Principles of Electricity

applied to

Telephone and Telegraph Work

A Training Course Text
Prepared for Employees of the
Long Lines Department
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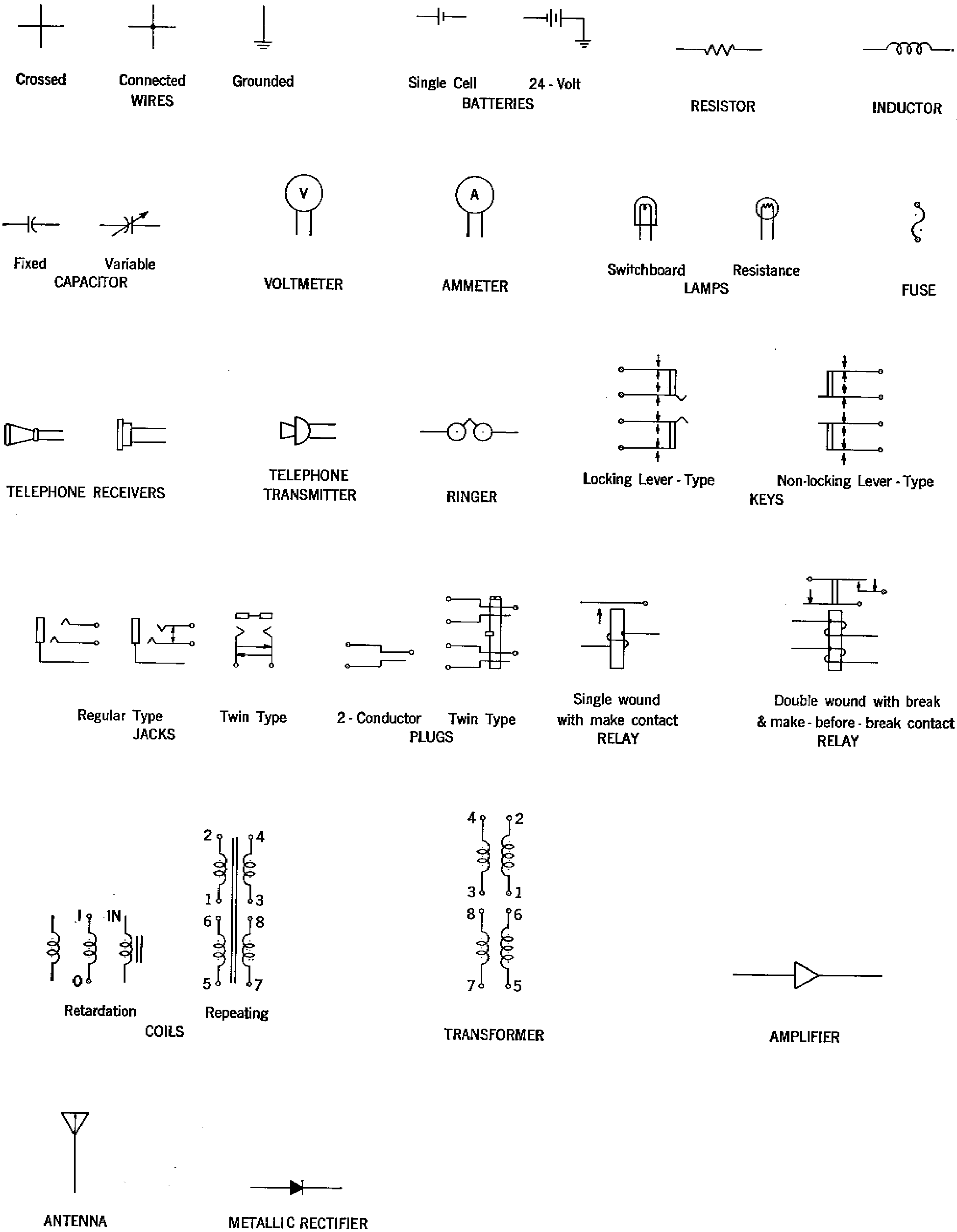


Fig. 2-7 Conventions Commonly Used in Telephone Circuit Drawings

CHAPTER 9

TELEPHONE PRINCIPLES AND BASIC APPARATUS

9.1 Sound

The telephone accomplishes the electrical transmission of speech by employing the mechanical energy of the speaker's voice to produce electric energy having similar characteristics, and in turn converting this electric energy into sound waves having similar characteristics at the listener's station. To understand its principle of operation we may well consider the nature of **sound.**

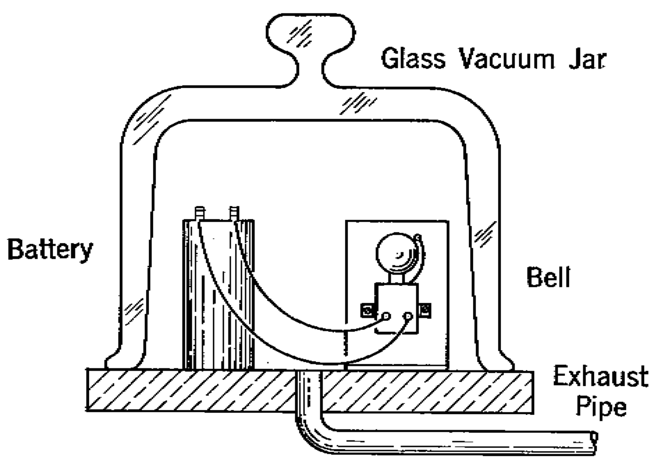


FIGURE 9-1

Sound in the scientific sense has two distinct meanings. To the psychologist it means a sensation, to the physicist it means an atmospheric disturbance or a stimulus whereby a sensation is produced in the human ear. In other words, it is a form of wave motion produced by some vibrating body such as a bell, tuning fork, the human vocal cords, or similar objects capable of producing rapid to-and-fro or vibratory motion.

Everyone is familiar with the series of waves that emanate from a stone cast upon the still water of a lake or pond. This is one of many forms of wave motion, and in a manner similar to that in which the stone coming in contact with the water establishes radiating rings formed by circular wave crests alternating with wave troughs, there emanate from a source of sound alternate condensations and rarefactions of the air. Instead of being rings on a single plane or surface, however, they are a series of concentric spheres expanding at a definite rate of travel. This rate of travel (or the velocity of the sound wave) is approximately 1,075 feet per second but varies to some extent with altitude and atmospheric conditions. The velocity of sound is very low as compared with the velocity of light, heat or radio waves, which are also a form of wave motion. We thus see a flash of lightning before we hear a clap of thunder or see the smoke dispelled from the muzzle of a gun before we hear the gun's report.

Unlike light, heat or electromagnetic wave transmission, sound is an atmospheric disturbance. If, as shown in Figure 9-1, a vibrating bell is placed under an inverted glass bowl resting on a plate that has an outlet to which an exhaust pump is connected, it may be heard almost as distinctly as though there were no glass container. But if the air is exhausted until there is a vacuum about the bell, no sound can be heard; yet the bell may be seen vibrating as clearly as before the glass container was exhausted. We thus learn that there must be a physical medium, usually atmospheric, for the transmission of sound.

If the sound's source is a vibrating mechanism in simple form, such as a simple to-and-fro motion of a tuning fork, and is sustained for a definite interval of time, the wave motion is said to be "simple harmonic". (A simple harmonic wave may be represented by the sine curve already dis-

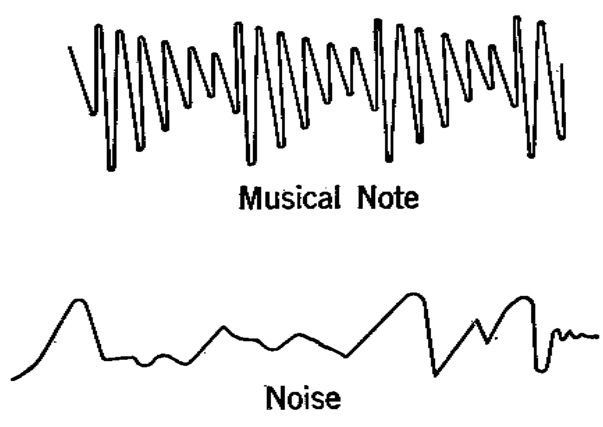


FIGURE 9-2

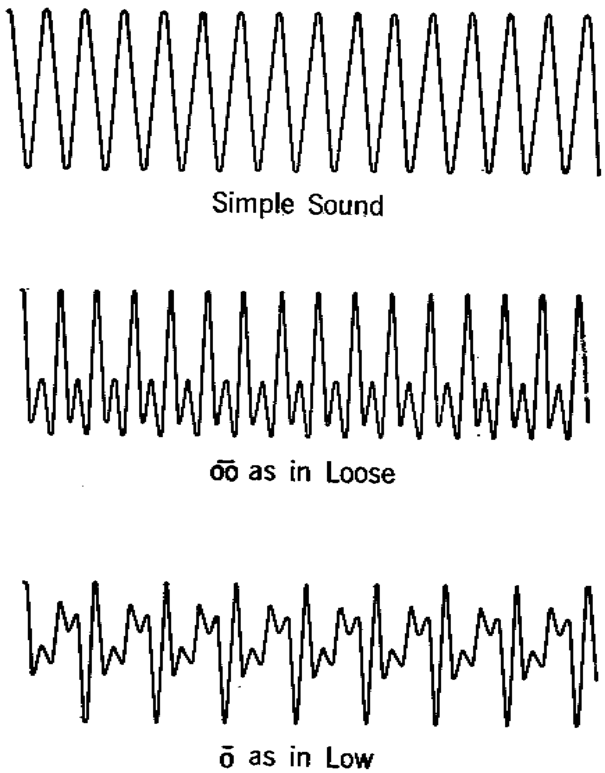


FIGURE 9-3

cussed in Article 6.2.) On the other hand, if the source consists of a complex mechanical motion or an object vibrating by parts as well as in its entirety, the wave is complex, or a fundamental sine wave with harmonics, the latter giving it "quality". A sine wave without harmonics is called a pure wave.

The sound sensation produced by a series of successive waves identical in form is called a tone, and if each wave is complex, it is a tone having timbre or quality, but if simple or a sine wave, it is a pure tone.

A vibrating mechanism giving a pure tone is said to establish a tone of low pitch if it is vibrating slowly, but if vibrating rapidly, it establishes a tone of high pitch. The lowest pitch which is audible to the normal ear lies somewhere in the octave between 16 and 32 vibrations per second. On the other hand, the normal ear has an upper limit of audibility lying somewhere in the octave between 16,000 and 32,000 vibrations per second. These two octaves are the extreme limits of the scale of audibility.

Audible sound is thus conveniently defined as a disturbance in the atmosphere whereby a form of wave motion is propagated from some source at a velocity of about 1,075 feet per second, the transmission being accomplished by alternate condensations and rarefactions of the atmosphere in cycles having a fundamental frequency ranging somewhere between 16 per second and 32,000 per second.

The waves superposed on the fundamental, which we have called harmonics, are present in most distinctive sounds, and particularly in the human voice. They permit us to distinguish notes of different musical instruments when sounded at the same pitch. They also establish subtle differences in the voice which may indicate anger or joy, or permit us to distinguish the voice of one person from that of another. Figure 9-2 illustrates wave forms for different kinds of sound and, similarly, Figure 9-3 shows the predominating wave shapes of certain spoken vowels.

Fortunately, in telephone transmission, which is essentially a problem of conveying "intelligibility" from the speaker to the listener, we are not seriously concerned with sounds having either fundamental or harmonic frequencies that extend throughout the entire scale of audibility. The sound frequencies which play the most important part in rendering the spoken words of ordinary conversation intelligible are the band of frequencies within the audible scale ranging from approximately 200 to 3,500 cycles per second.

9.2 The Simple Telephone Circuit

The original telephone, as invented by Bell in 1876, consisted of a ruggedly constructed telephone receiver, which at that time served as both transmitter and receiver. The telephone circuit in its simplest form consisted of two wires terminated at each end by such an instrument but without transmitter or battery and without signaling features. Figure 9-4 shows such a circuit.

At the speaker's station, the sound waves of the voice strike the metal diaphragm of the telephone receiver, and the alternate condensations and rarefactions of the air on one side of the diaphragm establish in it a sympathetic vibration. Behind the diaphragm is a permanent bar magnet and the

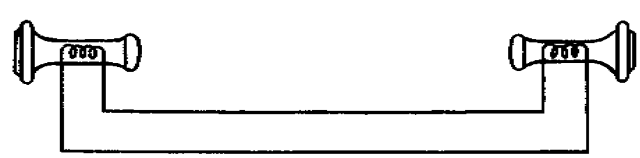


FIG. 9-4 ELEMENTARY TELEPHONE CIRCUIT

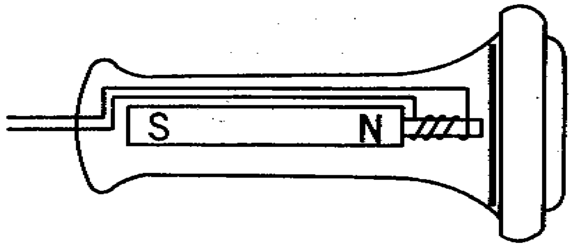


FIG. 9-5 BAR MAGNET RECEIVER

lines of induction leaving the magnet are crowded in the vicinity of the metal diaphragm. The vibration of this diaphragm causes a corresponding change in the number of lines that thread through the receiver winding, resulting in the turns of the winding being cut by these building up and collapsing lines. This establishes a varying electric voltage and current in the winding of the telephone receiver, having wave characteristics similar to the characteristics of the sound wave. This current passes over the connecting wires and through the receiver winding at the distant end. There it alternately strengthens and weakens the magnetic field of the permanent magnet, thereby lessening and increasing the pull upon the receiving diaphragm, which causes it to vibrate in unison with the diaphragm at the transmitting end, although with less amplitude. This vibrating diaphragm reproduces the original sound, conveying intelligibility to the listener at the receiving end.

9.3 The Telephone Receiver

The earliest forms of telephone receivers were made with a permanent bar magnet as shown in Figure 9-5. The efficiency of the receiver was later greatly increased by the use of a horseshoe magnet as shown in Figure 9-6. This permits the lines of magnetic force to pass in a much shorter path from one magnetic pole to the other through the iron diaphragm. The principle of operation

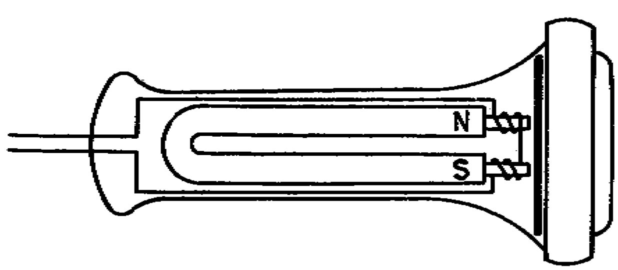


FIG. 9-6 HORSESHOE-MAGNET RECEIVER

of receivers currently in use in the telephone plant does not differ fundamentally from that of the early types although the receivers themselves are generally quite dissimilar in physical appearance.

Figure 9-7 is a cross-sectional drawing of a bipolar receiving unit which is in extensive use in the Bell System. This receiver employs in its construction no less than three of the comparatively new magnetic alloys that were mentioned in Article 4.1. It also differs notably from earlier types in the extent to which the motion of the diaphragm, which is made of vanadium permendur, is affected by "acoustic controls". One acoustic control is directly behind the diaphragm,

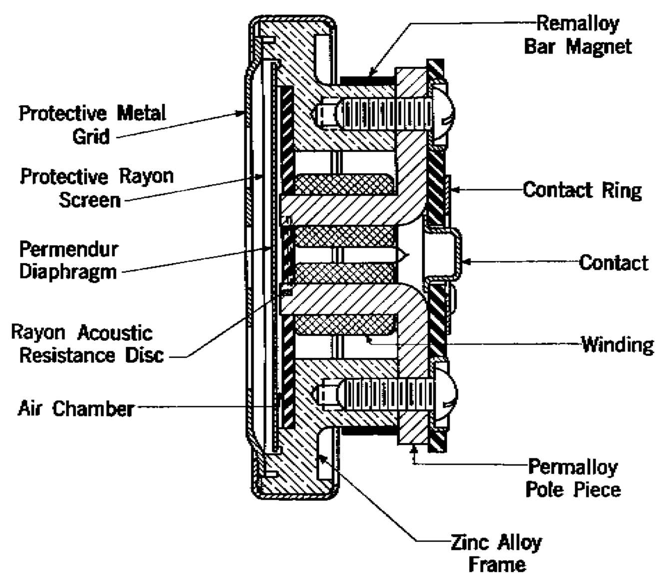
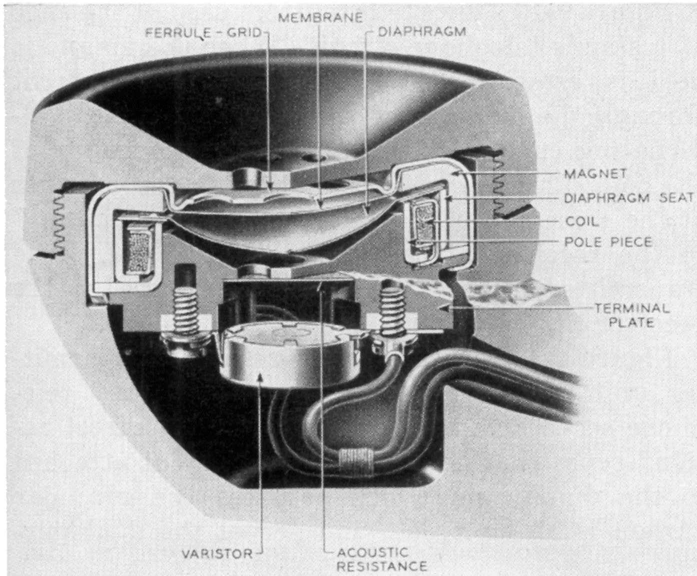


FIG. 9-7 CROSS-SECTION OF BIPOLAR RECEIVER UNIT

and the other is between the diaphragm and the inner surface of the receiver cap when the receiver unit is mounted in the telephone instrument. The former control consists of an air chamber with an outlet to the back of the receiver unit through a small hole covered with a rayon disc. The latter consists of an air chamber which opens into the air through six holes in the receiver cap. These air chambers are designed to have "acoustic impedances" which match the "electrical impedances" of the receiver and improve its overall efficiency appreciably. The diaphragm rests on a ring-shaped ridge and is held in place by the pull of the magnet. In this way variations in receiver efficiency at different frequencies are held to close limits. The two permalloy pole pieces are welded to a pair of very strong remalloy bar magnets, and the assembly is



RING-ARMATURE RECEIVER

fastened to a zinc alloy frame. The whole unit is held together by an aluminum ferrule on the back of which are mounted two silver plated contacts for the electrical connections.

A more recent design of receiver, which is currently standard for new installations, is shown in cross-section in the accompanying photograph. This is known as a **ring-armature** receiver. Differing radically in detail design from the bipolar types, it is substantially more efficient chiefly because the dome-shaped diaphragm is much lighter than that of the bipolar receiver. The diaphragm dome is made of lightweight plastic-impregnated cloth cemented at its outer periphery to a flat ring-shaped armature of vanadium permendur. The outer edge of the armature ring rests on a diaphragm seat of non-magnetic material and its inner edge extends into the air-gap between a pole piece of 45% permalloy and the permanent magnet which is made of remalloy. The entire diaphragm structure is thus driven like a piston under the influence of the magnetic fields existing in the air-gap across the inner edge of the armature ring.

Since telephone receivers are equipped with permanent magnets, it is of course important that the magnetism should not be impaired by jarring or other abuse. The permanent magnet is important not only because it increases the amplitude of vibration of the diaphragm when the voice current is flowing through the windings, but also because it prevents the diaphragm vibrating at twice the voice frequency. This principle is illustrated in Figure 9-8. When a piece of soft iron is held near an electromagnet, it is attracted by the magnet regardless of the direction of the current in the windings. Thus, an alternating current in a winding on a soft iron core will assert an attraction during each half cycle, which in the case of the receiver diaphragm will establish a vibration with a frequency twice that of the current. If, on the other hand, a permanent magnet is used, the alternating current establishes a vibration of the same frequency as the current by merely increasing or lessening the pull already exerted on the diaphragm.

9.4 The Telephone Transmitter

Although the principle of Bell's original telephone applies to the present day telephone receiver, it was appreciated in the early stages of telephone development that the electrical energy generated by a diaphragm vibrating in a comparatively weak magnetic field was insufficient for the transmission of speech over any considerable distance. The energy could, of course, be increased by using stronger magnets, louder sounds, and the best possible diaphragms, but even with any ideal telephone receiver that might be perfected, voice transmission would be limited to comparatively short distances. One year after the invention of the original telephone, the Blake transmitter was introduced. It worked on the principle of a diaphragm varying the strength of an already established electric current, instead of generating electric energy by means of electromagnetic induction. By this means it was possible to establish an electric current with an energy

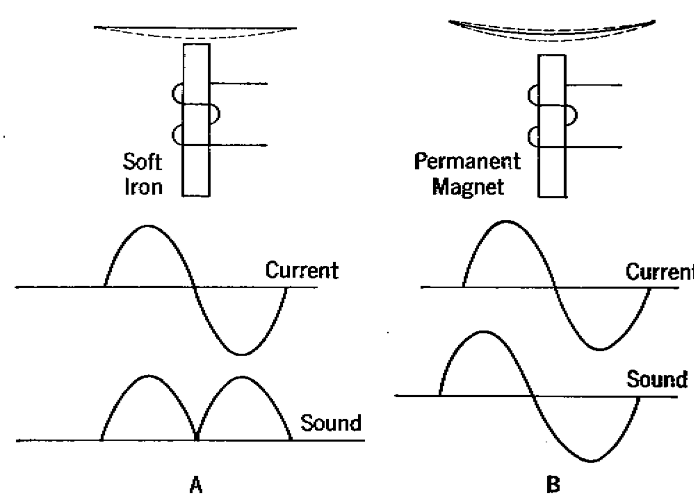


FIGURE 9-8

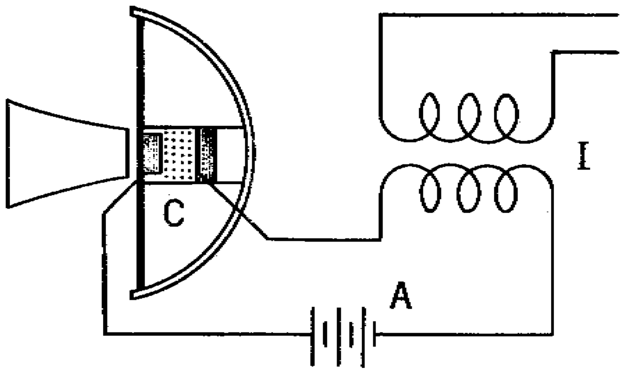


FIG. 9-9 PRINCIPLE OF THE TELEPHONE TRANSMITTER

value much greater than that conveyed to the instrument by a feeble sound wave. The battery in this case was the chief source of energy and the vibration of the diaphragm acted as a means for regulating or modulating this energy supply, rather than as a generating device.

The principle of the transmitter is illustrated by Figure 9-9. Battery *A* establishes a direct current in a local circuit consisting of the primary winding of an induction coil *I*, and a cup of carbon granules *C*. One side of this cup rests against a small carbon disc rigidly connected to the transmitter diaphragm. The vibrating transmitter diaphragm varies the pressure on the carbon granules, which causes the resistance of the electric circuit through the carbon granules to vary correspondingly, thereby causing fluctuations in the value of the direct current maintained in the circuit by the battery. These fluctuations, though represented by varying direct-current values instead of by an alternating current, as in the case of the telephone circuit in Figure 9-4, establish an alternating emf in the secondary winding of the induction coil. This, in turn, sets up an alternating current through the local receiver, over the line, and through the distant receiver. The operation of the distant receiver is the same as has been explained in connection with Figure 9-4.

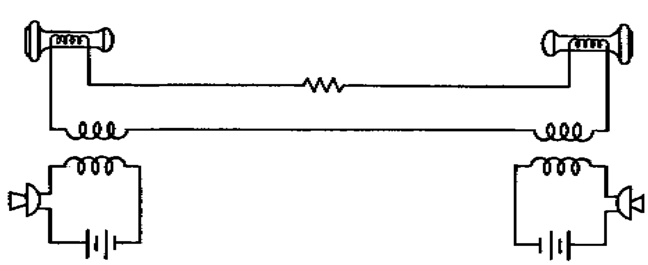


FIG. 9-10 TELEPHONE CIRCUIT WITH LOCAL BATTERY TRANSMITTERS

Figure 9-10 shows transmitters used at the ends of a simple telephone circuit. When the magnetic field is established by the fluctuating current through the primary of the induction coil, an alternating current is induced in the secondary of the coil. This current flows through the receiver at the same end of the circuit, giving "side-tone" to the receiver at the home station. It is also transmitted to the distant station, operating the receiver at that point.

Figure 9-11 shows in cross-section a transmitter unit that is standard for subscribers' telephone sets. This transmitter is of the "direct action" type; that is, the movable element attached to the diaphragm which actuates the granular carbon is an electrode, and serves the dual purpose of contact and pressure surface. As the drawing shows, this dome-shaped electrode is attached to the center of a conical diaphragm, and forms the front center surface of the bell-shaped carbon chamber.

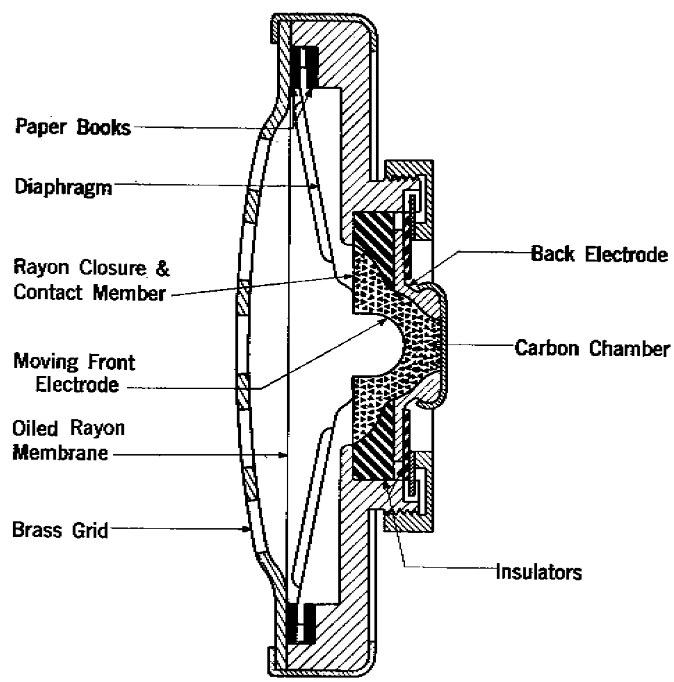


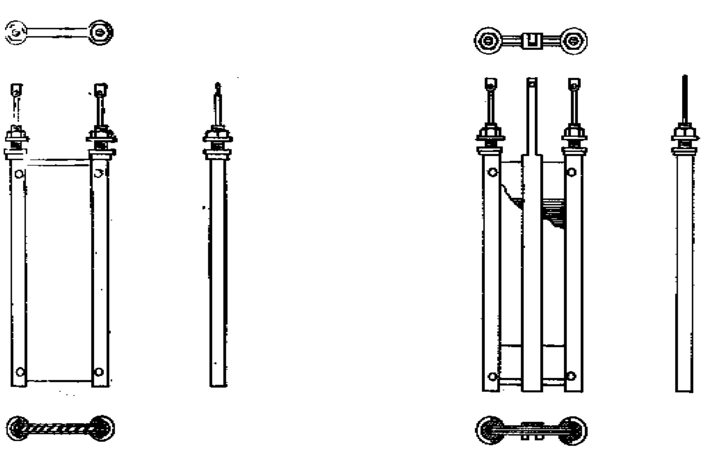
FIG. 9-11 CROSS-SECTION OF TRANSMITTER UNIT

The diaphragm is made of aluminum alloy with radial ridges to increase stiffness. Paper books, which consist of a number of thin impregnated paper rings, support the diaphragm at its edges on both sides. The carbon chamber is closed on the front side by a rayon membrane clamped under the flange of the diaphragm electrode. A light, spoked copper contact member, clamped under the diaphragm electrode, is the means of providing a flexible connection between this front electrode and the supporting metal frame. The fixed back electrode is held in place in the frame by a threaded ring and is insulated by a phenol fibre washer and a ceramic insulator which also forms one of the surfaces of the carbon chamber. The active surfaces of both electrodes are gold plated. A brass plate which is perforated with large holes protects the vibrating parts against mechanical injury. Moisture is kept out of the working parts by an oiled rayon moisture-resisting membrane placed between the brass plate and the diaphragm.

The shape of the electrodes and the carbon chamber provides sufficient contact force between the diaphragm electrode and the granular carbon in the zone of maximum current density so that this transmitter operates satisfactorily in any position. When new, it has a resistance of around 30 to 40 ohms.

9.5 Resistors, Inductors and Capacitors

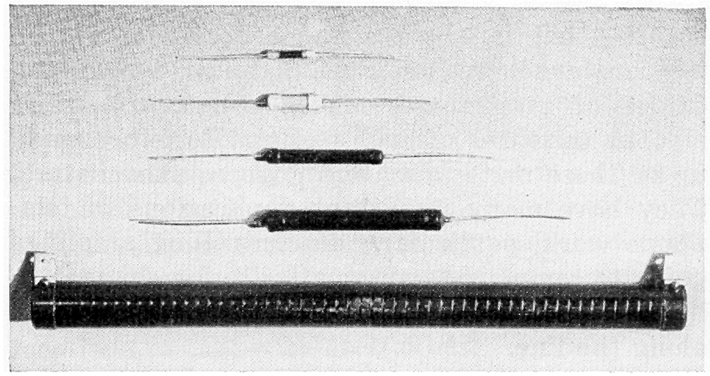
A resistor is a piece of apparatus designed for the specific purpose of inserting resistance into an electric circuit. Resistors are therefore designed in practice to have a definite value of resistance in ohms. They must also be designed in many cases to be capable of dissipating specified amounts of power without heating beyond safe limits. The applications of resistors in telephone and telegraph work are almost innumerable, involving ohmic values ranging from fractions of one ohm to many megohms; and power ratings (i.e., ability



18 - Type

19 - Type

Fig. 9-12 Flat Resistors



Deposited Carbon Resistors

to dissipate energy) ranging in general up to about 5 watts.

The great majority of the resistors used can be divided into two principal types—wire-wound and carbon. For relatively low resistances ranging from less than one ohm up to a few thousand ohms, most of the common resistors found in the telephone plant are the so-called flat types coded #18 and #19 and illustrated in Figure 9-12. As indicated, these consist of wire wound on a flat card of insulating material, the flat shape having the advantage of making the resistor relatively non-inductive. Where higher resistances—in the order of ten thousand ohms and upward—are required, some type of carbon resistor is usually employed. Most common of these is the so-called **composition** resistor in which the resistive element is a combination of finely divided carbon or graphite mixed with a non-conducting filler such as talc, with synthetic resin as a binder. These resistors are well suited for application in relatively high frequency circuits such as radio where great precision in ohmic value ordinarily is not required. They are usually built to tolerances of about 5% and are commercially available in values from 10 ohms to 22 megohms, with power ratings up to 2 watts. Where very high resistances are needed, the **deposited-carbon** resistor may be used. In this type the resistor element is an extremely thin film of carbon, or a mixture of carbon and boron, deposited on the surface of a ceramic core by thermodecomposition. A helical groove is then cut through the carbon film to leave a ribbon of the carbon film wound around the core between the terminal electrodes at the ends.

The resistance of any ordinary electric conductor, such as the wire used in wire-wound resistors increases as the temperature of the conductor increases. There are, however, many so-called semi-conducting materials in which the opposite effect occurs—that is, the resistance decreases as the temperature increases. Such materials include the oxides of manganese, nickel, cobalt, iron, and zinc, or mixtures of such oxides. Resistors made up of these materials are known as **thermistors.** They have many important applications in telephone work, particularly in controlling amplifier gains to compensate automatically for changes in line loss resulting from temperature changes along the line.

An inductor is a piece of apparatus designed primarily to insert inductance into a circuit. We have already noted the use of certain types of inductors, commonly called retardation or choke coils, in power circuits. Inductors, as was pointed out in an earlier Chapter, consist fundamentally of coils of wire, the amount of their inductance depending primarily upon the number of turns in the coil, its size and shape, and the nature of the core material about which the coil is wound. Inductors are usually classified under two main types—those having air cores and those with cores consisting of iron or iron alloys. Both types have numerous uses in communication circuits. As would be expected from our knowledge of magnetism, air core inductors have relatively low inductance values but are comparatively free from the core losses due to magnetic hysteresis and "eddy currents" that are inevitable when metallic cores are used. The principal field of use of air core inductors is in high frequency or radio work. Where relatively large amounts of inductance are needed, as in power circuits and telephone and telegraph circuits at ordinary frequencies, iron core inductors are employed.

Since any inductor consists of many turns of wire, it will always have resistance as well as inductance. In inductor design, however, every effort is made to keep the resistive effect as low as possible in comparison to the inductive effect. The ratio of the inductive effect to the resistive effect is known as the **figure of merit** or "*Q*" of the inductor.

Capacitors (or condensers) were discussed briefly in Chapter 8. It was established then, that the capacitance value depends on the plate areas, and the nature and thickness of the dielectric between the plates. The simplest dielectric is air, and most of the variable capacitors are "air condensers". Unless such capacitors are extremely large, however, their total capacitance is relatively low and their chief use is, accordingly, in high frequency work. For the many applications in communications work at lower frequencies, capacitors employing impregnated paper, mica, or ceramic materials as dielectrics are extensively used. The paper capacitor may be made as a continuous roll of two aluminum foil strips separated by thin Kraft paper impregnated with oil or wax. Or, to reduce its volume, metal films may be evaporated directly onto the paper strips. Such capacitors are made in a wide range of capacitance values extending up to 5 microfarads and may be designed to withstand substantial voltages (up to 4000 volts) without breakdown.

Mica capacitors are made in a smaller range of capacitance values. This is also true of the ceramic capacitors, which employ materials based on titanium dioxide mixtures as dielectrics. Neither will withstand as high a voltage as good paper capacitors but both have a higher degree of stability with respect to temperature change and aging. Their normal application, accordingly, is to situations where more precise and constant capacitance values are required.

Within reasonable limits of cost and size, none of the capacitors discussed above can be built to have capacitance values exceeding a very few microfarads. Where larger values of capacitance are needed, an entirely different type known as an electrolytic capacitor is widely used. In most designs this capacitor consists of plates of aluminum or tantalum, on which extremely thin oxide films have been electrochemically deposited, immersed in a conducting aqueous electrolyte. The aluminum or tantalum plate is one electrode of the capacitor, the conducting electrolyte is the other electrode, and the insulating oxide film on the plate is the dielectric. Because of the extreme thinness of this film, capacitors of this type may have a very high capacitance even though quite

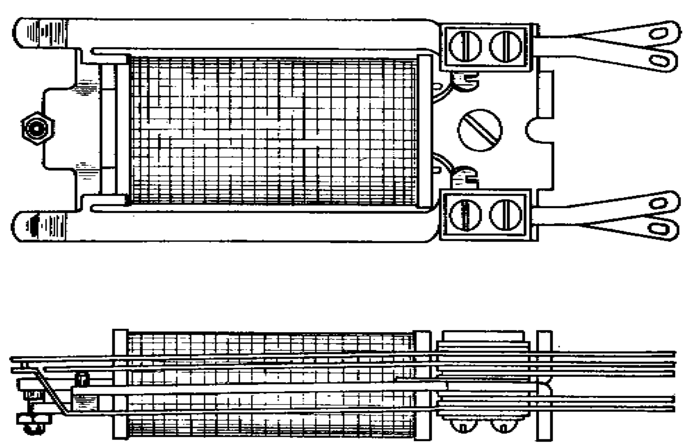
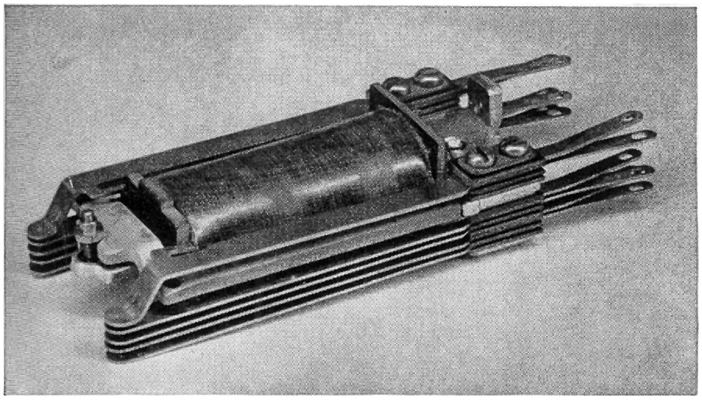


FIG. 9-13 E-TYPE RELAY



E-Type Relay

limited in size. For certain applications in telephone power plants, such as in voltage stabilizing filters, electrolytic capacitors may be built in large cells similar in external appearance to a storage battery. For much more extensive use in electronic devices such as amplifiers, they are usually built in small cylindrical forms not dissimilar in appearance to the small paper capacitors commonly employed in such apparatus. The electrolyte in this case is usually a viscous paste which includes some glycol or other conducting liquid. These capacitors are generally not as stable or long-lasting as paper or mica capacitors, principally because the partly liquid electrolyte offers a possibility for undesired chemical action if any impurities are present. There is a design of tantalum capacitor, however, in which the "electrolyte" is dry, solid manganese dioxide, with the metal container acting as one electrode. Since it is therefore chemically inert, this design makes for longer life and greater stability.

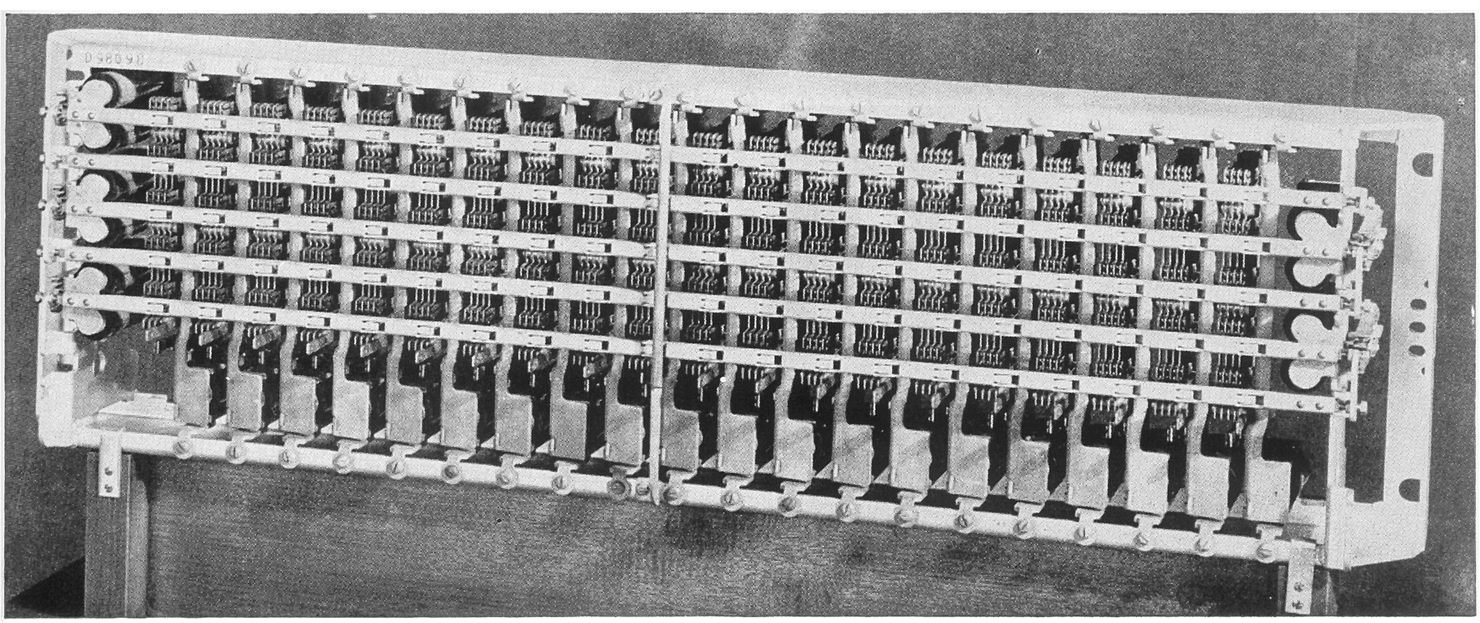
9.6 Relays and Switches

The fundamental instruments of telephony are the telephone transmitters and receivers that are described in some detail in a preceding Article. These instruments, when associated in appropriate circuits with other basic apparatus units such as coils, capacitors, resistors, etc. and connected together by means of appropriate transmission lines, make it possible for persons at different locations to talk with each other.

The problem of telephone service, however, is not just to make it possible for some one person to talk with another person at a distance, but for any subscriber to such a service to be able to talk with any other subscriber. This means that any practical working telephone plant must include vast quantities of **switching apparatus** designed to connect, disconnect and rearrange a great variety of circuits quickly and surely, as may be necessary to meet the ever-changing communication requirements of the subscribers.

Switching apparatus may be classified first into two fundamental categories—manually operated and electrically operated. Devices in the first category include jacks, plugs, cords, keys, push buttons, etc. Such devices are probably too well known to require any extended discussion here, although the reader who is familiar with them will also recognize that they can be, and are, built in many different designs to serve particular purposes.

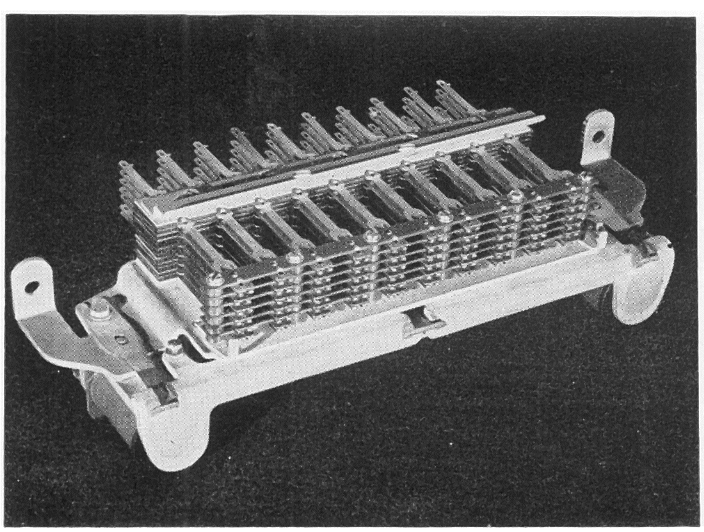
The most commonly used of the electrically operated switching devices is the relay. This is a



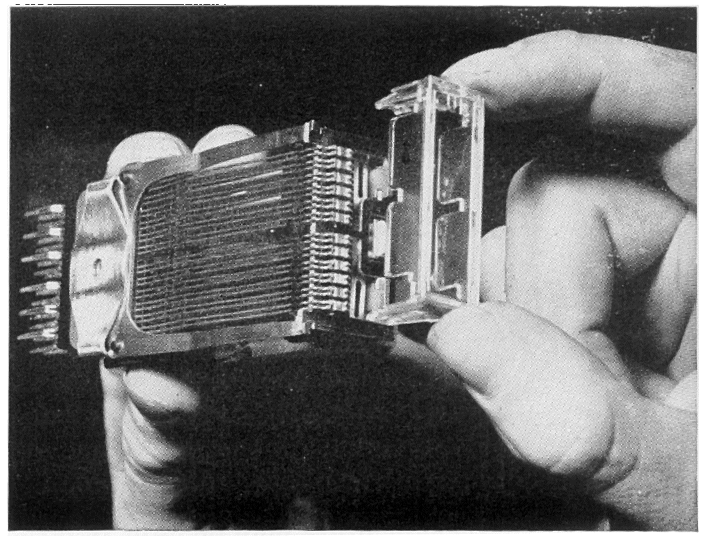
200-point Crossbar Switch

relatively simple piece of apparatus in which an electromagnet driven by one electric circuit may operate to open or close switching contacts in one or more other electric circuits. Figure 9-13 and the accompanying photograph illustrate the basic design of a general type of relay in wide use in the Bell System. Here pairs of electrical contacts, normally held closed by the tension of flat springs, may be opened by the movement of the armature that results from energizing the magnet coil winding. With other arrangements of the springs, normally opened contacts may be closed by operation of the relay armature; different sets of contacts may be opened and closed simultaneously, or in a desired order. Indeed, since relays of this type are built with as many as 24 springs, the number of possible circuit arrangements is very large and runs well up into the hundreds in standard telephone practice.

The relay shown in Figure 9-13 is equipped, as previously noted, with contact springs made of flat metal strips. Most of the relays currently manufactured by the Western Electric Company employ a pair of wire springs in place of the older flat spring, as shown in the accompanying photograph. To each wire is welded a contact point, usually of some precious metal to insure a good electrical connection. The twin contacts guard further against the possibility of faulty operation in the event of dust or other foreign particles lodging between one pair of contact points. Wire spring relays are built with the same variety of open and closed contact arrangements as the older types. Their construction, however, lends itself to better quality control in manufacture and to substantial cost savings.



Multi-contact Relay



Wire-spring Relay

Since relays are mechanical devices having moving parts with inertia and elasticity, their operation cannot be instantaneous. The operating time of the ordinary relay is in the order of 50 milliseconds, either on opening or closing. In some telephone circuits, however, it is desirable to control relay operating time in such a way that it will be longer than the nominal time. This can be effected within limits by adding a very low resistance path around the magnetic core of the relay in the form of either a short-circuited winding or a solid metal sleeve. Then, when the current in the regular relay winding is broken, the decaying flux in the core will induce a circulating current in the sleeve. This, in turn, tends to produce flux in the core additional to and in the same direction as the original flux. The time required for the total flux to decay is thus increased, which causes a proportionate delay in the relay release time. The lower the resistance of the added sleeve or short-circuited winding, the greater will be the current and the greater the retarding effect on the relay release time. Thus by varying the resistance of the sleeve, or the short-circuited winding, it is possible to obtain a range of delay times extending from a minimum of 50 ms up to as much as 500 milliseconds.

Where, as may frequently be the case in the operation of local or toll dialing machinery, it is necessary to operate more than a dozen or so switching contacts simultaneously and under one control, a special type of relay known as a **multi-contact** relay is used. As shown in the photograph, this relay has two coils and two armatures each of which operates half the contacts. The springs are arranged in ten groups, each of which may include as many as six pairs of springs. This provides for a maximum of sixty simultaneous contacts or switching operations when the two armatures are operated together. The complete structure may be used as two independent relays, each having up to thirty contact springs, or as a single relay with double this capacity when the operating coils are connected in parallel. All contacts are doubled to provide greater reliability of operation.

All relays used in telephone circuits are designed to operate and release at certain definite values of current in their windings. As these current values are frequently very small, this means that the springs which hold the armatures in their non-operated positions must be adjusted with precision. Practically all telephone circuits are

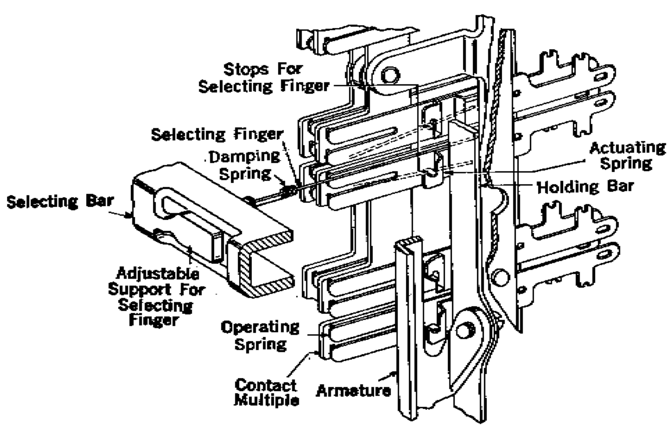


FIG. 9-14 CROSSBAR SWITCH CROSSPOINT

dependent for their operation upon the proper functioning of relays. In some of these the operating limits are sufficiently liberal to allow considerable margin in adjustments. But in others—and these are frequently the more important ones—the difference between an adjustment giving satisfactory operation and one under which the relay will fail to function properly, may be very small. In practice, specific instructions giving the exact operating and release current values for which each type of relay should be adjusted for each kind of circuit in which it may be used, are provided.

In many of the more complicated switching operations required in telephone and telegraph work, such as those involved in toll line dialing for example, it is necessary to operate switches which are electrically controlled by two rather than by only one external circuit as in the case of the relays already discussed. A commonly used switch of this type, which has many of the physical characteristics of a relay, is known as the **crossbar switch.** Such a switch arranged to provide a maximum of 200 different switching connections is shown in the accompanying photograph. (Note, however, that not all of these connections can be made simultaneously, but at each of the switch-points as many as six different contacts may be operated.) The 200 switching points or **crosspoints** of the switch shown are obtained by the use of 20 vertical bars and 5 horizontal crossbars.

Closure of any one crosspoint is effected by the coordinated operation of one of the horizontal and one of the vertical bars. As shown in the photograph, the horizontal and vertical bars are located in front of the contacts and arranged to be rotated by magnets through a small arc. Each of the vertical bars is provided with a magnet at the bottom of the switch. Only five horizontal bars are used but each bar is equipped with two magnets so that it may be rotated in two directions.

Figure 9-14 shows in more detail how the controlling magnets operate the crosspoint switches. Each horizontal or **selecting bar** carries twenty selecting fingers which are normally opposite an open space between two crosspoints. When one of the bars is partially rotated by its selecting magnet so that the fingers are tilted upward or downward, its twenty fingers lie across the backs of the contacts as indicated by the dotted lines in the drawing. If one of the vertical bars is now rotated so as to press against the vertical row of five selecting fingers, the selecting fingers that are in normal position will be pressed into the spaces between crosspoints, with no effect. The selecting finger that has been tilted upward or downward by the operation of the horizontal bar, however, will be pressed against the adjoining flexible contact spring assembly, thus closing the contacts at that crosspoint. Once this contact has been made in this way, it will remain closed as long as the vertical bar is held in the operated position even though the horizontal bar has been returned to normal, because the selecting finger will remain trapped against the contact spring. For this reason the vertical bar is known as a **holding bar** and its associated magnet is known as a **holding magnet.**

CHAPTER 10

TELEPHONE CIRCUITS

10.1 The Telephone Subscriber Set

Figure 9-10 of the preceding Chapter showed a simple telephone connection between two telephone sets, each equipped with a transmitter, receiver, induction coil and its own battery for supplying talking power. In most modern telephone station installations, talking battery is supplied to each subset from a common battery at the telephone central office to which each subscriber line is connected. The simplest subscriber station circuit arrangement under these conditions is shown schematically in Figure 10-1. When the receiver is lifted to close the contacts of the hookswitch, and the line is picked up at the central office by an operator or mechanical device, the central office battery is connected in series with the primary winding of the induction coil and the transmitter, and current is sent over the line.

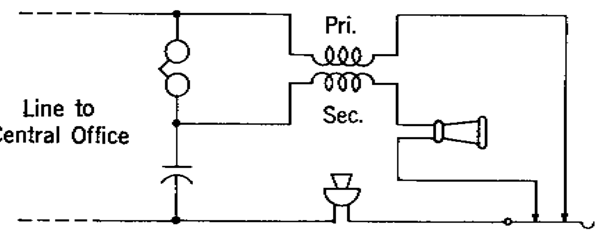


Fig. 10-1 Simple Station Circuit

Varying currents set up by the transmitter, when it is talked into, add to or modulate the direct current flowing from the central office battery. There is also a path for the varying transmitter currents (which are fundamentally alternating rather than direct) through the capacitor, the secondary of the induction coil and the receiver. Thus, there are varying currents in both windings of the induction coil and each induces a voltage, and a consequent current, in the other winding. The two currents in the primary winding combine to flow out on the line and thence to the distant receiver, and the two currents in the secondary winding combine and flow into the receiver and cause sidetone.

When receiving, the incoming varying (alternating) current, which carries the message, divides between the two parallel paths containing the transmitter and receiver respectively. In passing through the windings of the induction coil, in these two paths, the current in the primary winding induces a voltage in the secondary winding, which opposes the part of the incoming current flowing into that winding; but the circuit is so designed that the part of the incoming current in the secondary winding is greater than that in the primary so that the resultant current flowing in the receiver is still sufficient to operate it. Since in receiving, a substantial part of the incoming energy is dissipated in the transmitter circuit and in transmitting, energy is likewise dissipated to no useful purpose in the receiver circuit, the subset is fundamentally inefficient. Such inefficiency, however, is inherent in any circuit designed to operate in two directions without using directional switching arrangements.

The transmitting current flowing in the receiver as sidetone obviously serves no useful purpose and may be confusing or annoying to the speaker. The simple subset discussed above is modified generally in modern practice to a circuit arrangement such as that shown in Figure 10-2, which is one of several possible "anti-sidetone" connections. This circuit makes use of a different induction coil having a third winding S_2, the resistance of which is made high relative to that of winding S_1. For the receiving condition the current relationships are effectively identical with those of the sidetone circuit shown in Figure 10-1 because the resistance of S_2 is so high. For the transmitting condition there are, as in the sidetone circuit, two parallel paths for the current

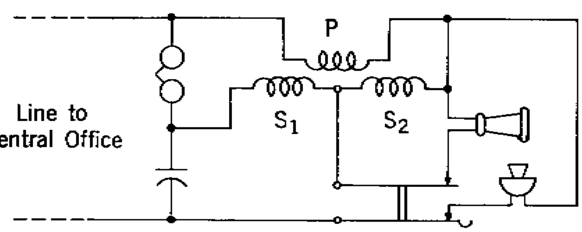


Fig. 10-2 Anti-sidetone Station Circuit

flow—one directly over the line through the primary of the induction coil and the other through the capacitor and S_1 and either through S_2 or the receiver. Because of the relatively high resistance of S_2 most of the current will tend to flow through the receiver, but the induction coil is so designed that current flowing in P and S_1 will induce a voltage in the winding S_2 which will tend to set up a current approximately equal and opposite in direction to that flowing through the receiver. The net effect is no current in the receiver, and hence no sidetone. This circuit is no more efficient than the sidetone circuit but it seems more so, principally because in receiving the listener is not distracted by extraneous noises coming from his own transmitter.

10.2 The Telephone Central Office

In practical telephone systems all subscriber stations are connected to a telephone "central office" by relatively short lines known as subscriber loops. The major purpose of a central office is to provide switching arrangements whereby any subscriber station connected to that office can be connected at will to lines leading to other subscriber stations also connected to that office; or to trunk lines leading to other central offices in the same or distant cities. The central office has numerous incidental functions, including that of providing common talking battery for all of its lines as discussed in the preceding Article. This requires comparatively large installations of storage batteries, power generating machinery and associated control equipment. Installed in the central office too, are numerous frames and racks, testboard and other testing equipment, signaling

500-Type Telephone Set

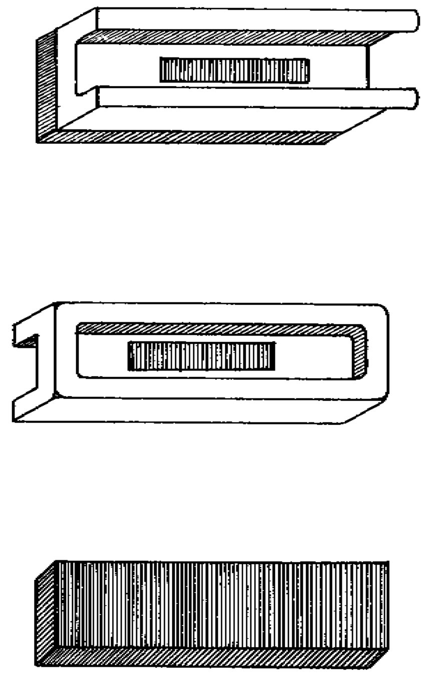


Fig. 10-3 Open-space Cutout

and control devices, and various other auxiliary equipment. Important, both at the central office and the subscribers' stations, is the installation of protective devices which will guard both telephone apparatus and people using it from dangerous foreign voltages that may be brought in on the lines as the result of some abnormal condition. This protection is of such basic importance that it may be well to digress here to review it in some detail.

Practically all outside telephone plant, except conductors that are completely underground from terminal to terminal, may be occasionally exposed to excessive voltages from such sources as lightning and other atmospheric disturbances, electric power lines running in close proximity to the telephone lines, high power radio sending apparatus, etc. Accordingly, such exposed conductors leading into a central office or subscriber station are connected first to appropriate protective apparatus. The particular protective units employed and the manner in which they are connected into the telephone circuits vary somewhat with particular situations, but in general protective devices are of three principal types—open-space cutouts, fuses, and heat coils.

The first and last of these devices ordinarily operate to ground the protected wire, while the fuse opens the wire in which it is inserted. Each of the protective units is designed so that, for the particular situation in which it is used, it will be

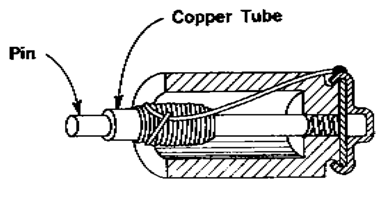


FIG. 10-4 HEAT COIL

sufficiently sensitive to operate before the plant which it is protecting is damaged, but on the other hand, not so sensitive as to cause an unnecessary number of service interruptions.

The standard form of open-space cutout used at subscribers' stations, in central offices, and at the junctions of cable and open wire lines, is illustrated in Figure 10-3. It consists of two carbon blocks having an accurately gaged separation of a few thousandths of an inch, one of which is connected to ground and the other to the wire to be protected. As shown in the Figure, one of the carbon blocks is much smaller than the other and is mounted in the center of a porcelain block. When the voltage of the telephone wire becomes too high, the wire will be grounded by arcing across the small air-gap between the carbon blocks. If a considerable current flows across the gap in this way, enough carbon may be pulled from the blocks by the arc to partially fill in the gap and cause permament grounding. Or, in the extreme case, when the discharge is prolonged and sufficiently high, the glass cement with which the small carbon insert is held in the porcelain block may be melted, with the result that the blocks are forced into direct contact by the mounting springs in which they are held. In the majority of protector operations, however, the blocks do not become permanently grounded.

The air-gap space between the blocks is designed so that the operating voltage of the protector will be less than the breakdown voltage of the weakest point of the circuit which it is designed to protect, and greater than the maximum working voltage of the circuit. The average operating voltage of the open-space cutouts used at subscribers' stations and in central offices is about 350 volts. For the cutouts used at junctions between open wire and cable lines, an average operating voltage of about 710 volts is standard.

When a telephone conductor is grounded by the operation of an open-space cutout, current will continue to flow through the telephone conductor to ground so long as the exposure continues. This current may be large enough to damage the telephone conductor or the protective apparatus itself. Accordingly, it is necessary to insert in the conductor, on the line side of the open-space cutout, a device which will open the conductor when the current is too large. Fuses are used for this purpose. The fuse is simply a metal conductor inserted in series with the wire to be protected, which is made of an alloy or of a very fine copper wire that will melt at a comparatively low temperature. Short lengths of cable conductors (six feet or more) of 24 or finer gage will serve effectively as fuses and will fuse on current values not high enough to overheat dangerously the central office protectors. Where the use of such inserted fine gage cable is not practicable, lead alloy fuses mounted in fire-proof containers or on fire-proof panels are employed. These are also designed to operate with a current of 7 to 10 amperes.

Finally, it is frequently necessary to protect telephone apparatus against external effects in which the voltage is not high enough to operate the open-space cutout, nor the current high enough to operate fuses, but still high enough to damage apparatus if allowed to flow over a long period. Such currents are usually called "sneak" currents and are guarded against by the use of heat coils. As illustrated in Figure 10-4, the heat coil consists of a small coil of wire wound around a cop-

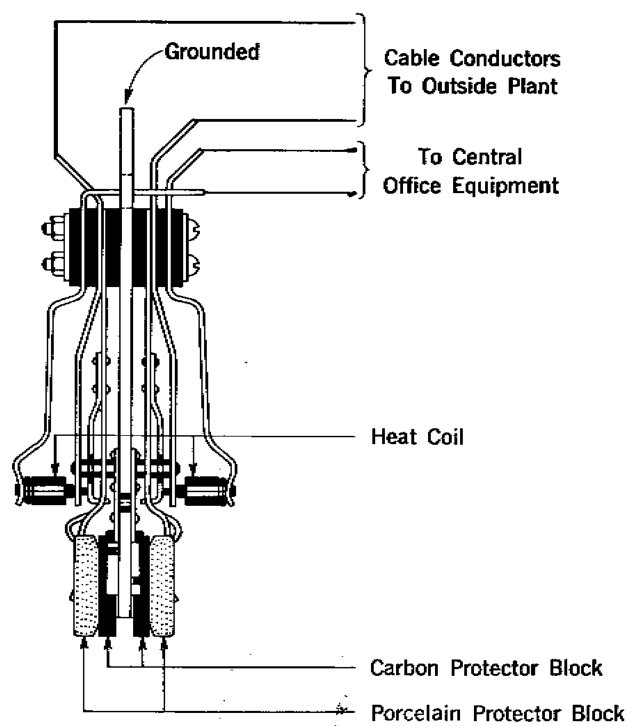


FIG. 10-5 HEAT COILS AND CUTOUTS MOUNTED ON PROTECTOR FRAME IN CENTRAL OFFICE

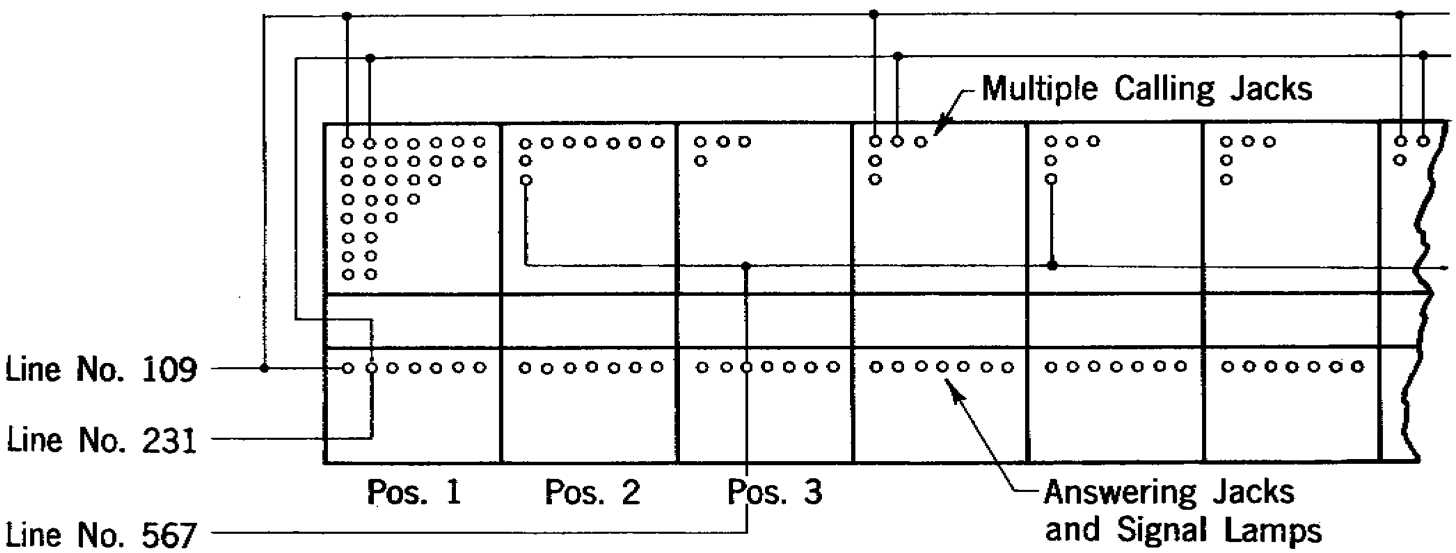


FIG. 10-6 MULTIPLE SWITCHBOARD

per tube which is connected in series with the wire to be protected. Inserted within the copper tube and held in place by an easily melting solder is a metal pin which is connected to the line side of the coil. If sufficient current flows through the coil to melt the solder, this pin will move under the pressure of its mounting spring and thus connect the line to ground. The heat coil now in general use in the telephone plant is designed to carry .35 ampere for three hours and to operate in 210 seconds on a current of .54 ampere. In certain cases heat coils of a generally similar nature are used to open circuits instead of to ground them. Where used in line circuits, as in the case of conductors entering a central office, the heat coil is mounted on the office side of the open-space cutout. In this position the heat coil wiring aids the operation of the open-space cutout by presenting a considerable resistance to suddenly applied voltages such as are produced by lightning discharges. The method of mounting heat coils and open-space cutouts on the protector frames in central offices is illustrated in Figure 10-5.

Let us return now to the switching function of the central office, which we have already pointed out as its main purpose. Switching equipment is designated as **manual** or **dial** depending upon whether the switching operations are performed primarily by people or by mechanical devices. Although both types perform the same function, the equipment and methods employed in each case are quite different.

10.3 Manual Switching Systems

In the manual central office, switching is performed by operators at switchboards. In a local single office exchange, all subscriber lines terminate in at least two jacks in these switchboards. One jack, mounted in the lower part of the switchboard panel, has associated with it a signal lamp by means of which a subscriber wishing to make a call can secure the attention of the operator. This is her **answering jack.** The other jack mounted in the upper panel of the board, is used by the operator to complete a connection to this same subscriber's line when it is called by some other station. This is designated the **calling jack.** Except in very small offices, each line appears in parallel at many other jack locations along the board. In other words, the terminations are **multipled** so that any line is within reach of any operator.

The principle of the multiple switchboard is that the answering jacks and associated signals are divided up among the various operators, each operator handling on the average about two hundred lines and being responsible for answering any signals from these subscribers. In addition to these answering jacks, there may be as many as 3,300 calling jacks in the position in front of each operator. These calling jacks do not have any signals mounted with them, as they are for calling only. The calling jacks are each multipled, that is, connected in parallel, with a similarly located jack in the third position to the left and right. Any operator can reach any one of about

10,000 calling jacks, either directly in front of her or in the adjacent positions on her left or right. A multiple switchboard is shown diagrammatically in Figure 10-6. In this Figure should subscriber Number 109 call subscriber Number 567, the signal would come in at position "1" where the answering jack for subscriber 109 is located and the operator would connect him by plugging into calling jack Number 567 in the multiple to her right (Position 2). On the other hand, if subscriber 567 called subscriber 109, the operator at position 3 would answer his call and connect him to subscriber 109 by means of the calling jack in the multiple to her right (Position 4). Each operator is warned against plugging into a busy line by means of a "click" which is heard in her head receiver when she starts to plug into a calling jack already in use somewhere else in the multiple.

Figure 10-7 shows a telephone connection between two stations terminating at the same central office. Here the telephone circuit at each station is normally open when the receiver is on the hook, with the exception of the ringer which is bridged across the circuit in series with a capacitor. It is a function of the capacitor to close the circuit for alternating current and open it for direct current. Accordingly, the line is open in so far as the subscriber's signaling the operator is concerned and is closed through the ringer in so far as the operator's ringing the subscriber is concerned; or we may say, the circuit is in such condition that the subscriber may call the operator or the operator may call the subscriber at will. The subscriber calls the operator by merely closing the line, which is accomplished by removing the receiver from the hook. Contacts C_1 and C_2 are made at the hook switch. C_1 closes the line through the transmitter in series with the primary of the induction coil. This permits current to flow from the central office battery B through one-half of the line relay winding R_1, over one side of the line L_1, through the primary winding of the induction coil, and the transmitter back to the central office over the other half of the line L_2, through the other half of the relay winding R_1, to ground. This energizes the line relay R_1 which connects the central office battery to the answering lamp A_1 in the face of the switchboard in front of one or more operators. This lamp, lighting, indicates that this particular line is calling. The operator answers the call by inserting plug P_1 into the answering jack associated with the lighted lamp and to which the line of the calling party is connected. A third battery connection to the sleeve of the plug closes a circuit through the winding of a second relay R_2, known as a "cut-off" relay, which disconnects the line relay from the circuit, putting out the burning answering (or line) lamp A_1. The operator learns the calling subscriber's wishes by connecting her telephone set to the cord circuit by means of the key K_1. She talks over the two heavy conductors of the cord circuit through the windings of the repeating coil, which by means of transformer action induces current into the other windings of the same coil; this flows back over the calling subscriber's line and induces a current in the secondary of the induction coil, which flows through the telephone receiver.

Not only does the operator's voice current flow from the central office cord circuit to the subscriber's receiver, but there is direct current furnished by the central office battery through two of the four windings of the repeating coil of the cord circuit, over the line, and through the subscriber's transmitter. This permits the subscriber to talk by virtue of the transmitter carbon resistance varying the strength of the current, which, by means of the repeating coil windings at the central office, induces an alternating voice current across to the opposite side of the cord circuit.

Upon learning the number of the party called, the operator inserts plug P_2 into calling jack J_2 which permits the lamp S_2 to burn because the circuit is closed from the central office battery through the sleeve connection and the cut-off relay winding. This lamp tells her that the receiver is on the hook at the called party's station and that she must give this connection attention by ringing the called party at frequent intervals. This is accomplished by operating the ringing key K_2. When the called party answers, current flowing from the central office battery through the windings of the repeating coil, and through the supervisory relay R_3, operates this relay. As a result the lamp S_2 is short-circuited and goes out, notifying the operator that the party has answered. At the same time, a resistance is inserted in the battery circuit to limit the current through the cut-off relay. When both parties finish talking and hang up their receivers, this supervisory relay, as well as the corresponding relay on the other side of the cord circuit, is de-energized, and since the short-circuit is then removed from the lamps,

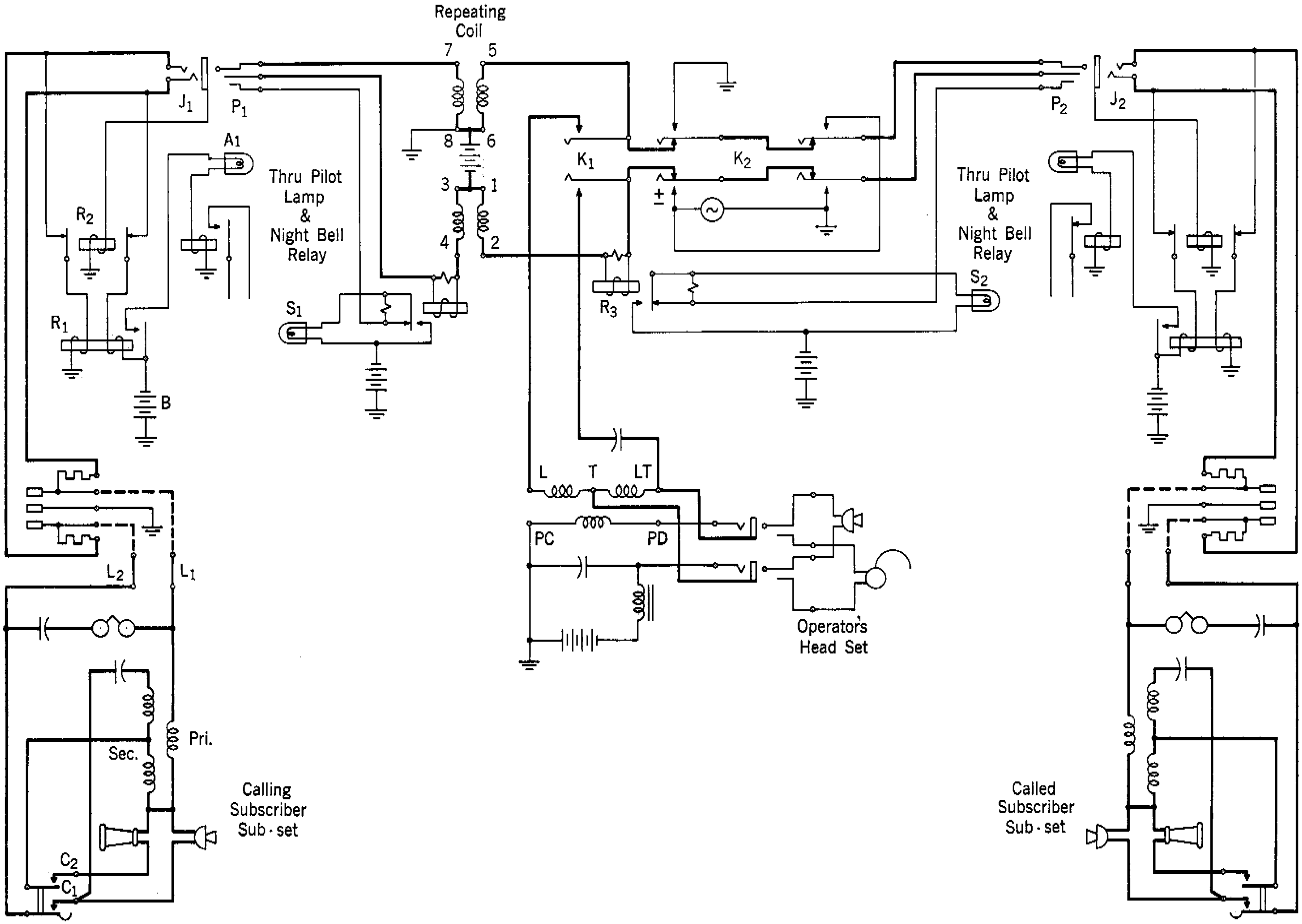


FIG. 10-7 TELEPHONE CONNECTION THROUGH COMMON BATTERY EXCHANGE

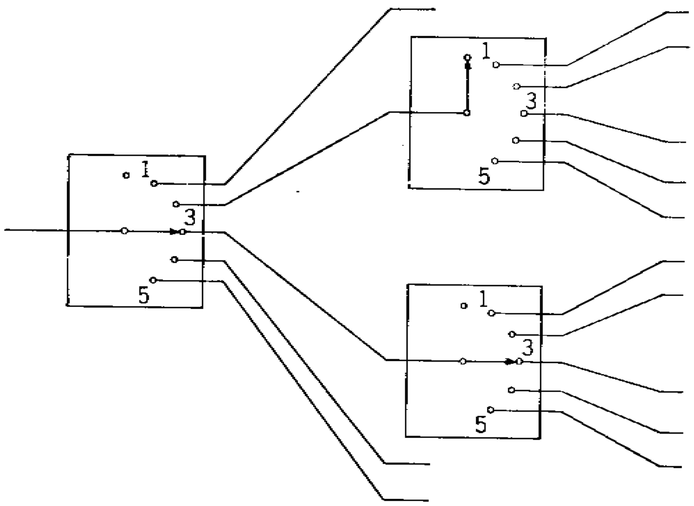


FIG. 10-8 PRINCIPLE OF STEP-BY-STEP SWITCHING

they light. This notifies the operator that both parties are through talking and that both cords are to be taken down. When the operator pulls down both cords, the sleeve circuits of the cords are opened at the jacks and the lamps go out.

What we have discussed above is perhaps the simplest example of a telephone switching operation—that is, a connection between two subscribers of the same single exchange established by one operator at an "A" switchboard. Where a city or other exchange area is of such size as to require more than one central office, a connection between a subscriber whose line terminates in one office and a subscriber whose line terminates in another office cannot be completed by one operator. In such case the "A" operator who picks up the call from a calling subscriber, uses her cord circuit to connect the calling subscriber's line to a trunk leading to a switchboard in the other central office in which the called subscriber's line is terminated. This switchboard is known as a "B" board. It differs somewhat in appearance and in the detail of its circuit arrangements from the "A" board. The incoming trunks are terminated in the "B" operators' key shelf in plugs, and the panels of the switchboard are used almost entirely for calling or multiple jacks.

When the "A" operator at a distant office connects a calling line to a trunk to this "B" board, a lamp associated with the plug and cord in which the trunk terminates in the "B" board key-shelf will light. At the same time the "B" operator's head-set is automatically connected so that the "A" operator at the calling office can pass her the number. The "B" operator then inserts the plug into the called jack. Ringing is usually automatic and the supervisory signal lamp at the "B" board remains lighted until the called subscriber answers. After the conversation is completed and the called subscriber hangs up, the supervisory lamp again lights indicating to the "B" operator that she should take down the connection.

There are other situations in large cities where it is uneconomical to provide direct switching trunks from each central office to every other central office in the exchange area. In these cases a third type of switchboard known as a "tandem" board is provided in some appropriately located intermediate central office. A connection then requires the service of a third operator. The "A" operator at a calling office connects to a trunk leading to the tandem board at the intermediate office; the operator there connects this trunk to another trunk leading to the called office; and the "B" operator there in turn connects the trunk to the called subscriber's line. Naturally, the switching circuits in these three types of switchboards vary in detail, particularly in respect to the supervisory signaling arrangements. Basic methods

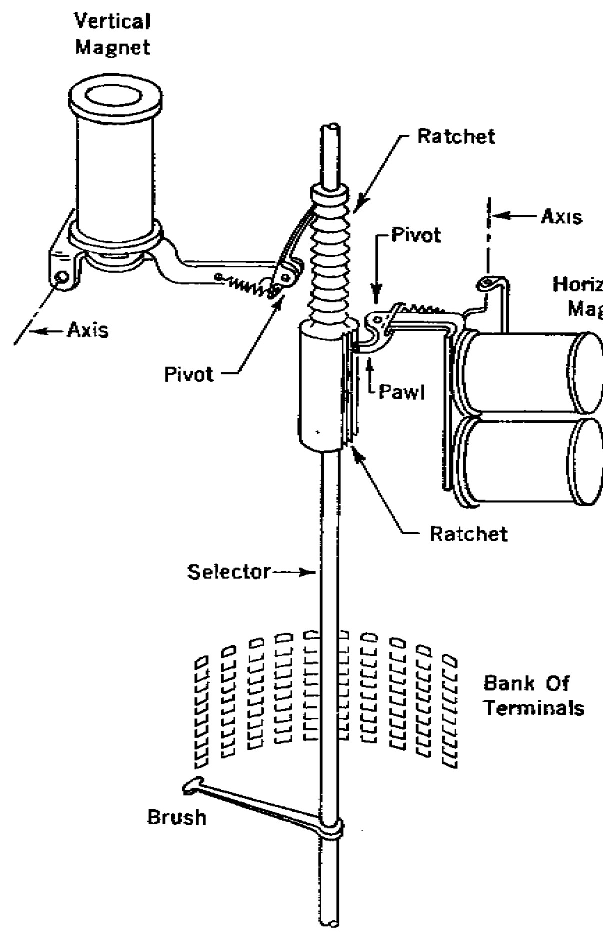


FIG. 10-9 STEP-BY-STEP LINE-FINDER SWITCH

and principles, however, do not differ fundamentally from those described in connection with Figure 10-7.

The requirements for long distance or toll switching are essentially similar to those for local switching. Again, there are three principal switching situations—between the calling subscriber and the toll trunk or line, between the toll trunk and the called subscriber, and where necessary, between two toll trunks. In long distance practice, these operations are performed at outward, inward and through switchboards, respectively. Signaling and supervisory facilities are necessarily somewhat different in toll switching than in local switching. In general, the toll switchboard must be designed to permit a larger variety of switching operations and the cord circuits and other equipment facilities associated with it are accordingly somewhat more extensive. Because of the variety of switching situations, there is no one specific design for toll switchboard arrangements that applies alike to all such switchboards. The reader who wishes to study switchboard circuit arrangements in detail may refer to the standard drawings and instructions applying to the particular switchboards in which he is interested.

10.4 Dial Switching Systems

The fundamental operations to be performed by a mechanical switching system are naturally the same as those discussed above. It is hardly necessary to point out, therefore, that any completely mechanical system must be made up of a considerable quantity of intricate electro-mechanical equipment. In the local dial exchange the operation of the mechanical switching system is controlled by a dial installed on the subscriber's telephone set, which transmits to the central office electrical impulses corresponding to each digit dialed by the subscriber.

The oldest type of dial central office machinery in use functions on a "step-by-step" basis. This means that each digit dialed causes the movement of a switch at the central office which will carry the connection a step forward toward its ultimate objective—the called subscriber's line. The basic principle involved can be readily understood by examination of the simplified example shown in Figure 10-8. Here only two steps are shown and there are only five contacts on the switches of each step. If the switches are arranged to move in order through the same number of contacts as the number of electric impulses coming from the dial, any one of twenty-five separate telephones could be reached by dialing only two successive digits between 1 and 5. If, as in the actual telephone dial, there are 10 digits and the system is designed for dialing as many as seven digits to reach the desired telephone, the simple diagram of Figure 10-8 could be expanded without any change in principle to show how any one of ten million telephones could be reached in the seven successive dialing steps. The trouble with such a simple arrangement as this is that it would require a tremendous number of switches and connecting wires, and still permit only one telephone to make a call to any of the others.

By suitable arrangements, however, this principle can be employed to permit the origination of the call by any of the telephones and still keep the total amount of switches and other equipment within reasonable bounds. The first step is to eliminate the necessity for having a separate selecting switch associated with each subscriber's line. Instead, switches known as **line-finders** are provided for groups of subscriber lines, each one of which is connected in multiple to the "bank" terminals of the switches. In the **step-by-step** system, the line-finder switch resembles that illustrated in Figure 10-9, which is arranged to move vertically through ten steps and horizontally through ten steps for each vertical step. When a subscriber picks up his receiver, a relay associated with his line causes an idle line-finder switch to go into operation and hunt for the terminal to which his line is connected.

With this arrangement, a simple dial system might take the form illustrated in Figure 10-10. Here the line-finder switch connects the calling subscriber's line to a trunk selecting switch which is installed in the same central office, and in the step-by-step system is of the same design as the line-finder switch illustrated in Figure 10-9. Dial tone is automatically sent back to the calling subscriber and as he begins to dial, the trunk selector switch in office "A" moves to a terminal at which a trunk corresponding to the initial digit dialed is terminated. This trunk may lead to a distant office or to terminating equipment in the same office. In the simple case illustrated, the first switch at office "B" selects a group of connecting lines under the direction of the second number dialed by the calling subscriber and moves the call on to a final selecting switch, which is operated by the third number dialed to connect to the called subscriber's line.

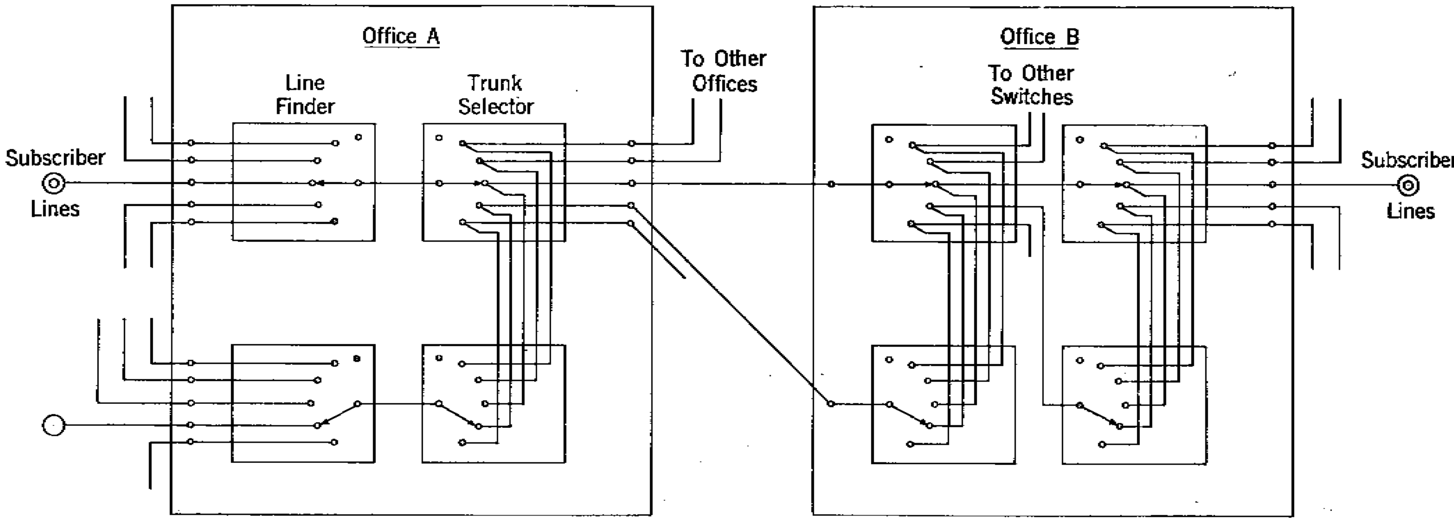


FIG. 10-10 INTER-OFFICE DIAL SWITCHING PRINCIPLE

The above illustration of course is over-simplified as compared to most practical telephone systems. In principle, however, the method indicated could readily be expanded to cover a larger number of telephones (and more digits to be dialed) by including more switches of the same type in the switching chain.

Figure 10-10 illustrates another principle which is of fundamental importance in any practical switching system. It will be noted that it shows two trunks between office "A" and office "B" each of which is multipled to selector switches in the two offices. This brings in an additional feature in the switching apparatus under which a switch directed toward a called trunk, but finding it already busy, will automatically move on and hunt for another trunk leading to the same called office. Just as in manual switching, practical economy requires that the numbers of trunks installed between any two offices (or between any other two points in the switching system) be kept at that minimum which (as determined by applications of the laws of probability) will be sufficient to take care of the busy-hour load under reasonably normal conditions. In the large office or exchange area, this may mean that the total number of trunks between two points in the over-all system may run to a considerable number. To keep the number of switching devices to an economical minimum, it is evident that any switch should be able to hunt automatically over the total number of trunks in a group, no matter what its size. Since the standard step-by-step switch can hunt over only ten terminals, graded multiple arrangements are provided when the number of trunks required per group exceeds ten. With this procedure some of the trunks are accessible to only part of the selectors while the others are accessible to all of the selectors. These trunks are then known as "common" or "individual" trunks. This arrangement increases the efficiency of the trunk groups and, therefore, requires less switches to handle a given amount of traffic.

Two other types of dial switching systems designed for application in large exchange areas are in use in the Bell System. These are known as the **panel** system and the **crossbar** system. Both depend on the principle of first transmitting the dial pulses from the calling subscriber's telephone to a "mechanical operator", usually known as a **sender,** which in turn translates them into other electrical impulses that will operate the necessary switches to establish the through connection. The panel system, although functioning today in many locations, no longer is being installed, so that we may confine our attention in what follows to the crossbar system.

If, as mentioned in Article 9.6, the crossbar switch is thought of as a kind of relay, the crossbar system may be considered as an all-relay system. It employs large numbers of these crossbar switches and of ordinary relays, as well as the multi-contact relays which also were discussed briefly in Article 9.6. Naturally the detailed arrangements are complicated; it will be practicable here to outline only the broad principles of the system's operation. These are illustrated schematically in Figure 10-11, where the through connection from the calling to the called telephone is indicated by the heavy line. As shown, the con-

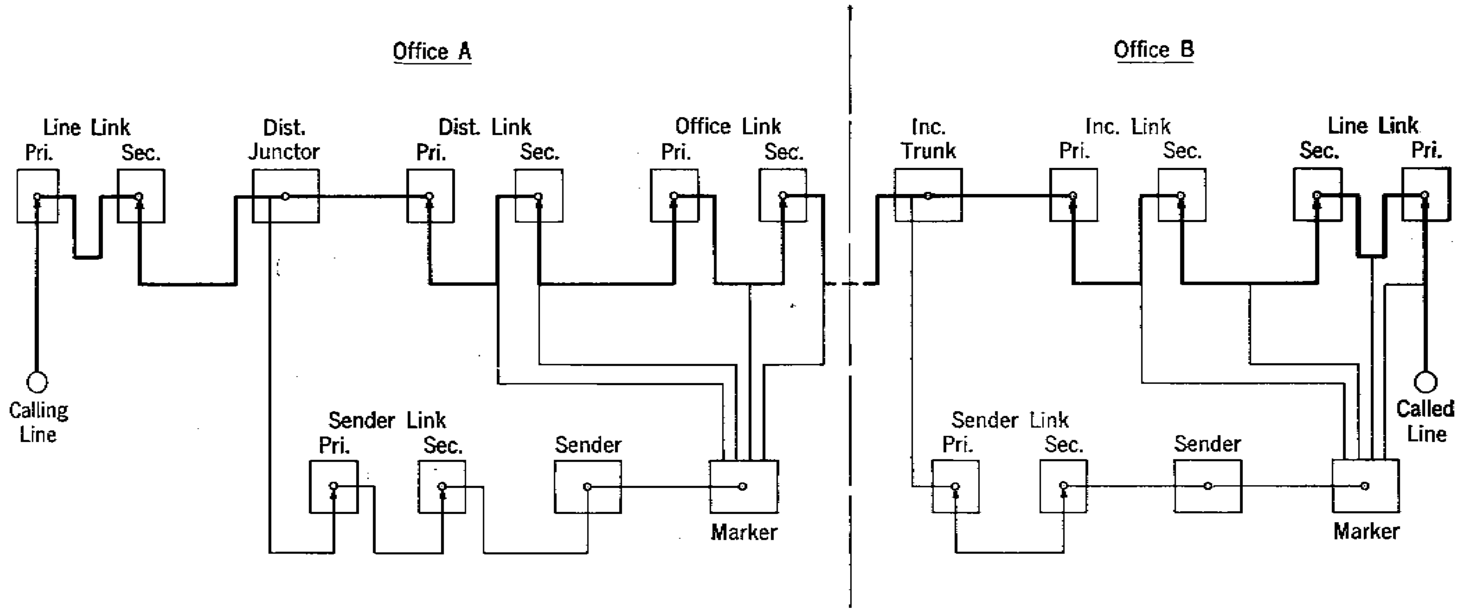
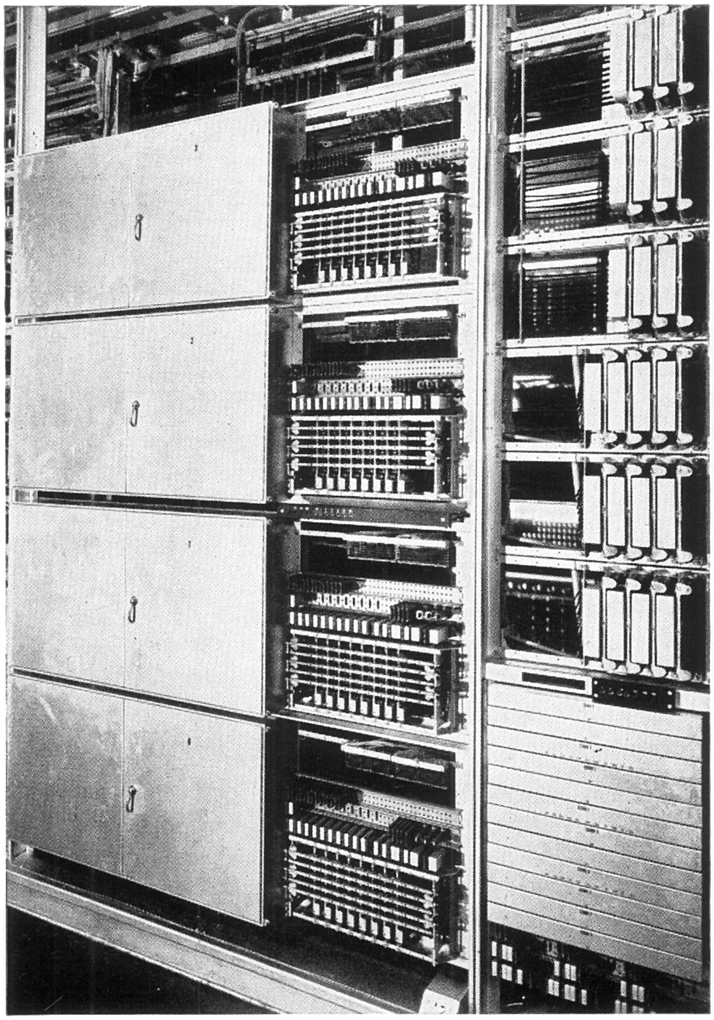


FIG. 10-11 LOCAL CROSSBAR SWITCHING ARRANGEMENT

nection goes through four different switching or link frames, including the line link frame, which acts as a line finder at the calling office and a final selector at the called office. In each one of these frames the connection routes through crossbar switches, generally known as the primary switch and the secondary switch. In the simplest situation where each switch has 100 crosspoints and the switching frame has 10 primary and 10 secondary switches, the arrangement offers the possibility of connecting any one of 100 incoming lines to any one of 100 outgoing lines.

When a subscriber connected to office "A" lifts his handset to make a call, his line is closed to a primary vertical in the line link frame at that office. At the same time relays are operated to call into play a **controller** circuit arrangement (not shown in the diagram) consisting of a number of relays of various types, and associated wiring. This device first definitely locates the calling line on the line link frame and operates the proper selecting and holding magnets to connect the line to an idle trunk or **district junctor** leading to the district link frame. The district junctors extend through a district junctor frame on which is mounted relay equipment that supplies talking battery to the calling line. It also maintains supervision over the call after the connection has been established, times and registers local calls, controls collections or returns of deposited coins at pay stations, etc.

At the same time, the controller hunts for and selects an idle sender and operates selecting and holding magnets in the sender link frame to connect the sender to the calling line. This connection causes dial tone to be sent back to the calling line, indicating that dialing may be started. The dialing pulses are received at the sender and registered there by the operation of relays or crosspoints of a crossbar switch. As soon as the sender has registered the digits indicating the office being called (the first three digits in the case of large multi-exchange areas) the sender operates to locate and connect itself to an idle **marker** through multi-contact relays. It then transmits to the marker information as to the office code dialed, the number of the frame in which the call is originating, the class of service of the calling line, etc. As soon as this information is registered by relays in the marker, the marker first hunts for and selects and "marks" or makes busy an idle outgoing trunk to the distant office. It also selects an idle junctor between the district link frame and the office link frame and then operates the proper selecting and holding magnets in both frames to complete the connection between the selected inter-office trunk and the district junctor to which the calling line had been previously connected. This total operation of the marker is accomplished in a fraction of a second and as soon as it is completed, the marker is automatically released to work on other calls.



SENDER FRAMES WITH MARKER CONNECTORS AT THE RIGHT

In the meantime, the calling subscriber continues to dial the digits corresponding to the number of the called telephone. These are likewise registered in the sender. As the hundreds digit is dialed, the trunk circuit to the distant office is closed to the incoming trunk frame, which causes a controller at that office to select an idle terminating sender and connect it by the closure of the proper switch-points in the sender link frame. Like the district junctor frame at the calling office, the incoming trunk frame mounts relay equipment which furnishes talking battery to the called subscriber's line, maintains supervision over the terminating end of the connection, furnishes the proper type of ringing current over the called line, and transmits busy tone to the calling line if the called line happens to be busy. After the terminating sender has been connected to the incoming trunk circuit, the called number registered in the originating office sender is transmitted to the terminating office sender where it is again registered in relays or crosspoints of a crossbar switch. At this point the originating sender having completed its function is disconnected and released for use on another call.

The terminating sender then connects to or "seizes" an idle terminating marker to which it transmits information on the called subscriber number and the number of the incoming trunk frame on which the particular incoming trunk is located. By means of its translator circuit the marker is able to locate the called subscriber's line out of a maximum of about 10,000 such lines terminating at the central office. If this line should be busy, the marker directs the incoming trunk circuit to transmit a busy signal to the calling subscriber. If the called subscriber's line is idle, the marker first makes it busy and then proceeds to test for and select idle links in both the line link and incoming link frames as well as an idle junctor connecting these two frames together. It then operates the proper selecting and holding magnets in the two link frames to operate the necessary crosspoints that will close the circuit through. With this, the incoming trunk circuit transmits ringing current to the called subscriber's line and the terminating sender and marker disconnect and return to normal. As already pointed out, the district junctor at the calling end and the incoming trunk at the called end jointly maintain supervision over the call. When the talking parties disconnect, they function to cause all connections to be restored to normal.

The reader will have noted that in the preceding brief description of a dial call, various apparatus units—particularly the senders and markers—have been spoken of much as if they were persons like manual telephone operators. The functions that they perform are indeed very similar to those performed by operators. Needless to say, therefore, their circuit arrangements are intricate—so much so that their detailed analysis would involve considerably more space than can be allotted to the subject in this book. It should be remembered, however, that they are only machines, having no capacity to exercise either initiative or judgment, but able to do only those things that they were specifically designed to do.

The accompanying photographs give some idea of the physical appearance of a typical sender and a typical marker. The latter may include as many as 1,700 relays. Not all of these operate in establishing any one connection, although it is interesting to note that a typical local dial connection involves the operation of about 700 relays. Markers and senders are naturally costly pieces of apparatus. As pointed out earlier, however, the marker performs its function in less than a second, which means that it can handle many calls within a short time. Actually it is necessary to provide no more than 5 or 6 markers to handle all the work in one dial system local office. The operating time of the sender is somewhat longer —up to about 15 seconds—so that proportionately a greater number of these apparatus units have to be provided.

10.5 Toll Dial Switching

The establishment of toll or long distance connections by mechanical or dialing methods is not essentially different from the setting up of local connections. As was pointed out in the earlier discussion of manual switching arrangements, long distance switching generally involves a greater number and variety of different situations than does local switching. Thus the long distance connection will frequently require a greater number of switches for completion from terminal to terminal.

In the more usual situation where direct circuits are available between two cities, toll switching equipment is required only at the calling and called points. When direct circuits are not available, however, it may be necessary to route the call through appropriate switching equipment at one or more intermediate points. Also important in toll connections is the fact that when a call extends beyond the area where toll charges are billed as message units, the details of the call must be recorded for billing purposes. These include the number of the calling line, the name of the place called, the called number, and the total time of the call. In **direct distance dialing,** the calling subscriber establishes a long distance connection without the aid of an operator by dialing a seven or ten digit code, depending on whether the called telephone is in his own or a distant numbering plan area. Recording equipment must be provided to register the necessary billing information in this case. In the absence of such equipment, an outward toll operator records the information on a toll ticket, as in full manual operation. She then proceeds to set up the desired connection by **operator distance dialing,** operating keys for the necessary code signals that direct the equipment in her own and other offices to complete the desired connection. In addition to the connection between the incoming calling trunk and an outgoing toll circuit, the overall connection may include one or more through connections at intermediate cities along the route, as well as an inward connection to the local central office in the called city and the loop from that office to the called telephone. The operation of the switching equipment is the same whether directed by an outward operator or by the subscriber's own dial.

Major crossbar dial offices are arranged to select alternate routes automatically in a predetermined order when all circuits on the first-choice route are busy. This important feature, together with the other complexities of toll switching noted above, make it necessary to employ two additional control devices to assist the marker in handling the "brain-work" of the toll switching machine. The first is known as a **decoder** and this is in turn assisted by one or more **translators.** Figure 10-12 illustrates schematically the general arrangement of the complete toll switching machine, including these two devices.

As previously mentioned, the machine is designed to work with either a seven digit or a ten digit code such, for example, as 415-WO6-1748. Here the first three digits designate the distant numbering plan area in which the called city is situated, which may be a State or a part of a State. The second three digits designate the local central office within that area, and the final four the called subscriber's telephone number. When a call is received over an incoming trunk or toll circuit, an idle sender is connected through the sender link frame, just as in the local dial office. As soon as the sender receives and registers the first three digits, it seizes an idle decoder through the decoder connector and gives it this code. The decoder passes this information to a translator which causes it to select the appropriate punched "card" from which it can "read" the routing and other information needed for forwarding the call. It transmits this information to the decoder and drops off. The decoder then seizes an idle marker to which it passes on this information. It also causes the sender to be connected to the same marker. The marker immediately tests the outgoing trunks or lines in the group corresponding to the code information with which it has been supplied, and seizes an idle one, if available. When this is done, it so informs the decoder, which then directs the sender to send all digits forward and leaves the connection. The seizure of the outgoing

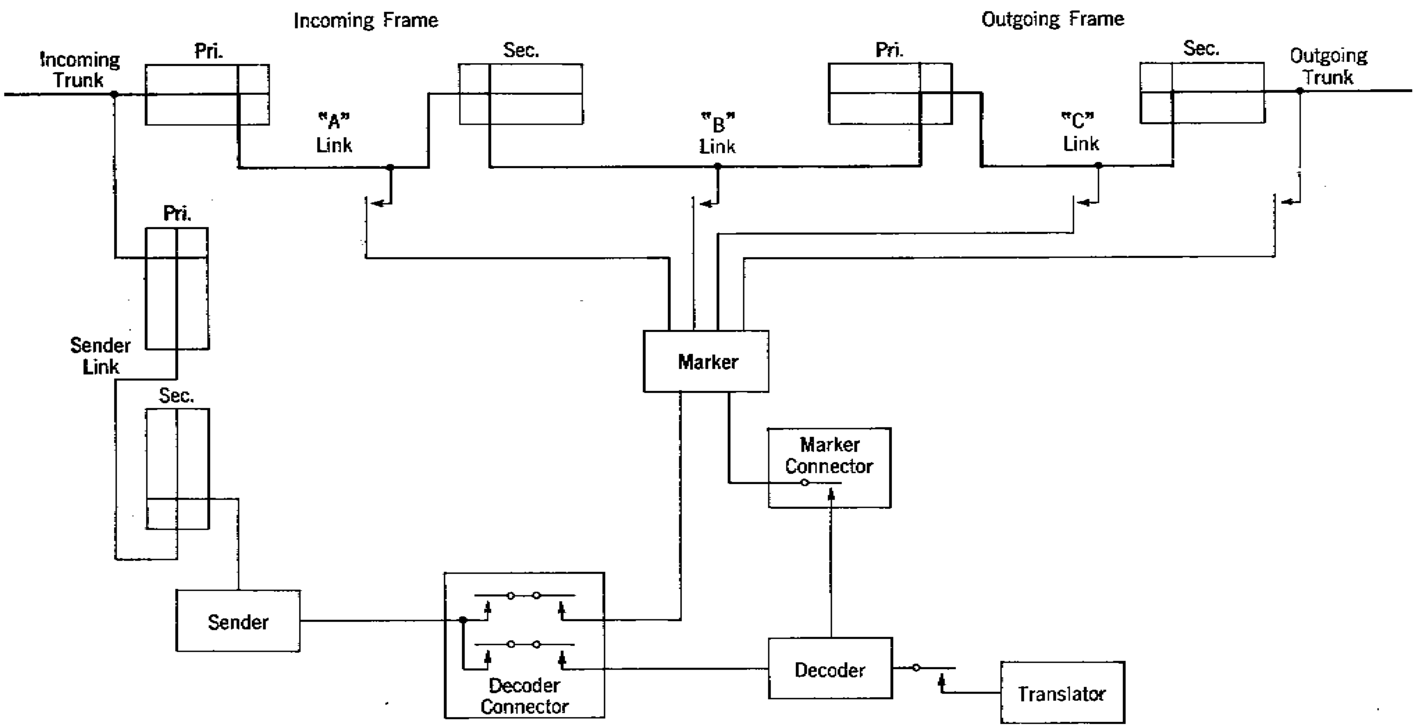


FIG. 10-12 TOLL CROSSBAR SWITCHING ARRANGEMENT

trunk by the marker automatically signals for a sender at the distant point to be connected to the trunk. When this sender is attached, a signal is passed back to the sender at the outgoing office. The latter then forwards the required digits to the distant sender. In the meantime, the marker tests for and selects idle links "A" and "C" in the incoming and outgoing frames and an idle junctor or "B" link between these two frames. It then operates the proper selecting and holding magnets to close the line circuit through the crossbar switches, advises the sender that the connection is completed, and leaves the connection. The sender in turn drops off as soon as this information has been received and it has completed the forwarding of the calling digits to the distant sender. Further progress of the call to another intermediate switch or to its final destination is then under the control of that sender.

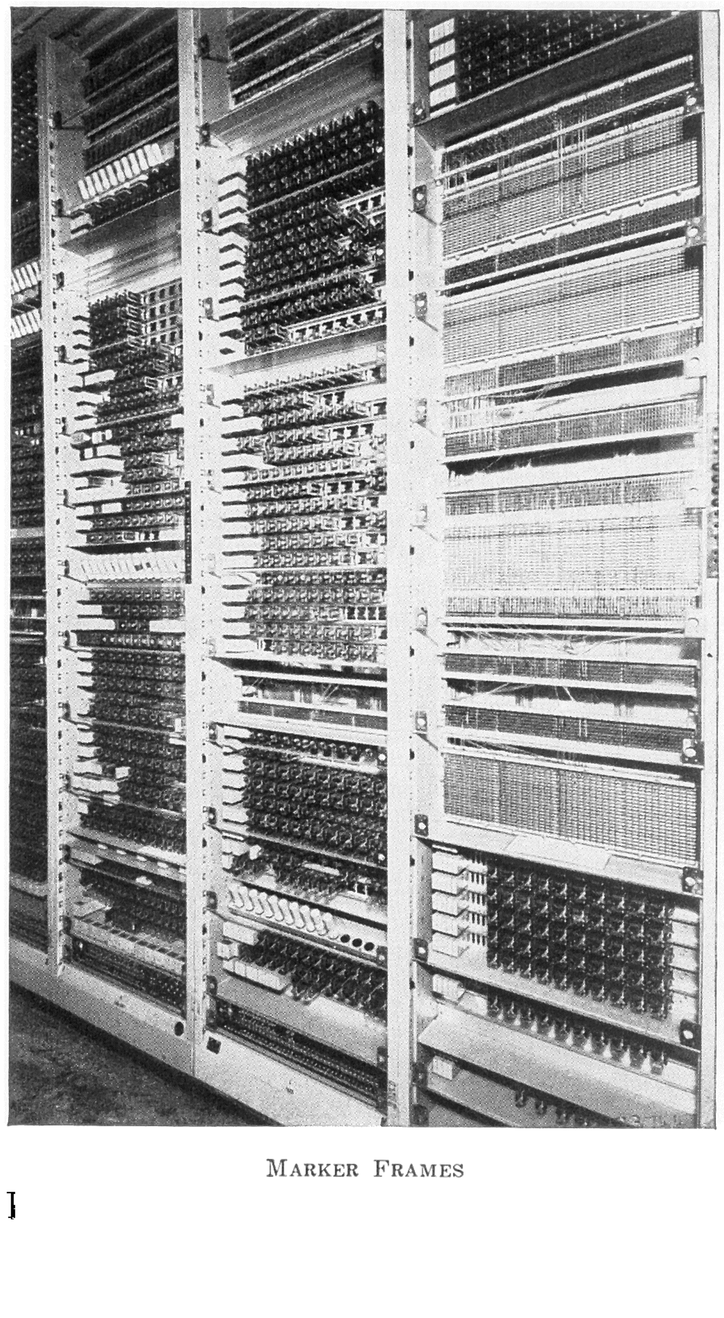
The above description deals with the simplest straight-forward connection where a circuit in the first-choice route is available and only the first three digits of the number code require translation. There are many situations when there are two or more routes to or toward a given numbering plan area. In such cases, the translator at the originating point needs to know the exchange code as well as the area code in order to provide the proper routing instructions. Six-digit translation is required. The translator that is first called in is supplied only with the three digit area code. On reading the card, it recognizes that this information is inadequate and signals the decoder to secure the next three digits from the sender. This translator then disconnects itself. When the decoder receives the next three digits, it calls in another translator to which it now passes the first six digits. From this, the translator is able to select a card that contains the information needed to direct the marker how to proceed to establish the desired connection to or toward the desired central office. With either three digit or six digit translation, the translator supplies the decoder with routing information for not only the first-choice route but for alternate routes as well in their order of priority. If the marker on first instruction finds all circuits busy on the first-choice route, it so informs the decoder which then directs it to search in the first alternate circuit group, and so on until an idle circuit is found. The additional operations required for selecting alternate routes, or for six digit translation, of course increase to some extent the time used in establishing the connection. However, the total time involved is not more than a few seconds. The work time of the individual common control units such as the marker and the decoder is normally less than one second.

With full dial operation, there is only one outward operator or a machine at the calling end of the connection. It is necessary in either case, for the calling end to know when the called party answers his telephone and when he hangs up. This means that supervisory signals must be automatically transmitted back from the distant end of the connection. The procedures used for this purpose are discussed briefly in the Article following.

10.6 Signaling

In any telephone switching system, it is naturally necessary to provide some means of signaling subscribers and operators. Thus, the subscriber is signaled by the familiar telephone bell which is ordinarily operated by a 20-cycle alternating current supplied from a local central office when an operator presses a ringing key, or when machinery performs a comparable operation. Such a signaling current is not suitable for use over toll circuits of appreciable length since, among other things, it might interfere with telegraph currents being transmitted over the same circuit. This difficulty may be overcome in relatively short toll circuits by using a signaling current of 135-cycle frequency, which is high enough not to interfere with the lower speeds of telegraph services. The necessity for relaying the 135-cycle signal around repeaters, however, limits its usefulness for application on the longer circuits. More reliable signaling on long circuits is obtained by the use of 1000-cycle signaling current. This is a frequency within the normal voice range which suffers no greater losses in transmission than do the voice currents themselves, and it is amplified at intermediate points by the same telephone repeaters that amplify the voice currents. In order to avoid false operation of the signals by voice currents, the signal receiving apparatus is designed to be operated only by a 1000-cycle current interrupted 20 times per second and sustained for at least several tenths of a second. The signals are usually generated by electron tube oscillators. They are in turn detected at the receiving end by appropriate electron tube circuits and converted into direct current or 20-cycle ringing current as needed.

The signaling methods discussed above are known as **ringdown** systems and are employed on "ringdown trunks". They are not suitable for use on circuits arranged for toll dialing operation. Such circuits must be so equipped that both pulsing and supervisory signals can be transmitted in both directions. Pulsing signals, originally generated by operation of the ordinary dial in the form of dial pulses, may be transmitted over relatively short distances in the form of d-c pulses similar to telegraph signals. In this case, composited or simplexed telegraph channels, separate from the telephone circuits, are used for the transmission. For longer circuits, dial pulses are generally transmitted by interrupting a single frequency tone which is transmitted over the telephone circuit in the same way as the voice signal. This single-frequency signaling method uses a frequency of either 2600 or 2400 cycles on circuits of sufficient bandwidth for such transmission and a frequency of either 1600 or 2000 cycles



Marker Frames

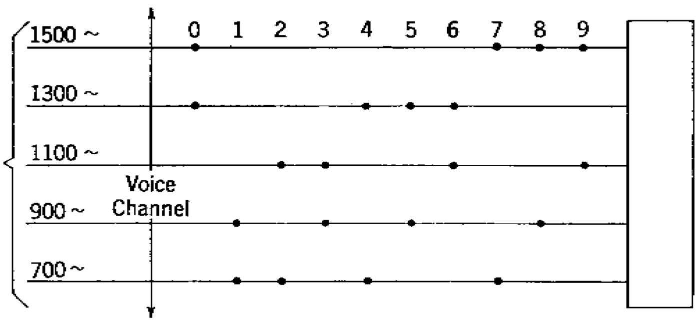


FIG. 10-13 MULTI-FREQUENCY KEY PULSING OF DIGITS

on circuits that cannot satisfactorily transmit the higher frequencies.

Where pulsing signals are generated by key-pulsing, which is much faster than dial pulsing, multi-frequency signals are employed. This generally applies to the longer toll lines. The frequencies used are 700, 900, 1100, 1300, 1500 and 1700 cycles. Each digit is represented by a combination of two of the first five of these frequencies. Figure 10-13 shows the combinations for each of the digits from 0 to 9, inclusive. The 1700-cycle tone, not shown in the Figure, is used in combination with 1100 to provide a priming or "get ready" signal; and in combination with 1500 for a "start" signal.

Supervisory signals are transmitted either in the form of direct current over separate telegraph channels, or by means of a single voice frequency transmitted over the telephone circuit. In the latter case, the supervisory signaling tone should of course not be present when the circuit is being used for conversation, since it is within the voice range. The supervisory signal tone is applied continuously to the line as long as the called telephone is in the "on-hook" condition. When the receiver is taken off the hook, the signaling tone is removed from the line. Its presence or absence causes the operation of relays at the calling end which show when the distant telephone answers or hangs up. These supervisory signal tones must of course be applied to a circuit from both ends in order that a circuit may be used for calls originating at either end. For circuits that are actually or effectively 4-wire, the single frequency of 2600 (or 1600) cycles can be used in both directions. For 2-wire circuits, a 2600 (or 1600) cycle tone is used in one direction and a 2400 (or 2000) cycle tone in the opposite direction.