation exceeding 0 to $\frac{1}{200}$ volt across the receiver circuit. This means that the balance must have an accuracy of 8,000 to 1. If, after the duplex has been established, the artificial cable varies $\frac{1}{8000}$ of its value, the balance will require readjustment to keep it useful for receiving.

AUTOMATIC FACSIMILE TELEGRAPH SYSTEMS

HUMMELL FACSIMILE TELEGRAPH

66. The **facsimile telegraph system** is one that transmits the facsimile of a drawing or writing that has been previously prepared upon a flat or smooth surface. The methods usually employed involve a synchronous rotation of two metallic cylinders, one at the transmitting end and the other at the receiving end.

In 1898, the New York Herald experimented with the **Hummell system** of picture telegraphy, and since then the same journal has made experiments with an improved form of the Hummell apparatus.

67. The apparatus, as described in the Telegraph Age, consists of a receiver and transmitter, which are similar in appearance and mechanism. The picture to be transmitted is drawn on a heavy piece of metal foil, the lines of the drawing being made with an insulating ink. The foil is then secured on the circumference of a horizontal cylinder of the transmitter, the cylinder being about the size of a typewriter rubber roller. There is a similar cylinder on the receiver, upon whose surface is clamped the paper on which the drawing is to be produced; over this is superposed carbon paper, which is covered in turn by a sheet of thin paper. A style actuated by an electromagnet is adjusted close to the surface of the latter, and each time a current is passed through the electromagnet the style is forcibly pressed against the moving surface of the cylinder and a corresponding mark is made on the two sheets in contact with the carbon paper; the outer sheet serves merely to form a smooth surface for the style and to enable the operator to see that the picture is being properly produced.

68. The transmitting cylinder passes under a similar style that closes the circuit between the receiving and transmitting ends when it rests upon the foil, and opens the circuit when it passes over the lines drawn with insulating ink, in the latter case causing the style magnet at the receiving end to leave a mark on the paper on the receiving cylinder in the form of a line corresponding to the width of the insulation over which the transmitting style passes. The style at each station is simultaneously advanced at the end of each revolution of the cylinders by a screw of small pitch. If the surface of the foil on the transmitting cylinder were entirely insulated, the receiving style would merely draw a number of parallel lines on the paper corresponding to the turns of the screw, and separated a distance corresponding to the pitch of the screw and the angle through which it is turned at each operation. Four different rates of advance may be given the style, corresponding to as many different angles of advance that may, by appropriate mechanism, be given the screw.

69. Method of Obtaining Synchronism.—The two cylinders have synchronous motion, so that all the marks or lines on the receiving cylinder correspond to widths of insulating ink marks on the transmitting cylinder. Synchronism is obtained as follows: Connected with both receiver and transmitter is an electric motor that, at the end of every revolution of the cylinder, raises a weight that acts upon a clock train when falling and thus gives motion to the cylinder. At the end of each revolution of the transmitting cylinder, a contact is made that locks for an instant the receiving cylinder when it arrives in a position corresponding to a similar position of the transmitting cylinder. Thus each cylinder begins its revolution from identical positions and at the same instant, and as the clockwork of both receiver and transmitter are duplicates, approximate synchronism is maintained during a revolution. Owing to the use of carbon paper, the lines made by the receiver are of considerable width, and in consequence the resulting picture has but slightly the appearance of being made up of parallel lines.

The Hummell apparatus appears to be entirely practicable, and its synchronizing mechanism is quite simple. The apparatus has been worked duplex with success. In one instance, a picture was sent from New York to St. Louis, while one sent from St. Louis was being received in New York, the latter picture, in addition, being received simultaneously at Boston.

DUN LANY FACSIMILE TELEGRAPH

70. The International Facsimilegraph Company, in which the managers of the Associated Press took an interest, developed the facsimile telegraph system patented on August 22, 1899, by P. Dun Lany and Thomas Mills. In transmitting a picture or drawing by this system, it is first stereotyped on a flexible metal plate. The outlines of the picture are exposed, while the remainder of the surface of the plate is covered with a non-conducting paint. The plate is then placed around a brass cylinder 5 inches long and 2 inches in diameter, and the machine, which is operated by an electric motor, is started. An arm bearing a tracer has its base upon a very finely threaded rod. The arm is gradually moved to the left, until the entire picture has been covered by the tracer. Both sending and receiving machines are governed by a simple synchronizing arrangement, so that both machines are automatically regulated in their speed and run exactly together. The tracer at the sending point controls the current on the wire and closes the circuit whenever it comes in contact with the exposed lines of the picture.

71. At the receiving end, the apparatus is similar to that at the transmitting point. The arm projecting over the cylinder, however, is provided with a style controlled by an ordinary telegraph sounder. Around the cylinder is wrapped several sheets of paper having carbon copying sheets between them. The sounder operating the style causes the latter to bear down upon the cylinder and copying paper, recording the most minute lines in the original picture as the tracer at the sending point passes over them. A portrait was successfully transmitted by this method over a 650-mile circuit between Cleveland and St. Louis.

In transmitting written or printed matter, the process is the same, except that the copy is either written or copied on a flexible metal plate, the circuit being broken whenever the tracer strikes the non-conducting ink. In this case the receiving instrument is reversed, so that it records on the paper the opening instead of the closing of the circuit. The synchronizing arrangement is very ingenious. It is said that the operator at the transmitting point, no matter how many receiving machines there may be cut in along the line, can easily correct or regulate the speed of all.

It is claimed that by using an enlarged cylinder, a half or even a full newspaper page, in matrix form, can be placed in a transmitting machine, operated, say, in New York or Chicago, and reproduced simultaneously in practically all the leading cities of the country within a very few minutes.

KORN PHOTO-TELEGRAPHIC SYSTEM

72. Selenium Cell.—Prof. A. Korn, of Berlin, has developed a photo-telegraphic method of transmitting photographs and drawings that is said to be practicable and to have given good results. Several periodicals are said to have used the method in 1912. The invention makes use of selenium, which changes its resistance as the intensity of light falling upon it varies. A resistance made of selenium is called a **selenium cell.** It consists of a piece of slate with two fine platinum wires wound parallel around it with a small space between them which is filled with selenium. The resistance between the two platinum wires will then depend on the resistance of the intervening selenium. A strong light falling upon the selenium lowers its resistance.

73. Description of Korn System.—A photographic film to be transmitted is wrapped around a glass cylinder on which a strong light is concentrated. The concentrated light rays pass through the film, the amount transmitted varying with the thickness of that point of the film directly in line with the light rays. By means of a mirror, the light that has passed through the film is thrown on a selenium cell, which, therefore, receives more or less light according to the tone of the various parts of the picture. The strength of an electric current passed through the selenium cell from a battery or other source of electricity will vary, for the resistance of the selenium cell varies in accordance with the quantity of light falling upon it.

This current is transmitted through the line and at the distant end controls the intensity of a strong light that is concentrated on a small portion of a sensitized film wrapped around a cylinder similar to that at the transmitting end. This cylinder revolves in a box impervious to light. Varying current is passed through two very delicate parallel silver wires suspended between the poles of a powerful electromagnet. A small shutter is attached to the wires, which, by their position, control the light from an electric lamp that can pass to the sensitized film. The displacement of the two wires in the strong, but constant, magnetic field varies with the strength of the line current passing through them.

74. The light falling on the receiving film varies in intensity in accordance with the transmitting current; this varies in accordance with the selenium resistance in the transmitter; and this, in turn, varies with the intensity of the light falling upon it, which in turn depends on the thickness, or density, of that part of the photographic film through which the light is passing at that particular moment. The two cylinders rotate synchronously and the light rays pass slowly from one end to the other end of the rotating cylinders. Thus light rays trace spirals over the entire surfaces of both transmitting and receiving films. The photograph of a woman's head was transmitted satisfactorily from London to Paris in 12 minutes.

TELAUTOGRAPH

75. The **telautograph** reproduces at a distance a writing or drawing by means of a pen whose motion is controlled by the pencil with which the writing or drawing is being made at the sending station. The principle underlying telautograph systems was invented by Elisha Gray, but the instruments at present used somewhat in America and England are called the Ritchie telautograph or telewriter, after Foster Ritchie who made essential improvements. In Fig. 13 is shown a sample of the work produced by the receiving instrument. The first telewriter exchange, having 50 subscribers, but providing for 750 more, was started in England in 1910. The following explanation is based upon one given in the London Electrician for July 1, 1910.

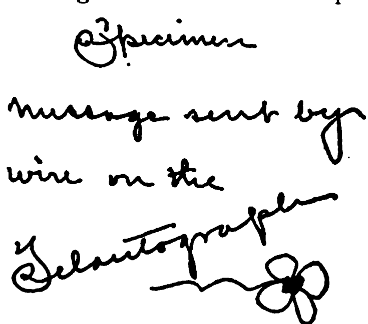


FIG. 13

The main principle employed in the telautograph is that of producing two independent motions by the movement of the transmitting pencil, each motion causing a change of current in a circuit. At the receiving end these two varying currents produce independent motions, the resultant of which is a reproduction of the movement of the transmitting pencil.

76. Writing Circuits.—In Fig. 14 is shown a diagram of the so-called writing circuit only. The transmitting apparatus is shown in the lower half of the figure. The writing or drawing is made with a pencil *a* on a paper resting on a plate or platen. The motion of the transmitting pencil *a* is transformed through the arms *b c*, and *d e*, into rotary motion of the two vertical shafts *f* and *g*, which have rigidly attached to their lower ends the rotating arms *h* and *i*. These terminate in rollers that pass over contacts of two rheostats, thereby varying the current flowing in the line wires, two of which are required, the earth serving as a common return.

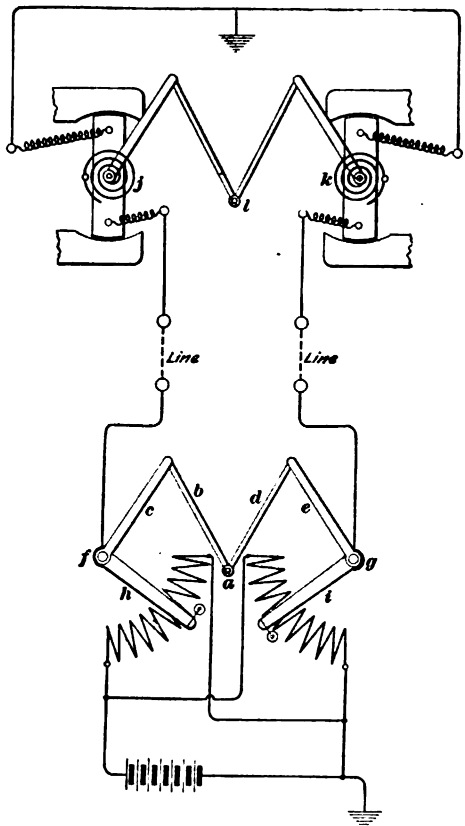


Fig. 14

The moving coils *j* and *k* in the receiving apparatus rotate in a magnetic field, produced by a strong electromagnet, and are controlled by spiral springs, very much the same as in Weston direct-current permanent-magnet ammeters and voltmeters, and take up a position corresponding to the strength of the current flowing in each coil. By connecting the receiving pen *l* to the shafts carrying the coils by arms identical with those at the sending station, the motion of the transmitting pencil is thereby reproduced.

77. The paper upon which the writing is produced is fed mechanically by means of a lever operated by the finger or hand at the sending station and electrically at the receiving station, being moved simultaneously at the two stations.

In Fig. 15 is shown the interior of the transmitter. The finger lever *m* is connected at its inner end by a rod with the paper shifter *n*. When the lever *m* is moved by hand, to and fro between its stops, the paper shifter rocks to and fro and feeds paper over the platen *o* at each movement. The rotating arms *h* and *i* control the rheostats.

Fig. 16 shows an essentially complete diagram of the circuits. The finger lever *m* also controls the switch *p*, which, when

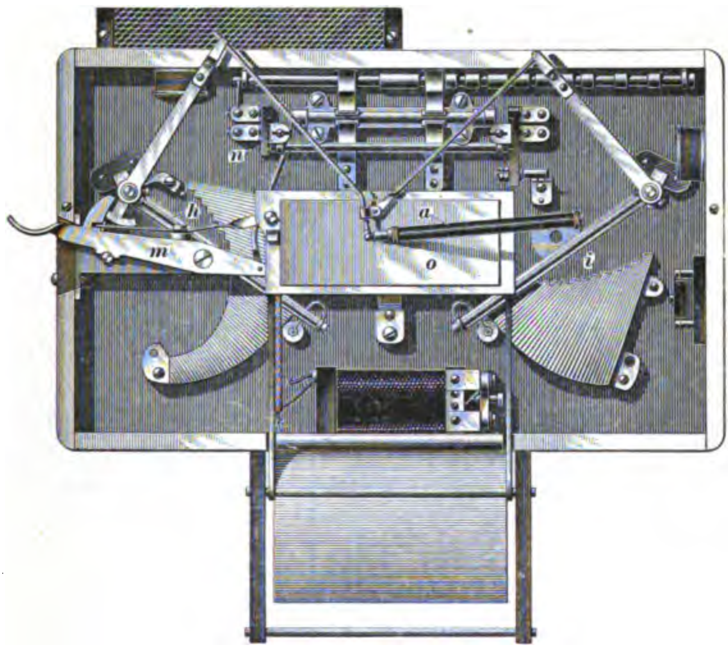


Fig. 15

closed, causes the paper to be fed forwards one step for each movement of the finger lever at the transmitter. For this purpose current from the battery *q* flows over the two sides of the circuit in parallel, then through relay *r* at the receiving end and returns through the ground. The relay *r*, which is kept energized as long as the switch *p* is held closed while a person is writing, in turn holds closed the pen-lifting coil *v* and a direct-current electric-lighting circuit containing the powerful electromagnet coils *t* and *u* inside the poles of which the moving coils *j* and *k* rotate.

78. Control of Receiving Pen.—As the pen at the transmitter may be moved, whether it is pressing against the paper or not, and it is necessary to have the receiving pen press against the paper only when the transmitting pencil is being used against its paper, it is essential to provide means for raising and lowering the receiving pen as the transmitting pencil is raised or pressed against the paper. This is accomplished by sending a superimposed alternating-current over the lines. The platen *w*, Fig. 16, over which the transmitter paper passes, is hinged and the spring *x* holds it up so that contact *y* is normally open. When the transmitting pencil presses against the paper, contact *y* is closed, thereby allowing current from the battery *q* to pass through the primary winding of a make-and-break induction coil *z*. The two secondary windings *a′* and *b′*, which are included in the two line wires, are wound in relatively reverse directions so that at any moment the induced current in one line will be in the opposite direction to the induced

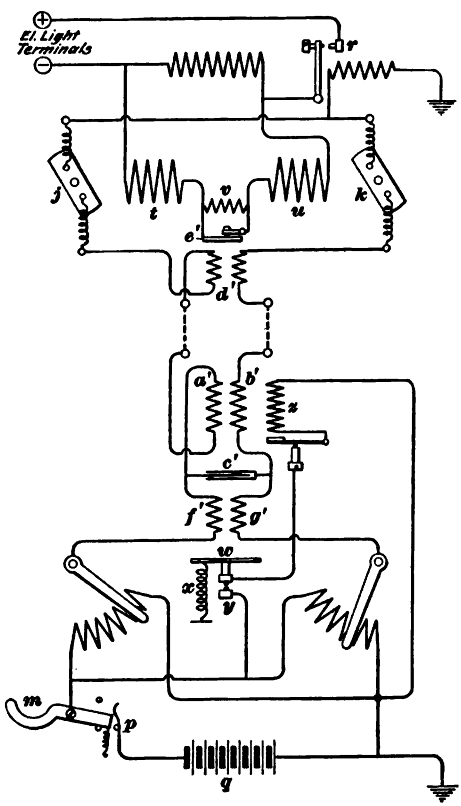


FIG. 16

current in the other line. The condenser c' completes the circuit for these induced currents from one line wire to the other. The alternating current, induced in the windings a' and b', is superimposed upon the writing (direct) currents passing through the line wires. At the receiver, this alternating current passes through the differential windings of a vibrator d' and the moving coils j and k. The vibrator has over its iron core a reed e', upon which rests a weighted lever. The contact between the two normally short-circuits the pen-lifter magnet coil v, but an alternating current through the windings d'

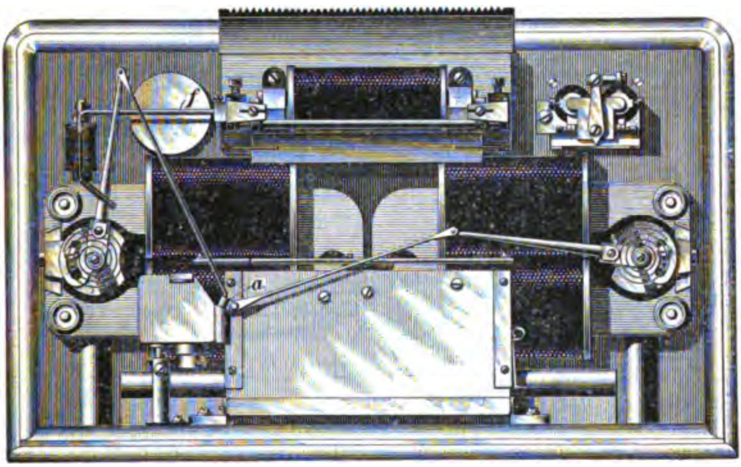


FIG. 17

causes the reed to vibrate and raise the resistance through the vibrating contacts at e' enough to allow the pen-lifting coil v to be energized, thereby causing the receiving pen to rest upon the paper. As the coils d' are differentially wound and connected practically in parallel, as far as the direct current is concerned, this writing current will not affect the pen-lifter magnet, but the coils are in series to the alternating current that passes through one winding on its way to the receiving station and through the other winding on its return, this circuit being completed by the condenser c'. A spring moves the armature of the pen-lifter magnet forwards and raises the pen off the paper when the coil *v* is short-circuited, which is the case when the transmitter pencil is not pressing against the paper. To prevent induction disturbances to neighboring circuits, the alternating current is confined, by the choke coils *f'* and *g'* and condenser *c'*, to the two line wires that are con-

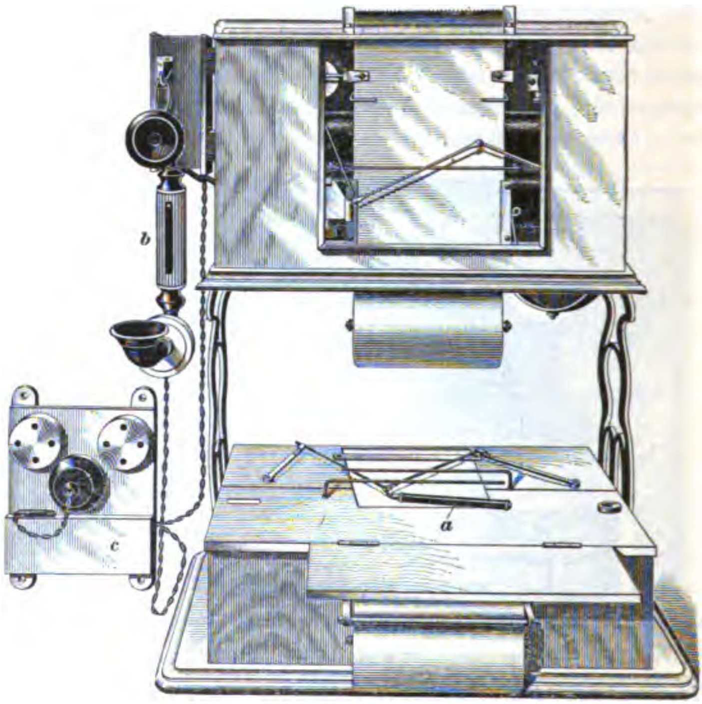


FIG. 18

nected in series. The alternating currents have practically no effect upon the writing coils *j* and *k*.

79. Appearance of Instruments.—The interior of the receiving apparatus is shown in Fig. 17. The receiving pen, when not in use, is held in the ink well by means of a rod *f*. It is also brought to this position every time the paper is shifted, and is thus kept fully supplied with ink.

80. There is, of course, a transmitter and receiver at each station, as shown in Fig. 18, the transmitter being horizontal and the receiver vertical. The telephone *b* is provided so that the subscriber can give the switchboard operator the number of the subscriber with whose station connection is desired. The box *c* holds the necessary fuses, etc. for connection with the direct-current electric-light circuit. The line currents are taken from a small storage battery, which is charged from the electric-light circuit when the finger lever *m*, Fig. 15, is in the receiving position. When the transmitter is in use, this switch disconnects the battery from the lighting circuit and connects it to the rheostats. The instruments are calibrated for circuits of a certain resistance and the lines are made up to this with added resistance. No attention is required at the receiver when messages are being delivered and a business man can see all messages received during his absence and has a permanent record of them.

HIGH-SPEED TELEGRAPHY

RAPID TELEGRAPH SYSTEMS

INTRODUCTION

1. In telegraphy, as in nearly all other industries, there are two ways of working—by hand and by machine. Naturally the hand method came first. Even now, probably 90 per cent. of the telegraph business of the world is done by hand. In America and England, it is done by hand and sound; in most all other countries, by hand and sight, although Belgium is using the sounder somewhat. France, Germany, Italy, Austria, Spain, Russia, and, in fact, the rest of the world, use the Morse key and a receiving instrument that records the dots and dashes in ink upon a paper tape. There are, however, a number of through circuits operated by the Hughes system. Transmission is by keyboard, and the message is received printed on a tape, similar to the type-printing system of Phelps, which was used to a small extent in the United States.

England has used automatic telegraph systems to a considerable extent, having long ago adopted, and is still using, the Wheatstone automatic telegraph system, which is an English invention. The use of the Wheatstone and printing telegraph systems are very favorably considered for transmitting the night-letter telegraph business in the United States.

WHEATSTONE AUTOMATIC SYSTEM

PERFORATOR

2. The **Wheatstone automatic telegraphic system** is capable of transmitting and recording in ink signals at a rate of 500 or 600 words per minute, the speed below 600 depending on the electrical properties of the line. 600 words a minute is about equivalent to an alternating current of 240 cycles per second. Over 225 words per minute can be transmitted between New York and Philadelphia, 190 words between New York and Chicago, and 110 words between Chicago and San Francisco. Between Calcutta and Bombay, which are 1,300 miles apart, 130 words per minute are transmitted without the use of repeaters. Where the line is long, repeaters are used. Between North Sidney and New York, over land lines, the Wheatstone is worked duplex, having a speed of about 100 words per minute. The Wheatstone system is extensively used in Great Britain, where it has given better results than in the United States.

This system consists of a perforator that punches holes in a paper tape to represent dots and dashes; a transmitter, through which the paper tape is fed and by means of which electrical impulses are sent into the lines; and a receiver that records in ink the electrical impulses as dots and dashes upon a paper tape that is drawn through the receiver.

3. The **perforator,** or punching apparatus, is shown in Fig. 1. It has three keys and five punches so arranged that pressing key *A* makes perforations in the paper tape *D* corresponding to a dot, pressing down *C* makes perforations corresponding to a dash, and pressing down *B* makes one perforation corresponding to a space and is also necessary for advancing the paper tape. The paper tape passes behind a punching plate *G* containing five holes into which the ends of the punches enter in the act of punching corresponding holes in the paper tape. When the key *A* is depressed, three holes corresponding to *m*, *n*, and *o* are simultaneously punched in the paper, as shown at A_1. When the key is released, the wheel F revolves and teeth on its surface engage the center line of holes made in the paper and so advance the paper a distance equal to the proper distance between two center holes. When the key B is depressed, one center hole is made by the punch at o in the paper, as shown at B_1; and the releasing of the key again advances the paper the same distance as before. When the key C is depressed, four holes corresponding to m, o, p, and q are simultaneously punched in the paper, as shown at C_1, and the releasing of the key advances the paper double the distance that is accomplished by the release of

FIG. 1

either of the other keys A or B. The double advance in this case is necessary; for otherwise, if A or B were depressed after C some of the punches would enter holes already made in the paper by the depression of C.

The perforations A_1 made by the left-hand key A, when passing through the transmitter, cause a dot; the perforation B_1 made by the center key B causes a space, and the perforations C_1 made by the right-hand key C cause a dash to be printed on the tape at the receiver.

4. This system will be understood better when the transmitter and receiver have been described. The operator sometimes manipulates these three keys A, B, and C by pounding, or striking, them with rubber-tipped pieces of wood, one held in each hand. As this is laborious, however, they are sometimes arranged so that a key that is very easily depressed will operate the punches by pneumatic pressure. The pneumatic pressure is sufficient to punch from four to eight tapes simultaneously at the rate of 40 words per minute. Although about 45 words per minute can be punched by pounding or pneumatic pressure by an expert operator, 40 words is considered a very good average speed. J. Willmot has made some improvements in the steel punches used in the Wheatstone perforator, and has also improved the Wheatstone transmitter.

TRANSMITTER

5. The object of the **transmitter** is to transmit the dot-and-dash alphabet by means of positive and negative currents, which are transmitted alternately in opposite directions. The arrangement of the transmitter and receiver is such that the current, whether positive or negative, continues to flow and produce a mark whose length varies according to the time that elapses before the current is reversed—such reversal producing an interval or space, whose length continues to increase until the current is again reversed in direction. As alternate currents flowing in opposite directions produce the to-and-fro motions of the ink wheel in the receiver, lines of various lengths, that is, dots or dashes, may be printed. Hence, it is necessary to send a current in the opposite direction through the line and receiver before a mark or a space that has once been started can be terminated. The contact device in the transmitter exists in several slightly different forms the result of improvements made from time to time.

6. Inside of a case is placed suitable clockwork and gearing for operating the transmitting mechanism, which is supported on the side of the case; this transmitting mechanism is shown in Fig. 2. The wheel *l*, which is driven by the clockwork, has teeth upon its surface suitably spaced to enter the holes along the center line of the previously punched transmitting tape and to draw it along at a steady desirable rate. This rate can be varied by an ingenious speed regulator to suit the conditions of the line circuit. The greater the *CR* of the line, the slower must be the speed of transmission.

The rocking beam *H*, as its name implies, has a rocking motion given to it by a shaft to which it is rigidly fastened at the center. This shaft is operated by the same clockwork that rotates the wheel *l*, and, hence, its rate of oscillation cor-

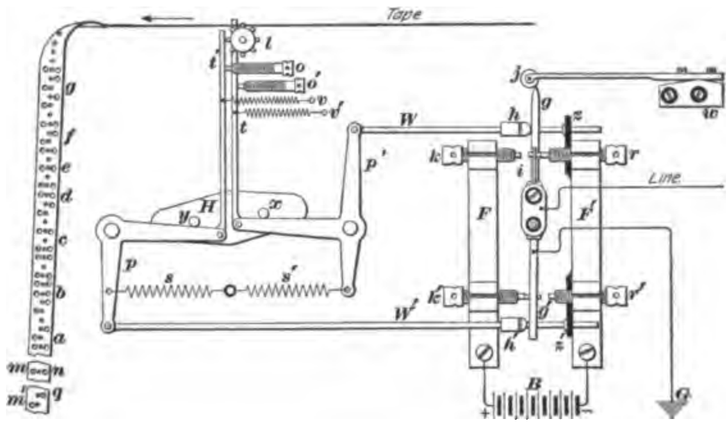


FIG. 2

responds with the rate of rotation of the wheel *l* whether the transmitter is running fast or slowly. On the rocking beam are two pins *x* and *y* against which the levers *p* and *p'* are pressed by the springs *s* and *s'*. Hence, the rods *t* and *t'* move up and down as the two pins *x* and *y* on the beam *H* move up and down.

7. The rods *t* and *t'* are so adjusted by the screws *o* and *o'*, against which they are held by the springs *v* and *v'*, that the horizontal distance between them is exactly equal to the distance between the centers of the two holes *o* and *p* in Fig. 1. Moreover, the distance between the two rods, at right angles to the plane of the figure, is exactly equal to the distance between the centers of the holes *m* and *n* in Fig. 1. Hence, the rod *t* is directly below whatever holes may have been punched on one side of the center line of holes, and the rod *t'* is directly below whatever holes may have been punched on the other side of the center line of holes. The springs s and s' always tend to force the rods t and t' upwards and to push the rods W and W' to the right.

8. Transmitter Pole Changer.—The apparatus at the right constitutes a pole changer. The lever $g\,g'$ is pivoted at the center and has attached to, but entirely insulated from, it a contact piece i, to which the line wire is connected. A metal piece F attached to the positive pole of the battery B has two contact screws k and k'; and a metal piece F' attached to the negative pole of the same battery, has the two contact screws r and r'. The insulated piece i moves between the two contact screws k and r, and the lower end of the lever $g\,g'$ moves between the two contact screws k' and r'. Two rods W and W', to which the collets h and h' are fastened, pass freely through the lever $g\,g'$ without touching it and have bearings in the pieces z and z', which are insulated from the metal piece F'. One rod W pushes the lever to the position shown, and the other W' pushes it over so that i rests against the screw k and g' against the screw r'. Neither rod, when moving to the left, can move the lever.

The wheel j, termed the *jockey wheel*, is fastened on the end of a flat spring that is adjustable at w. It is used to help move the lever $g\,g'$ sharply to one side or the other, to prevent the lever from remaining in an intermediate position, and to hold it against whichever side it may have been pushed by the rods W and W'.

9. Action of Transmitter.—When the pin x moves upwards, the rod t will move upwards; and if there is a hole directly above it, the rod t will enter the hole and continue to move upwards as far as the pin x will allow it. On the other hand, if there is no hole directly above it, the upper end will come against the paper tape, and although the pin x continues to move upwards to the end of its stroke, the rod t can go no farther. Similarly the rod t' will move upwards as far as the pin y will allow, provided there is a hole in the tape directly above it; otherwise, it is arrested in its upward movement by the tape. If the tape contained a series of holes, like those at A_1, in Fig. 1, representing a series of dots, there would be a hole directly above both t and t' every time these rods came up and this would transmit a succession of negative, or marking, currents the proper length for dots, and a succession of positive currents, producing the break or space between the dots. The motion of the wheel l and the rocking beam H is such that the tape is advanced exactly the distance between two center holes while the rod t or t' moves once down and up. Hence, these rods will pass through every hole that is punched on either side of the center line of holes.

10. For instance, assume that the rod t projects through the hole m. When the rod t is drawn down by the downward movement of the pin x, the paper will be moved forwards the proper distance to allow the rod t', as it moves up, to enter the hole n. At the start, when the rod t moves up through the hole m in the tape, the rod W pushes the collet h, and with it the lever g, over to the right so far that the jockey wheel j slips down and presses on the left side of the lever g and so holds i against the contact r and g' against the contact k', causing the negative pole of the battery B to be connected to the line and the positive pole to the ground G. This state will continue, in spite of the fact that W moves to the left, until the rod t' can enter a hole in the tape. Then the rod W' will push the end g' over until the jockey wheel j slips down on the right of the end g, and so holds contact g' against r' and contact i against k. This will reverse the battery B, connecting the positive pole to the line and the negative pole to the ground.

11. Suppose the rod t is in the hole m' and the negative pole of the battery is connected to the line. As the rod t moves down and the pin y moves up, the paper will advance, but t' can move up but little, if at all, because it comes up against the paper opposite the hole m' where there is no hole. Consequently, the lever $g\,g'$ is not disturbed and the negative pole of the battery B remains connected to the line. When y moves down and x moves up, the rod t comes against the paper opposite the hole *q*, where there is no hole, and again the lever *g g′* is not disturbed. When *y* moves up again, however, the hole *q* will be in line with *t′*; hence, the rod *W′* will push *g′* to the right and, by aid of the jockey wheel *j*, will reverse the battery, causing the positive pole to be now joined to the line. The time between reversals, in this case, when a dash is made, is three times (two dots and one space) as long as it was when a dot was made. A space is evidently started by a hole on the lower or right-hand side of the tape, and the space will continue until a hole on the upper or left-hand side of the tape comes opposite the rod *t*, thereby pushing *W* and *g* to the right and so starting a dot or a dash. Thus dots and dashes are transmitted by currents in one direction and spaces by currents in the opposite direction; a reversal of current is necessary in any case to terminate a signal, be it a dot, dash, or space.

12. Improvements Made by Willmot.—An improvement of the transmitter just described was made by J. Willmot, of England. He substituted a permanent magnet and a soft-iron tongue in place of the jockey wheel, and made quite a number of improvements in the details of construction that reduce the wear and tear to which high-speed apparatus is especially subject. The arrangement of the improved transmitter is shown in Fig. 3. The lever *g*, which is made of soft iron, vibrates between the poles *N* and *S* of a permanent magnet. The soft-iron piece *g* will, of course, be attracted by both the north and south pole of the permanent magnet and it will move rapidly toward and remain firmly against whichever pole it happens to be nearest. The use of magnetic attraction in place of the jockey wheel entirely removes the downward pressure of the jockey spring, and greatly increases the holding-over force operating upon the lever, thereby causing a better contact between the contact points. The force necessary to drive the instrument when fitted with the magnetic arrangement is considerably less than with the jockey roller, due to the fact that the downward pressure on the pivots is entirely removed. Furthermore, the laws of magnetism hold, and no sooner does the lever commence to move from the pole of the permanent magnet to which it is nearer than the attractive force of that pole from which it is receding diminishes inversely as the square of the distance, while the attractive force of the pole that it is approaching increases inversely as the square of the distance—a condition most favorable to the object in view.

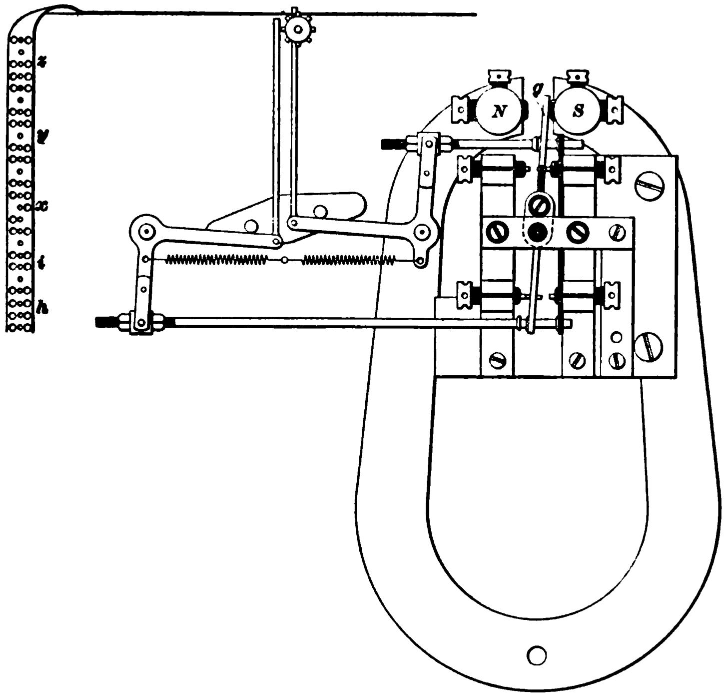


Fig. 3

If the Wheatstone transmitter is run at slow speed the signals may be read as easily as those produced by hand sending; as the Morse is plain and beautiful. The speed over the line may be run up to 200 words per minute, depending on the action of repeaters in the circuit, the CR limitations of the line, and the rapidity with which the receiving polar relay will work satisfactorily.

RECEIVER

13. The **Wheatstone receiver, or ink recorder,** as it is also called, consists of clockwork operated by a weight and a very sensitive polarized relay; it is shown in Fig. 4. Inside the case is placed the polarized relay and also the clockwork that revolves the wheel *c*, the ink disk *i*, and the ink-supply wheel *b*. The paper tape on which the ink records are made by

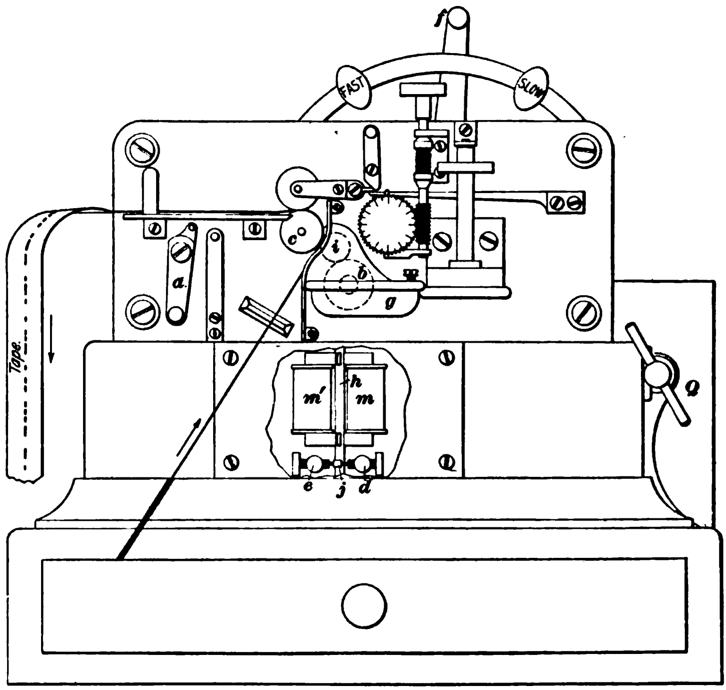


FIG. 4

the ink disk *i* is drawn by the roller *c* from the base of the instrument, where it is coiled away. The speed of the clockwork, and hence the speed of the tape, can be regulated by means of the handle *f* to suit recording at any speed from about 25 to 600 words per minute.

The ink wheel *b*, which dips into a covered ink well *g*, has a V-shaped groove around its periphery; this is shown better in

Fig. 5. The edge of the revolving ink disk *i* enters this hollow in the periphery of the wheel *b*, but it never actually touches the wheel; thus there is no friction between the revolving disk and wheel. During the revolution of the ink wheel *b*, capillary attraction keeps the hollow full of ink, and a constant and uniform quantity is supplied to the ink disk *i*. The clockwork is started and stopped by means of the handle *a* and wound up by the handle *Q* in Fig. 4.

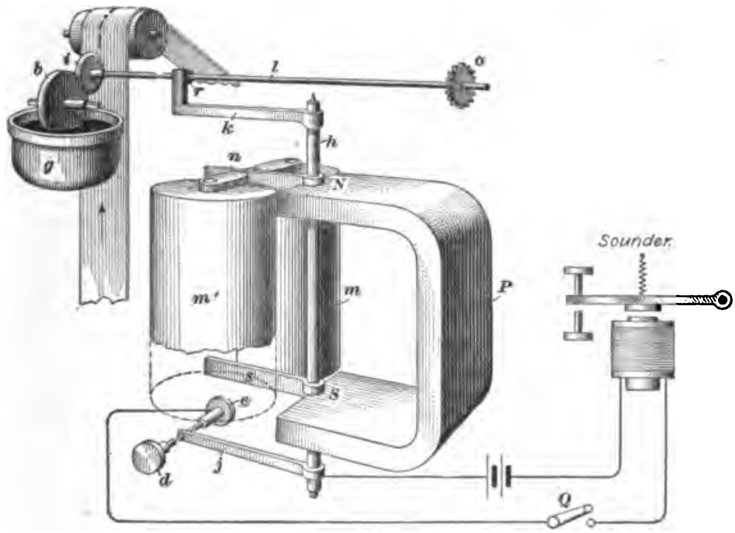


FIG. 5

14. The **Wheatstone polarized relay** that moves the ink disk *i* against the paper tape as it is drawn along is shown in Fig. 5. The relay consists of a permanent magnet *P* across whose ends is a vertical shaft *h* to which is rigidly fastened the soft-iron armatures *n* and *s* and the arms *j* and *k*. The soft-iron armatures are permanently polarized by the permanent magnet *P*.

Two vertical electromagnets *m* and *m'* have polar extensions opposite each other and between which the soft-iron armatures *s* and *n* can move. These two soft-iron armatures are rigidly fastened to the shaft *h*; but their motion, which is exceedingly small (about one-fourth degree), is limited and adjusted by the stop-screws *d* and *e*. When the magnets are energized by a current, the polar extensions opposite each other are oppositely magnetized; hence, each armature *s* and *n* is repelled by one and attracted by the opposite polar extension, and the polarities of the four polar extensions are always such that they all tend to move both armatures toward the same side. When the current is reversed, the polarities of the four polar extensions are reversed and both armatures move toward the other side.

The shaft *l*, which is pivoted at the end *o* and caused to revolve by the wheel *o*, rests lightly in a cavity at *r* in the arm *k*. When the armatures move away from the reader, the arm *k* moves the ink disk *i* toward the moving tape, on which it makes a dot or dash, depending on the length of time that the marking current lasts. When the current is reversed, the armatures move toward the reader and the ink disk away from the tape, making a space that lasts until the current is again reversed. Hence, a series of instantaneous, alternately positive and negative currents passing through the electromagnet will cause a to-and-fro motion of the marking disk *i*, a current in one direction pressing the marking disk against the paper, where it will remain until withdrawn by a current in the opposite direction.

15. The motion of the armature is limited by the screws *d* and *e*; one may be used as a contact screw at which is opened and closed the circuit of a local sounder that is used to attract the attention of the operator, and also for reading messages when the line is being operated manually by a key.

In the base of the transmitter is placed a triple switch, by means of which the automatic transmitting apparatus may be cut out and the battery connected to a hand transmitting key. This switch is worked by the lever used for starting and stopping the clockwork. By this arrangement, messages may be transmitted by hand. On the transmitting key there are also switches enabling the operator to cut the key and batteries out of the circuit when he is receiving messages by means of a local sounder controlled by the polarized relay of the automatic receiver.

16. Resistance and Inductance of Wheatstone Relay. The relay used in the Wheatstone receiver is generally wound differentially, so that the system may be worked duplex. To give the two coils exactly opposite magnetic effects for duplex working, the two wires are wound together as one upon the spool; the resistance of each coil is made equal to 100 ohms in the British service. The inductance of a 200-ohm Wheatstone receiver, with the two coils of the relay connected in series, is about 3.46 henrys; with the two coils in parallel, about .875 henry. When the two coils are differentially connected and the current flows in the proper direction to create an equal but opposing magnetization, the inductance is about .187 henry.

17. Non-Inductive Resistances and Condensers in Wheatstone System.—In practice it is found that when the Wheatstone receiver is connected directly in the line and is operated by the Wheatstone transmitter, the speed obtainable over most lines can be increased by the use of condensers properly arranged. The arrangement of condensers and resistances in actual use in England is indicated in Fig. 6. Common values of the resistance and capacity are about 8,000 ohms and 10 to 20 microfarads, respectively, which will vary according to the line. The non-inductive resistance is often larger than the impedance of the receiver. This arrangement reduces the retardation due to the self-induction of the receiver relay. It increases the total resistance of the circuit considerably without increasing the inductance; hence, the time constant of the receiving apparatus is considerably reduced. Moreover, the condenser connected in this manner also helps to make the current start and stop more abruptly, because the moment

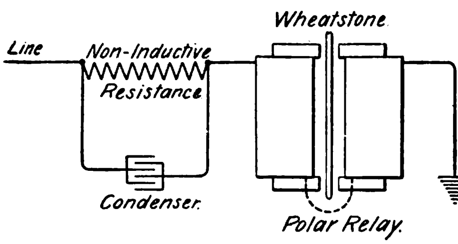


FIG. 6

the circuit is opened at the transmitter, the extra current due to the electromotive force of self-induction of the relay is opposed or neutralized by the current discharged from the condenser. In the Wheatstone system, this arrangement has proved to be better than connecting the condenser around the coils of the relay itself.

18. Non-Inductive Resistance Around Relay Contacts.—A small but important addition that has been made in England, has been the general introduction of a non-inductive shunt, or *spark coil* of high resistance connected across the terminals of relays. This has resulted in the suppression of the spark at the relay contacts and a consequent greater certainty of action. This improvement has been quite generally applied to all relays and not alone to the Wheatstone relay.

19. Limiting Number of Words per Minute.—The present perfection of the Wheatstone system is much superior to that obtained with the original instruments. This improvement is largely due to Mr. Preece, who gradually increased the speed from 100 or 200 to 600 words per minute. The Wheatstone system has been in commercial operation in England for so long a period that the speed expected on any given line is accurately known, and may be represented closely by an equation of the form

$$W = \frac{a}{CR},$$

in which C = total distributed capacity of line;
R = total resistance;
W = number of words per minute;
a = a constant.

The constant a depends on the kind of line used and differs for iron and copper wire and for cables. The values of the constant a determined by a series of experiments extending over a long period are as follows:

10×10^6 for aerial line of iron wire;
12×10^6 for aerial line of copper wire;
15×10^6 for submarine cable with condenser at one end;
18×10^6 for submarine cable with condensers at both ends.

A copper aerial line having a $C R$ equal to about 30,000 will reduce the Wheatstone speed to about 400 words per minute; when a line exceeds this it is customary to insert an automatic repeater, by which the speed is maintained over longer distances. Speeds of 400 words per minute are regularly maintained in England in commercial working.

WHEATSTONE DUPLEX

20. The arrangement of the Wheatstone apparatus, when worked as a polar duplex with dynamos as a source of current,

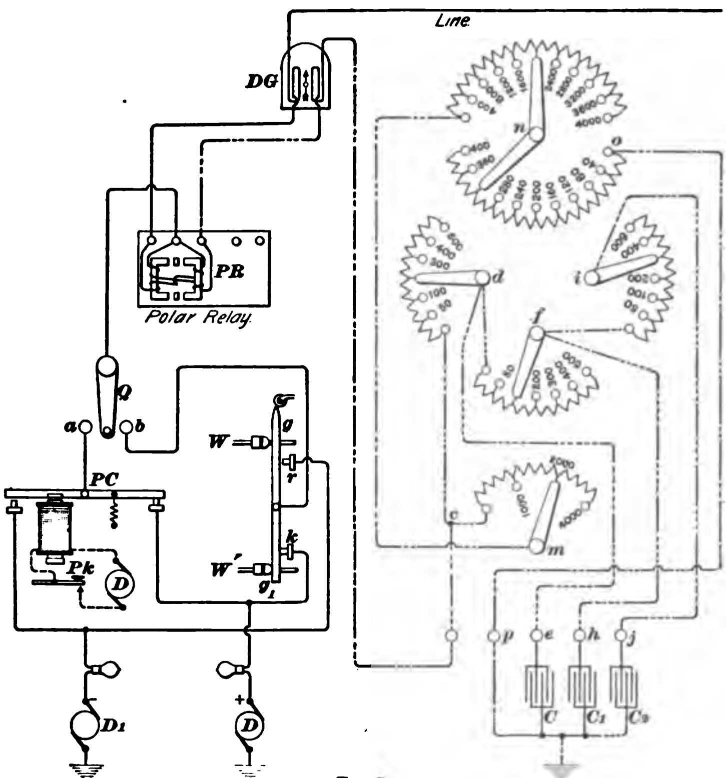


FIG. 7

is about as shown in Fig. 7. The polar relay is wound differentially and the line and artificial-line circuits run through separate coils of the differential galvanometer *DG*. The two coils of this galvanometer have the same resistance and the same number of turns and are wound in such a direction that equal currents through the two coils from the home station will not deflect the needle. The duplex system is balanced by means of this galvanometer. An expert is able to tell from the action of the galvanometer needle whether the pulses received from the distant station differ in strength or duration, whether the distant batteries are short-circuited or open, whether the home instruments, resistance, and condensers are properly adjusted, while grounds, crosses, and breaks on the line produce effects that are readily recognized.

21. When the switch *Q* rests on *a*, messages may be sent manually by means of the key *Pk* and the pole changer *PC*; when the switch rests on *b*, the automatic transmitter may be used. The latter instrument is somewhat altered when used with dynamos so that it resembles the ordinary walking-beam pole changer, $g\,g_1$ representing the beam or armature lever, and *r* and *k* the positive and negative contact stops, respectively. The lever $g\,g_1$ is joined to the point *b*.

For a high-speed duplex system, the line must be much more carefully balanced than for a manual duplex system. For this reason three retarding coils are required: one *c d e* in series with the condenser *C*; a larger resistance *c d f h* in series with the condenser C_1; and a still larger resistance *c d f i j* in series with C_2. The condenser *C* must have the largest and C_2 the smallest capacity; the rheostat consists of the coils in the circuit $c-m-n-o-p$.

22. Balancing.—The system is balanced by asking the distant operator to run his transmitter while the home artificial line is adjusted in the usual manner. If balanced properly, the galvanometer should give no deflection when the switch *Q* is placed on *a* and the key *Pk* is operated.

To eliminate further the disturbing effects of the static line charges, the home transmitter should be run and the condensers and the retarding coils adjusted until the incoming signals made by the receiver are clear and distinct.

WHEATSTONE REPEATER

23. Repeaters that are known, in Great Britain, as *fast-speed repeaters* are used in connection with the Wheatstone apparatus when the latter must be worked over long circuits. The value of the repeaters for high-speed purposes is shown by the fact that direct working between London and Aberdeen (560 miles) would not be possible at a higher speed than 40 words per minute, whereas with repeaters at Leeds and Edinburgh, the practical working speed is increased to 350 words. These repeaters in their present efficient form have been introduced within the last 25 years and are marvelous examples of ingenuity. The present form of this apparatus, for use on cable circuits, comprises forty-one instruments of twenty-six different forms; it is arranged to work bridge duplex on the cable side and differential duplex on the land side of the circuit.

REPERFORATOR

24. If a Wheatstone-received message is to be forwarded over another Wheatstone-operated line, the received-tape message is translated and typewritten and then the message repunched on transmitting-Wheatstone tape and transmitted over the second line. The Postal automatic system is identical with the Wheatstone in so far as concerns the preparation of the transmitting tape and the transmission of the signals from the sending end, but the reception of the high-speed signals is accomplished in a different manner. The Morse signals are received by an electromagnetic punch, or reperforator, which perforates the characters in a continuously moving paper tape, so that the received tape resembles the transmitting tape, which may therefore be passed through a local reproducer and the messages copied by sound from an ordinary sounder, or the tape may be used in another transmitter to relay it forwards to another office.

The reproducers are motor driven and are under the control of the reproducing operator so that the speed of reproduction may be regulated to accord with the ability of the operator to copy. The tape may be stopped, pulled back, and run through again in order to confirm doubtful words. The operation of the reproducers is quite simple and may be learned by any operator in an hour or two.

25. Automatic Perforator Circuit.—In Fig. 8 is shown the wiring of the Postal-Wheatstone reperforator circuit. The main-line polar relay *a* controls a pole changer *b*, the armature of which is grounded through two 3-microfarad condensers *c*. This pole changer controls two magnets *d* and *e*, which operate the punches. The free ends of the armatures of the punch magnets *d* and *e* are equipped with steel punches about $\frac{1}{16}$ inch in diameter and 1 inch long. When the magnets are energized, these move through holes in a die plate and perforate holes in a paper tape that is being drawn through a slot and past the holes in the die plate. The tape is moved continuously by an electric motor whose speed is regulated by a rheostat. A closed key at the distant station causes the marking current to energize the pole changer *b*, thereby permitting a charging current to flow through the punch magnet *d*. An open key causes a spacing current to open the polar relay *a*, thereby allowing the pole changer *b* to release its armature, which permits the retractile spring *h* to withdraw its punch, and allows electricity to flow in the opposite direction toward the condenser, which facilitates the flow of current and energizes the magnet *e*, which punches a hole in the tape.

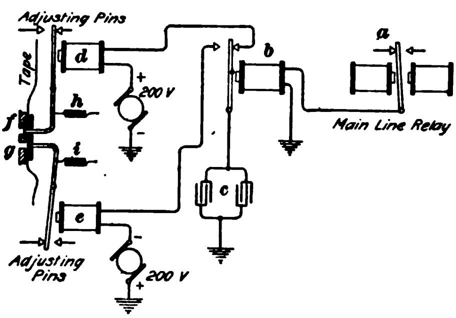


FIG. 8

26. The punches should be adjusted to move forwards just far enough to go through the paper, make a clean round hole, and move backwards just far enough to clear the face of the die plate. The punches must move very rapidly in order not to tear the paper, which is moving forwards but is allowed to slip enough to momentarily stop, as the hole is punched. The speed of punching is regulated by adjusting the condensers *c* and the strong retractile springs *h* and *i* attached to the armatures of the punching magnets to give a very rapid and not draggy action to the punches.

The tape is rolled up roughly by hand as it comes from the receiver or reperforator, which requires constant attention. The received tape may be parceled out in units of one or more messages, as the receiver attendant very quickly learns to read the tape. The end of each message is signified by a paragraph sign, four dashes, or by a succession of letters *a* without letter spaces between them.

DELANY ELECTROMAGNETIC AUTOMATIC SYSTEM

27. Outline of System.—In the electromagnetic automatic telegraph system devised by Patrick B. Delany a regular Morse telegraph key, some form of vibrating key, or Delany's transmitting typewriter, which he calls the *keyboard*, controls his perforating machine, which perforates a tape with holes corresponding to the Morse characters at any speed of which the operator is capable. The perforated tape thus prepared by four or more operators may then be fed in succession through his mechanical transmitter, which is capable of working at a speed of 100 words a minute, and the signals are reproduced at the receiving end by his reproducer as a similar punched tape. This in turn can be distributed to about four operators to transcribe on a message blank by reading the message directly from the tape by sight, or by running the tape through reproducers and reading the messages by sound from ordinary sounders.

28. The transmitting typewriter may also be used to transmit Morse signals directly through a line circuit. At the receiving end, an operator may copy the message by the aid of an ordinary typewriter, or the signals may be utilized at the receiving end to punch the message in a tape for further transmission over a busier trunk line by his mechanical or electrochemical transmitter.

Much of the following description is taken from a paper prepared by Mr. Delany and published in the Journal of the Franklin Institute for March, 1908. More detailed information concerning Delany's electromechanical and chemical systems are contained in United States patent specifications Nos. 709,752, 720,004, 720,233, 792,193, 800,364, and 906,618, which can usually be obtained for about 5 cents each from the Commissioner of Patents, Washington, D. C.

29. Transmitting Typewriter.—In Fig. 9 is shown the connections for one key in the transmitting typewriter, called the keyboard, which has a keyboard like a typewriter. As the key *k* is pushed down and locked at *l*, spring *s* presses on sliding bar *b*, clamping it between revolving rollers *r* and *r'*.

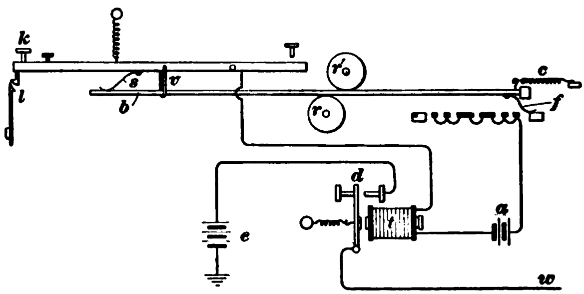


Fig. 9

Contact finger *f* is drawn over the row of contact segments, which in this case represents a period—two dots, two dashes, two dots. As the finger *f* passes over the segments the circuit of the transmitter relay *t* is made and broken through battery *a* and the characters formed. The armature lever *d* is connected to the line *w*. Its front stop is connected to the main battery *e*. At the completion of the forward movement of bar *b*, the latch spring at *l* is pushed back and the key *k* released. As *k* rises it pulls bar *b* up with it by means of the loop *v*, thereby releasing it from the grip of rollers *r* and *r'*, when it is pulled back to the starting point by spring *c*. This backward movement is so quick, the transmitter *t* is not actuated even with the lowest adjustment of the armature spring. In this way all mechanical or electrical contrivances for taking the contact maker *f* out of touch with the character segments on its return are unnecessary. The keyboard, together with an electric motor that supplies the power for operating it, is shown in Fig. 10.

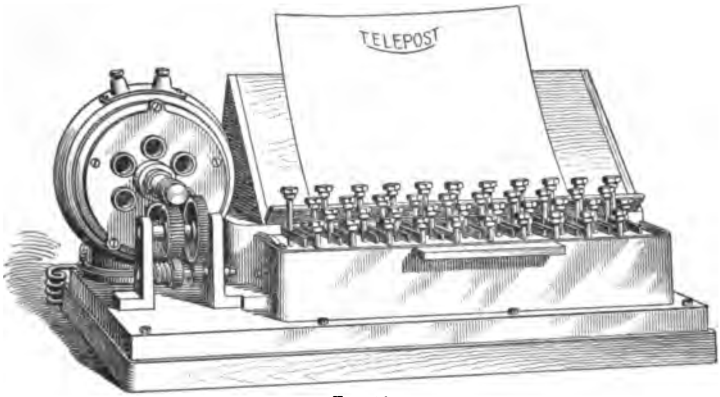


FIG. 10

This machine may be used by any one able to operate a typewriter to send messages in the Morse code directly through the line or to control the telegraph key in the electric circuit of his perforator.

30. Perforator Circuit.—Fig. 11 is a diagram of the perforator connections. When the Morse key k is pressed down the circuit of battery b is completed through magnet m'–contact c'–rocking beam d–back to the battery, thereby energizing magnet m', which attracts its lever l', thereby forcing the punch p' through the tape passing below at q. Just as the punch enters the tape the pin a on the lever l' pulls the tapering end of rocking beam d past its biasing spring x, on the end of which is a small roller, thereby breaking the circuit of magnet m' at c'. This allows lever l' to fly back to its stop v,

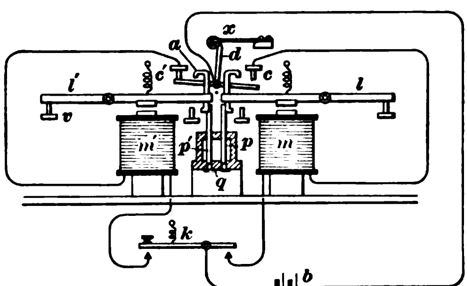


FIG. 11

after having made a hole in the lower or left-hand half of the tape. The rocking beam *d*, having been moved to the left, the circuit of the other magnet *m* is now closed at contact *c*, so that when the key *k* reaches its back stop, magnet *m* is energized, lever *l* attracted, and punch *p* is forced through the tape, making a hole in the upper, or right-hand half. The tape is kept constantly running, but the action of the punches is so quick, its movement is not perceptively checked. Thus, the perforating operator works his key in the regular way. Pressing down the key makes a hole on the lower half of the tape; as long as the key is held down the tape merely moves along; as soon as the key is released a hole is punched on the upper half;

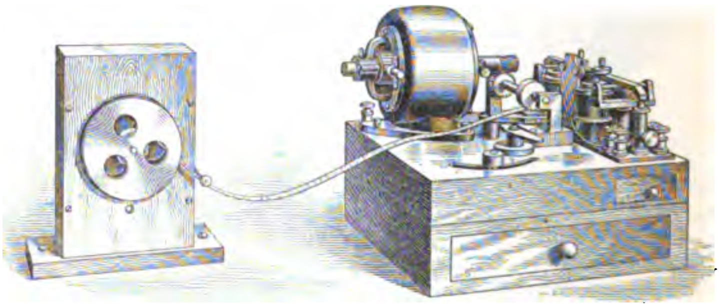


FIG. 12

hence, the horizontal distance between two holes on opposite halves of the tape (measured along the center line of the tape) depends on the length of time the key is held down.

31. The Morse signals produced by the transmitting typewriter, by a regular Morse key, or by some form of vibrating key may be passed through an electromagnet that is arranged to operate the key *k* which in turn controls the perforator. The general appearance of the perforator is shown in Fig. 12.

The transmitting key or other device may be located at the main office or at branch offices, the perforator being located at the main office where the perforated tape can be used for transmission at a higher speed over busier trunk lines.

The perforated tape may be passed through Delany's electromechanical transmitter and recorded as a punched tape by an automatic receiving device at the receiving end of the line, or it may be used in his chemical transmitter.

32. Advantages of Perforating Process.—The original manipulation of an operator in preparing the message, even by means of an ordinary key, is improved by the perforating process, because all impulses, whether regularly or imperfectly made by the operator's key, make the same sized hole in the tape. The impulses over the line are therefore very uniform. Of course, the variations in length of dots, dashes, or spaces will be faithfully duplicated on the receiving tape, but the evenness of impulses passing over the line from the uniform perforations greatly improves the general quality of the work.

Obviously, the original preparation of the message and the transcription by sound may be carried on at any rate that the operator is capable of perforating or reading by sound. For instance, a Morse keyboard transmitter can be used for perforating at 50 words per minute, there being no interruptions incidental to a line, and no operator at the distant end to limit manipulation by the perforating operator. Similarly, the operator reading by sound from the reproduced tape at the receiving station may regulate the speed of his tape to any rate that he is capable of reading and working his typewriter, and may confirm any doubtful word by looking at the perforation. Transcription may be done direct by those not proficient in reading by sound but who can read the tape by sight.

An inexperienced operator at some way station may perforate 10 words per minute, the message goes over the line at 100 words per minute, and is transcribed by sound, locally, at the receiving station at 25 words per minute. Ordinarily, if this message was sent directly over the line the entire use of the wire would be monopolized by the slow operator.

It is claimed that this system duplexed will yield 200 words per minute in perfect Morse, and without the slightest deviation from the regular Morse method, the sender working his key, and the receiver copying by sound, while the message capacity of the duplexed wire is increased from about 40 words per minute to 200.

DELANY CHEMICAL TELEGRAPH SYSTEM

33. Chemical Telegraph Systems.—By means of chemical telegraph systems, considerably higher speed is possible than with the quickest acting electromagnet used in the Wheatstone receiver. Receiving instruments all require a certain amount of energy to operate them, and, in addition, most of them have inertia in the moving parts. The Wheatstone receiver, which has proved very successful, may be taken as representative of a type of receiver possessing inertia in the moving parts. As a type of instrument having no inertia in the recording mechanism may be mentioned the various forms of chemical receivers acting by electrolysis.

34. A simple method of obtaining records of transmitted currents is to place chemically prepared tape upon a smooth metal surface, which serves as one electrode, and to draw over it a steel needle, which acts as the other electrode. If a direct current is used, no record appears when the current is in one direction, but it does appear when the current is reversed.

Many chemical transmitters used or proposed have heretofore consisted of a revolving wheel over which the perforated tape was drawn. This wheel was connected to the transmitting battery. On top of the tape pressed a scraping finger, which was connected to the line. When a hole in the paper came between the line and the wheel, an impulse was transmitted. Contacts made in this way were rather imperfect, and frequently missed altogether, on account of the collection of dirt and dust on the face of the wheel.

35. Tailing.—Suppose that the electromotive force has acted long enough for the current at the receiver to reach its steady value, and then that the circuit is suddenly broken at the transmitter. Some time will elapse before the current in the receiver is reduced to zero. The manner in which the break is made has considerable influence on the character of the record. A slow break when there is an arc, or a spark, is different from a rapid one. In any case the whole line has been charged to the limit of the electromotive force used and a current continues to flow from the line through the receiving end until the static charge has run out. This produces the effect commonly known as **tailing,** which means that a signal may become so drawn out at the receiver that it interferes with the following signal. With this plan, the effect of tailing is reduced or eliminated.

Furthermore, the current requires time to become established at the receiving end of the line after the electromotive force is introduced at the sending end. There is evidently a practical limit to the shortness of the time that the electromotive force must remain applied, which is determined by the smallest current that the receiver is capable of recording. If the potential between the terminals of the receiver is increased, the time required to make a given record is correspondingly reduced.

36. Chemical receivers possess many advantages, perhaps chief among them being the fact that a large part of the energy received is brought to bear directly upon making the record. Another feature is the simplicity of the essential mechanism involved, as no intermediate steps are used after the impulse is received from the line before the record is made. These qualities alone imply rapidity, and the chemical receiver is one of the most rapid known.

37. Telepost System.—Mr. Delany claims that he has overcome most of the foregoing obstacles to high-speed telegraphy by his chemical recording apparatus and automatic transmitters, which were used by the Telepost Company. The three essential features of his system are the perforator, transmitter, and receiver. An ordinary telegraph key, Delany's keyboard, or any form of vibrating key may be used to control the operation of the perforating machine which has already been described; the perforated tape is then passed through the transmitter and the signals in the form of dots and dashes are reproduced by chemical action on a chemically prepared tape that passes through the receiver.

38. Static Discharge.—The static discharge after each impulse runs out at the ends of a line wire, about two-thirds coming back to the sending station, and one-third following the signal impulse on to the receiving station. The portion coming back is an obstacle in the way of the next signal, and the portion running out has the effect of elongating the signal that it follows, and if the signals are too close together and the wire long enough, they will appear on the recording tape as a solid line without definition, so that a letter p, comprising five dots, would look like a letter l, which is a long dash. The remedies for this very troublesome obstacle in the past have been transmission of reverse impulses after each signal, so as to neutralize the static discharge in the line, or connecting the line to ground after each signal, so as to let the static run out. Another way was to put artificial leaks or partial grounds at different points along the line and work over them by surplus power.

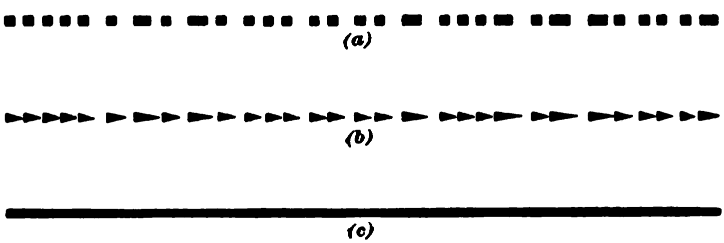


Fig. 13

The first of these remedies is the only one that is practically effective, as the static discharge can be neutralized in about one-tenth of the time taken for its discharge to ground.

Fig. 13 (*a*) represents a record at a speed of 300 words per minute over a line 10 miles long having very little, or inappreciable static capacity. (*b*) represents the same word at the same speed over a line 100 miles long, and having considerable capacity. (*c*) represents this word over a line 500 miles long.

39. Telepost Circuit.—In this chemical system, which Delany states is adapted to all distances and conditions, it will be shown that in the formation of dots the static discharge is neutralized by reversals, and the static discharge is utilized for completion of dashes, which are really dot impulses, supplemented by the discharge, and when under certain conditions, the discharge from the line is not sufficient to draw out the dash to the required length, it is increased by adding capacity through the medium of a condenser between the line and ground.

Fig. 14 is a diagrammatic representation of the telepost circuit. The sending tape *t* shows two rows of perforations. Each signal, dot or dash, is represented by two holes, one in the lower row, the other in the top row. Positive impulses are made through the lower row, negative impulses through the top row. All the positive impulses make a record on the receiving tape *r*, because current flowing from the line and brush *w* through the chemically treated paper to the metallic drum *a* and to ground will cause chemical action that will make a mark on the

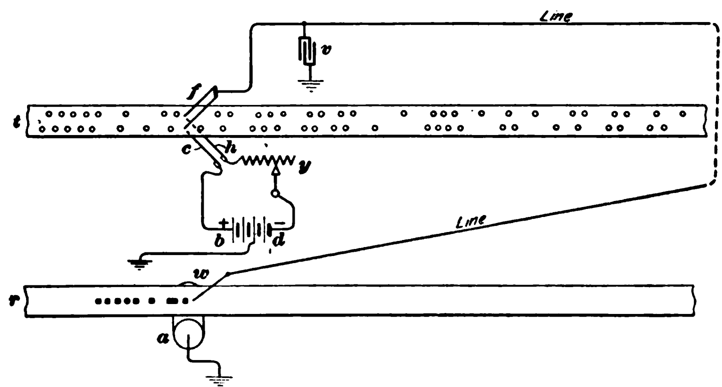


Fig. 14

tape. The negative impulses from the upper row do not record, because current in this direction produces no chemical action on the brush; hence, negative impulses are represented by the spaces between successive dots.

40. The pairs of perforations representing dots are just out of line, so that in passing between the contact fingers of the transmitter the fingers will not bridge and short circuit the battery The contact fingers *f* pressing on top of the tape are electrically one and are connected to the line, the contact fingers pressing upwards underneath the tape are separate, one *c* being connected to the positive terminal *b*, while the other *h* is connected to the negative terminal *d* of a battery. The battery is grounded in the middle. When the tape is drawn by a motor, and the lower hole allows contact fingers *f* and *c* to come together a positive impulse is sent over the line and is recorded on the receiving tape *r* as a dot. When a hole in the upper row permits contact *f* and *h* to come together a negative impulse goes over the line, but it makes no mark on tape *r*. It performs useful work, however, in preventing the positive dots from running together on the receiving tape. In the case of a dash, the positive and negative holes in the tape have a greater angle, that is, are farther apart along the tape. The negative does not follow the positive immediately, as in the dot. It is set back a distance so as to represent a dash; therefore, while the contact fingers *f* and *c* are separated by the tape some of the static charge is running out at the receiving station and continues the mark, that started with the dash impulse, until the contacts *f* and *h* come together in the delayed upper hole and a negative impulse is sent to cut off the dash at a corresponding length. It will be understood that the record on the receiving tape *r* is made by electrochemical action. This tape *r* is dampened with ferrocyanide and certain other chemicals, which when acted upon by a positive electric current decomposes the iron recording wire *w*, leaving an indelible mark.

41. Where there is not sufficient discharge at the receiving end of the line the condenser *v* can be regulated to make up the deficiency. This condenser is charged at the same time as the wire, and its discharge follows up the signal impulses so as to prolong the tailing on the receiving tape. If a few miles of underground cable are included in the circuit, the cable will take the place of the condenser, which shows that underground lines, so difficult for electromagnetic telegraphy, are conducive to the operation of this rapid system up to certain limits. Of course, it is possible to have an excess of static capacity, but when this point is reached the best results may be obtained by regulating the power of the negative impulses, and adapting them to the requirements for density and definition in the record. With a line having just enough capacity to fill out the dashes, the negative current should be considerably weaker than the positive. If of equal strength, the recorded impulses will be too short and faint. If on the contrary there is too much

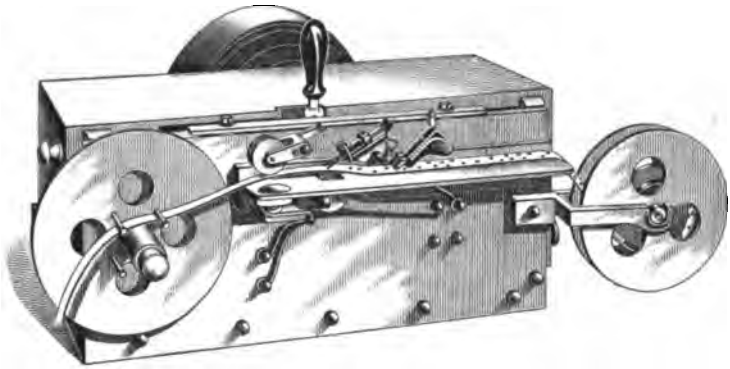


FIG. 15

capacity the negative current may be strengthened. The regulation of the negative is effected through the adjustable resistance *y*. The transmitter is shown in Fig. 15 and the receiver in Fig. 16.

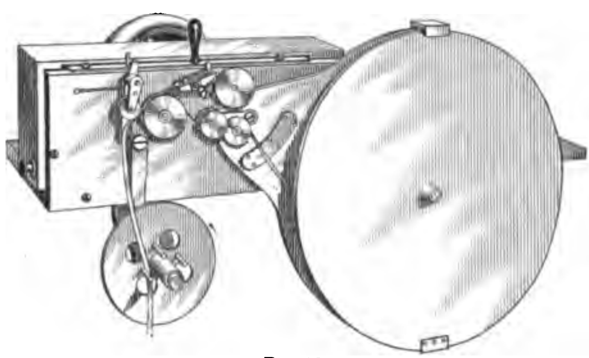


FIG. 16

42. Telepost Morse Alphabet.—In Fig. 17 is given the Morse alphabet used by the Telepost Company. It is practically the Continental, or as it is also called, the Universal code, with the addition of the character & (- - — —) and for brevity, the substitution of the Morse paragraph signal (— — — —) and a new combination (- — - — -) for the naught. With these exceptions it is the code used everywhere for cable and wireless telegraphy and on about all land lines outside of the United States and Canada.

43. Advantages of Chemical Telegraph System.—In the Delany chemical telegraph system three very important factors are combined for obtaining the best results from a telegraph circuit: First, a positive current sufficiently powerful to make the record electrochemically in the shortest possible time; second, a regular source of electrostatic capacity for use where the normal capacity is not enough to make a dash;

A	- —	O	— — —	. Period	- - - - - -
B	— - - -	P	- — — -	, Comma	- — - —
C	— - — -	Q	— — - —	¶ Paragraph	— — — —
D	— - -	R	- — -	1	- — — — —
E	-	S	- - -	2	- - — — —
F	- - — -	T	—	3	- - - — —
G	— — -	U	- - —	4	- - - - —
H	- - - -	V	- - - —	5	- - - - -
I	- -	W	- — —	6	— - - - -
J	- — — —	X	— - - —	7	— — - - -
K	— - —	Y	— - — —	8	— — — - -
L	- — - -	Z	— — - -	9	— — — — -
M	— —	&	- - — —	0	- — - — -
N	— -				

FIG. 17

third, adapting the power of the negative current to the normal or artificially augmented electrostatic capacity of the line, in order to give the record the maximum plainness consistent with safe separation of the characters, so as to make transcription easy and accurate.

The inventor thinks that in this organization is reached the highest signaling efficiency for all conditions of lines, overhead, underground, long, or short. There are no electromagnets to energize, no armature to actuate, no inertia to overcome, or electromechanical work to do. The chemically prepared tape is a part of the circuit, and the characters are made simply by the current passing through it. Once installed on a line, there is practically no adjusting to do. A change in weather conditions sufficient to put out of operation any electromagnetic system does not seriously interfere with the electrochemical. Half the current might be suddenly diverted during transmission without loss of any of the characters. The record will be fainter, but no impulses will be missing. The system can be superimposed on a telephone circuit and worked simultaneously with telephony at about two-thirds of its independent speed.

44. As the tape bearing the message comes from the perforator it is automatically wound upon a reel, and whether there be one or a dozen messages, or 500 words for a newspaper, the tape is a single unit, and goes through the transmitter last end first. At the receiving station, the tape is also wound upon a reel, which brings it right end first for transcription.

The received tape is drawn in plain view of the transcribing operator by means under his own control, not continuously moving, but in fixed steps, so that it is at rest while being read. The receiving machine is under control of the transmitting station. When the transmitting lever is put down to start the tape, an impulse that starts the receiving tape is sent. When the transmitting tape runs out another impulse which stops the receiving tape is automatically sent. Should the receiving operator wish to stop the transmitting machine he can do so, and the transmitting operator can stop the receiving machine at any stage.

45. As long as any current reaches the receiving station, the tape will record it, although with a mark of lighter shade as the current decreases. Interruptions that interfere with electromagnetic systems, due to bad insulation, are reduced in the chemical system and it is only necessary that the circuit shall be clear enough for operators to get intelligent Morse signals over it, to receive clear messages on the tape.

Among improvements in transmitting and receiving apparatus devised by Delany are electromagnetic starting and stopping devices by which the transmitter may be automatically started or stopped from the receiving station; or the receiving instrument automatically stopped or started from the transmitting station. The running out of the transmitting tape automatically stops the receiving instrument.

46. The offices are connected with each other over a circuit normally equipped with Morse instruments and when messages are to be sent by the chemical system, the sending operator notifies the receiving operator and by throwing one switch at each station the automatic instruments are put on the circuit and started.

One difficulty with receiving tapes has been that they expand when placed in the chemical solution after having been rolled

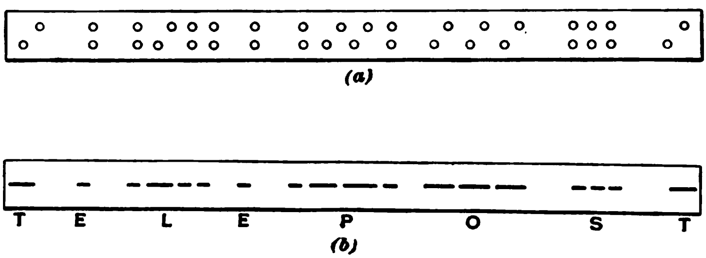


FIG. 18

up on a reel for use. This expansion tears the tape and unfits it for use. To remedy this Mr. Delany passes the tapes through crimping rolls, which corrugates them in different styles, longitudinal, transverse, in straight, and in wavy lines, thereby allowing them to be wound as firmly as may be necessary for handling and allows the fluid to saturate the tape without tearing it.

47. Chemical Tape Record.—In Fig. 18 (*a*) is shown a perforated tape used in the transmitter and in (*b*) the electrochemically printed receiving tape. The two top brushes being at a slight angle, instead of straight across the paper, accounts for the two dot holes being directly above one another.

At 1,000 words a minute eighty-two persons will be kept busy over a single wire, forty perforating messages for transmission, forty transcribing them by typewriter, and two machine tenders. This will be more than the equivalent of forty Morse circuits as at present operated.

48. Solutions for Chemical Receiving Tape.—The solution for saturating the paper tapes used in chemical telegraph receivers should be one that is easily decomposed; it should contain some so-called deliquescent chemical, that is, a chemical that does not dry out, but rather absorbs moisture from the air; the record made should be permanent; and the resistance of the moistened paper should not be too high. The resistance may be reduced by putting a little sulphuric acid in the solution; not enough, however, to act upon and corrode the marking styles. A good chemically sensitized paper will have a resistance of about 275 ohms between the marking style and the metal roller beneath it.

49. The following solutions for chemically sensitizing the paper tape for use in chemical telegraph receivers may be used:

Solution No. 1.—Potassium ferricyanide, 1 part; nitrate of ammonium, 30 parts; water, 2 parts.

Solution No. 2.—Nitrate of ammonia, 4 pounds; ferricyanide of potassium, 1 ounce; gum tragacanth, 4 ounces; glycerine, 4 ounces; water, 1 gallon.

Solution No. 3.—Nitrate of ammonium, 2 pounds; chloride of ammonium, 2 pounds; ferricyanide of potassium, 1 ounce; water, 1 gallon.

Solution No. 4.—Iodide of potassium, ½ pound; bromide of potassium, 2 pounds; dextrine or starch, 1 ounce; water, distilled, 1 gallon.

Of those solutions, No. 1 or No. 2 may be considered best for steady work on short circuits, and being also of comparatively high resistance, it is least affected by leakage from other lines. No. 3 is much more sensitive and can be made to record with the faintest trace of current; it is therefore well adapted for long circuits. No. 4 is highly sensitive and capable of the most perfect and beautiful work at an extremely high rate of speed.

DELANY SYNCHRONOUS MULTIPLEX TELEGRAPH SYSTEM

50. The synchronous multiplex telegraph system devised by P. B. Delany, of South Orange, New Jersey, is based on two main principles: That of synchronism, or the simultaneous motion of similar pieces of apparatus at two different places; that of distributing to several telegraph operators the use of a wire for very short equal periods of time, so that practically each operator has the line to himself during these periods.

As Delany's system is so entirely different from the duplex and quadruplex systems, it is proposed for clearer definition to give to the modes of working his system names based on the Greek word *hodos* (a way). Thus, a two-way mode of working,

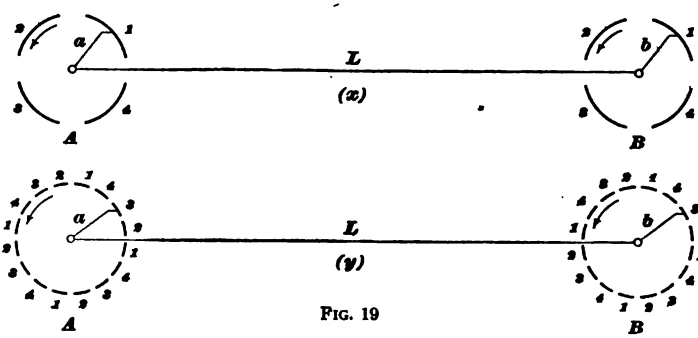


FIG. 19

or a mode by which two messages are practically sent at the same time, will be *diode* working; three-way, *triode;* four-way, *tetrode;* five-way, *penthode;* and six-way, *hexode.*

Duplex and quadruplex are such well-rooted and explicit terms defining particular modes of working by compensation, that their application to different modes of working based on a different idea may lead to confusion, while new and distinct terms will confine the attention to a new and distinct system.

51. In Fig. 19 (*x*), *A* and *B* are two offices connected together by a line wire *L*. If the arms *a* and *b*, which are in electrical connection with the line wire *L* at *A* and *B*, respectively, rotate simultaneously around the circles *1 – 2 – 3 – 4* at each station in the direction of the arrows, making contact upon the segments as they pass, when *a* touches *1*, *b* will touch *1*; when *a* touches *2*, *b* will touch *2*; and similarly for *3* and *4*. If *1*, *2*, *3*, and *4* at each office are each in connection with a set of similar telegraphic apparatus, the four sets at one office will be in direct communication with the four sets at the other office as the arms *a* and *b* touch their corresponding segments. Thus, for each rotation of the arms, the instruments connected to *1* at *A* and at *B* will be in direct communication with each other once; and so on with those connected to *2*, etc.

52. If each segment is divided into four segments, as shown in Fig. 19 (*y*), and every fourth one of these smaller segments is connected with one of the four instruments instead of one large segment being connected with only one of them, as in (*x*), then during one complete rotation, each arm will place corresponding instruments, one at each end, in communication with one another four times for each revolution. Thus the instruments are connected together for four short periods of time separated by intervals during which the other three instruments are successively connected together instead of being connected together once during a revolution for a single period of time four times as long. Furthermore, each circle may be divided into forty segments and each of these forty into four segments; then corresponding instruments will be in communication with each other forty times during each complete rotation of the arms *a* and *b*. The intervals of disconnection are so brief that the current impulses are practically continuous. In Delany's apparatus there are eighty-four segments in the whole circle, which are grouped according to the number of ways of working. Hexode working requires one grouping, triode another, diode another, and so on.

53. Maintaining Synchronism.—Two tuning forks pitched to absolutely the same note and set in vibration by currents like an electric trembling bell will move in synchronism, but the synchronism cannot be maintained. The deposition of dirt, dust, or moisture, changes of temperature, and variation of current produce changes that affect the rate of motion.

Paul la Cour, of Copenhagen, invented an ingenious way of maintaining synchronism. In Fig. 20, E is a tuning fork vibrating between the poles of the magnet F. At one contact point p is completed a circuit containing the battery H and an electromagnet M; the other contact q completes the circuit containing the battery I and the electromagnet F. Every time the tuning fork touches the contact point p a current is

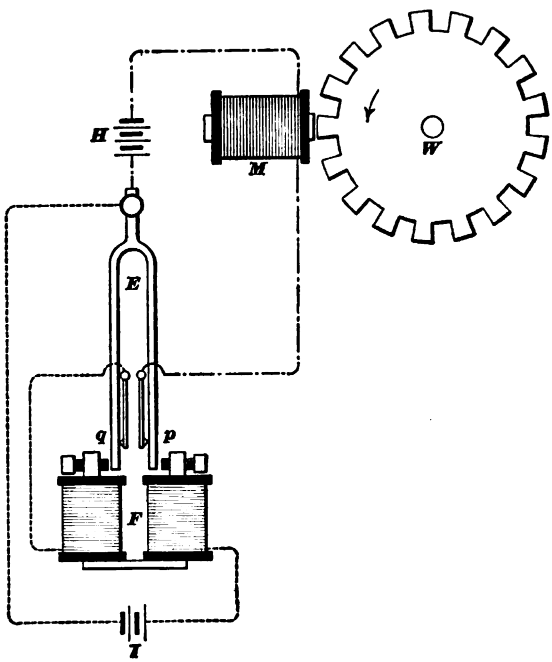


Fig. 20

sent through the electromagnet M which, therefore, is magnetized once for every movement to and fro of the fork. In front of the magnet M is a wheel W having iron teeth, and every time the magnet M is excited, attraction is momentarily exerted on the nearest tooth. If the tooth is approaching the pole, it is urged forwards, and if it is moving away from the pole, it is retarded; hence, the wheel can be propelled with wonderful uniformity and with considerable force. The electromagnet *F* is similarly excited, and it keeps the fork in constant vibration. The wheels must be started by giving them a turn by hand, as they will not start otherwise. Delany uses this *phonic wheel*, as it is called, but he has adopted a reed instead of a tuning fork.

54. Advantages of Synchronous Multiplex System. The Delany synchronous multiplex system somewhat modified and improved was used in England for a while. Its advantage over other systems is that it does not disturb the general mode of working. The sounder, relay, and key system is retained. All initial delay due to punching, as in automatic systems, is avoided. The skill of able operators is fully utilized and each operator has practically an independent circuit. When there is a rush of traffic in one direction, the system can be worked all in one direction, and not only half of it as in the quadruplex. However, this system requires rather a delicate apparatus that is liable to get out of order and out of synchronism, but as it involves principles employed in other similar systems it has been briefly outlined here. In Europe, synchronous systems have given better satisfaction and are used somewhat; no synchronous system has been used in North America for some years.

HARMONIC TELEGRAPH SYSTEMS

55. Harmonic telegraph systems depend on the sending of alternating currents of different musical frequencies through the same circuit. A number of electrically driven tuning forks, vibrating at different frequencies, are connected through telegraph keys to a line wire; depressing a key will send a series of electric vibrations of the frequency of the tuning fork associated with it through the line. At the distant station, each receiver is designed to respond to the vibrations from one particular tuning fork only. This system was originated by Elisha Gray in America, but has been developed and improved by Mercardier of France, where it is said to have given good results in 1909. The receiving device, which resembles a telephone receiver, is called a *monotelephone*, and each one is made and adjusted to respond to one frequency only. By the harmonic telegraph systems it is possible to send as many as twelve simultaneous messages in one direction and double that number if duplexed.

CREHORE AND SQUIER SINE-WAVE SYSTEM

56. Let the sine curve, Fig. 21 (*a*), represent a regular succession of simple alternating-current waves given to the line by an alternating-current generator. If the current passes through a key that may be opened or closed at pleasure, then, provided the key previously closed is opened at a time corresponding to the point *p* of the wave upon the horizontal axis, the current that was zero at the instant the key was opened will remain zero in circuits that have resistance alone. If the key could be closed exactly at a time correspond-

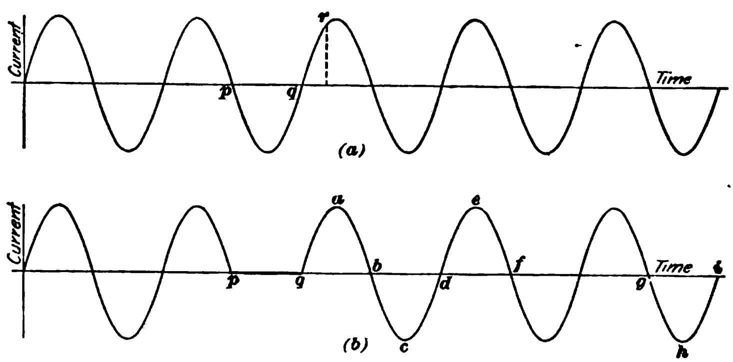


FIG. 21

ing to the point *q* on the curve, also upon the axis, the current would resume its flow undisturbed according to the sine curve. The true current obtained by opening the key at *p* and closing it at *q* is shown in Fig. 21 (*b*), where the current remains at zero between these two points.

If the key is closed at any other point than *q*, as at *r*, the current will not resume its flow according to the simple sine wave, but will give a succession of waves alternately smaller and larger than the normal sine wave for a very few alternations, after which it will practically coincide with the sine wave. Furthermore, if the key is opened at some other point than p, when, therefore, the current is not zero, a spark may be observed at the break, and it requires time for the current to fall to zero.

No spark is made in a transmitter adjusted to break the circuit at the exact times when the current is naturally zero. This makes it possible, if it is found desirable, to use comparatively large electromotive forces and currents on the line, for no matter what the maximum value of the current, it is made and broken by this plan with no sparking. It is also possible to use waves of high frequency upon the line, the upper limit obtainable from an ordinary alternator being probably much higher than can be utilized for telegraphic purposes.

57. If a receiver that could reproduce an exact trace of the actual waves sent over the line were used, the curve traced

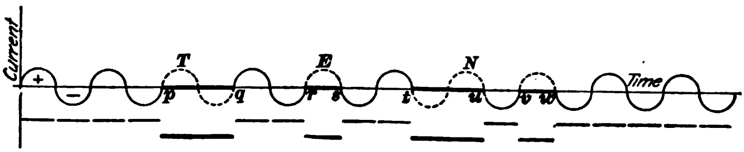


FIG. 22

would resemble that represented by the heavy curve in Fig. 22. The sine wave continues uninterrupted to the point p, when the key is opened and held open for one complete wave length $p\,q$, when it is again closed for a wave length $q\,r$, then opened for one-half a wave length $r\,s$, closed for a wave length $s\,t$, opened for a wave length $t\,u$, closed for half a wave length $u\,v$, opened for half a wave length $v\,w$, and finally closed. By this plan it is possible to use the ordinary Continental telegraph code, a dash being indicated when two successive waves, a positive and a negative one, are omitted by keeping the key open, and a dot when a single half-wave is omitted.

The space between parts of letters, as between the dot and dash of the letter *n*, is indicated by the presence of one-half a wave length, and the space between letters, as between *t* and *e* in the word ten, by the presence of two half-waves, while the space between words may be represented by the presence of three half-waves, and the space between sentences of four half-waves, or more. The foregoing is one example, of which there are many, of a method of using alternating-current waves and shows how these signals may be interpreted by a fixed code.

58. Speed of System.—A consideration of the time required to send the word ten by the above plan shows that it corresponds to the time of eleven half-waves of current. If the frequency is an ordinary one used in alternating-current work, viz., 140 complete waves per second, the time required to send the word ten is .0394 second, or, by allowing three additional half-waves for the space between the words, the word ten would be sent just 1,200 times in 1 minute. There is no difficulty in using over some lines a frequency as high as 560 periods per second. This would correspond to sending the word ten 4,800 times per minute. This limit in each instance is only determined by the particular line used. (It is doubtful if these very high speeds could be obtained in practice even on short lines.)

59. Action of System.—It will be sufficient to show how any single half-wave may be omitted; for obviously any word or sentence may be formed by the omission of half-waves at suitable intervals. Imagine one metallic brush bearing upon the smooth circumference of a metallic wheel and another metallic brush bearing upon the axle. One brush is connected through the armature of an alternating-current dynamo to the ground, and the other brush is connected to a line wire. The wheel and axle upon which the brushes bear are geared to the axle of the alternating-current dynamo and hence revolve in synchronism with it.

60. If the periphery of the wheel is divided into forty equal parts, and it is geared to run at one-fourth the speed of an armature that revolves in a field having ten poles, each division thereof corresponds to one semicycle of the electromotive force produced by the generator. If both brushes remain continually in contact with the wheel and axle, the current transmitted will have the regular sine form represented in Fig. 21 (*a*); and for each revolution of the wheel there will be forty half-waves, or twenty complete waves, transmitted. If one-fortieth of the circumference of the wheel is covered by paper or other insulating material, and the brush bearing on the circumference of the wheel is adjusted to ride on to and off this insulation just as the current is changing from one semicycle to the next, that is, changing its sign, while the other brush is in continuous engagement with the axle, the semicycle represented by the section covered will be suppressed, and without any sparking, even if the potential used is high. In practice, the brush bearing upon the circumference of the wheel is easily adjusted to this point by moving it slightly backwards or forwards around the circumference of the wheel until the sparking ceases; this adjustment having been once made, the brush is fixed in position. In each succeeding revolution of the wheel, this cycle of operation is exactly repeated, and the current sent over the line will resemble that shown in Fig. 21 (*b*), having every fortieth semicycle omitted. It is only necessary to cover other similar sections of the circumference of the wheel in a predetermined order according to a code, or to draw a properly punched tape over the wheel without allowing it to slip, in order to transmit intelligence over the line. By this method of operating upon the alternating current, there is control of the individual half-waves of the current, which may be changing direction thousands of times in a second, far beyond the range of possible control by hand.

It has been shown by Crehore and Squier that theoretically two messages may be sent simultaneously by this method in the same direction or one in each direction over the same line.

61. Sine-Wave Transmitter.—Messrs. Crehore and Squier perfected a practical telegraph transmitter using an alternating sine-wave current, which is suitable for cable and land lines. It will operate their chemical receiver, the Wheatstone receiver, or a siphon recorder. The transmitting tape, however, is punched somewhat differently in each case. This transmitter was described in a paper presented by them to the American Institute of Electrical Engineers in May, 1900. They have also invented a chemical receiver that produces a chemical record in page form instead of on one continuous tape. As the sine-wave system is not in use, it will not be further described.

62. The advantage claimed for this transmitter is the increase in speed that may be obtained with its aid over cables, and especially over long lines where higher frequencies may be used on account of the smaller electrostatic capacity. This increase in speed is partly due to the use of a higher voltage, as with a battery transmitter like the Wheatstone or Cuttriss, voltages over a certain value are not practicable owing to the sparking at the contacts, the line currents being interrupted at full strength; whereas, the sine-wave transmitter uses alternating currents that are interrupted only at the zero instants, whatever electromotive force is used. A trial made between London and Aberdeen without repeaters showed that the limiting speed was 107 words per minute with the ordinary Wheatstone transmitter, and 195 words per minute with the sine-wave transmitter, using an electromotive force of only 230 volts.

In telegraph stations where a number of sine-wave transmitters are used simultaneously, there would be a single alternating-current dynamo for the whole station and a separate small synchronous alternating-current motor at each desk. The sole duty of the latter is to draw a paper tape under contact brushes in step with the impulses of the generator. The single alternator not only drives the synchronous motors, but also supplies the line with alternating currents through the contact brushes. The use of sine-wave transmitters for submarine-cable transmission has been advocated.

63. Sine-Wave Transmitter and Wheatstone Receiver.—The sine-wave transmitter can operate the Wheatstone receiver about three times as fast as the Wheatstone transmitter on any line, provided the mechanical limit of the receiver, which is about 600 words per minute, is not already reached. Furthermore, it has been worked on circuits that ordinarily require two repeaters, without any repeaters, and at any speed up to the mechanical limit of the receiver. The sine-wave transmitter and Wheatstone receiver will work successfully on a line $1\frac{7}{10}$ times as long, at the same speed as the Wheatstone system, provided the mechanical limit of the receiver is not exceeded. With copper wire weighing 800 pounds to the mile, the sine-wave transmitter can operate to the limit of the Wheatstone receiver any distance less than 1,800 miles, while the Wheatstone system using the same wire can operate to the same limit any distance less than 1,260 miles.

64. Wheatstone Receiver Shunted by a Condenser. When the Wheatstone receiver is used in connection with the sine-wave transmitter, it is possible to increase the receiver current materially, making it even larger than the line current, by connecting a condenser of such a capacity around the receiver that the inductive reactance of the receiver is neutralized by the capacity reactance of the condenser. By knowing the inductance of the receiver and the frequency, the capacity of the condenser that should be used to give the best results can be calculated by the formula

$$C = \frac{1}{L\,(2\,\pi f)^2},$$

in which C = capacity of condenser, in farads;
L = inductance of receiver, in henrys;
f = frequency;
$\pi = 3.1416$.

From this it is seen that the capacity of the condenser should vary inversely as the square of the frequency f, although the value of the capacity for any frequency is not very critical; that is, a condenser of approximately correct capacity will improve the working for a considerable range of speed.

POLLAK-VIRAG TELEGRAPH SYSTEM

65. The method of high-speed telegraphy devised by Pollak and Virag, of Austria, has excited considerable attention. Experiments made over a metallic circuit 400 miles long, having a resistance of 4,000 ohms, and using a battery of 20 volts gave clear signals, both in wet and dry weather, at a speed of 70,000 words per hour, while with 25 volts a speed of 100,000 words per hour was attained. Trials between Budapest and Berlin, in the fall of 1899, gave distinct and readable signals at speeds of from 1,300 to 1,500 words per minute.

This system gives of course a great improvement in speed over ordinary telegraphy, but while the actual sending of the electric signals is much faster than the common methods, this advantage is lost in a great measure, if not fully offset, by the time and complication of making the messages ready for the wire and of translating them into a written language at the receiving end. The telegram must first be changed into the characters of the Morse system and the tape perforated, as in the Wheatstone system. After reception, photographed strips must be developed and then translated into ordinary language. This complicated manipulation may lead to many errors in transmission. This has been found to be the great objection to many high-speed systems heretofore, and is the reason why the Wheatstone system has not been more extensively used in America.

66. The transmission is effected by a perforated strip of paper, while a telephone fitted with a small concave mirror serves as the receiver. The diaphragm of the telephone is set into oscillation corresponding to the current impulses generated by the transmitter and these oscillations are made visible photographically. The dots and dashes of the Morse code are represented by strokes or zigzag lines on both sides of the central line of the receiver tape, resembling somewhat a submarine siphon-recorder tape record.

POLLAK-VIRAG WRITING TELEGRAPH

67. Pollak and Virag have also devised a writing telegraph system in which a suitably perforated transmitting tape put through a transmitter causes the receiver, having two telephone diaphragms governing the motion of a single concave mirror, to trace the letters with a beam of light in a rather stilted mechanical form on a light-sensitized moving tape. After developement, the writing appears on the tape ready for delivery.

In Fig. 23 is shown the letters telegraf as written by the receiving instrument. By this method a speed of 1,000 words a minute was secured over a pair of telephone-line wires. The Pollak-Virag systems do not seem to be used commercially, and hence no further descriptions will be given here.

68. In the Pollak-Virag systems, there is no need for the synchronizing of the sending and receiving apparatus, for variations in the speed at either end merely broaden or narrow the letters; and, therefore, the inventors claim that this system is simpler and considered more reliable from this point of view. With the aid of a distributor (such as Delany's) it is

FIG. 23

claimed that about thirty sets of apparatus could be arranged to work on one line. At a trial, allowed by the Hungarian Minister of Commerce, most excellent results were said to have been obtained over two pair of telephone wires from Budapest to Pozsony and back, a distance of nearly 230 miles. The rate of transmission, at which rate very good writing was produced, reached 1,000 words per minute through a resistance of 2,000 ohms.

DISADVANTAGES OF VERY HIGH-SPEED SYSTEMS

69. The disadvantages of sending messages at the high rate of 1,000 to 1,200 words a minute, where the characters are received in Morse code, and have to be transcribed manually, as in the chemical system, is the division and distribution of the pieces of tape among the large number of operators necessary to keep abreast of the work, the injurious effect of brief contacts caused by linemen and others, which result in the loss of several words, and last, but not least, the difficulty and delay in obtaining repetitions where errors, false signals, or missing words render this necessary.

While high-speed transmission systems may reduce the capital expenditure per message, very few of them increase the output per operator nor do they reduce the working cost in the instrument room; in fact, this cost may be higher for high-speed automatic transmission than with other methods. It is advantageous to reduce the cost of transcription at the receiving end as is attempted in the automatic printing systems.

ADVANTAGE OF SYSTEMS RECEIVING IN MORSE OR SIMILAR CODES

70. An advantage of the Wheatstone or other systems in which the received messages are translated from a tape record by an operator, is that signals mutilated in transmission that would appear unrecognizable in a printed record, may often be deciphered correctly from the tape by a good operator. Furthermore, the Wheatstone and chemical systems usually consist of less complicated mechanism than the printing systems. Inductive disturbances, especially from high-tension power and lighting circuits, and excessive retardation due to underground cables will reduce the speed efficiency at least in direct proportion to the sensitiveness of the respective systems.

Punching systems appear to involve a loss of time in handling individual messages, and in practice there is a saving of time in case of direct, that is unrelayed, transmissions only if everything works with smoothness and no mistakes are made. The correctness of the tape can be verified as it is being prepared and all errors eliminated, hence the loss of time while actually using the line is reduced to a minimum.

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Note.—All items in this index refer first to the section (see the Preface) and then to the page of the section. Thus, "Attenuation, §55, p40," means that attenuation will be found on page 40 of section 55.

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