THE MODERN TELEPHONE EXCHANGE.

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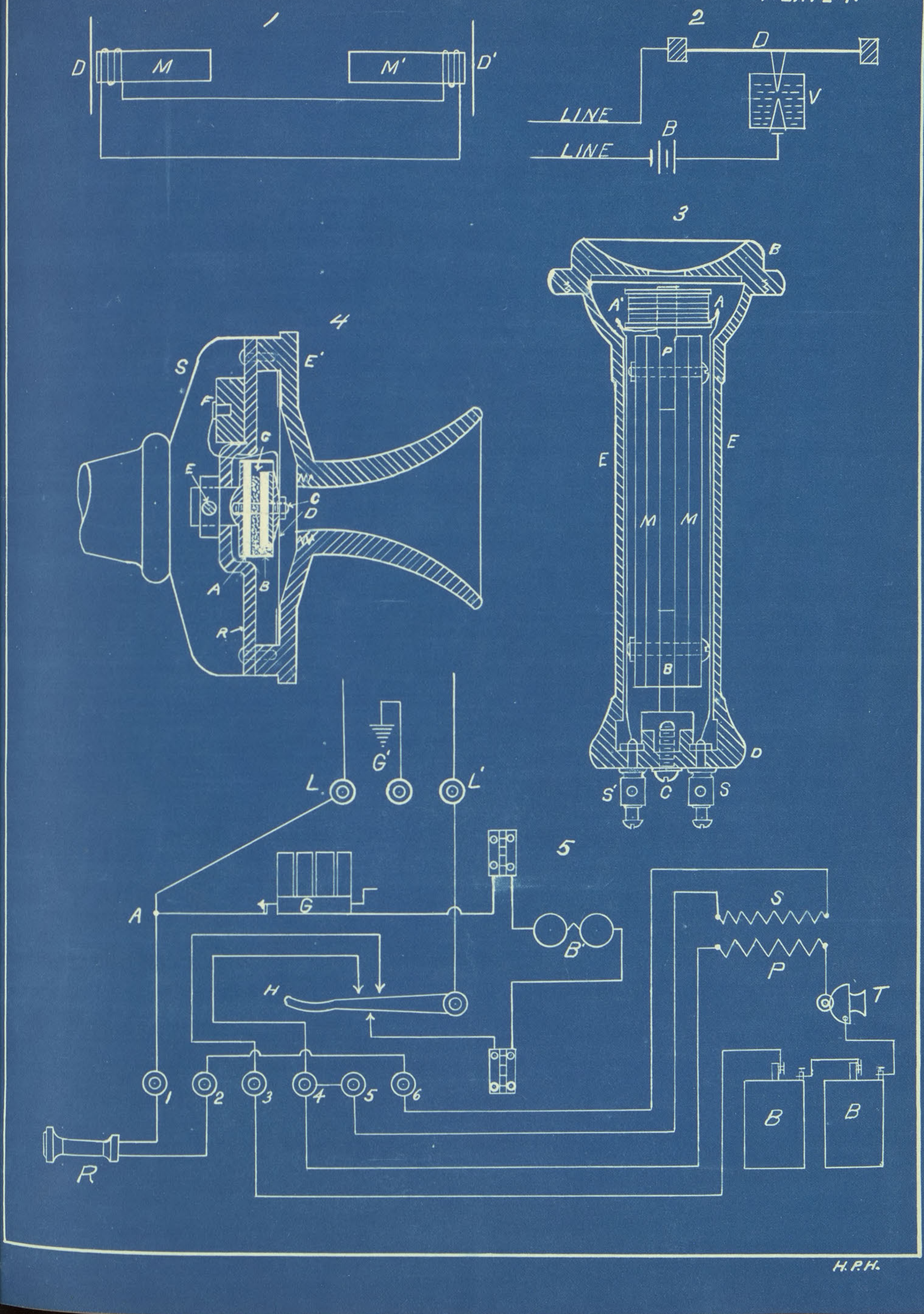
A MODERN TELEPHONE EXCHANGE.

The history of the telephone, from the most crude methods of speech transmission to its present perfection, is a most interesting one. The knowledge of the principles of electromagnetism dates back to the year 1820, and with this date begins the history of our modern telephone. The telephone of to-day has not been the work of one particular inventive genius, but has been developed step by step by many scientists and inventors whose names stand conspicious in connection with electrical progress.

In 1820, Oersted discovered that a magnetic needle tends to place itself at right angles to a wire carrying a current. To ~~Auspue~~ Ampere we are indebted for the laws upon which present electromagnitic thoery is based. Arago and Davy discovered that if a current be caused to flow through an insulated wire wrapped around a core of steel the latter would exhibit magnitic properties. In 1825 Sturgeon made an elector-magnet as we know it to-day. Farady and Henry discovered the converse of these laws of electro-magnetism--that if the intensity of a magnetic field enclosed by a conductor, be changed, a current of electricity will flow in the conductor. The current will flow only while such change is taking place and its strength depends directly upon the rate of change. These laws form the root of all telephone practice and by their various application the telephone has been brought to its present perfection.

PLATE I.


1
D
M
M'
D'
2
D
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LINE
3
B
A'
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E
M
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C
D
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L'
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1
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5
6
B
B
R

H.P.H.

One of the simplest forms of early telephones is the Bell-Magneto-Telephone, shown in Figure 1, Plate I. M M' are permanent bar magnets, D D' are thin soft iron diaphragms placed near the ends of the magnets. If D is caused to vibrate by the voice, the reluctance of the magnetic circuit of M is varied and currents are set up in the line which will transmit the vibrations to D'. It was found that speech could be transmitted only a short distance in this manner. As a receiver this instrument proved very efficient and in a modified form is the standard of to-day. The failure of the Bell instrument for transmitting purposes was due to the fact that not enough energy was generated by the voice. It was then found necessary to generate a current by some other means and cause vibrations in the strength of the current by a variable resistance. Numerous transmitters have been invented, the principle of all being the same -- that the vibrating diaphragm should cause the resistance of the circuit to be varied, thereby causing current enough to flow so that the receiver at the other end of the line may be actuated. A simple form of transmitter invented by Gray is shown in Figure 2, Plate I.

The battery B is placed in series with the two pins with platinum points placed in vessel V containing a fluid of low conductivity. When the diaphragm D vibrates the resistance of the circuit is varied by the varying distance between the platinum points. Berliner succeeded in obtaining a variation in resistance by varying the pressure between two loose contacts. The variation of pressure was accomplished by the vibrations of the diaphragm. Edison devised an instrument using carbon as the medium for varying the resistance of the circuit with changes of pressure. The instrument simply consisted of a button of carbon bearing against a small platinum disk on the diaphragm, the button being held in place by a spring, the tention of which could be adjusted. It was experimentally found by Professor Hughes that a loose contact between electrodes, no matter of what substance they are composed, is preferable to a firm strong contact, and the transmitters of to-day are nearly all based upon this principle. Carbon has been found to be the best variable resistance medium and no substance has yet been found that nearly equals it in efficiency. It has given most satisfactory results in granular form, and in the modern transmitters it is almost without exception so employed. With this form of transmitter the changes produced in the resistance are so small in comparison with the total resistance of the circuit that an induction coil is used in connection with it.

In Figure 2, Plate I is shown a Bell single pole receiver. The magnet is built up of two steel bar magnets with like poles together. Soft iron pieces, P and B are clamped between the ends of these magnets. The piece projects from the end of the magnet and forms the ~~case~~ core of the solenoid. The magnet and spool are encased in a hard rubber tube. Between B and E is clamped the diaphragm which is placed about one-hundreth of an inch from the ~~case~~ core of the solenoid. The case B is fastened to the tail piece D by means of the screw C. Two brass building-plates, S and S', are fastened to the tail-piece D, to which are soldered two large copper wires extending from the posts to the solenoid A A' where they are soldered to the two magnet wires. This receiver has proven very efficient and extremely sensitive and has been very extensively used.

Most of the changes that have been made in the design are more mechanical than electrical. The greatest change perhaps is found in what is called the double pole receiver, which has been used extensively the past few years. Two poles are used instead of one, the idea being that two poles give a more uniform field.

Figure 4, Plate I shows a white or solid back transmitter, and exclusively used by the Bell Telephone Company. Probably no transmitter has been given a more thorough test or proved more efficient than this one. A brass casting E' forms the base of the transmitter, to which is fastened the back piece R which carries the working parts of the instrument. The rear electrode A consists of a disk of carbon, one face being highly polished, soldered to a metal cap which forms the head of the threaded screw. This electrode is screwed into a piece of brass which forms the chamber for the carbon particles G, and which is held to the bridge piece R by the adjustment screw E. The front electrode B is composed of a similar piece of carbon, somewhat smaller in diameter, fastener to a cap C provided with a screw-threaded shaft. This electrode is insulated from the rest of the instrument by mica. The diaphragm D is fastened to shaft C and when it vibrates it acts as a piston compressing and releasing the granules of carbon. Two springs not shown in the diagram press on diaphragm to prevent it vibrating too much in its own natural period. The base piece E' is attached to a steel S, which supports the entire instrument, which in turn is fastened to the transmitter arm, forming one terminal of the circuit. A wire soldered to the metal block which is in contact with the front electrode, passes to a brass cylinder F, which is held in a piece of hard rubber fastened to R. A hole in F allows a plug to be inserted forming the other terminal of circuit. Aside from electrical considerations, the receiver or transmitter must be strong and compact so as to be able to withstand the rough usage to which they are liable to be subjected. The examples here given are two of the many which are in use, but the essential parts are shown and the principles are the same whatever the make of the instrument.

In Figure 5, Plate I is shown the connection of instruments in a telephone circuit. This is what is known as the series circuit. L and L' are the two line wire binding posts. G' on which the lightening arrester is placed, is grounded as shown. Two essential instruments in a telephone circuit, which have not heretofor been discussed, are shown in drawing -- the magneto-ringer G and call bell B'. The magneto-ringer is simply an alternating current generator, the armature being wrapped with many turns of fine wire and the fields being supplied by permanent magnets. The magnetic field is furnished by three or four bar magnets bent in the form of a horse-shoe. The ends of these magnets are fastened to blocks of soft iron which form the pole-pieces. These pole-pieces are hollowed out to fit the armature. The generator is operated by hand by a crank shown in figure, and enough pressure can easily be generated to ring through a large resistance. The common make and break bell cannot be used with alternating currents so that what is known as the polarized bell is used. The operation of the bell is simple and depends upon the principle of induced magnetic poles. When not in use the circuit is completed in the following manner: The receiver R rests on hook-switch H, making connection with arrow below. A current coming in over line L will pass through generator G, through the windings of bell B', thereby ringing the bell, and through hook-switch

H back over line L'. When the receiver is removed and the hook-switch makes contact with the two arrows above it, the bell and generator are cut out of the circuit and the circuit is completed in the following manner: A current coming in over line L, will pass through receiver R, through binding posts 2 and 6, through the secondary S of the induction coil, back to binding posts 5 and 4, and hook-switch out over line L'. The transmitter T is placed in series with the batteries B B and primary P of induction coil, through binding-posts 3 and 4 and hook-switch H. It is seen that when hook-switch is up with this connection, the generator and bell are out of circuit. In the bridging circuit the bell is permanently bridged across the circuit. This proves advantageous on party lines where a number of telephones are placed in series. For this purpose the bell magnets are wound with a great number of truns, producing a high inductance, and thereby preventing the passage of voice currents. For individual telephones connected to a central station, the series circuit is usually used, being somewhat cheaper than the bridging circuit.

These methods of telephoning were almost exclusively used form many years but the result of recent investigation has shown that they may be improved upon -- perhaps not in efficiency but in cost. Perhaps more has been done to eliminate the magneto-generator that any one thing connected with the circuit, because this instrument is one of the greatest items of expense in connection with the establishment of a telehpone.

The call bell is of course a necessary accessory to the circuit as no other means of calling the subscriber's attention is available. Telephones are in operation, and with success, with the generator, induction coil, and batteries absent, the power for the operation of each being furnished by the central station. The requisites of of a good telephone practice demands efficiency at least cost and the lack of good results are probably due more to ignorance or unfortunate circumstances than to principles involved.

Capacity and self-induction play an important part in telephony, especially in long distance work. An electric current flowing in a conductor sets up a field of force about the conductor its entire length. When these lines cut a conductor or are cut by a conductor an electro-motive force is generated, which tends to cause a current to flow. This phenomenon is called electro-magnetic induction. The strength of this E. M. F. depends upon the rate of cutting and the permeability of the medium. Iron has a permeability many times greater than air, therefore with iron adjacent to the circuit the E. M. F. generated will much greater. In a coil carrying a ~~circuit~~ current each turn of the coil has an inductive effect upon all the oth er turns when the ~~circuit~~ current is varying. When the current is increasing the E. M. F. of self-induction tends the check the flow of current while with a diminution of current, the opposite is true. The general effect, then of self-induction in a circuit is to tend to prevent any changes of current to take place in the circuit. In a circuit containing only ohmic resistance, the current equation is current $= \frac{\text{E.M.F.}}{\text{Resistance}}$. When the circuit has self-induction as well as ohmic resistance, this equation becomes current $= \frac{\text{E. M. F.}}{\text{Impedance}}$ where the impedance $= \sqrt{R^2 + (2\pi f L)^2}$. f = frequency and L = the coefficient of self-induction. Therefore the greater the self-induction the less will be the current flowing . It is seen then that the current decreases as the frequency increases. While this is objectionable on the line it may be applied advantageously in certain cases, one of the best illustrations being in the bridging bell system use on party lines, where the ringer magnets are purposly wound with a great number of turns and have heavy iron cores for the purpose of increasing the self-induction.

Capacity.

Every insulated conductor is capable of receiving a certain charge when subjected to an electro-motive-force. For instance, if an insulated conductor be connected to one terminal of a battery, the other being connected to the ground, a certain amount of the electricity will flow into the conductor until its potential is raised to that of the battery terminal. The quantity of this charge determines its capacity. It is also known that no charge exists by itself, there being always an equal and opposite charge induced by it upon neighboring bodies. Like charges repel, while unlike charges attract. If an uncharged body be brough near a charged body, an equal and opposite charge will be induced on the side which is toward the charge body, and a charge of the same sign as the charged body will be induced on the opposite side of the uncharged body. If now the body that was originally uncharged be connected with the ground, this latter charge will be driven into the ground, while the charge of the opposite sign will still be held by the charge on the first body. This action of charges of electricity through an insulating medium, is called electrostatic induction, and upon these principles the action of a condenser is based.. The capacity of a conductor is increased as the area of the conducting surface is increased, and is decreased as the distance between conductors is increased..

The insulating medium is termed a dialectric, and the specific inductive capacity of a dialectric is a measure of that quality which enables the dialectric to hold a charge between two conductors. Air is taken as a standard and has a specific inductive capacity of 1. It is seen then that these condenser properties may cause trouble in the line. In isolated lines, the trouble due to capacity, except in long lines, is negligable. In the construction of cables however, the specific inductive capacity of the dialectric is an important consideration, for here the capacity of the wires must be as small as possible and the insulating medium used must have as near as possible the specific inductive capacity of dry air. As in the case of self-induction, the current equation for a circuit having capacity is

$$\text{current} = \frac{\text{E. M. F.}}{\text{Impedance}}$$

$$\text{impedance} = \sqrt{R^2 + \frac{1}{2\pi^2 \chi^2 C^2}}$$

C is capacity in farads.

From the current equation with self-induction in circuit it is seen that the inpedance increases with the frequency , while in the latter equation the inpedance decreases with the frequency, and if sufficiently great the equation becomes simply

$$I = \frac{E}{R}$$

The E. M. F. of self-induction lags 90° behind the active E. M. F., while the E. M. F. due to capacity leads the active E.M.F. 90°. It would seem then that by properly proportioning the two forces they could be made to neutralize one another. The result is readily obtained in experimental work on short lines and the current will flow in accordance with Ohm's Law. For long distance lines, however, such balancing can be obtained for only one particular frequency at a time. This would give efficient transmission for only one particular frequency of vibration and is therefore impracticable since the frequency of the human voice has a large range. Again it has been found impossible to neutralize distributed capacity with anything but distributed self-induction, and this has not yet been accomplished in practice.

In the foregoing discussion, the elementary principles of telephony have been discussed and some of their applications given relative to the working of the circuit outside the exchange. What follows deals with the exchange in general and shows the different methods used in handling the work of the exchange.