TELEGRAPHY

MORSE TELEGRAPH SYSTEMS

Electric telegraphy is the art, science, or process of transmitting intelligible signals or signs between distant points by means of electric impulses moving between those points. The first successful system for an electric telegraph was patented by Samuel F. B. Morse in 1837.

Morse Closed-Circuit System.—Fig. 1 shows the arrangement of an ordinary telegraph circuit having two terminal stations *W*, *E*, and one intermediate, or way, station *I*. This, practically, is the arrangement devised by Morse, and is the one extensively used at the present time in America. At each station there is a relay *R*, a key *K*, and a battery *B* in series in the line circuit, the ground forming the return circuit. Each relay controls a local circuit containing a sounder *S* and a battery *LB*. Normally, all keys are closed; hence, the operation of any key, that is, opening and closing the key will cause each relay to open and close the local circuit containing its sounder. Thus, by sending a message in the Morse code by means of any one key, each sounder will give forth a

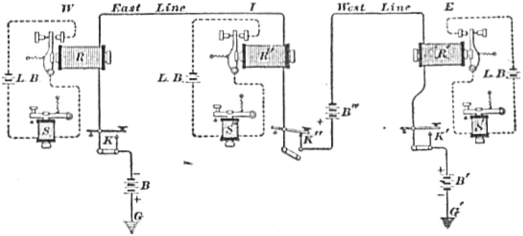

FIG. 1

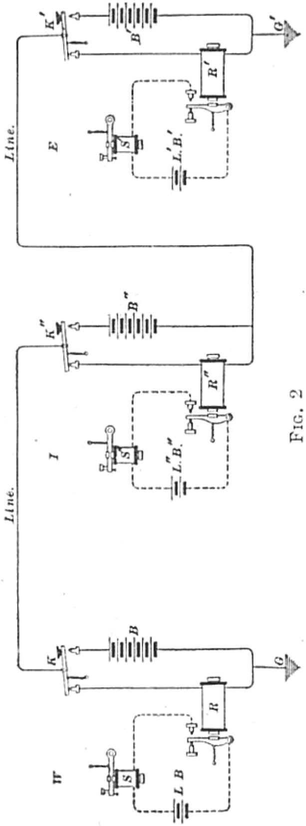

FIG. 2

click each time the line circuit is opened or closed, thereby enabling an experienced telegraph operator to read the message by sound.

Almost any number of intermediate telegraph offices may be connected in the same line circuit with two terminal offices. All cells required may be connected at any one point in the circuit, or they may be distributed at any two or more of the stations. This arrangement of apparatus is known as the *Morse closed-circuit system*, because, in normal condition, all keys are closed and current flows through the whole circuit.

Line circuits containing 150-ohm relays require about 40 milliamperes, and the local 4-ohm sounders, 250 milliamperes. For distances up to about 30 miles, main-line sounders having a resistance of 20 or 40 ohms and requiring about 180 or 70 milliamperes, respectively may be connected directly in the line circuit in place of the relays.

Morse Open-Circuit System.—The arrangement of apparatus in the Morse open-circuit system, as used in some European countries, is shown in Fig. 2. It will be noticed that equal main-line batteries B, B', B'' are required at each station, that only one is ever in use at any one time, and that each one must be powerful enough to operate all relays in the line circuit. However, all batteries are on open circuit when not in use.

TELEGRAPH CODES

The *Morse telegraph code* for letters and numerals and the *Phillips code* for punctuation are used throughout the United States and Canada. The *Continental code*, or *universal code*, as it is sometimes called, is used for submarine telegraphy all over the world and for land telegraphy in nearly every country except the United States, Canada, and parts of Australia. The Morse and Continental codes for alphabets, numerals, and punctuation marks and the Phillips code for punctuation marks are given on pages 352 and 353.

The dot is taken as the unit by which the length of the dashes and spaces are measured. The dash is made equal to the length of 3 dots. Theoretically, the extra-long dash (*0*, cipher) should be 9 units in length, but in practice it is usually made only 7 units. The space between parts of a letter is made 1 unit in length, while the space between spaced letters, as in *c*, *o*, *r*, *y*, *z*, &, in the Morse code, should be 2 units in length. The space between the letters should be 3 units, and the space between words 6 units in length.

The *Phillips code of abbreviations* is a sort of shorthand applied to telegraphy, and consists of single letters and combinations of two or more letters that arbitrarily represent figures, words, and whole phrases. For instance, *Cqas* means "closed quiet and steady," an expression extensively used in reporting stock quotations. This code, which contains several thousand characters and abbreviations, is published separately in book form. There are numerous other so-called codes, which are really abbreviations used to

ALPHABETS

Letters	Morse	Continental
A	·—	·—
B	—···	—···
C	·· ·	—·—·
D	—··	—··
E	·	·
F	·—·	··—·
G	——·	——·
H	····	····
I	··	··
J	—·—·	·———
K	—·—	—·—
L	——	·—··
M	——	——
N	—·	—·
O	· ·	———
P	·····	·——·
Q	··—·	——·—
R	· ··	·—·
S	···	···
T	—	—
U	··—	··—
V	···—	···—
W	·——	·——
X	·—··	—··—
Y	·· ··	—·——
Z	··· ·	——··
&	· ···	

NUMERALS

Figures	Morse	Continental
1	·——·	·————
2	··—··	··———
3	···—·	···——
4	····—	····—
5	———	·····
6	······	—····
7	——··	——···
8	—····	———··
9	—··—	————·
0	———	————— or —

PUNCTUATIONS, ETC.

		MORSE	CONTINENTAL		PHILLIPS
.	Period	· · — — · ·	· · · · · ·		· · — — · ·
:	Colon	— · — · ·	— — — · · ·	*KO*	— · — · ·
:—	Colon dash			*KX*	— · — · — · ·
;	Semicolon	· — · — ·	— · — · — ·	*SI*	· · · · ·
,	Comma	· — · —	· — · — · —		· — · —
?	Interrogation	— · · — ·	· · — — · ·		— · · — ·
!	Exclamation	— — — ·	— — · · — —		— — — ·
–	Fraction line	·	— —		·
—	Dash			*DX*	— · · · — · ·
-	Hyphen		— · · · · —	*HX*	· · · · · — · ·
’	Apostrophe		· — — — — ·	*QX*	· · — · · — · ·
$	Dollars			*SX*	· · · · — · ·
c	Cents			*C*	· · ·
£	Pound sterling		· — · — · · —	*PX*	· · · · · · — · ·
/	Shilling mark		· · ·		· · — —
d	Pence			*D*	— · ·
	Capitalized letter			*CX*	· · · · — · ·
:“	Colon followed by quotation			*KQ*	— · — · · — ·
.	Decimal point		· — —		— · — —
¶	Paragraph	— — — —	· — · — · ·		— — — —
	Italics or underline		· — · · · — · ·	*UX*	· · — · — · ·
( )	Parenthesis	· — · · —	— · — — · —	*PN*	· · · · · — · · · · · · — ·
[ ]	Brackets			*BX*	— · · · · — · · — · · · · — · ·
“ ”	Quotation marks		· — · · — ·	*QN*	· · — · — · · · — · — ·
	Quotation within a quotation “ ‘ ’ ”			*QX*	· · — · · — · · · · — · · — · ·

reduce the cost of telegraphing, especially in submarine-cable telegraphing.

Speed of Telegraphing.—The highest recorded speed of legible telegraphy, in which the Morse code was used, was made in a contest in which 265 words were sent in 5 min. However, a steady working rate of 25 to 30 words per minute is regarded as good sending. The proper way to hold a telegraph key while sending a message is shown in Fig. 3.

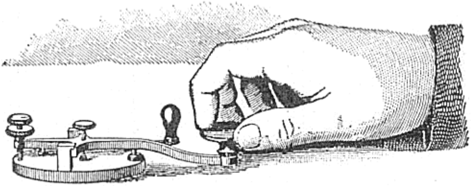

FIG. 3

TELEGRAPH SWITCHBOARDS

A *terminal switchboard* used where dynamos supply the current for the line circuits is shown in Fig. 4. The long vertical brass strips are connected to the part of the spring jack immediately below it. A side view of six jacks and the various ways of connecting them, also instruments connected through flexible cords and wedges, are shown. All metal disks in any one horizontal row are connected together, and different voltage dynamos may be connected through incandescent lamps L, L', or through non-inductively wound coils used as safety resistances to 5 or 6 rows of disks. Thus, by means of metal plugs, any vertical strip may be connected to any horizontal row of disks, thus enabling a large variety and number of connections to be made on a switchboard of this character. In this one, a circuit is formed from ground through dynamo–lamp L'–fourth row of disks–vertical strap q–jack Q–set W–third row of disks–vertical strap c–jack C–line. On some switchboards, every other pair of disks in hori-

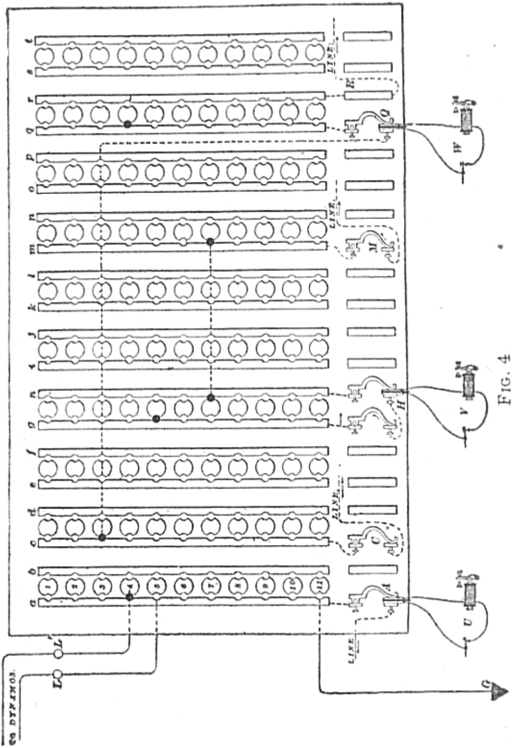
a
b
c
d
e
f
g
h
i
j
k
l
m
n
o
p
q
r
s
t
1
2
3
4
5
6
7
8
9
10
11
LINE
LINE
LINE
LINE
LINE
A
C
H
M
Q
E
U
V
W
T
L
G
TO DYNAMOS

FIG. 4

zontal rows across the board have saucer-like depressions to enable the chief operator to follow connections that he makes across the board more easily, thus reducing the liability of making wrong connections.

The way in which line wires and relay sets are connected by means of a small plug switchboard at an intermediate station is shown in Fig. 5. By properly placing metal plugs between metal strips *t* *s*, *p*, *o* and metal disks *m*, *l*, *c*, *a*, *n*, *i*, *d*, *b*, either relay may be connected in either line circuit, or the relays may be cut out entirely, or any line may be grounded with or without the relay in circuit with it. A plate *g* is connected with the grounded terminal *h*, being separated from the metal strips *t*, *s*, *p*, *o* by a thin sheet of mica, thus forming a static lightning arrester. With four plugs placed in the black holes *2*, *21*, *10* and *16*, the set *A* is connected in series with wires No. *2* west and No. *1* east and lines No. *2* east and No. *1* west are connected together. At larger intermediate and terminal stations, larger switchboards of very much the same construction are generally used.

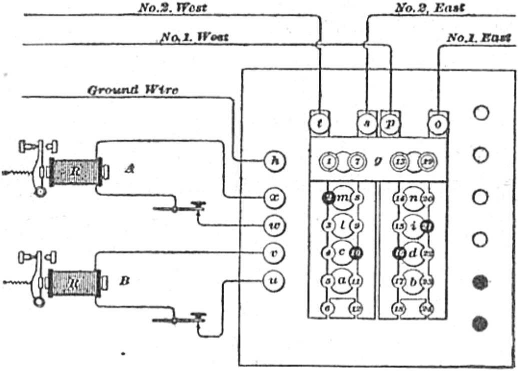

FIG. 5

SOUNDERS OPERATED FROM LIGHTING CIRCUITS

Current for operating both the local and the line circuits of telegraph systems is now being obtained as much as possible from dynamos or electric-light or power circuits instead of from primary batteries, as it is much more economical. Fig. 6 shows an arrangement now extensively used for supplying local sounder circuits with current from electric-light, 110-volt, direct-current mains. Each sounder *S* is wound to a resistance of 200 ohms and connected in series with a 4,000-ohm, non-inductive, resistance coil *r*, this circuit being connected through the contacts of the relay and across the leads running to the street mains.

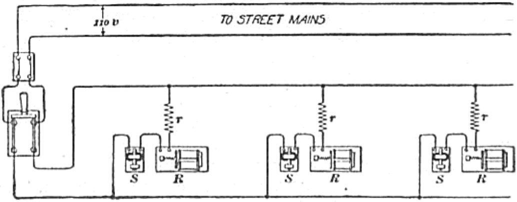

FIG. 6

TELEGRAPH REPEATERS

A *telegraph repeater* consists of an arrangement of telegraph instruments and apparatus whereby signals coming over one line are repeated or sent forward on another line by a separate battery. By the use of repeaters it is possible to work longer lines with wires of a reasonable size, fair insulation, and E. M. F.'s not unreasonably high, than would be possible with only one continuous and unbroken wire. In the United States, it is not customary to operate a circuit over about 600 mi. in length directly, although in some cases circuits up to 1,200 mi. are worked without repeaters. Repeaters may be divided into two classes: button repeaters and automatic repeaters.

A *button repeater* requires the turning of a switch, formerly called a button, manually by an attendant, in order to change from repeating in one direction to repeating in the opposite direction. With such repeaters, the repeater attendant must listen to what is passing and be ready at any moment to turn the switch in order to reverse the direction in which the message may be sent and thus allow the operator at the receiving end to become the sender and vice versa. Button repeaters are generally employed for temporary purposes only, and are not very extensively used.

An *automatic repeater* is one that will automatically repeat in either direction without the necessity of turning a switch. An operator, however, is always needed at the repeater station to adjust the instruments and care for the batteries. There are a large number of automatic repeaters, some of which are no longer in use. Only one automatic repeater will be described.

ATHEARN REPEATER

In Fig. 7 is shown a general view of an *Athearn repeater* used by the American Telephone and Telegraph Company. Two ordinary 150-ohm relays are provided with the usual front stops *e*, *e′*, and back stops *f*, *f′*. In addition, each relay has two slender springs *a*, *b* separated by a hard-rubber washer *n*. These springs are fastened to the base and fit in between the two coils of the relay, although for the sake of clearness they are shown in this diagram as being in front of the coils. The armature lever *c* is very light and extends downwards from the pivot *d* to *o*, where it has a second armature facing the holding magnet *H* of 20 ohms resistance. Both relays, with their respective holding magnets, are mounted back to back on one long base.

In the normal condition, all circuits are closed. If the western operator desires to send and opens his key, there is no current in the circuit: west line–*c*–*b*–west relay–*MB′*–*g*, and hence the west relay releases its armature. The first backward movement of this armature opens the circuit between *e′* and *a′*; this opens a shunt circuit to ground around the holding magnet *H*. This prevents the release of the armature *o* of the east relay when, a moment later, the balance of the backward movement of the armature *c* of the west relay opens the east line by breaking the contact between the spring *b′* and the armature lever *c′*. Thus, the east line is opened at *c′*, but the *west line does not open* at the repeater. When the western operator closes his key, the west relay attracts its armature, closes the east line between *b′* and *c′*, and then closes the shunt between *e′* and *a′* around the holding magnet *H*. All circuits are now restored to their normal condition.

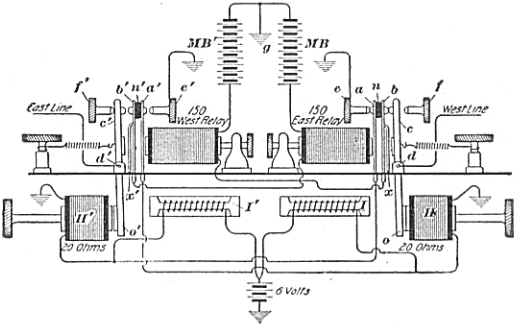

FIG. 7

Should the eastern operator, desiring to break, open his key while the east line is also open between *c′*, *b′*, the first complete forward motion of lever *c′*, due to the closing of the western key and west relay, closes the circuit between *a′*, *e′*, and shunts the magnet *H*, which then releases the lever *o*, which, in its first backward movement, opens the circuit between *a*, *e*, thus removing the shunt from around the magnet *H′*, which then holds the west relay lever closed. The eastern operator can then send to the western operator.

A novel feature of this repeater is the limiting resistances *I*, *I′*, which instead of being non-inductively wound are wound on iron cores with heavy end lugs. It is stated that because of this inductance the magnets H, H' are rendered much quicker in action because, when the shunt is removed from one of these magnets, the inductance coil gives an instantaneous kick of much more than 6 volts, which helps to overcome the high impedance of the holding magnet for a rapidly increasing current and, therefore, to more rapidly build up its magnetism.

MULTIPLEX TELEGRAPHY

Multiplex telegraphy is the transmission of two or more messages over the same wire at the same time. The transmission of two telegraphic messages simultaneously over the same wire is called *duplex telegraphy.* In the duplex system there is one sending and one receiving operator at each end office, that is, four operators in all. There are three systems of duplex telegraphy: the *differential,* the *polar,* and the *bridge.* The simultaneous transmission of four independent messages over one wire, two in one direction and two in the other, is termed the *quadruplex.* In the quadruplex system, there are two sending and two receiving operators at each end, or eight operators in all.

DUPLEX TELEGRAPHY

Differential Duplex.—The theoretical arrangement of apparatus and circuits constituting the *differential-duplex system* is shown in Fig. 8. In order to show clearly the principles only of the differential-duplex system, the diagram has been made as simple as possible by omitting practical details and the local sounder circuits controlled by the levers of the relays in the usual manner. The keys K, K_1, which have rear and front contacts, are operated by electromagnets, the coils of which are connected with batteries in local circuits under the control of ordinary telegraph keys. The batteries B, B_1 contain the same number of cells, and hence have the same E. M. F. The resistance and capacity of the circuit from m through the coil c, resistance r, and condenser C to 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 n through c_1 to 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 g to G, containing r and C, and the circuit from h to G_1, containing r_1 and C_1, are called the *artificial lines;* the coils c and c_1, the *artificial-line coils*, and the coils d and d_1, the *line coils* of the differentially wound relays R and R_1. The resistance J, which is equal to the internal resistance of the battery B,

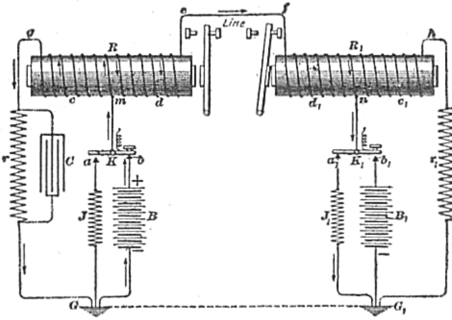

FIG. 8

gives a path of equal resistance from m to the ground G, whether the key K rests on the front or the rear contact. J_1 is a similar resistance equal to the internal resistance of B_1.

The condensers C, C_1 are arranged to give a capacity equivalent to that of the line wire. The differential relays have two coils of equal resistance and the same number of turns. Hence if a current flows from K to m and there divides equally through the two windings of the relay R, the relay will not be magnetized at all; but if the current flows in only one of the two coils, or if the current flowing in one coil is enough stronger than the current flowing in the other coil, the relay will be magnetized. In this figure, the relays are represented as having only one core, but as a matter of fact they would have two cores, as in the ordinary relay, and half of each coil would be wound on each core.

When both keys are open, there is no current in any part of the circuit; consequently, the armature of neither relay will be attracted and both local-sounder circuits will therefore be open. If the key K is closed, current from the battery B will flow to point m, where it will divide, half flowing through the line coil d–c–f–d_1–n–a_1–J_1–G_1–G, and half through the artificial-line coil c–g–r–G. However, little of the current will flow from n through the artificial-line coil c_1–h–r_1–G, because r_1 has a very large resistance compared with J_1. The magnetizing effect of the current in the coil d will neutralize the magnetizing effect due to the current through the coil c, because the currents in these two coils are equal and are flowing around the iron core in opposite directions; consequently, the relay R will not attract its armature. However, the relay R_1 will attract its armature, because a current of sufficient strength flows in coil d only, thereby causing the core to attract its armature.

For similar reasons, when key K_1 is closed and K is open, the relay R will attract its armature, whereas, the relay R_1 will not be affected. When both keys K, K_1 are closed, the positive pole of B will be connected to m, and the positive pole of B_1 to n; consequently, there will be no difference of potential between the points m and n, and hence no current will flow in the line coils of either relay. However, there will be a current of normal strength flowing in both artificial-line coils c, c_1, and hence both relays R, R_1 will be magnetized and will attract their armatures, thus closing both local-sounder circuits. It has now been shown that the operation of key K controls the action of the relay R_1 only, and the operation of key K_1 controls the action of relay R only. The levers, K, K_1 can be constructed so as to operate very quickly; consequently, the interval during which the lever K touches neither the front nor the back stop is so short that any trouble this tends to produce can be overcome.

Polar Duplex.—In the *polar-duplex system*, differentially wound polar relays and pole-changing keys are used; in other respects, the system resembles the differential duplex. A *polarized relay* is one that requires the direction of the current flowing through it to be reversed in order to move the armature from one stop to the other. A current in one direction will keep the local-sounder circuit closed at the front stop of the relay, and a current in the reverse direction is required before the local-sounder circuit can be opened at this point. The mere absence of a current will leave the armature of the relay against whichever stop the last current may have moved it. Dots and dashes are made by currents flowing in one definite direction, and spaces by currents flowing in the opposite direction, the length of the dots, dashes, and spaces depending on the interval of time during which the current is allowed to flow in the same direction. Polarized relays are used principally in polar-duplex and quadruplex systems.

In Fig. 9 are shown the theoretical connections of the polar-duplex system extensively employed in the United States. PR, PR_1 are differentially wound polar relays, and K, K_1 are keys that control battery reversing instruments called pole changers. The resistances Rh and Cr and the condenser C represent the artificial line at the left-hand station, and Rh_1 and C_1 represent the artificial line at the right-hand station. These artificial lines are arranged somewhat different, but they accomplish practically the same purpose; that is, the arrangement in each case gives a circuit of equal resistance and electrostatic capacity to that of the line wire. All four main-line dynamos, two at each end, generate the same voltage. When both keys K, K_1 are open so that the levers k, k_1 rest upon their rear contacts a, a_1, there will be no difference of potential at the two ends of the line circuit; consequently, there will be no current in the line coils of either relay. There will, however, be a current at each end, flowing from the batteries into the ground through the artificial-line coils of both relays and back into the battery. The relays are so polarized that current flowing in this direction through only the artificial-line coils will cause the permanently magnetized armatures to rest against their back stops, and thus keep both local-sounder circuits open. If key *K* is closed, the dynamo *B* has its positive pole connected through contact *b* to *K*. Hence, the dynamos *B* and D_1 are connected in series in the line circuit and, consequently, there will be a current in the line circuit of double the strength that would be produced by one dynamo acting

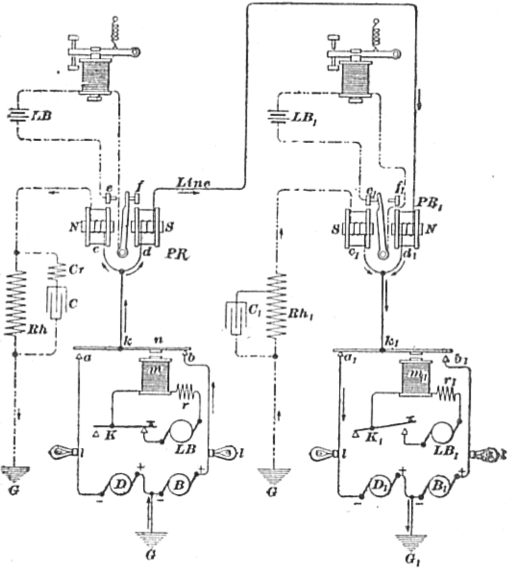

FIG. 9

alone in the same circuit. There will also be a current flowing from *k* through *c–Rh–G–G–B*. There is now flowing through *c* a current of the same strength as before, but in the opposite direction, and through *d* a current of twice the strength of that through *c*, and in such a direction as not only to neutralize the magnetizing effect of *c*. but also to magnetize the relay in the same direction as before, consequently, the relay *PR* remains open. Furthermore, the current flowing from the line through the coil d_1, having twice the strength of the current flowing through c_1, not only neutralizes the effect of the current in c_1 but also reverses the polarity of the relay PR_1, and hence causes the permanently magnetized armature to move from the back to the front stop e_1 and thereby close the local-sounder circuit; consequently, only the local sounder at the right-hand station will reproduce the signal made with key *K*. In a similar manner, the closing of key K_1 will cause the polarized relay *PR* and its sounder to respond without affecting the polarized relay PR_1. When both keys *K*, K_1 are closed, the positive poles of equal dynamos will be connected at each end of the line circuit; consequently, there will be no current in the line circuit. Current, however, will be flowing through both artificial-line coils *c*, c_1. This current flows through the artificial-line coils of the relays in the right direction to reverse the normal polarity of the relays, and hence both armatures will be moved and both local sounders will be closed.

Bridge Duplex System.—The *bridge duplex system*, a simple diagram of which is shown in Fig. 10, is similar in its action to the Wheatstone bridge. *S* is a rheostat so arranged that as the lever is turned upwards, resistance is taken out of the arm *ac* of the bridge, and is added to the arm *ad* and vice versa if the lever is moved in the other direction. The four arms of the bridge are *ad*, *ac*, dG_1, and from *c* through the line and apparatus at the other station to the grounds G_1 and G_2. Hence, 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, assuming, as is usually the case, that the resistance of ac is equal to that of ad. When this is the case, there is no difference of potential between the points d and c. The resistance Z, key K, and battery B are controlled in the same manner as already explained in connection with the differential duplex.

If ac bears the same relation to ad that the circuit from c through the line and apparatus at the distant station to ground bears to dG_1, then the relay R, which in this case corresponds to the galvanometer in the Wheatstone bridge, will not be affected by the outgoing current from the battery B, for the same reason that the galvanometer in the Wheatstone bridge is not deflected when the bridge is balanced. If key K' is pressed down and key K is up, that is, open, some current will pass along the line and will divide at the point c, part of it passing through and operating the relay R. The position of the key K will in no way affect the operation of the relay R, because the position of K does not alter the resistance of the circuit between a and G.

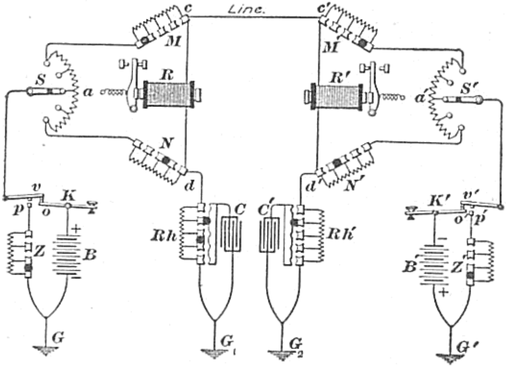

FIG. 10

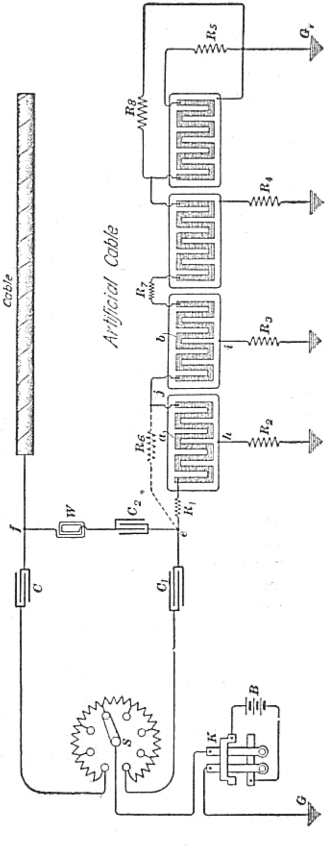

FIG. 11

Thus, the relay at one position will be operated only by the key at the distant station.

Cable Bridge Duplex.—In Fig. 11 is shown the bridge duplex as used for submarine cables. As the signals depend on the electrostatic capacity of the cable as well as on its resistance, condensers are freely used in the various arms. The artificial cable is made up of a large number of sections, each consisting of a pile of tin foil and paper strips. On one side of the paper, the tin foil is cut in zigzag strips, as indicated in the figure, while on the other side the tin foil strips are rectangular. The zigzag strips are connected in series; thus, their resistance is made equal to that of the cable conductor. All rectangular strips are grounded, either directly or through high resistances, which retard the charges. This arrangement of tin-foil strips gives the necessary capacity to the artificial cable. The key K has two handles that are normally grounded through a top grounded metal strip. When either is pressed, the battery is connected in the circuit, one handle connecting the positive pole toward the line, and the other the negative pole toward the line. When the key is operated, equal charges flow into the condensers C, C_1 and into the cable and the artificial cable; thus, the points f and e have no difference of potential and the siphon recorder W is not affected. Charges produced at the distant end and arriving at f, however, will affect W, because e is not necessarily at the same potential.

The *siphon recorder*, which is extensively used as a receiving device at W, is a modified form of the D'Arsonval galvanometer, the moving coil being arranged to deflect a light glass siphon across a paper tape that is moved along under it by clockwork or motor mechanism. One end of the siphon dips into an ink well and the moving end is kept vibrating, thus producing a dotted wavy-line record that can be read by cable operators.

QUADRUPLEX SYSTEM

All *quadruplex systems* are operated on about the same principle, which is a combination of the polar and the Stearns differential-duplex systems. The apparatus at each end is exactly the same. For the operation of quadruplex systems, dynamos are rapidly displacing primary batteries. The principle of the quadruplex system may be explained by the aid of Fig. 12. Four dynamos are connected as shown to the contact points a, b, c, d of an instrument PC, called a *pole changer*, the levers of which are connected to the contact points e, f of an instrument T, called a *transmitter*. NR is a differentially wound ordinary relay, called a *neutral relay*, and PR is a differentially wound *polar relay*. The neutral relay will attract its armature if the magnetism developed by the current through its coils is strong enough to overcome the spring s. This spring is so adjusted that the magnetism must be three, and in some cases four, times its normal strength in order to draw the armature against the back stop *j*. The polar relay has a permanently magnetized armature and is so adjusted that it would remain against either stop if no current flows in either winding of the relay. If the current magnetizes the cores of the relay in one direction, the armature will be held against the stop *o*; if the magnetism is reversed, the armature will move against the other stop *m*. The weakest current used will move the armature of this relay if the current is reversed in direction. When both keys *Pk* and *Tk* are open, the negative pole of the 100-volt machine is connected to the point *h*. Closing *Tk* only will connect −300 volts to *h*. Closing *Pk* only will connect +100 volts to *h*, and closing both *Pk* and *Tk* will connect +300 volts to *h*.

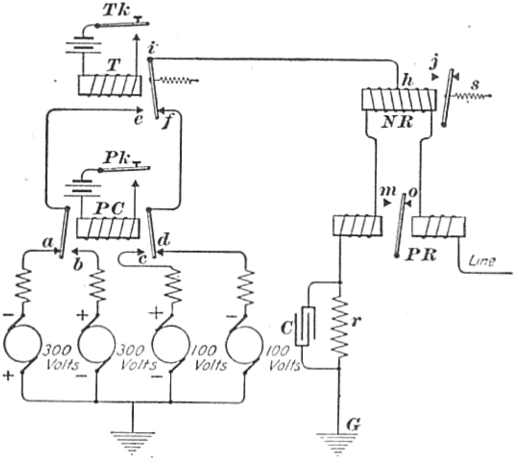

Fig. 12

Thus, it will be seen that *Pk* controls only the direction in which the current tends to flow in *ih*, while *Tk* controls only the intensity of the E. M. F. and, hence, only the strength of the current that tends to flow in *ih*. The two windings on each relay have equal resistances and the same number of turns, and *r* is equal to the resistance and *C* to the capacity of the line circuit, this combination of *r* and *C* being called the *artificial line*. Whatever current flows in *ih* tends to divide equally through the line and the artificial-line circuits that are joined together at *h*.

Since whatever dynamo is connected to *h* tends to send a current of equal strength through the two windings of each relay, it follows that these two relays will not move their armatures, no matter which one of the four dynamos at this station may be connected to *h*. These relays can be operated, however, by varying the potential applied to the line at the distant station, due to the operation of a transmitter and pole changer located there. For instance, normally −100 volts is applied to similar points *h* at each end; no current therefore flows in the line, and the current in each artificial line leaves all the relays open. The neutral relays are open because the current due to 100 volts in one winding only is not sufficient to overcome the springs *s*. The polarized relays are open because they are so polarized that a current flowing from *h* to *G* holds the armature against the back stop. Suppose that +100 volts is applied at the distant end by closing the key corresponding to *Pk*. There is now 200 volts acting in the line circuit, which sends a current from the line to *h*; this current is so strong that it not only neutralizes the effect of the current flowing from *G* to *h*, due to the 100 volts applied only at this end, but also remagnetizes both relays in the opposite direction. Hence, the polarity of *PR* is reversed and it will attract its armature. The polarity of *NR* is also reversed, but the magnetization produced is not strong enough to overcome the spring *s*. The operation of the distant key corresponding to *Tk* would operate only the neutral relay *NR*, because it increases the potential applied at the distant end and, hence, the current is increased enough to overcome the spring *s*; but the current has not been reversed in direction, consequently the polar relay *PR* is not affected. Moreover, it can be shown and is a well-known fact that all four transmitting keys may be operated simultaneously or in any practical manner, and that each key will operate only one particular relay at the distant end.

SIMULTANEOUS TELEGRAPHY AND TELEPHONY

The transmission of telephone and telegraph messages over the same circuit at the same time, without one interfering with the other, is called *simultaneous telegraphy and telephony*. An arrangement of circuits that will allow the transmission of one telephone and one telegraph message at the same time over *one pair* of wires is termed the *simplex system*. When telephone apparatus is substituted for telegraph apparatus in the arrangement just mentioned, thus permitting two telephone messages to be transmitted over the same pair of wires at the same time, the arrangement is called *duplex telephony*. *Multiplex telephony* is applied to arrangements whereby it is possible to transmit, simultaneously, three or more telephone messages over two or more pair, respectively, of line wires.

An arrangement of circuits that will allow the transmission of one telephone and two telegraph messages at the same time over one pair of line wires is termed the *composite system;* this term is also given to a similar arrangement of apparatus that will allow the transmission of one telephone and one telegraph message at the same time over a single line wire. In the latter arrangement, the ground is used as a common return for both telephone and telegraph currents.

SIMPLEX SYSTEM

Impedance-Coil Simplex.—In Fig. 13 is shown a *Bell simplex system*, using two 500-ohm impedance coils, which are bridged across each end of a pair of long-distance telephone wires. The condensers prevent the flow of telegraph

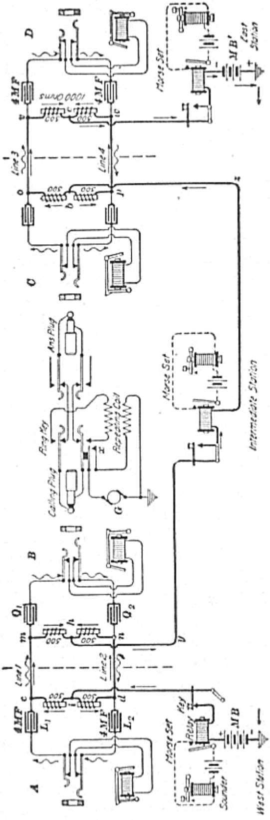

FIG. 13

currents through the jacks and the telephone apparatus therewith connected, while the impedance coils prevent the flow of the telephone current through the telegraph apparatus or from one line wire to the other through the impedance coils. In this figure are shown two terminal telephone and telegraph offices and one intermediate telephone and telegraph office. The ringing generator, which is usually grounded at all telephone exchanges, is arranged as shown at *G*, with a repeating coil or transformer interposed between it and the ringing key, so that neither line wire is grounded, which would unbalance the circuit, even while ringing over the line. The straight arrows show the path taken by the telegraph currents, while the wavy arrows show the path taken by the rapidly fluctuating voice currents. It will be seen that the

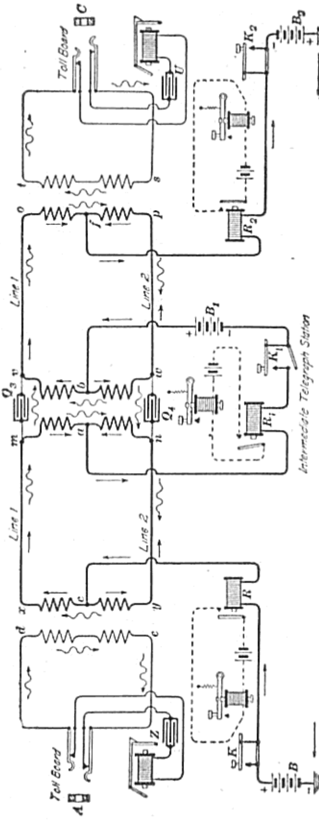

FIG. 14

two line wires are used in parallel for one side of the telegraph circuit, the ground being used as a return circuit, while the same two line wires constitute a complete metallic circuit for the telephone currents, the ground not being used for these currents.

Repeating-Coil Simplex.—A simplex system using one repeating coil across each end of a pair of long-distance lines and wherever an intermediate telegraph station is required is shown in Fig. 14. The repeating coils *dexy*, *mnvw*, and *opts* must be designed to transmit both voice and ringing currents, but such coils are not the best for transmitting voice currents over long toll circuits. This system, as used by the American Telephone and Telegraph Company, has proved to be superior to the impedance-coil method, and it has the advantage that regular cord circuits and ringing machines may be used in connecting together two such circuits, without affecting the telegraph apparatus adversely.

Composite System. A *composite system* is shown in Fig. 15. One pair of line wires is used as a telephone circuit, while each line wire with a ground return constitutes two separate telegraph circuits. The telephone currents are prevented from entering the telegraph circuits by the use of the impedance coils Dc, Dc_1, Dc_2, Dc_3, while the telegraph currents are excluded from the telephones by the use of the condensers i, i_1, i_2, i_3. Whatever sharp telegraph impulses may happen to get through the condensers f, f_1, f_2, f_3 can readily pass through one-half the

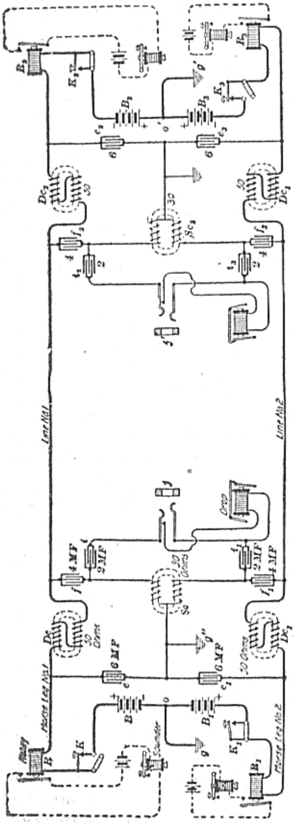

Fig. 15

impedance coil *Sc* or Sc_2 to ground. The impedance coils *Dc*, Dc_1, Dc_2, Dc_3 have their two coils so connected as to magnetize the iron core in opposite directions when the relatively slow changing, telegraph current passes through them; thus, each one presents but little inductive opposition to the flow of the telegraph current, and hence does not appreciably affect the operation of the telegraph apparatus. However, the two windings on each coil act, to the rapidly fluctuating voice currents, practically as two separate inductance coils connected in series, and hence compel the voice currents to pass through the various condensers and telephone apparatus connected, when in use, to the jacks *jj'*.

For signaling over the telephone circuit, it is customary to use a special ringing apparatus that converts the usual ringing-generator current into an alternating current of much higher frequency; therefore, this current will not readily pass through the coils *Dc*, Dc_1, Dc_2, Dc_3, and interfere with the operation of the telegraph relays which would otherwise be the case.

DUPLEX AND MULTIPLEX TELEPHONY

For *duplex telephony*, the circuits are arranged in about the same manner as in simplex telephone and telegraph

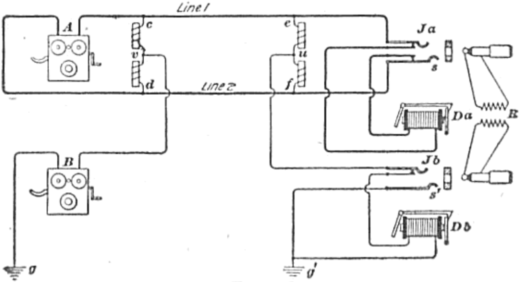

FIG. 16

systems, telephone instruments being substituted for the telegraph apparatus.

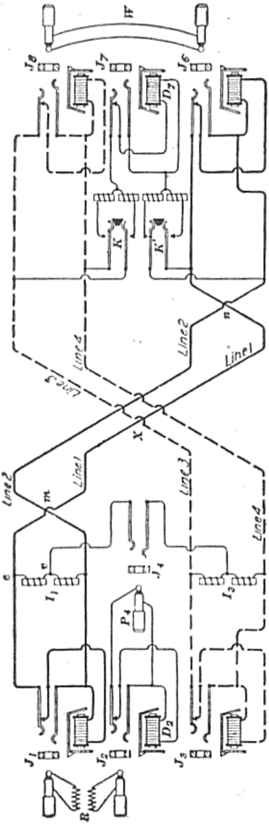

FIG. 17

Impedance-Coil Method.—In Fig. 16 is shown a duplex telephone system using *impedance coils cd* and *ef* across one pair of line wires. Telephone *A* uses the metallic circuit and has a jack *Ja* and a drop *Da* at the exchange, while telephone *B* uses the two line wires in parallel as one conductor and the ground as a return conductor; the latter also has a jack *Jb* and a drop *Db* at the exchange. The circuit $B-v-\left\{\begin{matrix}c-e\\d-f\end{matrix}\right\}-u-Db-g'-g$ is called a *phantom circuit*, because it is an extra circuit obtained without the actual addition of any more line wires than were already in use for the telephone *A*.

Three Circuits Over Two Pair of Wires.—Usually, more satisfactory results are secured by arranging two complete metallic circuits, as shown in Fig. 17, so as to obtain three telephone circuits. The third circuit may be brought through a jack J_4 and a plug P_4 to jack J_2 and drop D_2 or two keys K, K' may be used to connect the impedance coils across the two line circuits. To use the third, or phantom, circuit, the plug P_4 must be inserted in the jack J_4 and the keys K, K' closed. The line wires constituting the metallic circuits should be transposed, as indicated at m, n, as would any two pair of parallel and adjacent telephone line wires, to eliminate cross-talk between the two pair. Furthermore, one pair of wires should be transposed with respect to the other pair, as shown at X, in order to eliminate cross-talk between the phantom circuit and any other circuit parallel and adjacent but not associated with this duplex circuit.

Repeating-Coil Method.—In Fig. 18 is shown a duplex telephone system using *repeating coils cd* and *ef* across one pair of telephone line wires. The ground is used as a return for the phantom circuit containing the telephone B. *Ja* and *Da* are the jack and the drop, respectively, for telephone A, and *Jb* and *Db* for telephone B.

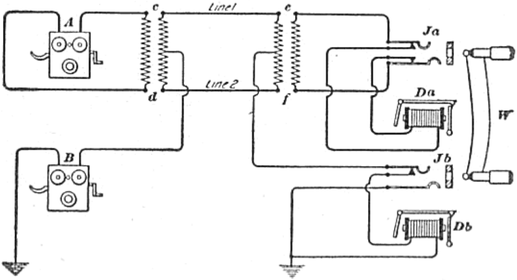

FIG. 18

Three telephone circuits may be obtained over two pair of line wires by the arrangement shown in Fig. 19. When the phantom circuit is to be used, the plug P_4 is inserted in jack J_4 and the corresponding plug at the other station is also inserted in its jack.

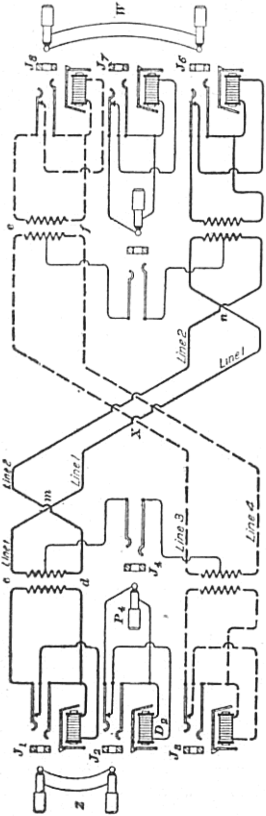

FIG. 19

Phantom Cord Circuits.—Where phantom circuits are obtained by the use of impedance coils, as in Figs. 16 and 17, a *cord circuit* containing a repeating coil should be employed to connect a telephone on a phantom circuit with a telephone on the metallic circuit from which that particular phantom circuit is derived. Otherwise, the half, for example, *cv*, Fig. 16, of the impedance coil connected to one side of one metallic circuit will be short-circuited, while the other side of the same metallic circuit, for example, line wire *2*, will be connected directly to the ground, or to the middle of the impedance coil I_3, in Fig. 17, across the other metallic circuit. In either case, the sounds heard in one telephone due to talking in the other would be due mostly to a large amount of cross-talk caused by a badly unbalanced circuit. To connect the circuits terminating in jacks J_6, J_8, Fig. 17, and J_a, J_b, Fig. 18, a cord circuit W without a repeating coil may be used. Generally, repeating coils should not be inserted in cord circuits W, Z, Figs. 18 and 19, used in duplex systems obtained by means of repeating coils.

WIRELESS TELEGRAPHY

The most successful methods for telegraphing through space without connecting wires depend on the propagation through space of electromagnetic waves frequently called *Hertzian waves*. These waves are identical in some respects to light waves, but have different frequencies and wave lengths. The principles of transmitting and receiving apparatus for wireless telegraph systems may be briefly explained by the aid of Fig. 20.

At the left is shown the *transmitting apparatus*, which consists of a Ruhmkorff induction coil, through the primary p of which current from the battery B may be sent by closing the key K. The secondary s has its terminals connected to brass rods terminating in small brass balls. The gap ab between the balls is called the *spark gap*. When the spark gap is properly adjusted and the apparatus is in working order, closing the key K will cause a torrent of sparks to pass across the spark gap. These sparks cause electromagnetic waves to pass out in all directions through space.

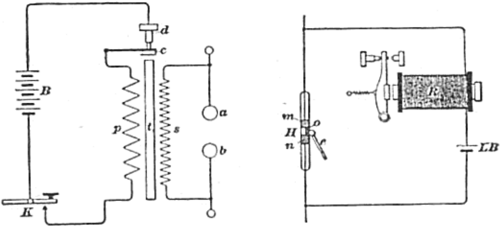

FIG. 20

The *receiving apparatus* is shown at the right of Fig. 20, and consists of a device *H* called a *coherer*, which is connected in series with the relay *R* and a weak battery *LB*. The coherer consists of a glass tube, usually exhausted, in which are placed two silver plugs. The small space between the faces of the two silver plugs is only partly filled with coarse filings—usually 90% nickel and 10% silver. Normally, the resistance through these filings is very high, several thousand ohms, but if the coherer is placed where electromagnetic waves of sufficient intensity strike it, its resistance decreases enormously, thereby allowing sufficient current from the local battery *LB* to flow through it and the relay, to close the relay. The tapper *e* of an ordinary vibrating bell is arranged to tap the tube whenever the relay closes its local circuit. The slightest tapping will readily restore the resistance of the coherer to its high normal value, provided the electromagnetic waves are no longer present to act upon the coherer. The current through the relay is thus reduced to its normal strength and the relay will open. It is impossible to show here all the apparatus and details of the circuits necessary in a successful wireless-telegraph station. Usually, the terminals *b* and *n* are grounded, and the terminals *a* and *m* are connected to wires that may extend high in the air and are called the *aerials*. The electrical disturbances emanating from high aerials produce waves that are able to travel greater distances than would otherwise be possible.

It is usually necessary to prevent sparking at relay or other contacts and to reduce the inductance of receiving devices as much as possible. For these reasons, it is customary to shunt all make-and-break contacts with condensers or high non-inductive resistances and to connect in parallel with each relay or other electromagnetic device a non-inductive resistance of at least four times the resistance of the device.

The distance over which it is possible to transmit signals depends on the power of the transmitter, the sensitiveness of the receiving device, and the height of the aerial conductors; whether the intervening surface is comparatively smooth like the ocean, or rough like the land; and whether it is day or night. With the same apparatus, greater distances can be covered at night, and about three times as far over the ocean as over the land; the distance varies about as the square of the height of the vertical conductor. The energy received is said, by different authorities, to vary as twice the square of the distance to the transmitter, as the square of the distance, and even as the distance itself.

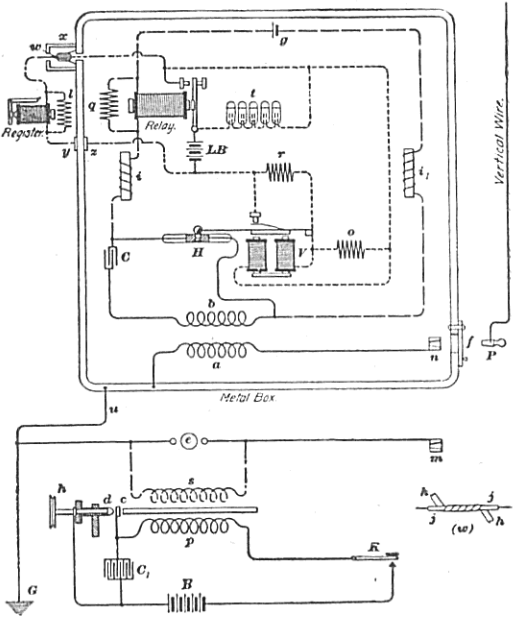

FIG. 21

Marconi's System.—One arrangement of transmitting and receiving apparatus used by Marconi is shown in Fig. 21. The aerial wire ends in a plug P that may be connected to the transmitting apparatus by inserting it in m, or to the receiving apparatus by opening the metal door f and inserting it in n. The receiving apparatus is enclosed in a metal box, so that no waves from the home sending apparatus can damage the coherer. a, b are the two windings of an induction coil without any iron core; this induction coil is frequently called a *jigger*. All electromagnets and sparking contacts are shunted by non-inductive resistances except the relay contact, which is shunted by five polarizing cells t. The choke coils i, i_1 assist in compelling the rapidly alternating current to pass through the coherer H instead of through the relay. The wire coming out at x is first covered with insulating material and then tin-foil, as shown at (w), so as to make a metallic screen through which no waves will pass into the box.

Electrolytic Wave Detectors.—The *electrolytic wave detector*, which was first described by Fessenden, and shortly afterwards by Schlomilch, consists essentially of a cell having a fine point, usually of platinum, as one electrode and a larger piece of platinum or some other metal as the second electrode. The cell in its most effective form contains an electrolyte, the decomposition products of which are gases. When an E. M. F. is applied to such a cell, powerful polarization ensues, so that scarcely any current passes unless the E. M. F. exceeds a certain critical value. When electric oscillations pass through this cell, the resistance is decreased, and the current for the moment is increased, only to return to its former small value as soon as the oscillations cease.

Fig. 22 shows the simple connections for using the electrolytic wave detector. A telephone receiver t is used to detect the oscillatory currents that pass through the cell e and produce the change in its resistance. The cell made by the National Electric Signaling Company consists essentially of a minute platinum cup, containing the electrolyte into which a platinum wire about .002 mm. in diameter dips. This platinum wire is drawn in silver, and the silver is dissolved in acid, leaving the bare platinum point ready for use. By means of the resistance *r*, any desirable potential due to the battery *b* may be applied to the circuit containing the electrolytic wave detector *e*. The potential applied to the circuit containing this electrolytic cell may vary from about 1 to 2.7 volts, but the best pressure across the cell is 1.6 volts. The telephone used in this circuit has a resistance of about 1,300 ohms. For the electrolyte, a 50% solution of hydrochloric acid, a 20% solution of nitric acid, or a 30% solution of sulphuric acid may be used. The hydrochloric-acid solution seems to be the most sensitive. The resistance of the detector for small alternating currents varies from about 20,000 to 400 ohms, according to the polarizing E. M. F. applied. For rapid oscillations, the capacity effect of the point electrode probably has some influence on the action of the cell. When the E. M. F. is increased or decreased .02 volt, using a solution of hydrochloric acid, the resistance change is about 13,000 ohms. The action is likely to be more regular with the point electrode as the anode. The current changes are ample for a telephone receiver, but are too small to operate a relay with certainty.

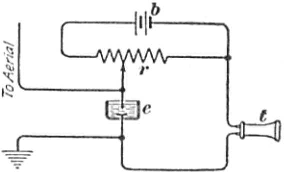

FIG. 22

Instead of connecting the terminals of the electrolytic cell *e* to the earth and to the aerial wire, a transformer or jigger may be interposed, in which case the terminals of one winding of the transformer will be connected to the aerial wire and to the earth, while the terminals of the other winding will be connected to the terminals of the electrolytic cell. The arrangement would otherwise be the same as already shown.

De Forest Audion.—The *audion*, so called by De Forest and shown in Fig. 23, consists of an exhausted incandescent lamp *c*, preferably a tantalum 4- to 6-volt lamp, to which are added two metal parallel wings *e*, *f*. The battery *a* varies from 4 to 8 volts, for which three storage cells are generally used, and *b*, from 6 to 18 volts, for which dry cells that will last at least 6 months are used, as the current produced by them is very small. De Forest claimed, in 1906, that tuning with the audion was sharper than with any other form of receiver, and that the same signals, for practical distances, were louder than with the electrolytic receiver. The relay will operate fast enough to allow a speed of at least 35 words a minute. The oscillatory waves passing from the wings to the filament reduce the conducting power of the attenuated gas between them, and thus the current through the relay is decreased.

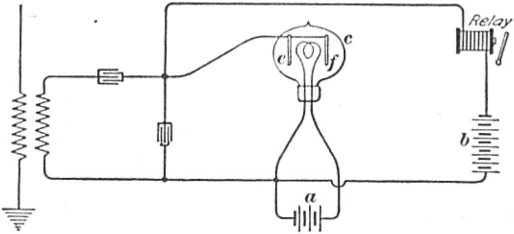

FIG. 23

Other Wave Detectors.—Besides those already explained, there are several other devices used to some extent to detect the waves produced by wireless transmitting apparatus. The *carborundum detector* consists of a crystal of carborundum clamped between metal electrodes. This detector is connected in the circuit in exactly the same manner as a coherer, but a telephone receiver is used to receive the message instead of a relay.

The *silicon detector*, invented by G. W. Pickard, consists of a piece of pure silicon held across two low-resistance metal electrodes. The incoming oscillations in passing across the contacts heat one more than the other, thereby causing a direct thermoelectric-current impulse for each oscillation and producing a sound in a telephone receiver as long as the oscillations persist. A fragment of silicon held with suitable pressure against two flat-ended brass rods is said to give excellent results. The silicon detector requires no battery in the telephone-receiver circuit and is claimed to be twice as sensitive as the carborundum detector, and about as sensitive as the electrolytic detector.

Poulsen's Undamped Oscillation Transmitter.—Most oscillations produced by wireless telegraph transmitters are very much damped, that is, succeeding waves decrease greatly in amplitude, so that only a few waves have sufficient intensity to be effective. Poulsen has succeeded in producing waves that are so much less damped that they are called *undamped waves.* Undamped oscillations are very desirable for selective or tuned systems, but so far it has not been possible to produce damped waves that are as powerful as undamped waves.

Poulsen's undamped transmitter is a so-called singing, or flaming, arc maintained between a positive copper and a negative carbon electrode. When the capacity and the inductance that shunt the arc are suitably adjusted, rapid oscillations of uniform amplitude are produced in the circuit, including the aerial wire. The energy given off by this method is low, however, and it remains to be determined whether weak, undamped waves are as useful as stronger damped waves, or whether more powerful undamped waves can be produced by this or some other method.

WIRELESS TELEPHONY

For a wireless telegraph transmitter, it is necessary to have some method for modifying the electromagnetic waves so as to impart to them the fluctuations characteristic of the current in a circuit containing a telephone transmitter. The form of the electromagnetic wave must be varied exactly to correspond with the sound wave due to the words spoken at the transmitting station; and at the receiving station the apparatus must be capable of retransforming the energy into sound waves of like character to those originated at the distant end of the system.

Fessenden's arrangement of apparatus, in 1906, for transmitting telephone messages between two stations about 10 miles apart is shown in Fig. 24. The battery *b* excites the field *f* of a special dynamo, the armature *a* of which produces a sine-wave alternating current having a frequency of 60,000 cycles per sec., a voltage of 60, and an output of about ¼ kilowatt at a speed of 10,000 rev. per min. This dynamo, when run by a steam turbine, is capable of giving 100,000 cycles per sec. The internal resistance of the armature is approximately 6 ohms, and the drop due to inductance at full load is about equal to the drop due to its resistance. The

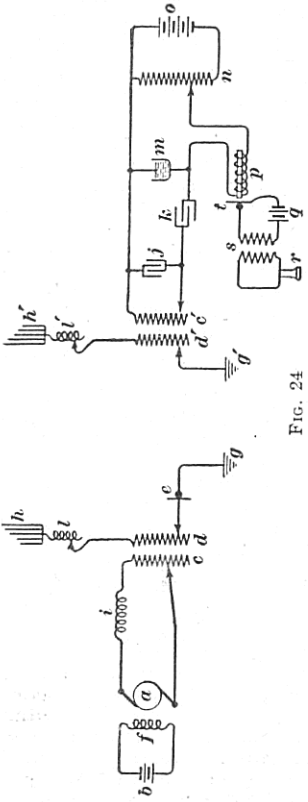

Fig. 24

bearings are kept cool by forcing oil through them with an air pump. The machine, which was designed and built by the General Electric Company, has run daily for 6 or 7 hr. with practically no attention. The dynamo current passes through an inductance *i* and one winding *c* of an air-core transformer, thereby inducing a constant E. M. F. in the other winding *d*. Both windings are arranged so that the number of turns may be varied to suit different conditions. In series with the winding *d* is connected a variable inductance *l*, which is adjusted to tune the circuit *g–e–d–l–h* with *a–i–c*. The aerial wires are shown at *h* and a variable-resistance telephone transmitter at *e*. Thus, *e* varies the strength of the current produced in the circuit *g–e–d–l–h*, and hence the electromagnetic waves emitted, in accordance with the sounds spoken into the transmitter *e*.

The receiving aerial circuit contains the aerial wires *h′*, an adjustable inductance *l′*, and a winding *d′* of an air-core transformer, as at the transmitting station. The condenser *j* is adjustable, while *k* has a fixed capacity; *m* is a liquid barreter, or electrolytic cell, consisting of a minute platinum point dipping into a 20% solution of nitric acid contained in a minute platinum cup. The electrolytic cell has a voltage of about 1.6 applied to it by means of the cells *o* and the potentiometer arrangement *n*. The telephone receiver may be connected directly at *p*, and the variation of current produced by the varying polarization of the cell *m* when variable electromagnetic waves are received at *h′* will cause the receiver to reproduce the sounds spoken at *e*. However, these sounds are probably weak, as a telephone repeater at *p* was used for a distance of 10 mi. between *h*, *h′*, this repeater may be described as follows: It is an ingenious type of relay, using differential windings on the cores of magnets, between the poles of which is mounted an armature attached to one electrode of a microphone transmitter. Variation of the current traversing the windings causes a shifting of the magnetic field to one side or the other, producing a corresponding series of changes in the position of the plate controlling the movable transmitter electrode. This relay is claimed to be very sensitive and improvements made in 1907 are expected to improve its efficiency. A double relay of the same type has been used as a calling device to operate a loud-speaking telephone, or a bell, or a Morse register.

It is claimed that the speech is as distinct as over a short open wire line, somewhat more distinct than over cables, and that there is a total absence of extraneous noise, also no distortion of sounds with increase of distance, as in wire lines. With an ordinary granular transmitter, ½ ampere is all that can be used, and even with special transmitter buttons, 2½ amperes seem to be the limit. A multiple-button transmitter cannot use over 10 amperes. At the transmitting station the transmitter and a primary battery may be connected in a local circuit with one winding of a telephone induction coil, the other winding of which is connected to the winding of a telephone repeater, the transmitter part of the telephone repeater being connected in place of the transmitter *e*. This description was abstracted from an article in The American Telephone Journal, for February 2, 1907.

RUHMER'S PHOTOPHONIC SYSTEM

An ingenious system for the wireless transmission of speech has been developed by Ruhmer, who used the photophone originally devised by Bell. A beam of light from an

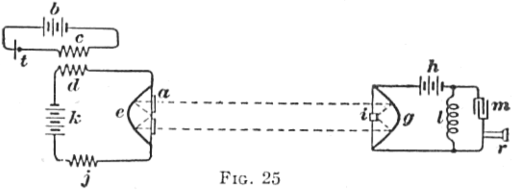

FIG. 25

arc light *a*, Fig. 25, is allowed to fall on a parabolic mirror *e*, which reflects the light in a parallel beam through the space to the receiving station. The light is here converged to a point in the focus of a parabolic reflector *g* and impinges upon a selenium cell *i*, which is in series with a battery *h*, condenser *m*, and a telephone receiver *r*. The selenium cell is constructed by forming a grid of conducting wires between fused selenium, the resistance of the selenium cell varying with the intensity of the light that falls upon it.

Varying the resistance of the transmitter *t* by speaking into it, varies the current from *b* in the primary winding *c* of an induction coil. This induces an alternating current in the secondary winding *d*, which, being superimposed on the steady-direct current produced by battery *k*, causes a variable current to flow through the arc *a*. This produces both a light and a sound, which vary in intensity and character with the sound waves produced before the transmitter. The light waves strike the parabolic mirror *g*, which reflects them to a point at its focus, where the selenium cell *i* is placed. The resistance of the selenium varies with the light that is reflected upon it, and hence the current developed by the battery *h* varies; sounds are therefore produced by the receiver *r* corresponding to those produced before the transmitter *t*. An inductance coil *l* allows a larger direct current to flow through *i* but confines all the fluctuating current to the condenser *m* and receiver *r*.

The transmission depends on an uninterrupted line of view between the transmitter and receiver, and on the power of the light and the sensitiveness of the receiving device. By this method messages have been transmitted about 9 mi. Ruhmer used a regular 350-mm. diameter, parabolic, searchlight reflector with carbons fed by hand, a battery supplying from 4 to 5 amperes for a distance of 2 Km., 8 to 10 amperes for 3 to 4 Km., and 12 to 16 amperes for 5 to 7 Km. The electromagnetic waves produced are short, and the selenium cell decreased in resistance from 120,000 ohms in the dark to about 1,500 ohms when placed near a 16-c.-p. incandescent lamp. A permanent record of the sounds may be obtained by passing a sensitive photographic film through the beam of the talking arc and developing it; then, by drawing the film over a seleneum cell with a strong light behind it, a telephone connected with the cell will reproduce the original sounds.

DE FOREST SYSTEM

Dr. Lee De Forest, by his wireless telephone system, has succeeded in transmitting telephone messages a distance of 12 mi. without connecting wires. In Fig. 26 (*a*) is shown the transmitting circuit. The source of current may be a storage battery or lighting mains with suitable impedance coils *cd* to eliminate undesirable variations in the current. At *e* is shown the oscillator, which may be any form of high-frequency interrupter, although De Forest uses an enclosed arc and an alternating current, thereby producing in *fh* an alternating current of sufficient frequency. There is thus produced a high-frequency current in the winding

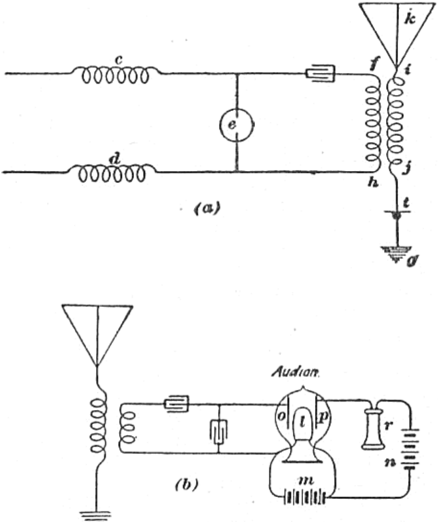

FIG. 26

fh of a transformer. The current induced in the secondary *ij* has its strength varied by the variation in resistance produced in the ordinary microphone transmitter *t* when speaking into it. Thus, variable radiations are sent out from the aerial wires *k*. The intensity of these radiations and the distance at which they are effective depend on the length and frequency of the waves produced by the oscillator, the power supplied to the oscillator, and the height of the antenna, which project into the air.

In Fig. 26 (*b*) is shown the receiving circuit, which resembles the transmitting circuit. The De Forest audion, which is a modified incandescent tantalum lamp, has its filament *l* lighted by a storage battery *m*. One side of the circuit is connected to a platinum grid *o*, while a platinum wing *p* is connected to an ordinary telephone receiver *r*, which is in turn connected to a battery *n*. The incandescent filament is said to cause the highly rarefied gases in the bulb to separate into very minute particles, called *ions*. When the waves reach this receiving device, they produce a change in the resistance of the interior and the receiver promptly responds. The received waves apparently pass between *o* and *l*, while the variable current from the battery *n* passes between *p* and *l*.

ELECTROLYSIS OF CABLE SHEATHS

Earth Currents.—*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 comparatively low resistance.

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 to the probable destruction of the conductor. So long as the cable sheath is negative to all of the 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 rail or return feeder of the electric-railway system, or other conductor, to which the readings indicate the current to be flowing.

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 mo. At the end of that time, note the difference, by weighing or by observation, in the effect on the insulated and uninsulated similar pieces of metal. The relative effects of corrosion from the two sources can thus be determined.

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 impurities, which form a kind of scale on the cast-iron pipe and protect it.

Locating Danger Points.—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. The voltmeter may be connected to the upper ends of two metallic rods, about 10 ft. long, the lower end of one being provided with a conical steel tip for making contact with the earth, rails, or other conductors, and the lower end of the other rod being provided

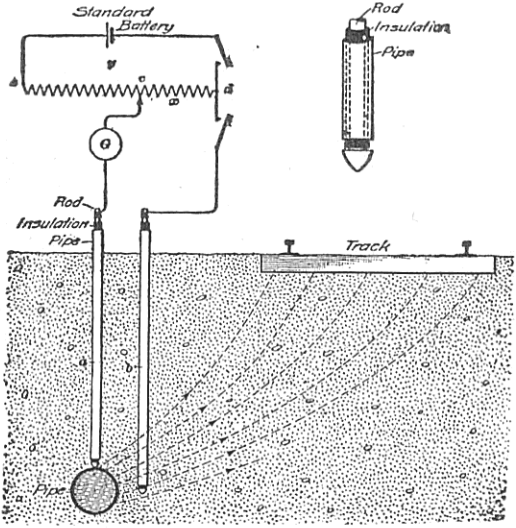

FIG. 27

with a wedge-shaped tip for making contact with the lead sheaths of the cables. The readings should be recorded in tabular form and a curve constructed from them; their location may also be useful.

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 method of using a millivoltmeter. An insulated pointed rod *a*, Fig. 27, 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 E. M. F. set up, which will disturb the difference of potential due to the earth currents. Also, the E. M. F. existing between the pipe and the test point is measured not by means of a voltmeter, which would disturb the normal current flowing between pipe and ground, but by balancing the unknown E. M. F. against a known E. M. F. from a standard battery. The resistance *cd* is adjusted until the galvanometer *G* indicates zero current, and the E. M. F. between the pipe and ground then bears the same relation to the known E. M. F. 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 = E. M. F. between pipe and ground;
E = E. M. F. of standard battery;
x = resistance *cd*;
y = total resistance *de*.

It is not necessary to know the values of x and y, in ohms; it is sufficient 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.

Prevention of Electrolysis.—A large system of piping forms a conducting network of very low resistance in parallel with the car track, hence it is a very difficult matter 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 trolley 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 out 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 covering them with glazed tile or by placing them 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.

The remedy given under 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 especially 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% 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.

Another method consists in providing, at a danger point, a very large ground plate, which may be cheaply and efficiently provided by excavating a hole, at the bottom of which a ton or two of coke is placed, and on top of this a load of old iron, such as worn-out car wheels, old rails, chips from machine shops, etc. The cable sheath 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. Since 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 directly from the cable sheath, and the resulting electrolytic action is reduced. Of course, there will be more or less electrolytic action at the ground plates, but this plate is so large that it will resist corrosive action for a long time, and, moreover, it is cheaper to occasionally replace this ground plate, if necessary, than to have the cable sheath damaged by electrolysis. This 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.

Method of Bonding to Cable Sheaths.—With most telephone companies, a standard method has been adopted for bonding the cable sheaths. Bonds are placed between all the cables of an underground line in every manhole through which they pass. The wire used is No. 8 B. & S. gauge bare copper tinned. The surfaces of all the sheaths are scraped clean of mud, but great care must be taken not to cut away too much of the sheath. The end of the bond wire 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 cleaned in turn, and the bond wire bent down and soldered to it.

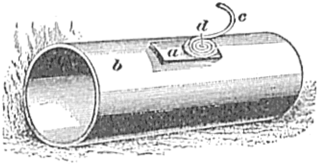

FIG. 28

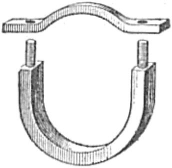

FIG. 29

If the bond wire runs to a gas pipe, it may be soldered as in Fig. 28, in which *a* is a piece of sheet copper, which is 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.

Where it is necessary to bond to a water pipe, with which, while containing water, it is almost impossible to make a soldered connection, a yoke, shown in Fig. 29, 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

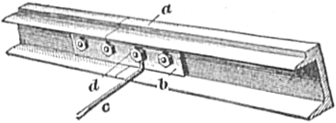

FIG. 30

of asphaltum to prevent corrosion. The method of bonding to a rail is shown in Fig. 30, which needs no explanation, except to say that the contact surfaces must be clean and bright when the bond is made.