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DEPARTMENT OF THE ARMY TECHNICAL MANUAL

FUNDAMENTALS OF TELEPHONY

DEPARTMENT OF THE ARMY • MARCH 1953

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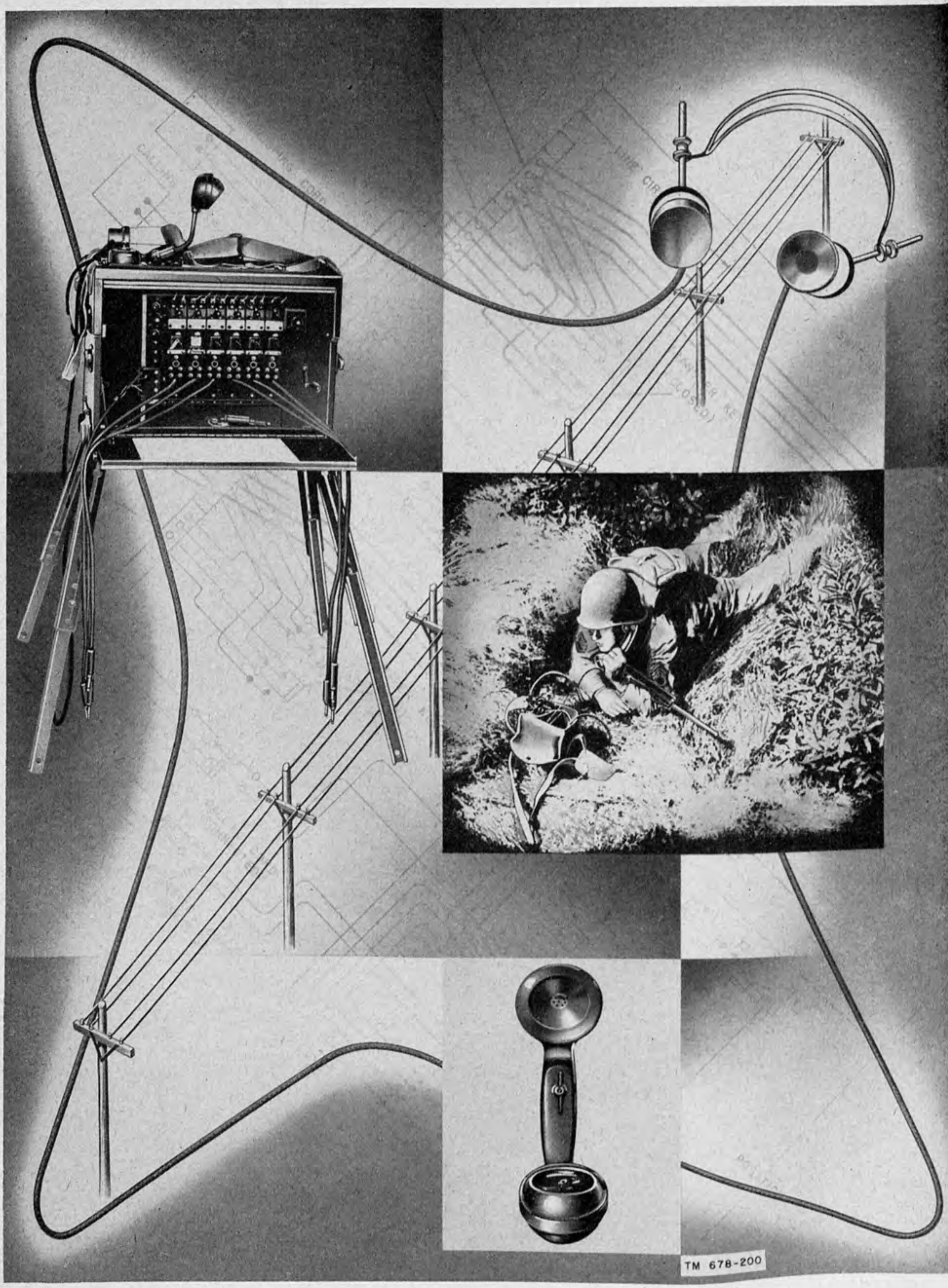
CONTENTS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CHAPTER 1

SOUND

1. Sound and Telephony

Until the invention of the telephone, the distance over which the human voice could be used for communication was limited by the lung power of the speaker and by the ear sensitivity of the hearer. This limited distance could be extended slightly by a megaphone, a large horn which concentrates the power of the human voice in a given direction. Megaphones increased intelligibility where it was necessary to shout in order to be heard, as from ship to ship at small distances. It is interesting to note that the words *mega-phone* and *tele-phone* both are made up in part of the English equivalent of the Greek word *phone*, which means sound. The word megaphone means simply a big sound, and the word telephone means sound at-a-distance, or far sound.

a. The telephone, as its name implies, solves the problem of distance limitation on sound transfer from point to point. Of course, the first telephone was crude and its usefulness was limited. Many stages of development were necessary to bring it to its present efficiency and flexibility. But development was rapid, and today, spurred by enormous demands, the service provided by telephone reaches almost everywhere; a business executive or a commanding general by picking up a telephone can communicate not only with an associate in the next room or in his immediate vicinity but, almost at once, with someone on the other side of the earth.

b. The sound of the voice of the speaker actually is not transmitted over long distances, but a sound *like* the voice of the speaker is generated at the distant point by means of electrical power. The small voice power of the speaker is transformed into electrical power, which may be amplified at will, and then this electrical power is transmitted over wires to any given point, where it is changed into sounds that resemble the voice of the speaker. Radio communication, which was a later solution of the same problem, transmits electrical energy without wires, and hence in its early stages of development was called *wireless* to distinguish it from the telephone and the telegraph. The *radio telephone*, a more recent development, uses both the wire and the wireless forms of transmission. For instance, the transatlantic telephone uses wire wherever the local telephone system is capable of handling the message, and wireless is used for the long hop over the ocean from the terminals in New Jersey and on Long Island to the terminals of Europe.

c. Any telephone system begins and ends with sound, and therefore this chapter will concern itself with the origin and characteristics of sound waves and will serve also as an introduction to the elements and operational techniques of the basic telephone system with which the following chapters are concerned. The coils, capacitors, transformers, switches, switchboards, transmission lines, power sources (including both wet and dry-cell batteries), and the transmitters and receivers in the telephone instrument itself are described in detail. A major portion of this manual is devoted to an analysis of local-battery and common-battery circuits, either of which are basic to any telephone system, including Army field telephones and the more intricate circuits of dial systems.

2. Nature of Sound

Sound is the sensation caused in the nervous system by vibration of the delicate membranes of the ear. An analysis of sound as sensation is outside the province of this text, but the cause of sound by physical vibrations can be analyzed and measured with accuracy. As illustrated in figure 1, the sensation of sound results from the rapid vibrations of a rigid or semirigid body such as a hacksaw blade, a tuning fork, a drum head, or a bell. If a pencil is held lightly against the vibrating body, the physical motion often can be felt by the hand; but without the pencil as a medium for the transfer of energy, the vibrations cannot be felt by the hand at even a small distance from the source. At the same time, however, these vibrations are recognized by the ear as

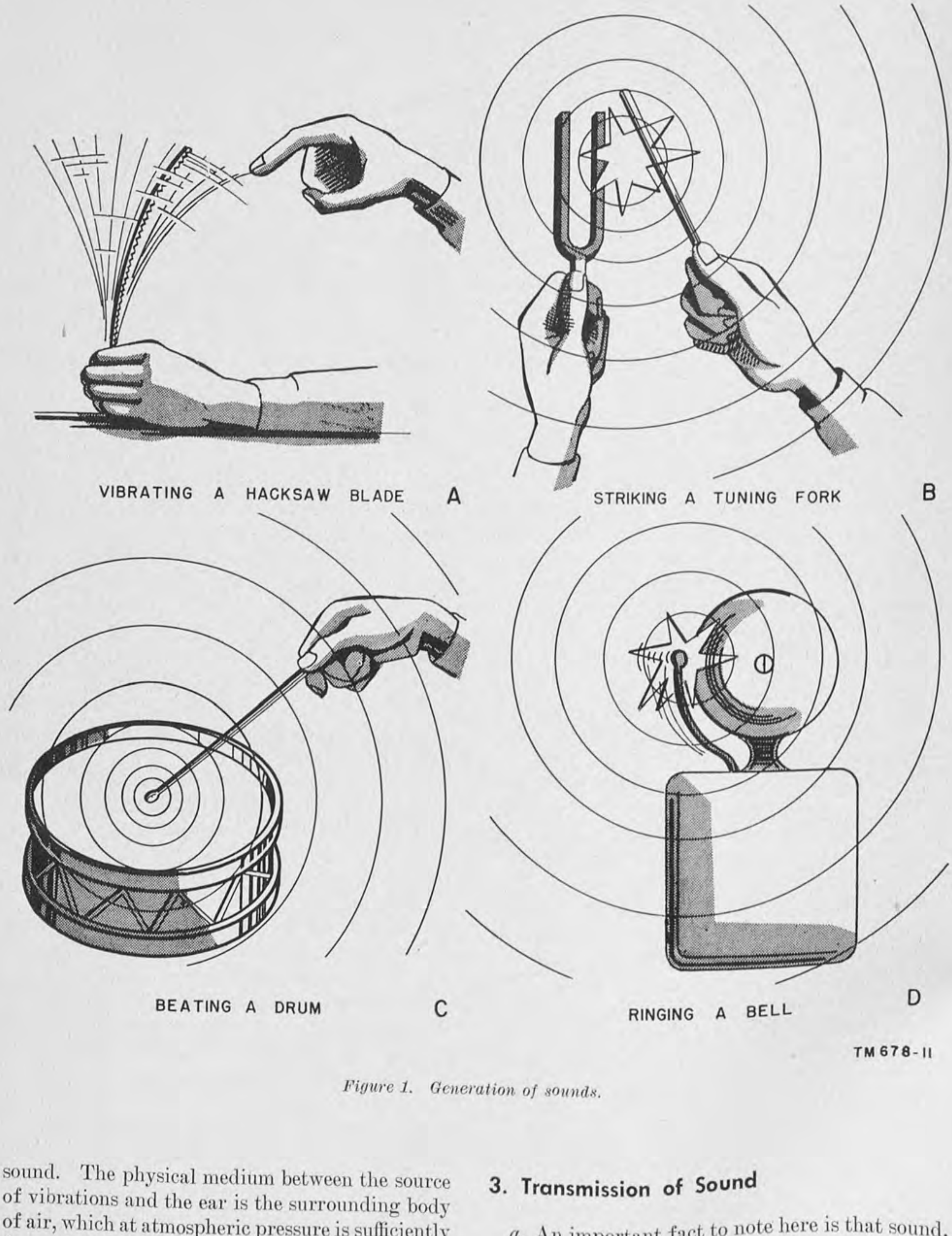


Figure 1. Generation of sounds.

sound. The physical medium between the source of vibrations and the ear is the surrounding body of air, which at atmospheric pressure is sufficiently dense to be set in motion by the vibrating body and to convey the vibrations to the delicate and sensitive membranes of the ear.

3. Transmission of Sound

a. An important fact to note here is that sound, unlike light and electromagnetic (radio) energy, requires a conducting medium. This fact is illustrated by figure 2, which shows an electric bell

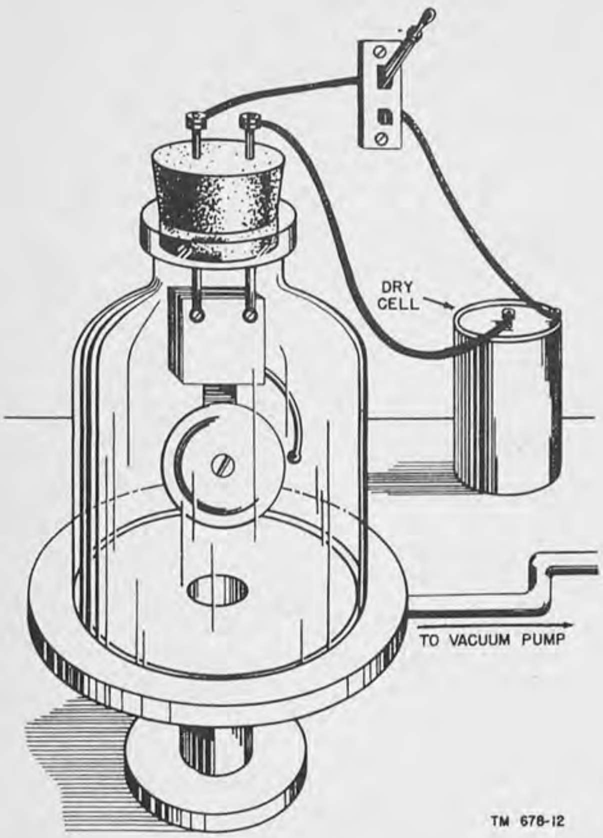


Figure 2. Bell operating in vacuum.

suspended by its terminal wires from the stopper of a jar which itself rests upon a plate connected to a vacuum pump. A dry cell and a switch are connected to the wires, and the place of exit of the wires is sealed.

(1) When the air is removed from the jar and the bell circuit is closed, no sound is heard, even though the bell is seen to be vibrating.

(2) When air is readmitted slowly, the ringing begins to be heard, and, as more air is admitted, the sound becomes louder.

(3) In the vacuum, sound was not transmitted, whereas in air it was transmitted. Air, therefore, constitutes a medium through which sound can be transmitted.

b. The transmission of sound *always* requires a medium. The transmission of light and electricity does not. Thus, sound cannot be transmitted in a vacuum, but light and electricity can. In the direct transmission of sound, the medium is usually the air intervening between the source and the listener, but other mediums, either solid or liquid, can transmit sound. For instance, a boy lays his ear against a railroad track to detect the presence of an oncoming train which is to far away for its sound to reach him through air; and the American Indian is reputed to have been able to detect far-away footsteps by pressing his ear to the ground. In both cases, the denser medium carried a given amount of sound farther than the sound traveled in air. This principle is used also in underwater detection of ships. Sensitive listening devices attached to the hull of the ship pick up the sound of propeller vibrations carried by the sea from other ships in the vicinity, particularly from submarines.

4. Sound Waves

The motion of the air molecules set up by a body vibrating in air produces *sound waves* which travel outward in all directions from the vibrating source. The manner in which sound waves are produced can be understood by considering a vibrating strip of metal, such as the hacksaw blade illustrated in figure 3.

a. A hacksaw blade is fastened to a table in a vertical position, as in A, and, with a finger, is caused to vibrate rapidly back and forth. As it makes its initial trip to the right, two events of opposite nature occur, as shown in B. One, the blade increases the pressure existing in the group of air particles adjacent on its right, causing a local *condensation*, or bunching-up, of the particles on that side. Two, the blade decreases the pressure existing in the group of air particles adjacent on its left, causing a local *rarefaction*, or dispersion of the particles on that side. Condensation and rarefaction occur at the same time, and are caused by the single motion of the blade to the right.

b. Free to vibrate by itself, the blade starts to move back to its vertical position of rest, as in C; but *motion* has been imparted to the particles on each side and their subsequent behavior is affected. The bunched-up group on the right has been given a velocity outward, and pushes against the layer of particles still farther to the right. Great numbers of minute collisions occur, and gradually but very rapidly the striking particles give up to their neighbors their own motion and bunched-up arrangement. This accounts for the new position of the regions of condensation and rarefaction. This progress outward continues, the wave of sound energy moving outward, and the individual

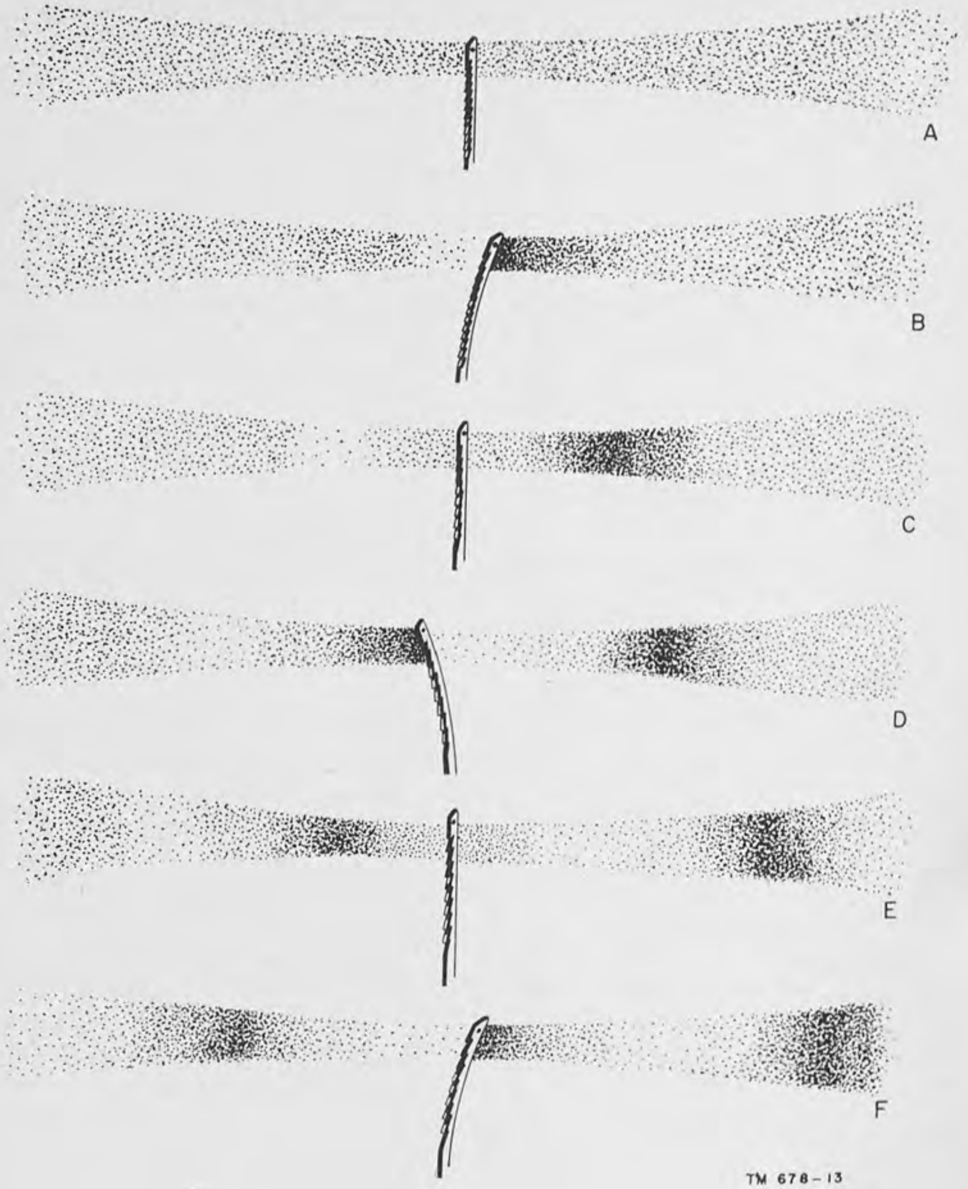


Figure 3. Sound wave produced by vibrating blade.

air particles that transmit the motion remaining behind.

c. As the blade returns left toward the vertical and the condensation travels outward to the right, an increasing gap occurs between them, as shown in C. This region becomes one of lessening pressure, because the nearby air particles tend to rush in and fill the gap to normal density. By the time the blade reaches the vertical, the pressure immediately to its right has decreased to about normal, and normal pressure has been restored just to its left.

d. The blade at this point has a good deal of velocity, and continues to the left as in D. It now has caused a condensation on its left and a rarefaction on its right. The initial condensation on the right, meanwhile, has progressed still farther from the blade, and the initial rarefaction still farther to the left.

e. In this way, at each advance of the blade on either side, a crest of condensation is sent traveling outward; and at each retreat of the blade an intervening trough of rarefaction is established. The energy of each wave, crest to crest, was given to it by transfer of the energy of motion of the blade. This energy, now called a *sound wave*, continues outward. The air particles which transmit the energy do not go along with it; each collides with its outside neighbors, imparts its energy, and returns to a point close to its original position.

Thus, with the blade again vertical, normal pressure is restored on both sides of the blade, as in E. By this time, both condensations and rarefactions have moved farther out from the source, and they are followed, in F, by a new wave which has been forming. The process continues, and a train of waves is sent out as long as the vibration continues. A wave such as this, in which the transfer of motion (energy) occurs in the same line as that along which the particles of the medium are oscillating, is called a longitudinal wave.

5. Representation of Sound Waves

a. Sound waves may be represented on a graph by plotting against *distance* the relative compression of the air particles of successive groups along the path of motion, or by plotting against *time* the relative compression of the air particles of successive groups along the path of motion.

(1) In figure 4, a portion of E, figure 3, is redrawn, showing the particles comprising several sound waves. The alternate regions of condensation and rarefaction are moving toward the right, as described in the preceding paragraph. Below this representation is a graph, on which the vertical distances correspond to the relative compression of the air particles along the path of the wave. Note that the highest points of the curve (positive peaks) lie beneath places of maximum condensation, the lowest points of the curve (negative peaks) lie beneath places of maximum rarefaction, and points on the horizontal axis lie beneath places of medium density.

(2) Since the wave is traveling to the right, the ear of the listener experiences variations of pressure identical with those existing along the path of the wave (fig. 4): first, the rarefaction farthest to the right, then the adjacent condensation to the left, and so on. This is because the entire train of waves is moving toward the ear from the left. For this reason, the graph of pressure against time at any point is identical with the graph of pressure against distance at any instant, and horizontal *distances* may represent intervals of time.

(3) The curve represents the sound waves set up by an object vibrating 400 times each

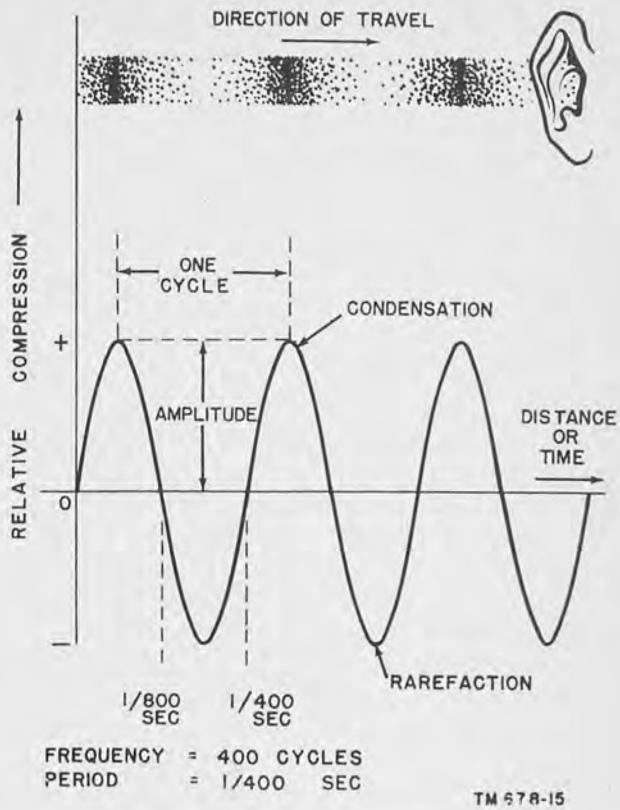


Figure 4. Waveform of simple sound.

second. The time required for each complete vibration is, therefore, 1/400 second, or 2.5 milliseconds.

b. The number of complete vibrations of the object that occur in 1 second is the same as the number of cycles of the wave that occur in 1 second. This number is called the *frequency* of the wave. A *cycle* is a complete set of pressure values, from one positive peak to the next, anywhere along the path of the wave. The words *per second* usually are omitted, but understood, in referring to frequency, so that the frequency is expressed only in cycles—though sometimes cps (cycles per second) is used. The time required for 1 cycle to occur is called the *period* of the wave. It usually is measured in seconds or milliseconds. The period is the reciprocal of the frequency. For example, the frequency of the waveform illustrated in figure 4 is 400 cycles, but the period is 1/400 second, or 2.5 milliseconds.

c. The maximum value of the wave measured from the zero axis is called the *amplitude* of the wave. The expressed value of the amplitude of a wave depends upon the units used in measuring the relative compression of the particles. The ordinates of the graph may represent dynes per square centimeter—a unit of pressure—in order that the amplitude of the wave may correspond to the maximum pressure exerted on the particles.

6. Velocity and Wavelength

a. Velocity. Since a definite length of time is required for sound to travel from one point to another, sound waves possess velocity. In air at 0° C., the velocity of sound waves is about 1,090 feet per second. This velocity increases as the temperature rises, so that at 20° C. the velocity of sound is about 1,130 feet per second. In denser mediums the velocity of sound is greater. In water, for example, sound waves travel at 4,700 feet per second. In solids, the velocity of sound waves is usually many times the velocity in air. Light waves and electromagnetic waves, by comparison, travel at the extremely high velocity of 186,000 *miles* per second—more than 700,000 times as fast as sound. This huge difference in velocity explains why the lightning flash (light) is seen several seconds before the far-off thunder (sound) is heard. Since light travels practically instantaneously for short distances, the distance between a storm center and an observer can be calculated readily by counting the number of seconds between the flash of lightning and the peal of thunder, and then multiplying this figure by the velocity of sound. For example, if there is an interval of 5 seconds between flash and peal, and if the velocity of sound is taken as 1,100 feet per second, the center of the storm is 5 times 1,100, or 5,500 feet from the observer. At ordinary speaking distances, the time required for sound waves to travel from one person to another is too short to be of any importance. It can prove disturbing, however, when the distance separating the source and the observer is relatively great, as it frequently is in a large public hall or stadium.

b. Wavelength. A sound wave, like an electromagnetic or light wave, may be characterized or identified by its *wavelength.* The wavelength is the actual distance between successive condensations or successive rarefactions along the path of the sound. Thus, in figure 4, the distance covered by the portion of the wave designated as *one cycle* is the wavelength. The wavelength of a sound wave can be calculated by using the relationship:

$$\text{wavelength} = \frac{\text{velocity of the sound.}}{\text{frequency of the sound}}$$

A sound wave with a frequency of 1,000 cycles, traveling at a velocity of 1,130 feet per second, has a wavelength of 1,130/1,000 or 1.13 feet. At the same velocity, the wavelength of the 400-cycle sound represented in figure 4 is 2.82 feet. As the frequency increases, the wavelength decreases; as frequency decreases, wavelength increases if the medium remains the same. Audible sounds, which range approximately from 20 to 20,000 cycles, have wavelengths ranging from 55 feet to ⅔ of an inch, if the medium is air. Electromagnetic waves, in air, of the same frequencies as these have wavelengths ranging from about 9,300 miles to 9.3 miles. These latter wavelengths are much longer because their velocity is much greater. Light waves, even though their velocity is the same as electromagnetic waves, have such extremely high frequencies that their wavelengths are less than 1/1,000,000 of an inch.

7. Complex Sounds

a. Harmonics. Most sound sources in telephony do not produce sounds of the simple form represented by the sine wave of figure 4. Those usually encountered are called *complex sounds.* Complex sounds consist of two or more simple sounds, each having its own frequency and amplitude. A graph of such a sound would not be a simple sine wave. Any complex sound may be separated into its component simple sounds and their frequencies, however, as is shown by the graph of a musical tone in figure 5. The lowest frequency contained in such a sound is called the *fundamental frequency*, often simply called the *fundamental.* All others are *harmonic frequencies*, also called *overtones.* Harmonic frequencies are whole-number multiples of the fundamental. The fifth harmonic, for example, has a frequency five times that of the fundamental. For a complex sound having a fundamental of 400 cycles, the fourth harmonic is 1,600 cycles, the sixth harmonic is 2,400 cycles, and so on. It should be noted that, by this definition, the first harmonic is identical with the fundamental frequency.

b. Voice Sounds. All voice sounds are complex sounds. The existence of the different sets of harmonics contained in voice sounds helps us to distinguish the voices of different people, and does much to make the voice expressive of such feelings as gladness, sorrow, and anger. The harmonics of the voice are of considerable importance in telephony, for any part of the telephone system which suppresses or distorts them makes the trans-

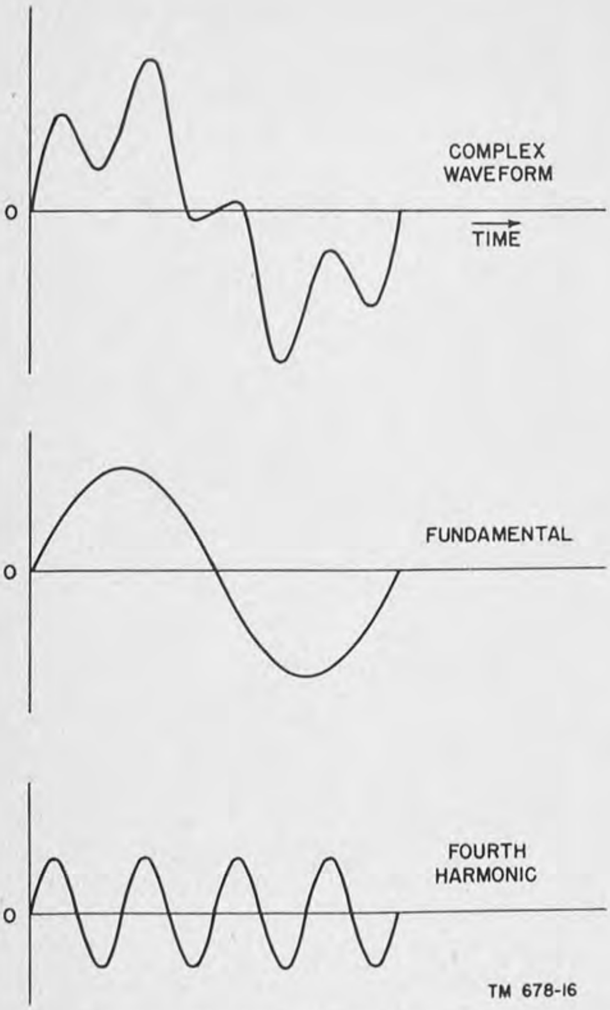


Figure 5. Analysis of complex waveform.

mitting voice less intelligible. Basic voice sounds occur in the variations and combinations of the five vowels (a, e, i, o, u) and the consonants. The basic voice sounds of different languages vary somewhat. Waveforms of two vowel sounds are shown in A, figure 6.

c. Musical Sounds. Just as the different harmonics contained in the sound waves produced by voice enable the listener to distinguish one voice from another, so the different harmonics contained in the sound waves produced by different musical instruments playing the same note enable him to distinguish one instrument from another. Middle C struck on a piano is distinguished easily from the same note played on a violin. It is largely the richness in harmonics of a musical sound that makes it pleasing to the ear. Chords are pleasing because all the harmonics of the individual notes blend. The waveform of a musical note is illustrated in B.

d. Noise. Noise can be distinguished from either speech or music by the irregularity of its waveform. An examination of the waveforms illustrated shows that the waves of the sounds of speech and music are similar in that they have regularity of variation. In both, portions of the wave recur at regular intervals; but this is not true of the waveform representing noise, in C. Noise results in a relatively unpleasing sensation. It rarely has any perceptible rhythm, and its frequency content is difficult to determine. The random or background noise in a room often has a disturbing effect on a listener, and actually may render a conversation unintelligible. Distorted speech or music also may be mere noise when it becomes unintelligible.

8. Characteristics of Sound

Every sound made by musical instruments and the human voice has three identifying properties or characteristics: pitch, loudness, and quality.

a. Pitch of Sound. Pitch is the relative highness in frequency of a sound, and its value depends on the frequency of the wave, which in turn de-

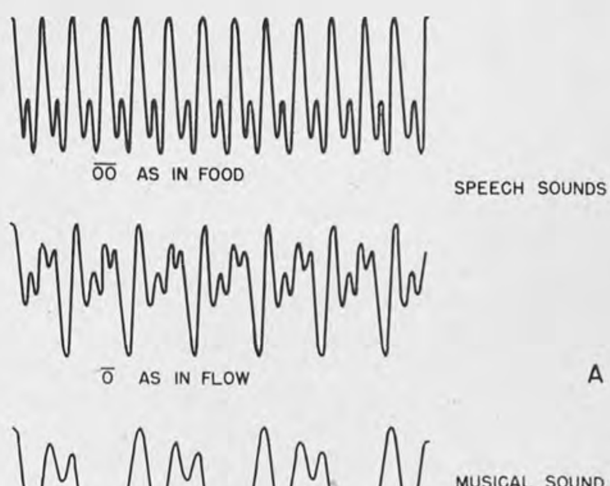


Figure 6. Waveforms of speech, music, and noise.

pends on the number of vibrations or cycles (per second) produced by the vibrating body. The voice of a soprano is higher in pitch than the voice of a basso, the yowling of a tomcat is higher in pitch than the roaring of a lion, the sound made by a peanut vendor's whistle is higher in pitch than that of a fog-horn. The pitch of a complex wave is determined by the fundamental frequency: the higher the frequency, the higher the pitch. The lowest musical sound that the human ear can detect has a frequency of about 20 cycles; the highest has a frequency of about 20,000 cycles. In order for the sound produced by the vibrating hacksaw blade to be audible, it must vibrate at a rate between 20 and 20,000 vibrations per second. Since sounds having frequencies appreciably above 20,000 cycles are beyond the audible range, they are called *ultrasonics*. The musical standard of pitch is the note middle C, which has a frequency of 256 vibrations per second.

b. Loudness of Sound. The *loudness* or intensity of a sound refers to a *sensation* created in the human ear. Since estimates of loudness made by people vary greatly, a standard instrument must be used to measure loudness accurately. So measured, the loudness of a sound is found to depend on two factors: the amplitude of vibration of the source, which determines the amplitude of the sound wave produced, and the distance between the source and the measuring instrument or ear. With constant distance and a uniform medium, the loudness of a sound depends only on the amplitude of vibration of the source. The harder the prong of a tuning fork is struck, the harder a drum is beaten, the larger is the amplitude of vibration, and the louder the sound produced, since the amplitude of vibration depends on the initial energy imparted. Sound usually is measured in watts per square centimeter. Figure 7 and table I illustrate relative intensity of some commonly heard sounds.

c. Quality of Sound. The third characteristic of sound, quality, sometimes called *timbre*, is vital to the *recognition* of sounds and voices. The note A played on a violin has a special quality (peculiarity) which the same note played on a flute does not have: A note from a violin is recognized as coming from a violin; a note from a flute is recognized as coming from a flute. A sleeping mother wakes at the cry of her own child but not at the cry of the one next door, because even though asleep she recognizes the particular quality of the voice of her own child. Much of this recognition of quality depends on the particular combination of harmonics contained in the sound, as has been explained; the rest depends on the frequencies and intensities of the harmonics of the sound, relative to the fundamental. A particularly pleasing voice (for other than sentimental reasons) is generally a voice rich in overtones. Note that the word *quality* has two meanings, a lesser one associated with pleasantness and a principal one associated with identity. To any individual, the quality of a particular sound may or may not be pleasant, but the quality helps to identify the object or instrument or person that is its source.

Table I. Relative Intensity

Sound	(Watts/cm²)	Description
Artillery, thunder, nearby riveter, boiler factory.	10^{-5}	Deafening.
Loud street noise, noisy factory, unmuffled truck, police whistle.	10^{-7}	Very loud.
Noisy office, average street noise, average radio, average factory.	10^{-9}	Loud.
Noisy home, average office, average conversation, quiet radio.	10^{-11}	Moderate.
Quiet home, private office, average auditorium, quiet conversation.	10^{-13}	Faint.
Rustle of leaves, whisper, soundproof room.	10^{-15}	Very faint.

Note. $10^{-5}=1\times10^{-5}=.00001$
$10^{-7}=1\times10^{-7}=.0000001$

9. Characteristics of Speech

a. Human speech has all the basic characteristics of sound, as previously explained, but it has in addition certain peculiarities of its own. The vocal cords are the vibrating source in the production of most vocal sounds. They are vibrated by the power of the air stream forced between them by the lungs. Vocal cords can be compared to the vibrating strings of a violin, which changes pitch by varying the length of strings of different thicknesses. The range of pitch of the voice is determined similarly, the vocal cords becoming thicker and shorter, or thinner and longer, while speaking. The power furnished by the lungs determines the loudness or volume of the sound produced. Thus, we are aware usually of the greater

Figure 7. Relative intensity of natural sounds.

effort required to shout than to whisper. This action of the lungs in generating power is like the compressive action required in the playing of an accordion.

b. The throat, mouth, and nasal passages contribute to the quality of the sound produced by the voice. Also, the size and shape of the tongue, the palate, the jaws, and the lips vary the size and shape of the vocal passages and, therefore, determine the number and proportions of the various harmonic frequencies in the resulting sound. Even the upper nasal cavity and the bone structure of the head affect the quality of the voice; they reinforce some of the harmonics and weaken others. The action of these organs can be compared to the action of various wind instruments, differences in size and shape and materials affecting the quality of the musical sounds produced.

10. Inflection

The inflection or modulation which is imparted to the human voice in speaking indicates to a great extent the thought of the speaker and the significance of what he says. Inflection is the small variation in pitch or loudness which a speaker uses to place emphasis or special meaning on his words. A crisp *no* and a long-drawn-out *no-o-o* mean different things, even though both sounds essentially are the same. Inflection is also the use of pauses of varying length for imparting meanings. Thus, different inflections are used for commands, questions, or statements of fact, and to express attitudes, feelings, and emotions. Inflection is an important factor in determining the intelligibility of a spoken word or phrase, and therefore persons who use devices or equipment for the transmission of speech—telephones and microphones—must be conscious of their speech habits. They must concentrate on correct inflection and on the shaping of their tones, so that as much as possible of the meaning of their words is transmitted to their listeners. Vowel sounds must be made with the proper amount of mouth opening, and consonants must be formed by the correct placement of the tongue and lips.

11. Frequency Range of Voice Sounds

a. The *frequency range of the voice* is one of the most important factors affecting the design and construction of telephone lines and equipment. Figure 8 illustrates the frequency range of the piano keyboard, together with the ranges of the voices of men and women and those of a number of musical instruments. The sounds of the normal speaking voice contain fundamental frequencies between 100 and 300 cycles. The overtones contained in these sounds extend the range of frequencies to approximately 5,000 cycles. Voices of different individuals vary in their frequency content. Men usually have voices with lower fundamental and harmonic frequencies than those of women and children. The range of fundamental frequencies of the singing voice is greater than that of the speaking voice; it varies from about 80 cycles for a deep bass to about 1,200 cycles for a high soprano. The overtones contained in the sounds of the singing voice reach as high as 10,000 cycles. For purposes of comparison, the frequency range of the instruments of a symphony orchestra includes fundamentals of about 16 to

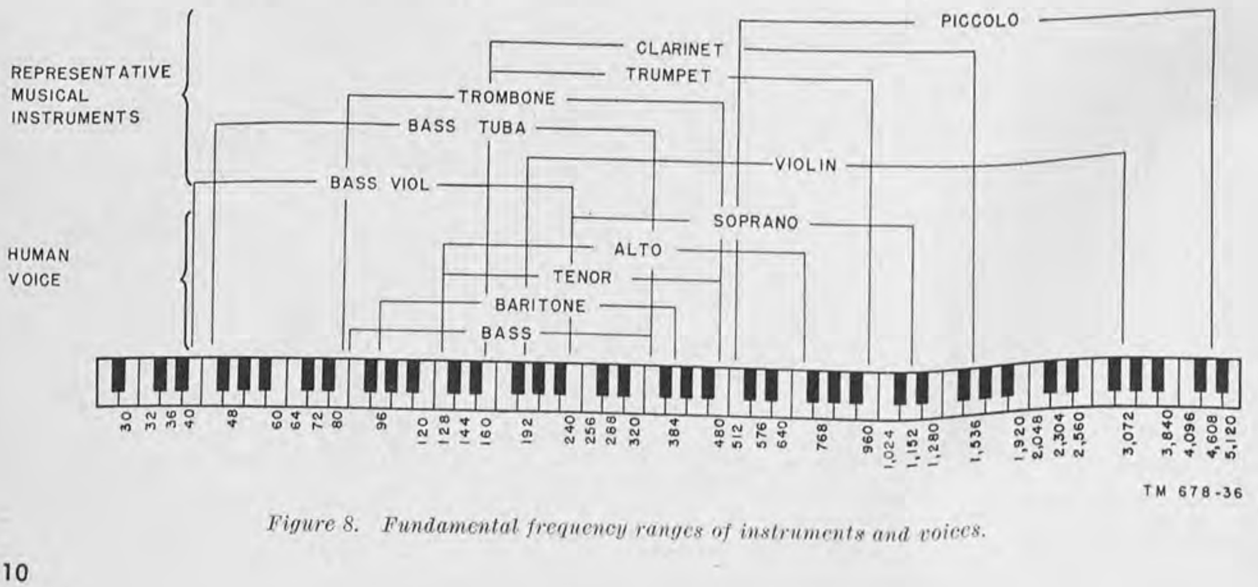


Figure 8. Fundamental frequency ranges of instruments and voices.

4,000 cycles, with overtones ranging to 12,000 cycles or higher.

b. Because of the greater range of frequencies contained in musical sounds—voice and instrument—telephone circuits designed for their transmission must be more complex, and must be constructed to more rigid specifications, to prevent distortion. This increases both the initial cost of the equipment and the expense of maintaining it. For transmission of ordinary conversation, however, it has been found that a sufficiently high degree of intelligibility can be achieved if the frequencies transmitted are limited to those between approximately 200 and 2,700 cycles. This is the range of frequencies with which the various circuits and equipment to be discussed in this manual are concerned.

12. Sound Power

The *power* contained in the sounds of speech depends on the power furnished by the lungs. It varies considerably during an ordinary conversation, with the inflections given to the voice. The average power contained in speech at a normal conversational level is about 1/100,000 watt, or 10 microwatts. By comparison, the average power of speech conducted as loudly as possible is about 1,000 microwatts. Words spoken in as weak a voice as possible, without whispering, have an average power of about 1/10 microwatt; words whispered may have an average power as low as 1/1,000 microwatt. In ordinary speech, the vowels contribute the greatest power, reaching a maximum of about 2,000 microwatts. The power in speech sounds is an important factor in the design and operation of telephone equipment, because the equipment must be able to respond to the differences in power delivered by the voice.

13. Hearing

a. Hearing is the perception of sound by the brain. It involves the response of the ear to sound waves, the transmission of impulses through nerves to the brain, and perception by the brain of the transmitted intelligence. There is a measurable variation among individuals in the ability to hear, since hearing for a given person depends on the loudness and pitch of the sound. An approximate determination of hearing ability in terms of loudness only can be made by measuring the maximum distance at which the ticking of a watch can be heard. A more complete and accurate method involves the use of a device called an audiometer. The audiometer enables an experienced operator to construct a scientific graph of the hearing ability of an individual. This graph then may be compared to what generally is accepted as normal hearing ability. The audiometer consists of a calibrated audio oscillator, the frequency and amplitude of which may be varied, and a telephone receiver for the reproduction of sound waves. The frequency can be varied from 0 cycle to about 25,000 cycles per second, and the amplitude can be adjusted to make the intensity of the sound (loudness) vary through a wide range.

b. In conducting a test with the audiometer, the instrument first is adjusted to any chosen frequency—for example, 1,000 cycles—then, at that frequency, adjusted to an amplitude so low that the sound from the receiver is inaudible. The amplitude then is increased gradually until a point is reached where the sound becomes just perceptible to the ear of the person being tested. This point is called the *threshold of audibility* for that frequency. For any given frequency, it is the lowest intensity at which sound is audible. In the normal ear, the threshold of audibility varies with the frequency of the sound, so that its ability to hear some frequencies is greater than the ability to hear others. In addition to this variation, the threshold of audibility for different frequencies is different for different individuals. For these reasons, a number of frequencies are tested in the measurement of hearing with an audiometer. The lower curve of figure 9 shows how the average, or normal, threshold of audibility varies with sound frequency. The dip in the lower curve indicates that the average ear is most sensitive to frequencies in the vicinity of 2,000 cycles. As a person grows

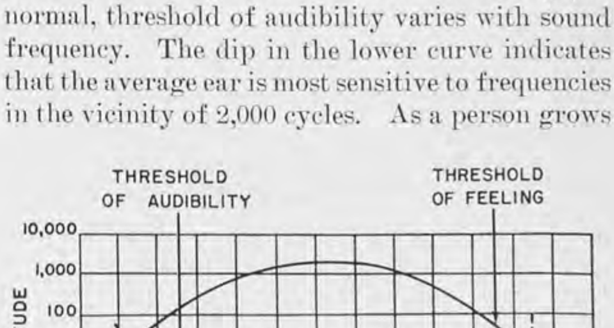


Figure 9. Curves of normal hearing ability.

older, the ability to hear sounds of higher frequencies gradually diminishes.

c. As the amplitude of a sound wave is increased, the sound becomes louder, until a point is reached where the sound is no longer heard. The body continues to feel the vibrations, however. If the amplitude is increased still further, a point is reached where there is a sensation of pain. This point is called the *threshold of feeling*, and it, also, varies with frequency and with the individual. The upper curve of figure 9 shows the threshold of feeling of the average person, and how it varies with frequency.

14. Face-to-Face Conversation

A statement of the larger factors involved in face-to-face conversation will prove of value in helping the reader to grasp the more complex problems encountered in the transmission of sound over telephone wires. In face-to-face conversation, the speech sounds of one person are transmitted to the ears of another by means of the intervening air. The distance between the individuals usually is small, so that there is very little loss (attenuation) of power in the transmission process, and the speakers may keep their voices at a normal conversational level. One is accustomed to the way the voice of an acquaintance sounds during face-to-face conversation, and hears in the voice what he feels is complete *naturalness* of tone and quality. (He even hears in his own voice what he thinks is complete naturalness of tone and quality, although surprised at the differences revealed by a voice recording.) Also, in face-to-face conversation, additional meanings are received from the facial expressions and gestures which accompany the spoken words. This is an important factor, especially for the many people who are hard of hearing, for it aids in comprehension of the ideas being transmitted. It also helps any listener to concentrate on conversations taking place amid sources of distraction, such as other conversations and unusual noise.

15. Conversation by Telephone

The relatively low power of speech sounds limits the maximum distance over which individuals may conduct face-to-face conversation. An attempt to converse at greater distances usually results in a lower degree of intelligibility. For communication over greater distances, some other means of transmitting the voice is required, and the telephone is the simplest device for this purpose. However, although the telephone succeeds in performing this primary function, its operation presents some rather complex problems which do not occur in transmission of sound through air. These problems include distortion of the sound, noise generated mechanically and electrically in the telephone system, noise from external sources, the cutting off of some of the low- and high-frequency components of the sound, and the reduction in volume (attenuation) which occurs in long-distance transmission. All of these problems tend to reduce the intelligibility of the words, the naturalness of the tone, and quality of the sound. They arise from the wires, from the component parts of the equipment, and from the associated circuits required for the generation of power. The engineer must take account of these problems in designing telephone equipment, and both the operator and the maintenance man must be familiar with them to secure the best possible operation of the equipment. Particularly, distortion of sound and distraction from external sources must be kept at a minimum, since personal contact, so important in face-to-face conversation, is lacking.

16. Summary

a. Sound waves are caused by the vibration of a rigid or semirigid body.

b. The transmission of sound always requires a medium; the transmission of light or electromagnetic waves does not require a medium. Air is usually the medium for sound transmission, but either liquid or solid mediums can be used.

c. Vibrating bodies set up alternate condensations and rarefactions in adjacent groups of air particles. These particles transfer their motion in turn to the next group, and this continuing action produces a wave of energy.

d. A cycle is a complete set of pressure values, from one positive peak to the next, anywhere along the path of the wave. The maximum pressure value, measured from the zero axis, is called the amplitude of the wave.

e. Wavelength is the actual distance between successive condensations or successive rarefactions along the path of the sound.

f. The time required for 1 cycle is called the period of the wave.

g. Frequency is the number of cycles per second.

h. The velocity of a sound wave is the distance the energy travels in a unit of time, usually expressed as feet per second. The velocity of sound in air is 1,090 feet per second at 0° C, and 1,130 feet per second at 20° C. By comparison, light and electromagnetic waves travel at a velocity of 186,000 miles per second.

i. The wavelength of a sound wave can be calculated by the following relationship:

$$\text{wavelength} = \frac{\text{velocity}}{\text{frequency}}$$

j. The frequency range of audible sound is approximately 20 to 20,000 cycles per second.

k. In air and at a velocity of 1,100 feet per second, the wavelength of the audible frequencies ranges from 55 feet to approximately two-thirds of an inch.

l. Sound waves may be simple or complex. A simple sound wave is a wave made up of a single frequency varying sinusoidally. A complex sound wave is one made up of more than one frequency.

m. The lowest frequency present in a complex waveform is called the fundamental frequency. Whole-number multiples of the fundamental frequency of a sound wave are called harmonics or overtones. The fifth harmonic of a 1,000-cycle sound is 5,000 cycles.

n. Pitch is the relative frequency of a sound. Loudness or volume is the relative amplitude of the wave producing a sound.

o. Quality or timbre is that charactertistic of a sound which makes it recognizable as a certain kind of sound. Quality depends on the number of harmonics present and on the relationship between the fundamental and its harmonics.

p. A musical tone is a complex but regular waveform rich in harmonics; noise is a complex but irregular waveform.

q. Human speech is characterized by its quality, inflection, and range. Inflection is the small variation in pitch or loudness which a speaker uses to place emphasis or special meaning on his words.

r. The sounds of the normal speaking voice are at fundamental frequencies between 100 and 300 cycles. The overtones contained in these sounds extend the voice range of frequencies to approximately 5,000 cycles.

s. The range of fundamental frequencies of the singing voice varies from about 80 cycles to 1,200 cycles; the overtones reach as high as 10,000 cycles.

t. The range of fundamental frequencies of a symphony orchestra varies from about 16 to 4,000 cycles, with overtones to 12,000 cycles or higher.

u. Most telephones are limited in frequency response to the range from 200 to 2,700 cycles.

v. Speech transmitted by telephone introduces some distortion, noise, and frequency limitation, causing loss in intelligibility, naturalness, and quality.

w. The average power contained in speech at a normal conversational level is about 10 microwatts; at the loudest level it is about 1,000 microwatts; at the weakest level it is about 1/10 of a microwatt; at a whisper it is about 1/1,000 of a microwatt.

x. For any given frequency, the threshold of audibility is the lowest intensity at which sound is audible, the threshold of feeling being the lowest intensity causing a sensation of pain.

17. Review Questions

a. How is sound produced?

b. How can it be demonstrated that a medium is necessary for the transmission of sound?

c. Explain how a vibrating body transmits its motion to the adjacent air particles.

d. Define (1) frequency, (2) wavelengths, (3) cycle, (4) period, (5) velocity, and (6) amplitude.

e. What is the velocity of sound in air at 0° C. and at 20° C.?

f. Give the formula for determination of wavelength by velocity and frequency.

g. Thunder is heard 10 seconds after a lightning flash is seen. If the temperature of the air is 20° C., how far away did the lightning strike?

h. What is the wavelength in air of a 2,500-cycle sound, if the velocity is 1,100 feet per second?

i. What are the differences between simple and complex waveforms?

j. What is the difference between the fundamental frequency of a sound wave and its harmonics and overtones?

k. What is the frequency of the first harmonic of a 400-cycle note? Of the fourth overtone of middle C?

l. Define (1) pitch, (2) loudness, and (3) quality.

m. How does noise differ from speech or musical sounds?

n. What is the range in frequency of a normal speaking voice? Of singing? Of a symphony orchestra?

o. What is inflection?

p. What is the approximate frequency range of the human ear?

q. What is the frequency range of a telephone?

r. What is the average power, approximately, in the sound of (1) the normal speaking voice, (2) a loud shout, and (3) a whisper?

s. Define (1) the threshold of audibility, and (2) the threshold of feeling.

t. What are some of the advantages of face-to-face conversation?

u. What factors must be overcome in the transmission of sound by telephone?

CHAPTER 2

TRANSMITTERS AND RECEIVERS

18. Introduction to Telephony

a. Historical Background of Telephone.

(1) The combination of principles on which the operation of the telephone is based was discovered in 1875 by Alexander Graham Bell. At once, Bell started a series of experiments to perfect practical instruments for the transmission of sound over wires. After 9 months, the first complete sentence was transmitted, over an indoor line extending a distance of about 150 feet. By 1877, an outdoor line from Boston to Cambridge, a distance of about 2 miles, was in use. The early instruments were crude and not too effective. They operated on the principle that a diaphragm, vibrating in a magnetic field, can induce an electric current in a wire. The same device was used as both transmitter and receiver. The strongest magnets and best diaphragms then available would not permit transmission over long distances.

(2) One year after the invention of the original telephone, however, the perfection of the Blake transmitter made possible good, practical telephone transmission. This transmitter operates on the principle that the vibration of a diaphragm can vary the strength of an already existing electric current. Immediately, the problem was presented of establishing a means to connect the lines of different subscribers, whenever they wished to talk. This problem was overcome in 1878 with the opening of the first central office, or exchange, in New Haven. By 1900, means were evolved for the telephone user and exchange to signal (ring) each other when calls were to be initiated or completed. Present-day telephone systems provide vast improvements over those of earlier design and construction in the distances over which satisfactory transmission can be accomplished, dependability of established plant facilities, and the quality of the reproduced signals.

b. Basic Functions of Telephone System.

(1) By means of the telephone, conversations may be held over great distances. To accomplish this, the sound waves of speech must be converted into a form of energy that can be transmitted efficiently over wires. The conversion is effected by *electrical waves* (current) in the *transmitter* of the speaker's telephone set. There, electrical waves are created which correspond to sound waves both in waveform and frequency. The electrical waves are transmitted over the wire, or *transmission* line, and enter the *receiver* of the listener's telephone set. The receiver converts the electrical waves back into sound waves which, again, correspond in waveform and frequency to the original sound waves. The listener in his receiver thus hears words corresponding to those spoken into the distant transmitter.

(2) This process is shown in block form in figure 10. Above, on each side, is a graph of the sound waves as spoken and heard. The electrical wave is shown in the center.

(3) The fundamental principle of the telephone can be summarized by the explanation that electrical waves, traveling over wires, are substituted for sound waves, traveling in air, over the major portion of the distance separating the speaker and listener. Various types of telephone systems are in use, but this underlying principle is common to them all.

19. Telephone Transmitter

a. Function of Telephone Transmitter. The function of the *telephone transmitter* is to convert waves of sound into waves of electric current of corresponding waveform and frequency. The

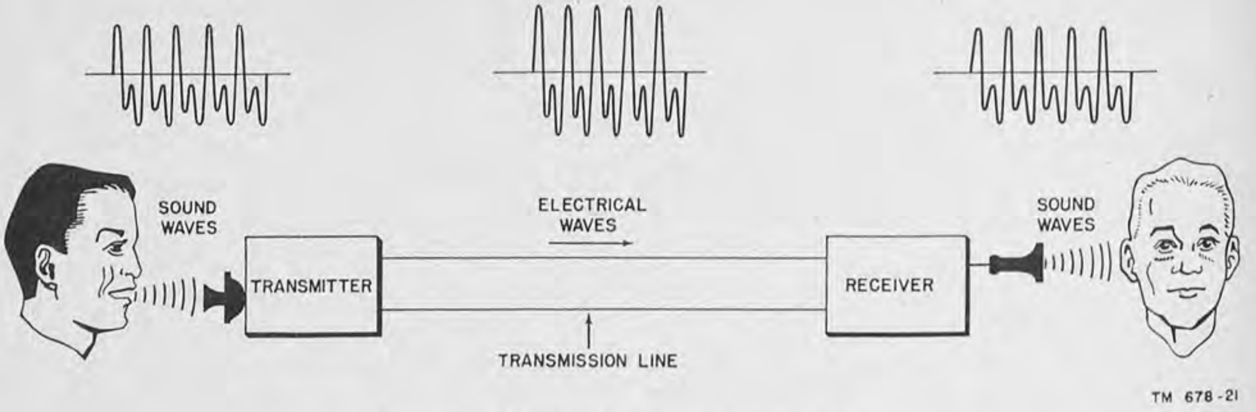


Figure 10. Transmission of sound by telephone.

energy of the waves of electric current so generated must travel over wires for relatively long distances, and arrive at the receiver at a level providing normal listening. But energy is lost in transmission over wires. Because of this loss, the initial energy of the electrical waves must be made *greater* than the original energy of the sound waves. The circuit of the transmitter therefore must provide a means of supplying this extra energy to the electric waves which it generates.

b. Telephone Transmitters.

(1) Paragraph 18*a*(1) describes the principle of operation of the earliest type of instrument used as a transmitter. This type of transmitter had a coiled wire wound around one pole of a permanent magnet, and a thin metal wafer of magnetic material, called the diaphragm, mounted adjacent and at right angles to the magnet. Sound waves colliding with the diaphragm would cause it to vibrate at a frequency determined by the frequency of the condensations and rarefactions of the air molecules, as illustrated in figure 4. It will be understood that the intensity of these condensations and rarefactions vary with each change in characteristic among the various sound waves, and that the amplitude of each diaphragm motion also will be affected by the same conditions; accordingly, the frequency and the amplitude of the diaphragm vibrations will cause the density of the magnetic field, in which it is located, to change with each change of position of the diaphragm. Since this varying magnetic field is cutting across the coiled wire, a voltage is induced in the wire. The voltage thus induced is alternating, since all induced voltages are alternating voltages.

(2) If two wires now are connected to the coiled wire ends and their extremities are connected in turn to another instrument similar in construction to that described in (1) above, the induced a-c voltage will cause a variation in the strength of the associated permanent magnet, and, since the strength of the permanent magnet field determines the instantaneous position of the diaphragm, each change in current intensity and direction of flow will cause a change in the position of the diaphragm. Because these changes are at the same frequency as those of the diaphragm at the originating point, the diaphragm at the terminating point will reproduce the same waves established originally.

(3) This entire process encompasses the changing of sound energy into electric energy, transmitting the signals electrically and then reconverting the electric energy into sound energy.

(4) The distance of which this process can be applied usefully is quite limited, since no provisions are made for amplifying the original energy provided by the sound waves present at the originating end. If all of this energy could be reserved for operating the diaphragm at the distant end, the distance between telephones could be extended almost indefinitely; however, this cannot be so, because part of the original energy is used in overcoming the inertia of the adjacent dia-

phragm; there are, also, further energy losses in the connecting wire, in the coils at both ends of the connections, in the two permanent magnets, and again in overcoming the inertia of the diaphragm at the distant end. The useful energy then is that which appears as sound at the distant end and it can be only the original energy minus all the energy losses.

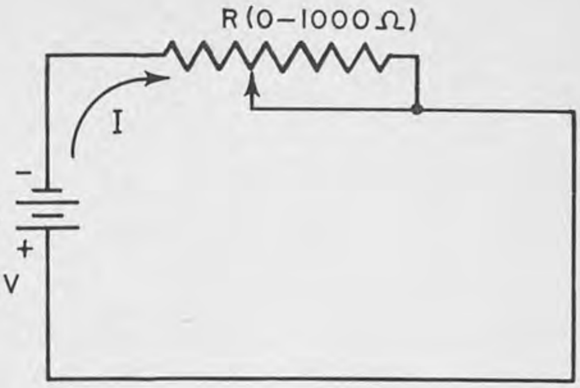
(5) The only source of power furnished the instruments discussed above is that supplied by the person speaking, assuming speech transmission. Such transmission thus is said to be accomplished by use of a sound-powered transmitter, which is discussed further in chapter 8. As a matter of interest, such a transmitter actually is used in present-day communications as a receiver. As explained in paragraph 12, the average power contained in speech at a normal conversational level is about 10 microwatts. It is this power limitation, plus the lack of amplifying facilities, that limits the distances over which such instrumentalities can provide satisfactory sound transmission.

(6) The transmission limitations of the sound-powered transmitter were overcome with the advent of the carbon transmitter, the operating principles of which are described below.

20. Carbon Transmitter

a. Operating Principle of Carbon Transmitter.

(1) The *operating principle* of the *carbon transmitter* can be explained with the help of the simplified circuit shown in figure 11. The circuit consists of battery B and variable resistance R which represents the variable resistance of the carbon granules. Assume that the battery has an emf (electromotive force) of 6 volts, and that R may be varied from 0 to 1000 ohms, with a normal setting of 300 ohms. The normal or average value of current I that flows is 6 volts divided by 300 ohms, or 20 ma (milliamperes). If the resistance, R, is reduced to 240 ohms, the current increases to 25 ma, and if the resistance is reduced further to 200 ohms, the current increases to 30 ma. Similarly, if R is increased to 400 ohms, the current decreases to 15 ma, and if R is increased further to 600 ohms, the current decreases to 10 ma. If the resistance is varied continuously about its normal value of 300 ohms in a certain manner, the variations of current about its average value of 20 ma can be tabulated as follows:



TM 678-22

Figure 11. Equivalent circuit of carbon transmitter.

Time (milliseconds)	Resistance (ohms)	Current (milliamperes)
0	300	20.0
1/3	240	25.0
2/3	209	28.7
1	200	30.0
1 1/3	209	28.7
1 2/3	240	25.0
2	300	20.0
2 1/3	400	15.0
2 2/3	531	11.3
3	600	10.0
3 1/3	531	11.3
3 2/3	400	15.0
4	300	20.0

(2) Figure 12 shows the graph of current versus time constructed from this tabulation. The current waveshape is one of pulsating direct current. This consists of an a-c (alternating-current) wave superimposed on a d-c (direct-current), or average, value of current. The d-c component is 20 ma, and the a-c component is a sine wave with an amplitude of

10 ma. The period of the wave, or the time for 1 cycle, is 4 milliseconds, or .004 second. The frequency of the wave can be calculated by using the formula:

$$f=\frac{1}{\text{period}}$$

$$f=\frac{1}{.004}=250 \text{ cycles.}$$

The rate at which the current varies about its average value depends on the rate at which the resistance is varied about its normal value.

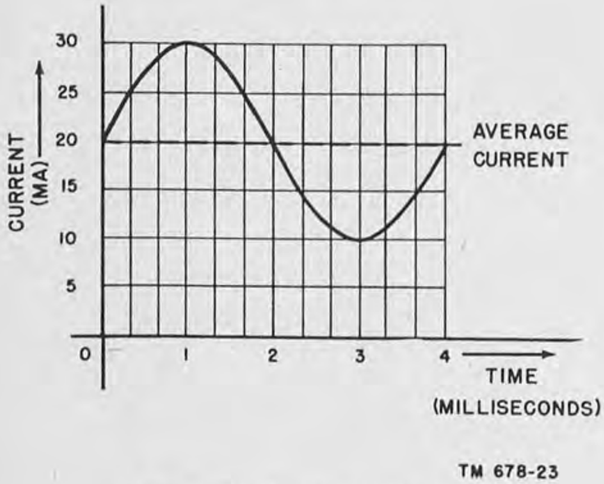
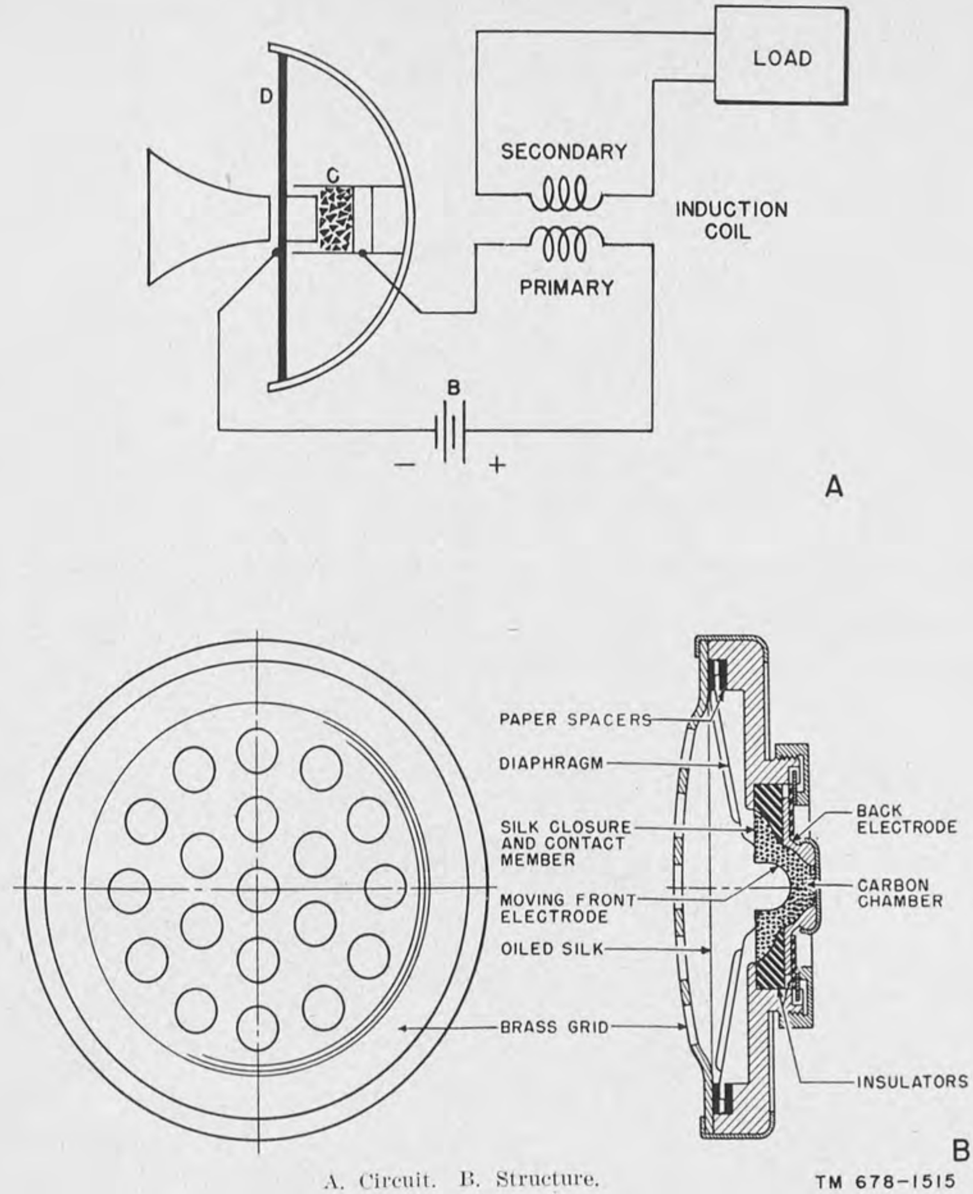


Figure 12. Current versus time.

b. Application of Operating Principle To Carbon Transmitter. A, figure 13, illustrates the operation of the carbon transmitter, the principle of which is based on the simplified circuit in figure 11. The basic circuit components are battery, B, a cup of carbon granules, C, metal diaphragm, D, and an induction coil. The negative terminal of the battery is connected to a small carbon disk which is fastened rigidly to the diaphragm. This disk rests against one side of the cup of carbon granules; the other side of the cup is connected to one end of the primary of the induction coil. The circuit is completed by the return of the primary to the positive terminal of the battery.

(1) When no sound waves strike the diaphragm it remains stationary, the resistance of the carbon granules remains constant, and, as a result, a steady direct current flows through the circuit (A, fig. 13). The value of this current depends on the combined resistance of the carbon granules and the d-c resistance of the primary of the induction coil. Since an induction coil is, in effect, a transformer, no emf is induced in the secondary when steady direct current flows in the primary. Therefore, when no sound energy is transferred to the diaphragm (that is, when the diaphragm does not move), no current flows in the secondary of the induction coil. The normal resistance of an actual new transmitter unit is approximately 35 ohms; the d-c resistance of the primary of the induction coil varies with the type of coil used. These coils will be discussed more completely in a later chapter.

(2) When sound waves strike the diaphragm, it vibrates in accordance with the variations of intensity and frequency of the waves (A, fig. 13). This vibration causes a varying pressure to be exerted on the carbon granules, which changes their state of compression. As the compression increases, the resistance of the granules decreases, causing the current in the circuit to increase. As the compression decreases, the resistance of the granules increases, causing the current to decrease. Because the amplitude and frequency of the current vary directly as the amount and rate of change of the compression of the carbon granules, they vary as the amount and rate of change of the pressure exerted on the diaphragm, and, therefore, vary as the intensity and frequency of the sound waves which strike the diaphragm. The varying current is a pulsating direct current. (Figure 12 shows such a current, resulting from a simple wave. The a-c component of a current resulting from speech is, of course, a complex wave, but again it is superimposed on a direct current to form a pulsating direct current.) Because the emf induced in the secondary (A, fig. 13) depends only on the varying component of the current in the primary, an alternating emf is induced in the secondary. When a load, such as a meter or receiver, is connected to the secondary, an alternating current flows in the secondary circuit.



A. Circuit. B. Structure.

Figure 13. Carbon transmitters.

21. Structure of Carbon Transmitter

a. B, figure 13, shows the front view and a cross-sectional side view of a carbon transmitter. This unit is one of several types in common use, all with a similar basic structure. The path of current within the unit is from the moving front electrode, which is fastened to the diaphragm, through the carbon granules, to the back electrode. A bell-shaped carbon chamber is used, so that there is sufficient contact between the carbon granules and the electrodes. Since the contact is uniform, and operation is equally good in whatever position the transmitter is held, this is called a *nonpositional transmitter*. The moving front electrode exerts varying pressure on the granules in accordance with the vibration of the diaphragm, and the transmitter consequently is of *direct-action type*. As the diagram shows, the moving electrode is attached to the center of the conical diaphragm, and forms the front center surface of the carbon chamber.

b. The diaphragm is made of an aluminum alloy (B, fig. 13). Its thickness is .003 inch, and it has radial ridges to increase its stiffness. Paper spacers, consisting of a number of thin paper rings, support the diaphragm at its edge without interfering with its movement. The carbon chamber is closed on the front side by a silk covering, clamped on the flange of the front electrode. A light, spoked, copper contact member, clamped under the front electrode, provides a flexible connection between the front electrode and the metal frame. The stationary back electrode is held in place in the frame by a threaded ring, and is insulated from the frame by a fiber washer and a ceramic insulator, which also forms part of the rear surface of the carbon chamber. The surfaces of both front and back electrodes are gold-plated where they make contact with the carbon granules. The perforated brass grid protects the vibrating parts from mechanical injury. The working parts are kept free of moisture by an oiled-silk membrane stretched between the brass grid and the diaphragm.

c. The transmitter unit is mounted in a handset, as shown in the disassembled view of figure 22. It is held in place by the transmitter cap, along with contact springs which press against its contact. The unit may be removed for servicing by unscrewing the plastic cap or mouthpiece.

d. An improved type of carbon transmitter is shown in figure 14. The frequency response of this unit has been improved by use of an acoustic network which couples the back chamber of the diaphragm through an acoustic resistance to the cup chamber. Woven rayon fabric is used for the acoustic resistance material. This transmitter, in addition to an improved frequency response, has a high modulation efficiency. Note that the diaphragm of this transmitter is clamped rigidly at its outer edge, whereas the diaphragm of the element in B, figure 13, is floated between paper spacers.

22. Noise-Canceling Transmitter

a. The transmitter shown in B, figure 13, has a major disadvantage in that it is susceptible to in-

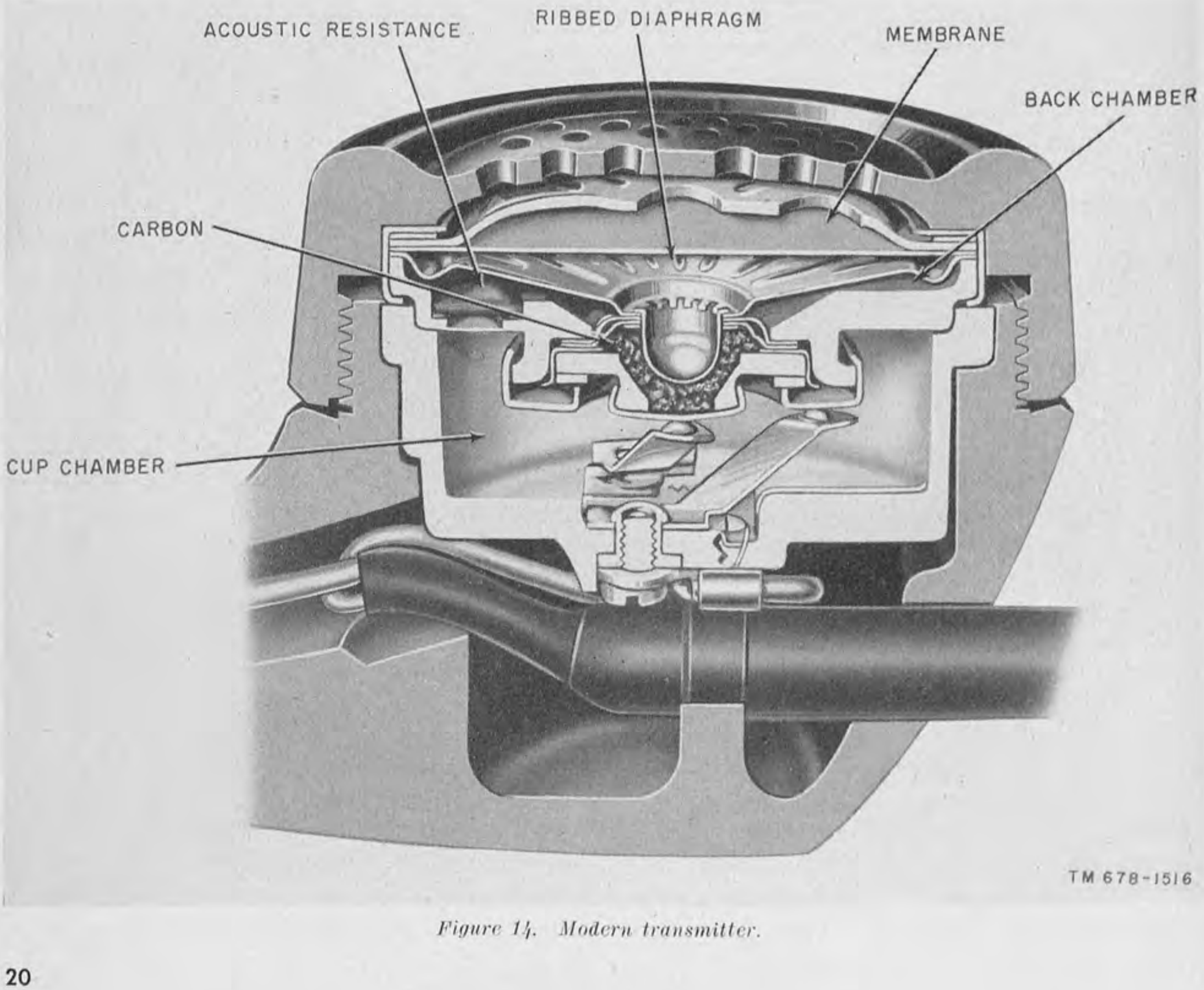


Figure 14. Modern transmitter.

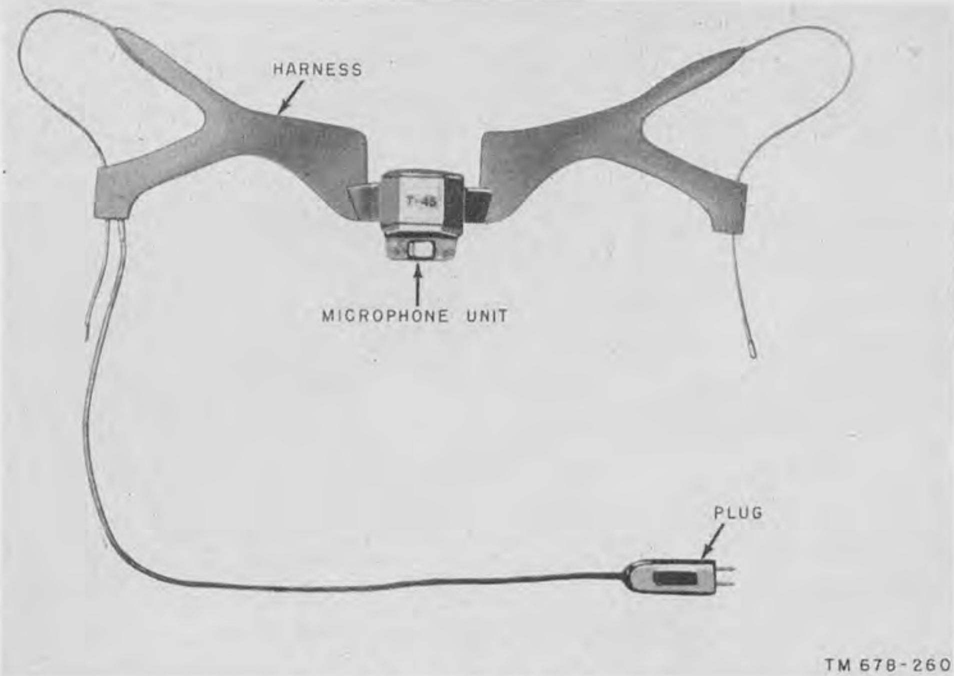


Figure 15. Differential transmitter.

terference from noise. This disadvantage is most noticeable when the transmitter is operated in places where the noise level is high, such as near railroad trains, airfields, the interior of tanks, and areas where gunfire or bombardment is taking place.

b. A number of transmitters have been developed which reduce interference from noise sources. Among these are the throat transmitter and various kinds of directional transmitters, which restrict the movements of the operator and produce some distortion of his speech. Recently, however, a transmitter has been developed which largely eliminates noise interference without restricting movement. It is called a *noise-canceling* or *differential* transmitter.

c. The United States Army Type T-45 lip transmitter is an example of this type. In operation, sound waves activate its diaphragm only if they are introduced close and perpendicular to the front surface of the diaphragm. Sounds which originate at some distance enter the transmitter through two openings, on the front and back of the diaphragm. Since this equalizes the pressure exerted on both faces, the resultant motion of the diaphragm for distant sounds is practically zero. There is almost no change in the resistance of the carbon granules and, therefore, almost no change in current as a result of these sounds. Since, in responding to distant sounds, the diaphragm neutralizes pressures of relatively low frequencies more than those of high frequencies, the noises most canceled are those originating in tanks and from gunfire, mainly in the low-frequency range. By proper design, it is possible to make the cancellation of noise practically complete. This feature makes the differential transmitter much more suitable than others for many military applications, and also makes it valuable for many civilian uses.

23. Telephone Receivers

a. Function of Telephone Receiver. The function of the *telephone receiver* is to reproduce the sound made in the transmitter at the other end of the transmission line. It is accomplished by reconverting to sound waves the electrical waves transmitted to it. The function of the receiver, therefore, is the reverse of that of the transmitter. The receiver also must prevent leakage of sound. This requirement is satisfied by the construction of the earpiece, which is designed to be held close to the ear.

b. Types of Telephone Receivers. According to their means for converting electrical waves to sound waves, telephone receivers may be either magnetic-diaphragm or moving-conductor types.

(1) The *magnetic-diaphragm receiver* (A, fig. 16) contains a permanent magnet, and operates by variation of the strength

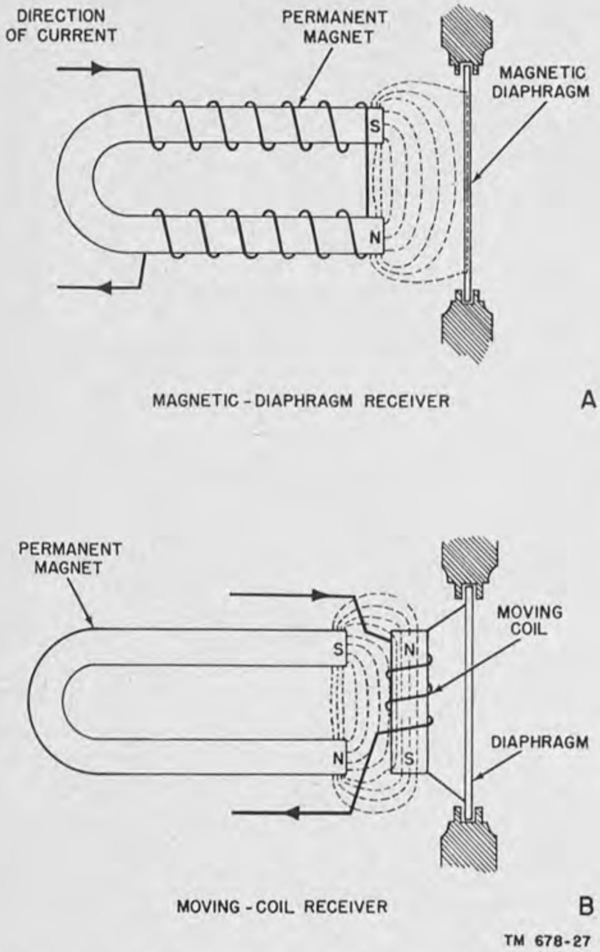


Figure 16. Comparison of operating principles of two receivers.

of its magnetic field. The amplitude and frequency of the variation of the magnetic field cause a corresponding variation of the motion of the magnetic diaphragm. This is the receiver most commonly used in telephone communications.

(2) The *moving-conductor receiver*, shown in B, also contains a permanent magnet, but it operates on the principle of the electrical meter. The moving conductor is usually a coil or ribbon of aluminum alloy, attached to the diaphragm. As the current in the coil varies, the magnetic field around the coil varies. This varying field reacts with the field of the permanent magnet, causing the coil to vibrate. The vibrations of the coil are transferred to the diaphragm, which generates sound waves of the same frequency and waveform characteristics as the current in the coil. The moving-conductor receiver is called also the *moving-coil receiver* and the *dynamic receiver*. The dynamic loudspeaker used in radio receivers is similar to it in action.

24. Magnetic-Diaphragm Receiver

a. Operating Principle of Magnetic-Diaphragm Receiver. The *operating principle* of the *magnetic-diaphragm receiver* (fig. 17) is based on an elementary principle of magnetism—the ability of a magnet to induce a magnetic field of opposite polarity in a magnetic material placed near it. Because the induced polarity is opposite, attraction always results between the magnet and the material. For example, a magnet and an iron nail are attracted to each other.

(1) When a magnetic diaphragm is placed near the bar magnet, as in A, and its range of motion is limited suitably, it will be attracted to the magnet without actually touching it. The magnet exerts a permanent pull on the diaphragm. If a coil is wound around the magnet as in B, C, and D, and current is caused to flow in the coil, the pull on the diaphragm will be increased or decreased, depending on the direction and magnitude of the current. If the current in the coil is a sine-wave alternating current, it varies the strength of the magnetic field accordingly. During the positive half-cycle of such current, shown in B, as the current varies from 0 to maximum and back to 0, the strength of the magnetic field varies from its original value to *maximum* and back to its original value. The pull on the diaphragm at the same time varies from its normal value to maximum and back to its normal value. During the negative half-cycle in C, as the current varies from 0 to maximum in the opposite direction and back to 0, the strength of the magnetic field varies from its original value to *minimum* (because of the reversed direction of current) and back to its original value. The pull on the diaphragm at the same time varies from its normal value to minimum and back to its normal value. These actions in sequence cause a vibration of the diaphragm. The vibration is actually a

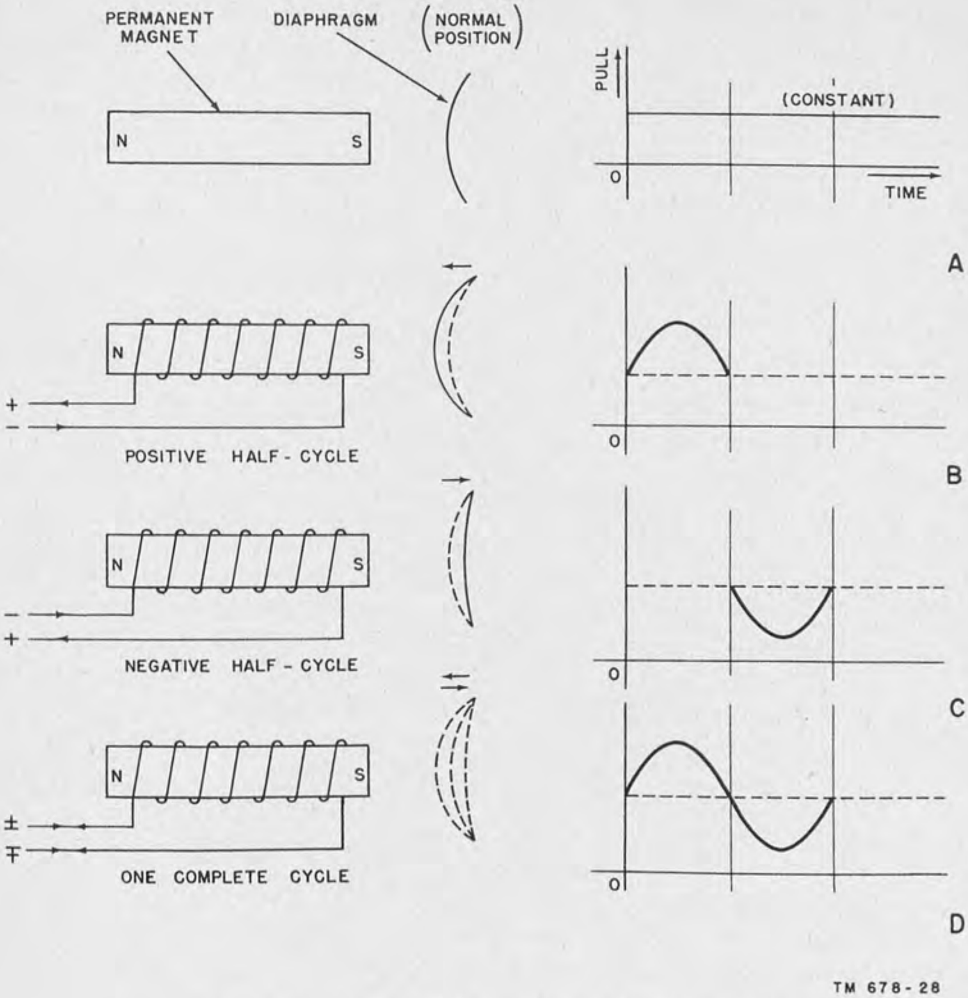


Figure 17. Operation of magnetic-diaphragm receiver.

sinusodial displacement of the diaphragm about a normal, or neutral, position, shown in D. A series of vibrations results in the generation of a series of sound waves of corresponding frequency and waveform. Figure 18 shows comparative graphs of the sound-wave input at the transmitter, the current in the transmitter, the magnetic pull on the diaphragm, and the sound-wave output at the receiver.

(2) Figure 19 illustrates the reason for using a permanent magnet in the telephone receiver. The permanent magnet is replaced by an electromagnet, with a coil wound on a soft-iron core. When no current flows in the coil, there is no magnetic field; therefore the diaphragm remains in its neutral position, as in A. When a sinusodial current flows in the coil during the positive half-cycle, a magnetic field of similar variations is produced, as in B, and this field attracts the diaphragm so that its motion corresponds to the variation of the field. During the negative half-cycle, in C, the polarity of the magnetic field is reversed, but the displacement of the diaphragm is exactly as before, since only attraction (not repulsion) can be exerted on it; consequently, the diaphragm moves inward for *both* half-cycles of current, instead of alternately inward and outward as described in (1) above. The sound wave produced by this action would have *two* condensations and *two* rarefactions for each cycle of current. The sound, therefore, would have a fundamental frequency twice as great as that of the current, as well as a distorted waveform.

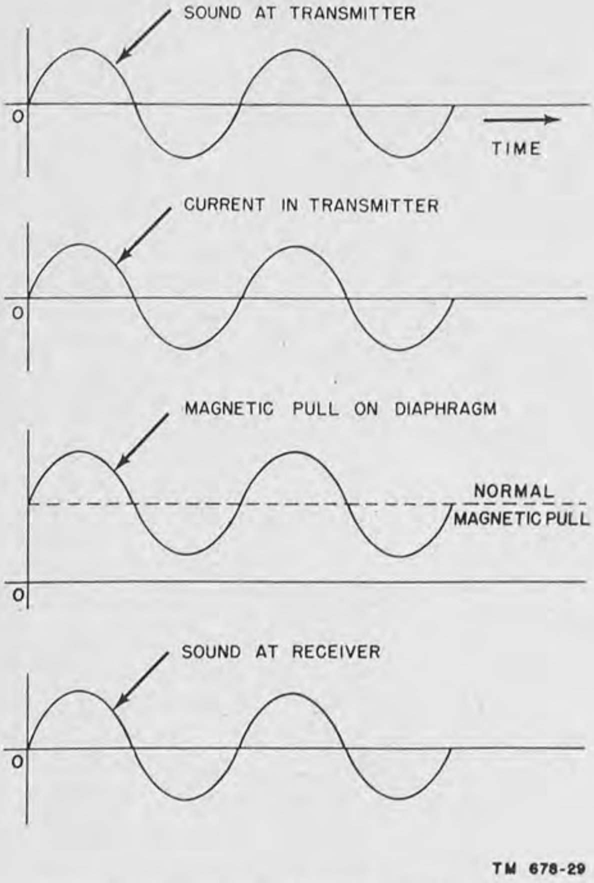


Figure 18. Waveforms in simple telephone system.

Since these results would cause the sound to be considerably different from the original sound introduced at the transmitter, this system, which does not contain a permanent magnet, would be useless for telephone transmission.

b. Application of Operating Principle To Practical Magnetic-Diaphragm Receiver.

(1) In the early telephone receivers devised by Bell, a bar magnet was used to supply the permanent magnetic field (A, fig. 20). Bell actually used two receivers of this type in his early telephone system, one serving as the transmitter and the other as the receiver. Later, the efficiency of the receiver was improved greatly by using a *horseshoe magnet* in place of the bar magnet, as shown in B. Because the length of the magnetic path is much shorter in the horseshoe magnet, the magnetic field is concentrated in the region between the poles. This increases the pull on the diaphragm for a given value of current, and therefore produces sound waves of greater intensity. The modern receiver unit incorporates a modification of the horseshoe magnet. This, with the use of better magnetic alloys, has improved the design and performance of the receiver.

(2) In a later chapter it will be shown that the receiver winding occasionally must have direct current flowing through it. Because of this requirement, the receiver is connected in such a manner that the field produced by the direct current in the coil aids the field of the permanent magnet. This increases the strength of the field, and results in a stronger pull on the diaphragm. The process by which direct current in the winding produces an aiding field is called *poling*, because the polarity of the direct current must be correct.

(3) Permanent magnets operate uniformly if they are not subjected to shocks or other abuse. Sudden and violent jarring partially destroys their magnetism, and makes them less effective in telephone receivers. A weak magnet exerts a weaker normal pull on the diaphragm, causing unequal displacement on each side. This results in distorted vibration and distorted sound.

25. Structure of Modern Receiver

a. C, figure 20, shows the front view and a cross-sectional side view of a *modern receiver unit*, designed to be mounted in several types of telephone instruments. The receiver winding is wound around two permalloy pole pieces, each of which is welded to a cobalt-steel bar magnet. These magnets are made of a recently developed magnetic alloy which has high permeability, giving a strong magnetic field. The magnets and pole pieces are fastened to a zinc-alloy frame. The diaphragm is made of a special steel alloy. It is not clamped, but rests on a ring-shaped ridge; the pull of the magnets holds it in place. It is protected in front by a silk screen, and its vibration is controlled by a silk acoustic resistance disk attached at the rear. The entire unit is held together by a brass clamping ring. Two silver-plated contacts, for electrical connections, are mounted on the back.

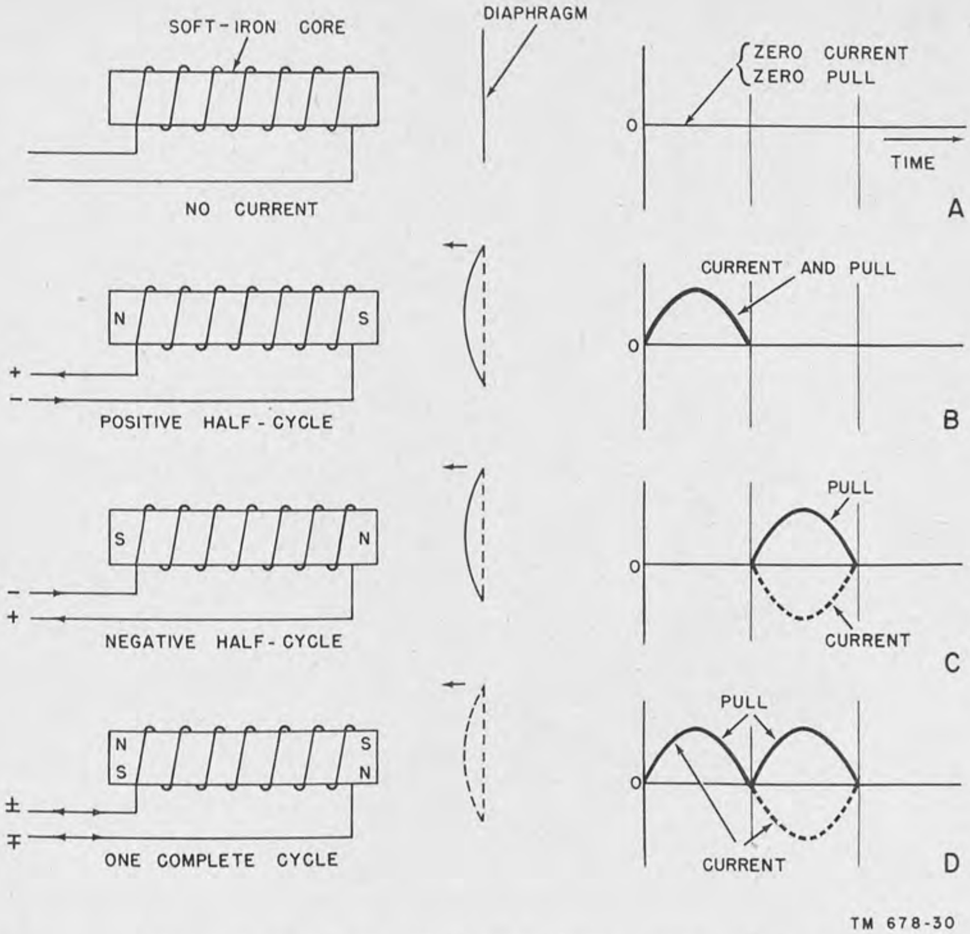


Figure. 19. Action of soft iron-ore electromagnet on diaphragm.

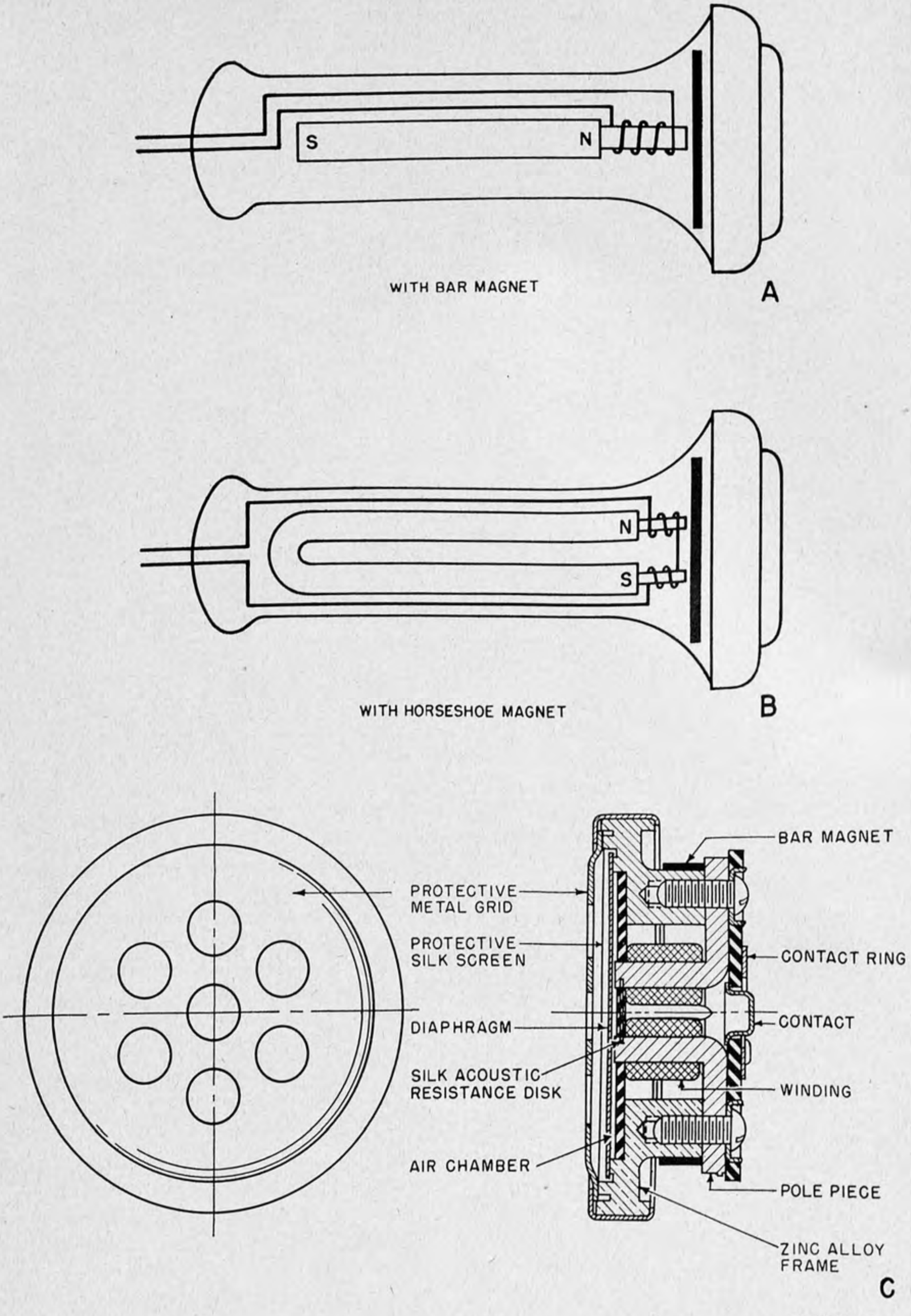
b. A recently developed receiver that provides improvements in efficiency and frequency response is shown in figure 21.

(1) The simple diaphragm of earlier receivers is replaced by a ring armature, a dome-shaped diaphragm of phenolic impregnated fabric cemented to a circular magnetic ring. The outer edge of the ring rests on a circular seat of nonmagnetic material. The inner edge is close to a circular pole piece which conducts the flux from a ring-shaped permanent magnet. This design lowers the mechanical impedance of the diaphragm and improves the radiation efficiency. As a result, when the receiver is held off the ear, the intelligibility of speech is much better than that of other receivers.

(2) An acoustical network couples the back chamber of the diaphragm through four holes covered with acoustic resistance fabric to the handset cavity. The chamber above the diaphragm exhausts through the holes in the receiver cap. The receiver response is virtually flat from 400 to 3,500 cps (cycles per second)—an improvement over earlier receivers.

(3) A varistor, or nonlinear resistance, protects the user from high acoustic levels caused by transient electrical disturbances in the telephone circuit. This varistor also protects the receiver magnet from demagnetization hazards of such disturbances.

c. The receiver and transmitter units are mounted for convenience in an instrument called a *handset.* Figure 22 is a disassembled view of a handset, showing the transmitter element, transmitter cap, receiver element, and receiver cap. When the receiver cap (earpiece) is screwed on tightly, it exerts a pressure on the receiver element, forcing the two contacts against two contact springs. These contact springs are connected



A and B, Early types. C, Modern unit.

Figure 20. Telephone receivers.

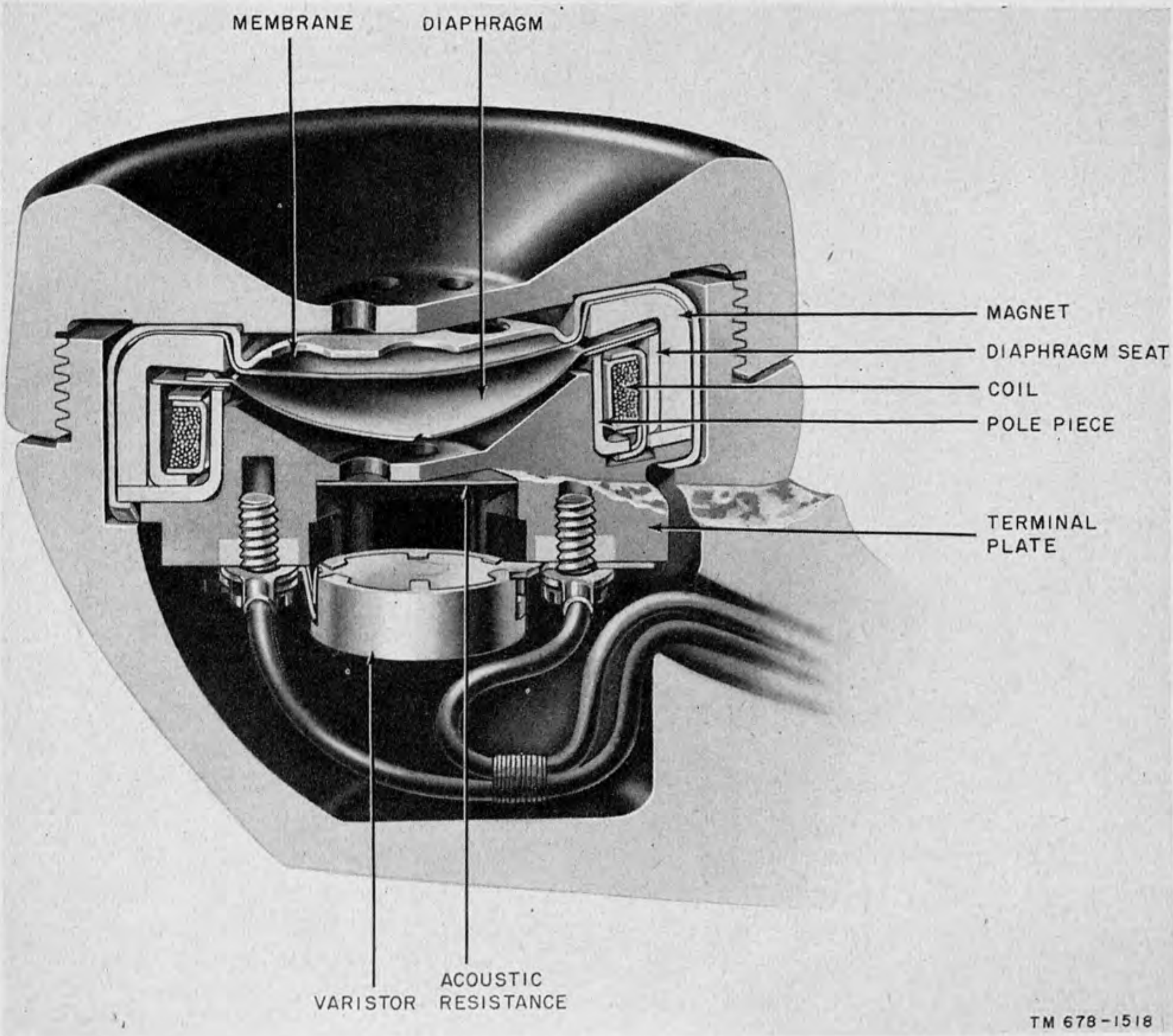


Figure 21. Modern receiver unit with ring armature.

to the external wiring of the receiver. Like the transmitter, the receiver element may be removed for servicing or replacement by unscrewing the cap. In the typical modern combined hand-telephone set shown in figure 23, the handset rests on a cradle base when not in use.

26. Circuit Diagrams

a. Identification of Components of Circuit Diagrams. The study of telephony involves an understanding of the operation and assembly of equipment consisting of many component parts. Some of the parts are small, some rather large. The process of learning is simplified greatly if these parts can be identified readily. Identification means more than recognizing them, however. It includes the ability to visualize how and where each part is connected in a circuit, and knowledge of the theory and function of the part in that circuit. It includes a thorough understanding of the relation of each part in a circuit to other parts, for only with this understanding can the skill necessary for tracing circuits be acquired. In later chapters of this manual which deal with actual telephone circuits, the theory and function of each part will be explained as soon as the part is introduced, and the relation of each part to the others in the circuit will be presented by means of text and diagrams.

b. Types of Circuit Diagrams (fig. 24). Three basic types of circuit diagrams—pictorial, wiring,

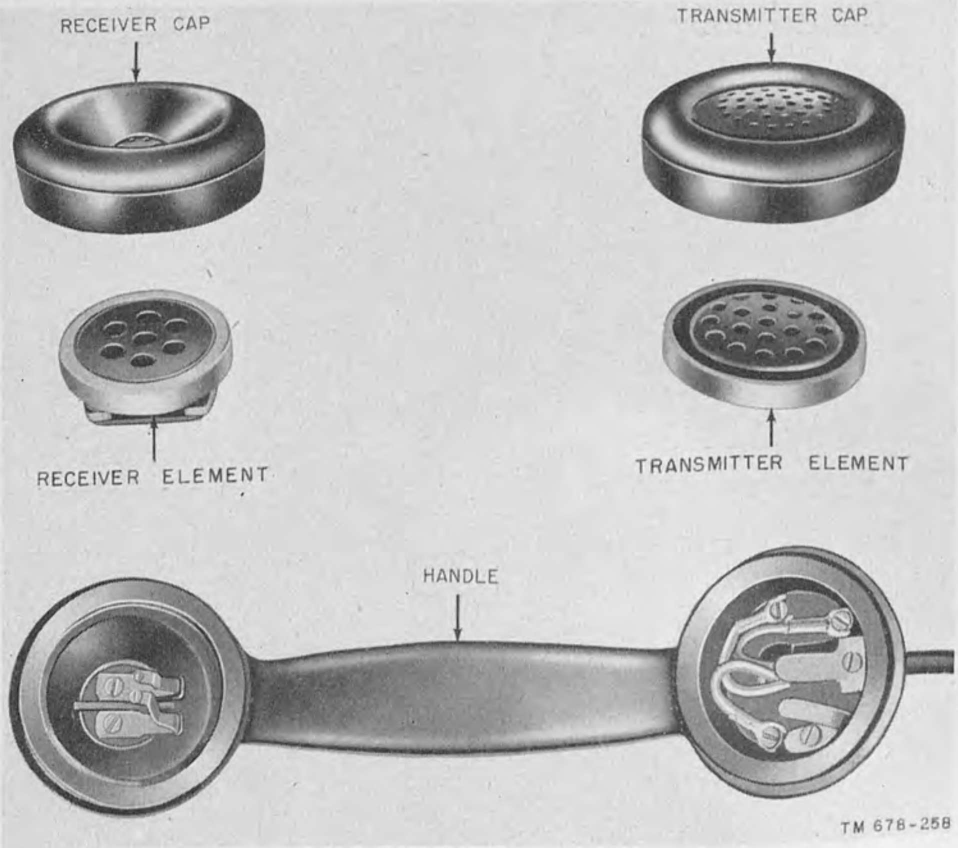


Figure 22. Handset, disassembled.

Figure 23. Modern combined hand-telephone set.

and schematic—will be used extensively in this manual, and now will be described. In addition, frequent use will be made of block diagrams.

(1) An example of a *pictorial diagram* is shown in A. This is a picture drawing of the actual physical layout or assembly of the component parts of a circuit, showing the parts either as they appear to the eye, or in a form which emphasizes some feature of their operation. The parts may be photographs of equipment, if they are arranged to show the relationships among them. Pictorial diagrams are useful particularly to people untrained in the theory of operation of the circuits they illustrate.

(2) B is an example of a *wiring diagram.* This type is used primarily to show a wireman or serviceman the proper hookup for a piece of equipment. The emphasis in wiring diagrams is on the connection of cables and other wires to appropriate terminals, not on the operation of the circuit.

(3) The *schematic diagram*, shown in C, is not a lifelike drawing of the component parts of a circuit, or a means for indicating their connection. Instead, stand-

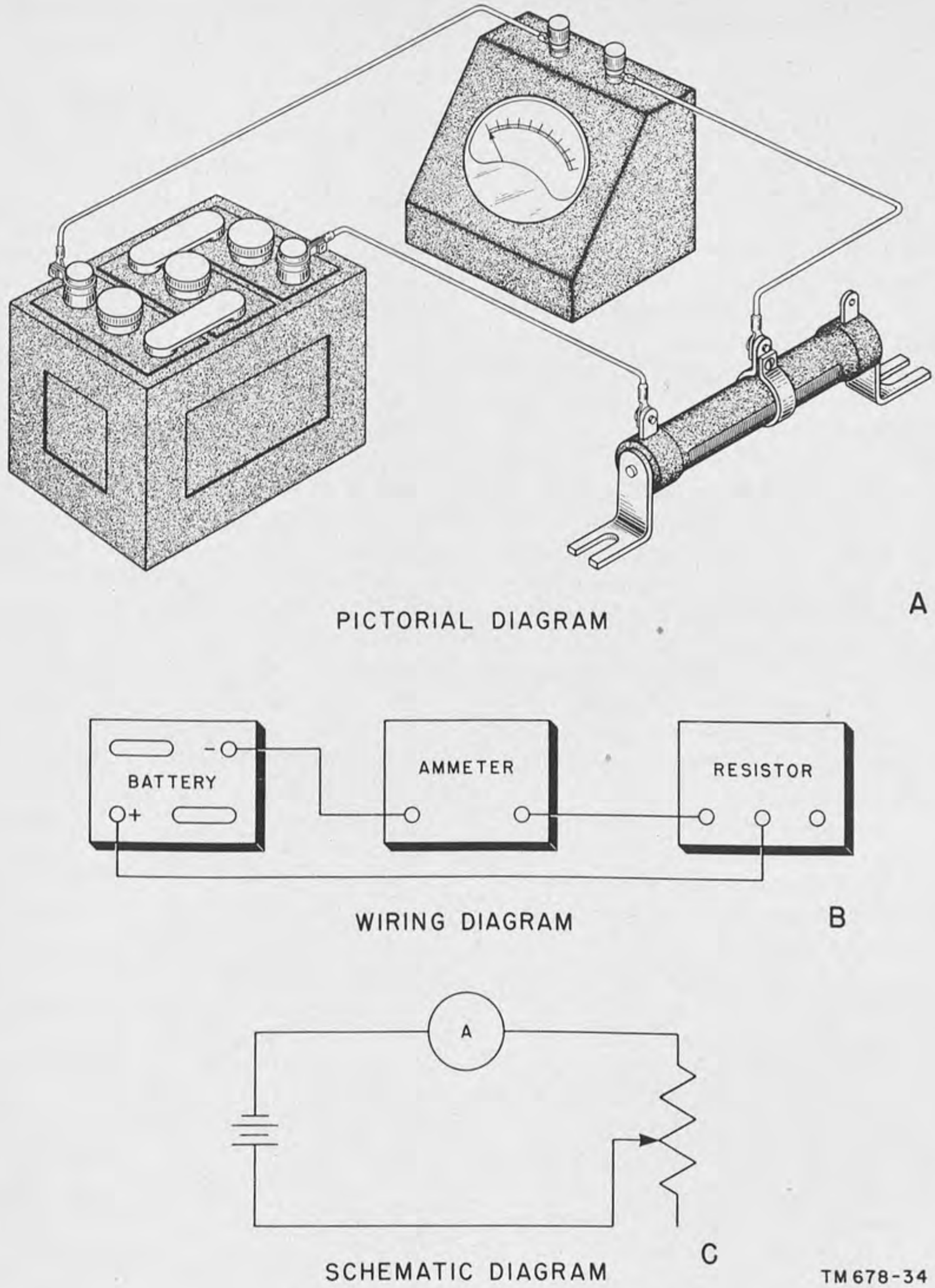


Figure 24. Types of circuit diagrams.

ard, conventional *symbols* are used, and the position of the symbols in the diagram does not necessarily correspond to the location of the parts in the actual equipment. Schematic diagrams usually are more compact and easier to trace than pictorial diagrams, and they are used more often. They make it possible to present a more logical explanation of the voltage and current relationships in electrical circuits than is possible with other types, and they allow the emphasizing of important features of the circuits. Schematic diagrams will be used extensively in explaining the operation of the telephone circuits discussed in this manual.

27. Reading of Schematic Diagrams

The ability to trace and understand the schematic diagrams of telephone circuits can be obtained rapidly if the problem is approached in an intelligent manner. Do not attempt to memorize complicated diagrams. The principles and procedures followed by telephone men, described below, should be followed to acquire skill in reading and understanding schematic diagrams.

a. Learn the *electrical principles* underlying the operation of the particular circuit. This includes a knowledge of the kinds of current flowing in the various parts of the circuit, the voltage across the various parts, and the power dissipated in the circuit.

b. Memorize the *symbols* for the component parts of telephone circuits. These symbols will be introduced at the time the operating principle of each part is explained. Learn to identify the symbol with the actual appearance of the part.

c. Break down a complex circuit into a number of simpler circuits. Frequently, certain small groups of parts form relatively simple units within a complex circuit. For example, a diagram of a complete telephone system can be broken down into a transmitter circuit, a receiver circuit, a ringing circuit, relay circuits, and several other smaller circuits. Learn to recognize these small groups as units, and to relate these units to the others. In the following pages, complete circuit diagrams will be built up step by step; and frequently, as each new smaller unit is introduced, its position in the circuit will be emphasized by the use of heavier lines than those in the rest of the circuit. Take advantage of this, not only to learn the function of the unit itself, but to understand its relation to the rest of the circuit.

d. Learn to think of each part or unit in a circuit in terms of its *function* in the circuit. An understanding of *why* a particular part is included is extremely helpful in learning its position in a schematic diagram. The reader actually will find himself looking for a particular part in a circuit diagram, if he understands its function.

e. Form the habit of visualizing the *position* of a unit in the actual equipment from its position in a schematic diagram of the equipment. This will prove helpful when it is necessary to work on the equipment from a schematic diagram. Remember that the position of the symbol in a schematic diagram does not correspond necessarily to the location of the unit in the equipment.

f. Learn to distinguish between the electrical circuit and the mechanical operations associated with the circuit.

g. Review, from time to time, the symbols learned previously, and the relationships among the smaller units which make up the complete circuit.

h. Follow faithfully all of the foregoing principles and procedures, for they are indispensable to the rapid acquiring of skill in the reading of schematic diagrams.

28. Telephone Symbols

This chapter has included discussions of the operating principles of telephone transmitters and receivers. These units, together with such electrical devices as batteries and resistors, are basic components of telephone systems. Figure 25 shows most of the *symbols* for the units and devices so far discussed. A more complete list of the fundamental electrical symbols used in telephone circuits is contained in the appendix.

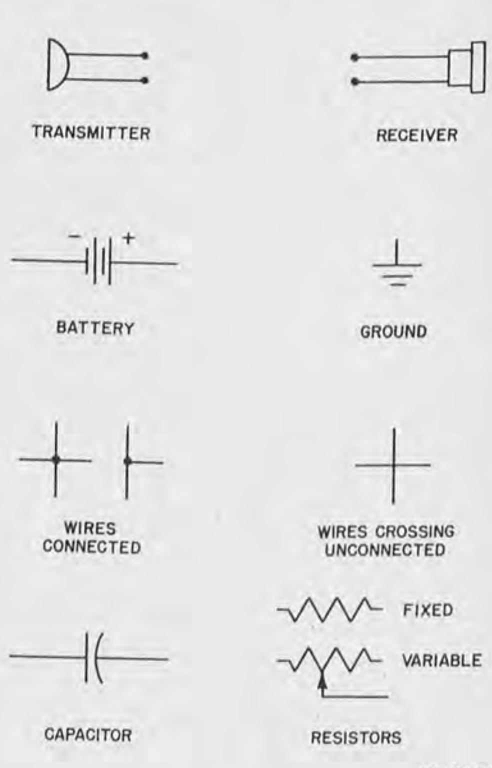


Figure 25. Telephone symbols.

29. Summary

a. The telephone as invented by Bell in 1875 was crude and limited in efficiency. Extending its area of usefulness presented many problems. Within only a few years, many of its basic problems were solved.

b. Present-day telephone systems are very different from early ones, but they have the same basic principles of operation.

c. Sound waves, striking the diaphragm of a carbon transmitter, cause the diaphragm to vibrate with variations of frequency and amplitude corresponding to those of the waves. This causes a corresponding variation in the resistance of a chamber of carbon granules, which in turn causes a corresponding variation in the magnitude of a direct current produced by a battery. This pulsating direct current flows through the primary winding of an induction coil, and induces an *alternating* emf in the secondary winding. An alternating current flows through a load connected to the secondary.

d. Modern transmitters are designed, electrically and mechanically, for maximum efficiency and minimum distortion and interference from external noise.

e. The carbon transmitter is the most common of several types of transmitters in current use.

f. The electrical waves produced by the transmitter are sent over the transmission line and reconverted to sound waves in the receiver.

g. The magnetic-diaphragm receiver contains a permanent magnet which exerts a constant attraction on a diaphragm of magnetic material placed close to it. Around the magnet is a coil. The intensity of the magnetic field of the magnet in the receiver varies with the alternating current it receives from the transmission line running to the transmitter, and this causes an alternate increase and decrease in the pull exerted upon the diaphragm. The vibration thus set up produces sound waves which correspond in frequency and amplitude to both the electrical waves in the line and the originating sound waves at the transmitter.

h. Modern telephone receivers efficiently reduce interference from surrounding noise.

i. Skill in reading and understanding circuit diagrams, particularly schematic diagrams, is important in the study of telephony. Acquisition of skill is relatively easy if the proper procedure is followed.

30. Review Questions

a. Discuss, with the aid of a block diagram, the operation of the transmitter, transmission line, and receiver in a simple telephone system.

b. Describe the operation of the carbon transmitter.

c. State and explain the kind of current that flows in a carbon transmitter when the diaphragm is stationary; when the diaphragm is vibrating sinusoidally.

d. Describe the construction of a modern carbon transmitter with regard to its electrical operation; its mechanical strength and protection.

e. Describe the operation of the magnetic-diaphragm receiver.

f. Why is it necessary to use a permanent magnet with its associated coils rather than an electromagnet with an iron core and no permanent magnet in a magnetic-diaphragm receiver?

g. Why must care be taken to avoid sudden jarring of a telephone receiver?

h. Describe the features of construction of a modern telephone receiver which are concerned with mechanical protection.

i. Define poling, as applied to telephone receivers. Why is it necessary?

j. Explain the distinction between wiring and schematic diagrams.

k. Draw neat sketches of the conventional symbols for a battery; a transmitter; a receiver; a resistor; wires connected; wires crossing but not connected.

CHAPTER 3

INTRODUCTION TO TELEPHONE SYSTEMS

31. Components of Telephone Systems

To provide satisfactory service, the telephone system must include, besides transmitters and receivers, components such as ringers, switchboards, and transmission lines. This chapter explains the over-all functions of these additional components and shows how they are used in a number of common telephone systems. Later chapters will present in detail the principles of their operation.

32. Simple Telephone Circuit

a. The simplest telephone circuit is obtained by connecting a transmitter to a receiver, as in figure 26. In such a circuit, the transmitter may be located a considerable distance from the receiver, perhaps several miles away, and yet a person speaking into the transmitter at station A can be heard by another person at the receiver at station B. One-way telephone communication is effected.

b. One-way communication serves for the transmission of intelligence in one direction, but it is inadequate for most of the purposes for which the telephone is used. Two-way conversation is indispensable. Figure 27 shows how simply this can be arranged. A receiver is added at the transmitting end and a transmitter at the receiving end. With two transmitters and two receivers, so connected, the voice of a person speaking into either transmitter can be heard in both receivers, and two-way communication is effected between stations A and B.

c. Although the circuit in figure 27 can be used as the basis for a simple telephone system, its usefulness is limited. How can a person at station A signal someone at station B to come to the phone so that conversation may begin? Although the circuit does not provide any means, this, too, is arranged simply (fig. 28). At each station, A and B, *signaling* (ringing) *circuits* are added, and these make it possible for a person at either station to signal the other station when conversation is desired. A signaling circuit includes a *ringer* (bell or buzzer) and a *hand generator*. A person at station A, wishing to talk with someone at station B, turns the crank of the hand generator. This generates an a-c voltage which sends a signaling current over the transmission line to operate the

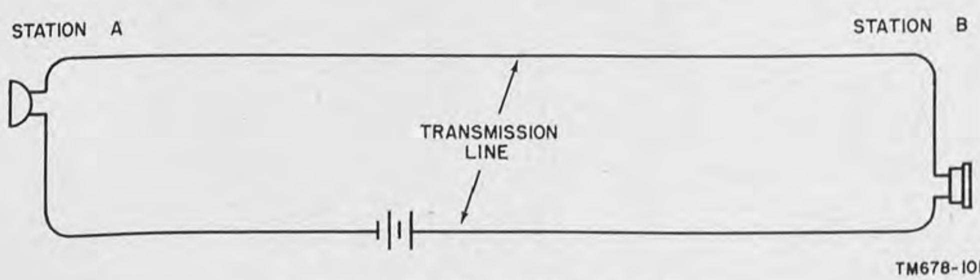


Figure 26. Simple telephone circuit.

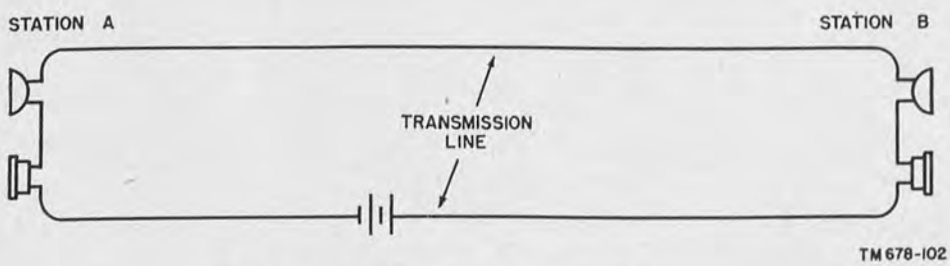


Figure 27. Practical telephone circuit.

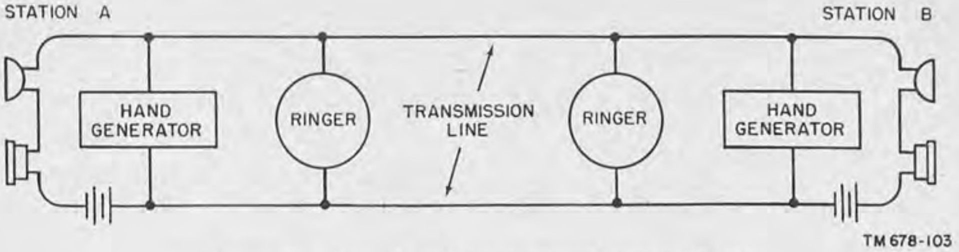


Figure 28. Circuit with hand generator and ringers.

ringer at station B. The sounding of the ringer attracts the attention of someone, who thereupon answers the call. The transmission line connecting the two stations conducts both the voice currents and the signaling current; also, although a ringer has been mentioned as the signaling device and a hand generator as the source of signaling current, other devices may be used for the generation of signaling current and the signaling itself. These will be considered later in detail.

33. Telephone Switchboard

a. A telephone system frequently consists of hundreds, even thousands, of telephone stations. In operation, the system permits voice communication between any of the telephone stations which are part of it. The simple circuit of figure 28 can be used in a telephone system if each station is connected by a similar circuit to all the other stations in the system. Such an arrangement would require the use of two wires and a switch from each station to every one of the other stations. It would be impractical for serving a large number of telephone stations; for even a few, the system would be a maze of wires. The block diagram of figure 29 shows the wiring required to interconnect eight stations.

b. An important saving in line wire is obtained by including in the system a centrally located *switchboard.* Each telephone station then is connected directly to the switchboard, not to each of the others. The connecting wires and their attachments constitute a *transmission line.* Conversation between any two stations is made possible by interconnecting their transmission lines at the *switchboard.* The connections are made by a switchboard operator or attendant by means either of *switches* or, more frequently, *cords* with *plugs* for insertion in *jacks* connected to the ends of the lines from the two telephones. The block diagram of figure 30 shows the eight telephone stations of figure 29 connected to a switchboard.

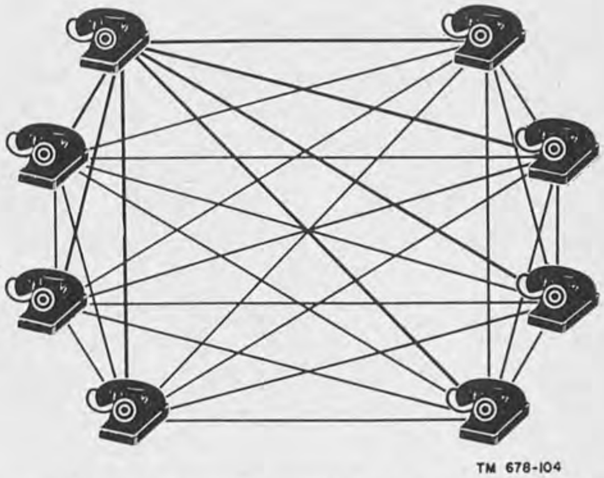


Figure 29. Station interconnections of telephone system without switchboard.

c. With the circuit arrangement of figure 30, all conversations take place through the switchboard. A person at station A wishing to call a person at station B first signals the switchboard operator. When the operator replies, the caller supplies the name or number of the station being called—station B, in this case—and the operator then completes the connection at the switchboard

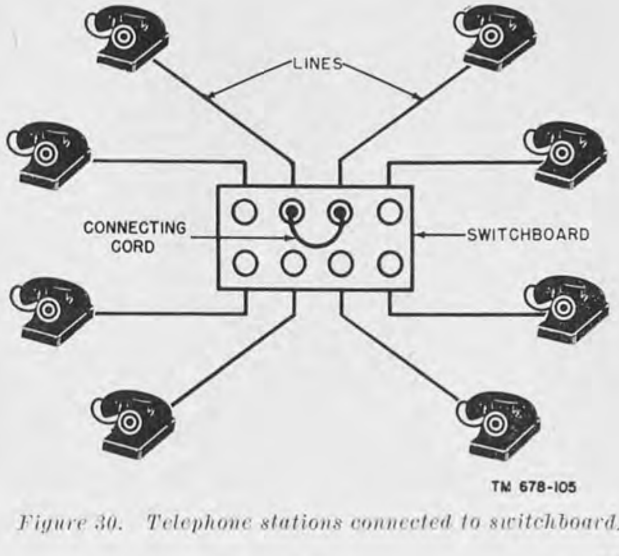


Figure 30. Telephone stations connected to switchboard.

and signals station B. When station B answers, conversation between the two telephone stations proceeds.

34. Telephone Central Office

A switchboard or other switching device, together with associated equipment, is located at a *telephone central office.* More accurately, they comprise the telephone central office. The equipment may include a switchboard of one or more positions so interconnected that telephone service can be given to a greater number of telephone stations in an area. *Switchboard* is the name given to that component of a telephone system where connections are made among the associated lines or stations by an operator. The service requirements determine the capacity of the switchboard, and the traffic (number of connections) requirements determines the number of operators attending at the switchboard. As switchboards increase in size, beyond the ability of one operator to handle the traffic, and a second operator is engaged at the switchboard, the switchboard is designed especially to accommodate the second operator, and to distribute the line jacks in such a way that the traffic load is distributed fairly evenly between the operators. Since each operator will occupy a position at the switchboard, and since two positions are required to accommodate two operators, a switchboard so designed is referred to as a two-position switchboard. In many instances, switchboards reach to 30 or more positions. Figure 31 shows the various elements of one type of military telephone central office.

35. Telephone System

A *telephone system* with one central office consists of a number of telephone stations connected by lines to the central office, so that any two telephones of the system may be interconnected for two-way conversation. Such a system may serve a few or thousands of stations; it may have more than one central office. A system includes the individual telephone stations, the outside plant equipment for connecting each telephone station to a central office and for interconnecting central offices, and all the central-office equipment required for making connections between the telephones and switchboards. Whatever the size and extent of the system, and however many switchboards, and central offices are a part of it, any telephone station can be connected with any other telephone

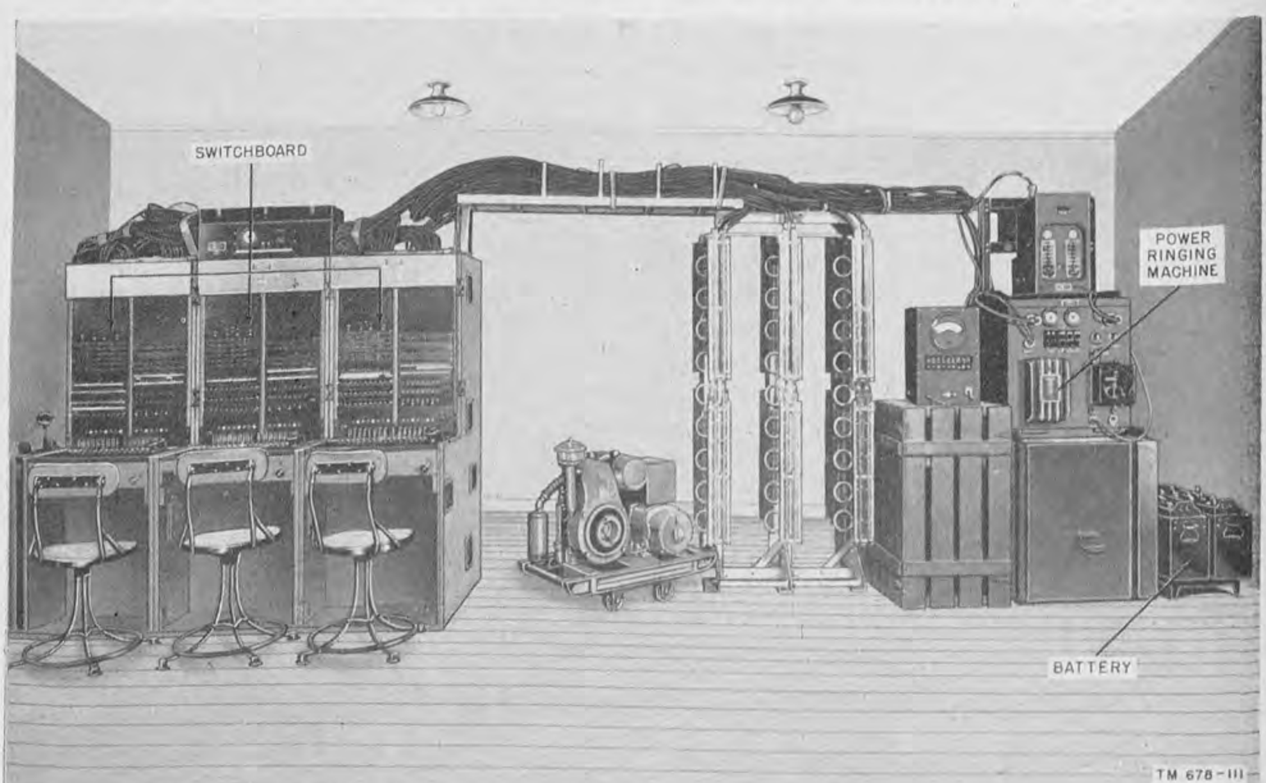


Figure 31. Central-office telephone equipment.

station. The telephone stations, central office, and connecting lines shown in figure 30 constitute a telephone system with a single central office.

36. Telephone Exchange

A telephone system which provides telephone communication within a particular local area, such as an Army post, maneuver area, town, village, or city, is a *telephone exchange*. It may have one or more central offices, depending on the extent of the telephone service and traffic that is handled.

a. The switchboard and eight telephone stations of figure 30 would be called an exchange, although an exchange usually includes hundreds of telephone stations and their associated lines, switching facilities, and accessory equipment.

b. By interconnecting telephone exchanges, service can be provided between telephone stations served by two or more exchanges. The transmission lines interconnecting the central offices of different exchanges are called *trunk lines*, or *trunks*. When a person at station A in exchange I (fig. 32) wishes to call a person at station B in exchange II, the procedure is only a little more extended than the procedure within a single exchange. The caller at station A signals (attracts the attention of) the switchboard operator in exchange I and asks to be connected to station B in exchange II. The operator responds by relaying the number of the called station over the trunk to the switchboard operator in exchange II, who then signals station B and completes the connection. The figure shows the connecting cords and completed connection between station A and station B through the trunk connecting exchange I and exchange II.

37. Types of Telephone Systems

Telephone systems are classified according to the method of switching used at the central office. The two basic systems are the *manual system* and the *dial system*. As the names imply, in manual telephone systems the connections between telephones are made manually, by operators, and in dial telephone systems the connections between telephones are made automatically, without the service of operators.

a. Manual Telephone Systems. Most of the smaller military telephone systems are manual sytems, classified according to the sources of electrical energy supplied to the transmitters. The two basic kinds are the local-battery system and the common-battery system.

(1) In a *local-battery system*, the sources of electrical energy for the transmitters and signaling devices are included in the telephone sets located at each of its telephone stations. The term *local* means that the sources of the electrical energy for the transmitters and for signaling are

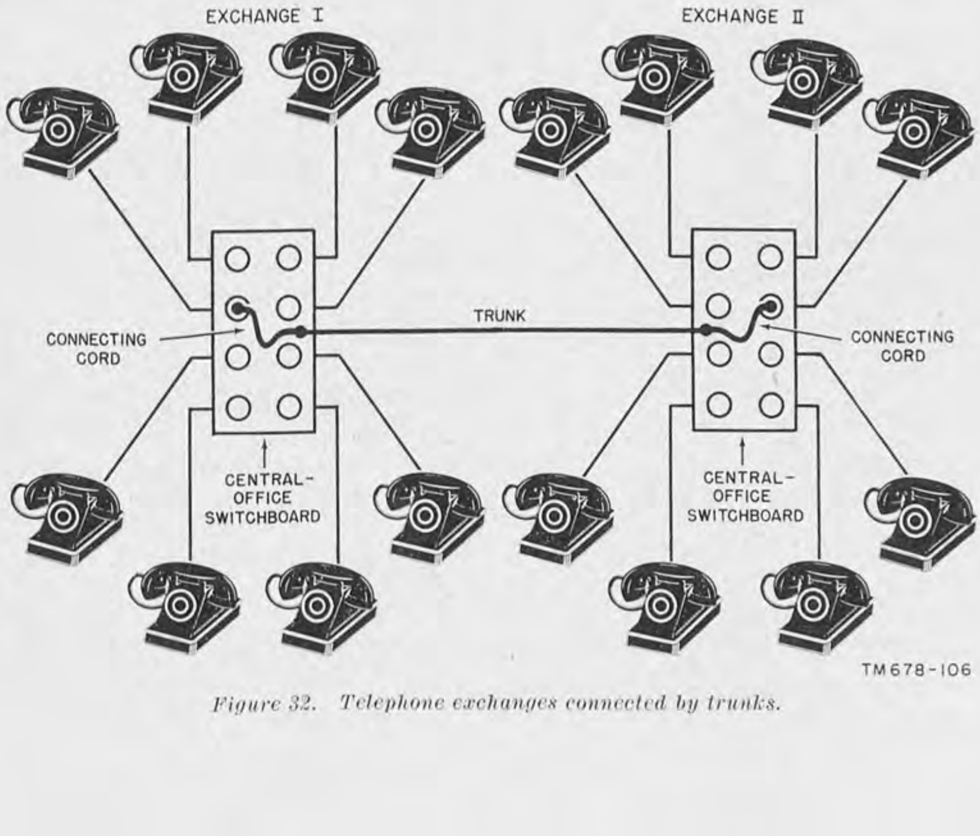


Figure 32. Telephone exchanges connected by trunks.

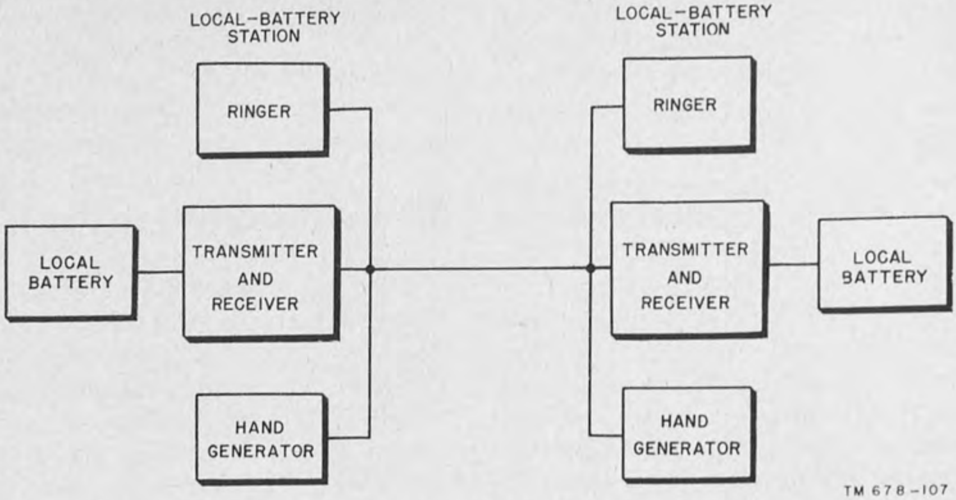


Figure 33. Local-battery stations connected directly.

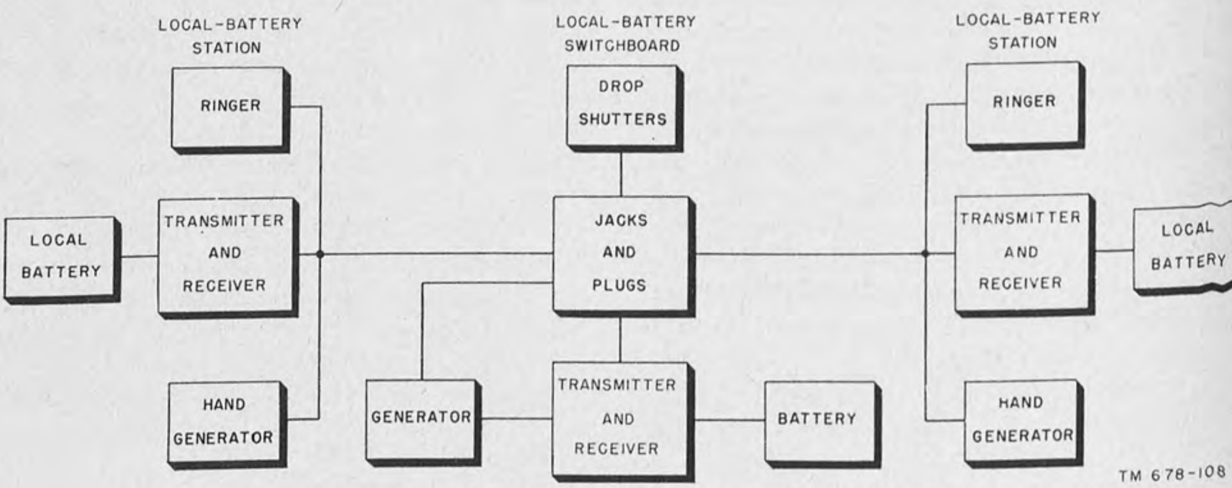


Figure 34. Local-battery stations connected to switchboard.

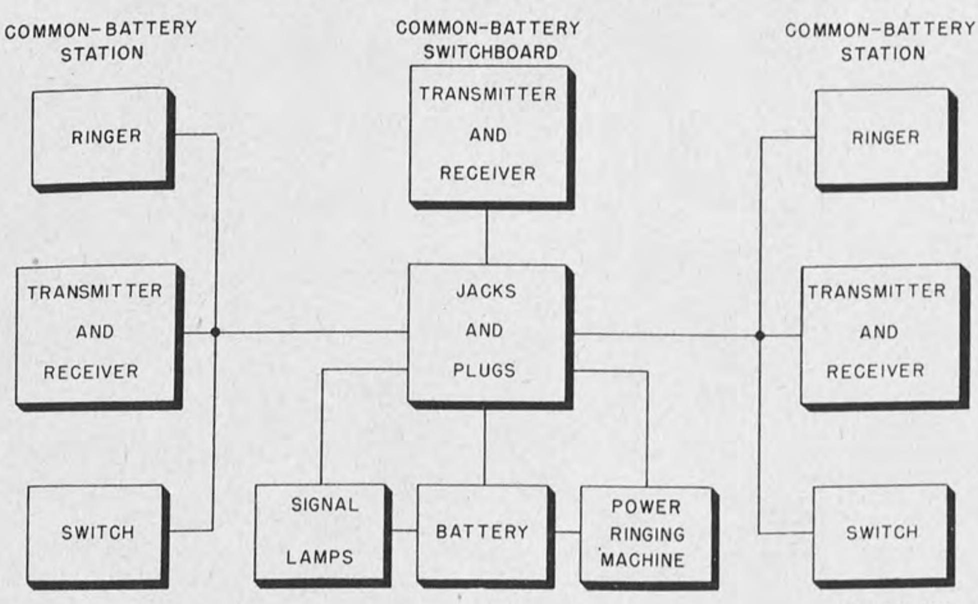


Figure 35. Common-battery stations connected to switchboard.

a part of the individual telephone stations. A local battery supplies the current for the transmitter circuit, and a *hand generator* or magneto supplies the current for signaling. The block diagram of figure 33 shows the arrangement when two local-battery telephone sets are connected directly to each other. Figure 34 shows the arrangement when two local-battery telephone sets are connected to a switchboard. Note that a local battery is provided not only for each telephone station, but also for the switchboard. Also note that at the local-battery switchboard, *drop signals* are used as a signaling means. The drop signal is an electromechanical device with a *shutter* which falls and attracts the attention of the operator when the user of a local-battery telephone set signals with his hand generator. The shutter usually is arranged so that, when it is dropped, a signaling buzzer will operate at the switchboard.

(2) In a *common-battery system*, the sources of electrical energy for the transmitters and signaling devices are located at the central office; that is, all of the stations obtain their transmission and signaling energy from one common, central source. A primary source of power such as a generator and a large storage battery at the central office supply the current for the transmitters and also supply current for

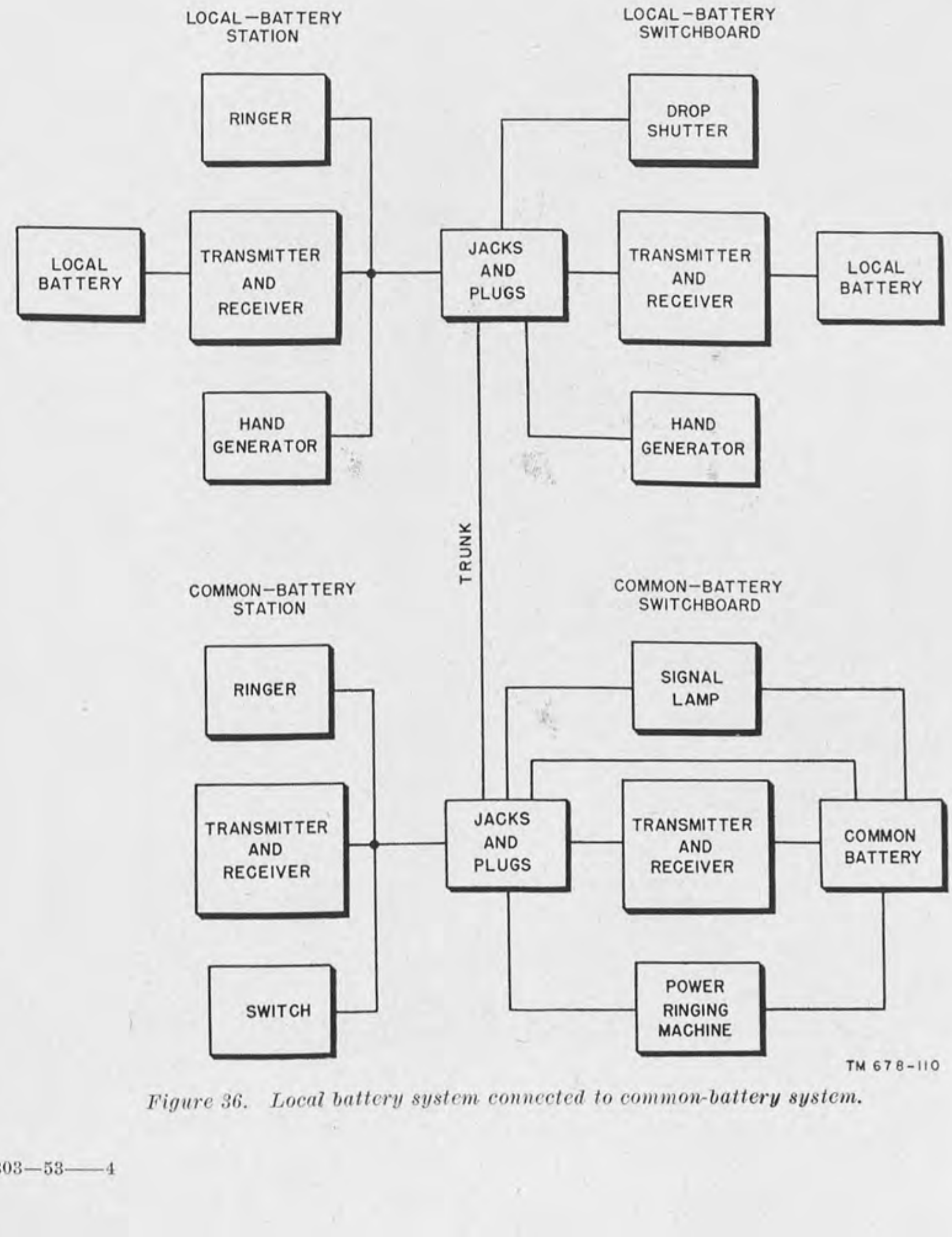


Figure 36. Local battery system connected to common-battery system.

the switchboard signal lamps; a ringing machine supplies ringing current for all the telephone sets. Figure 35 shows two common-battery telephone sets connected to a common-battery switchboard. There is no battery at the sets, and the signaling devices of the manual common-battery switchboard are signal lamps which light automatically when the receiver is removed from the hookswitch, not the drop signals of the local-battery switchboard. Local-battery systems may be interconnected with common-battery systems, and thereby permit telephone conversation between a telephone station connected to a local-battery central office and one connected to a common-battery central office (fig. 36).

Figure 37. Dial telephone set.

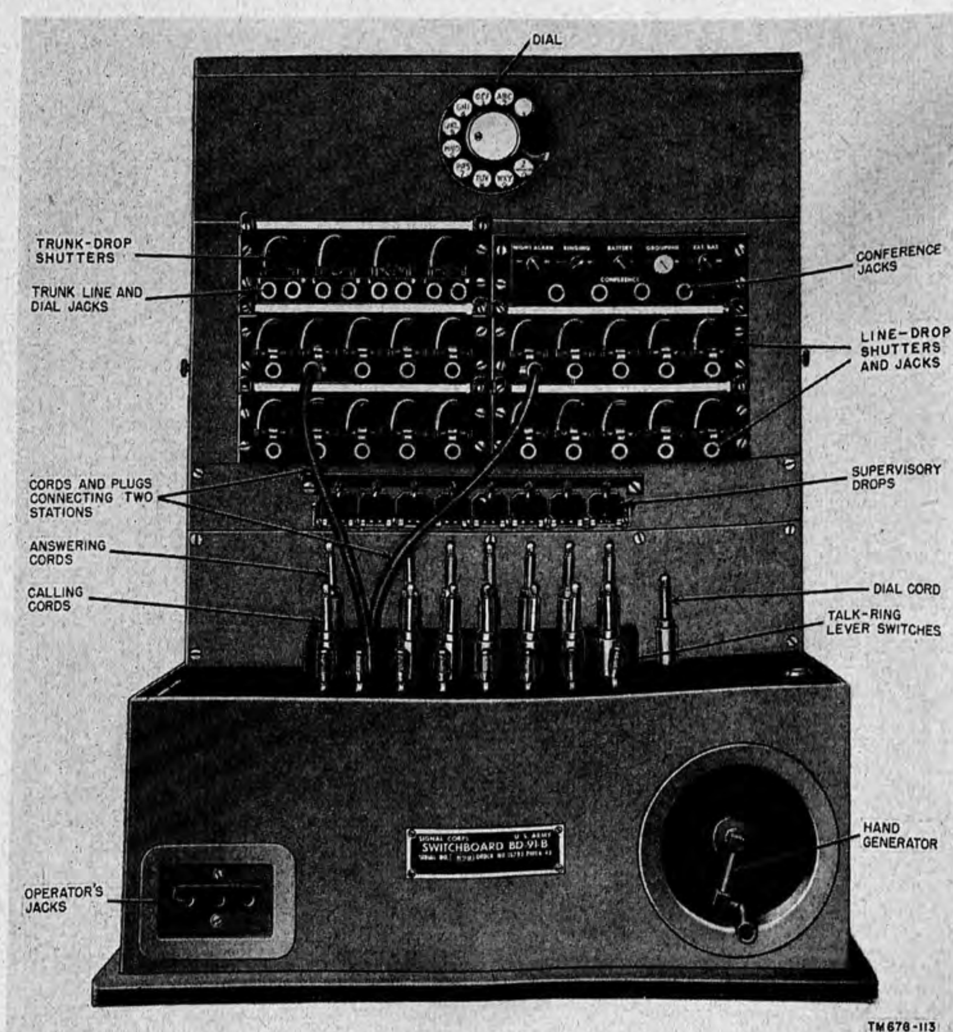


Figure 38. Local-battery switchboard.

b. Dial Telephone Systems. The *dial telephone system* is one in which the connections between telephones are set up automatically by electromechanical switching apparatus controlled by the operation of a dial on the telephone set of a calling telephone. These connections are made without the aid of an operator. Figure 37 shows a dial telephone set. In placing a call on a dial telephone system, the operation of the dial sends electrical pulses over the line from the dial telephone set to the central office. There the pulses control switching equipment which automatically makes the interconnection between the calling and called telephones. By electromechanical means, all the operations of an attendant at a manual central office are performed in sequence. Specifically, the automatic-switching equipment in a dial central office connects calling lines through interoffice trunks to called lines in other central offices; determines whether a line is in use, and, if it is not, rings the called telephone; transmits a busy-tone signal to the calling telephone, if the called telephone is in use; disconnects the calling and called lines when the users hang up.

38. Comparison of Telephone Systems

a. Telephone communication systems used by the Army must provide good telephone service under many kinds of operating conditions, both favorable and unfavorable. Each system has its

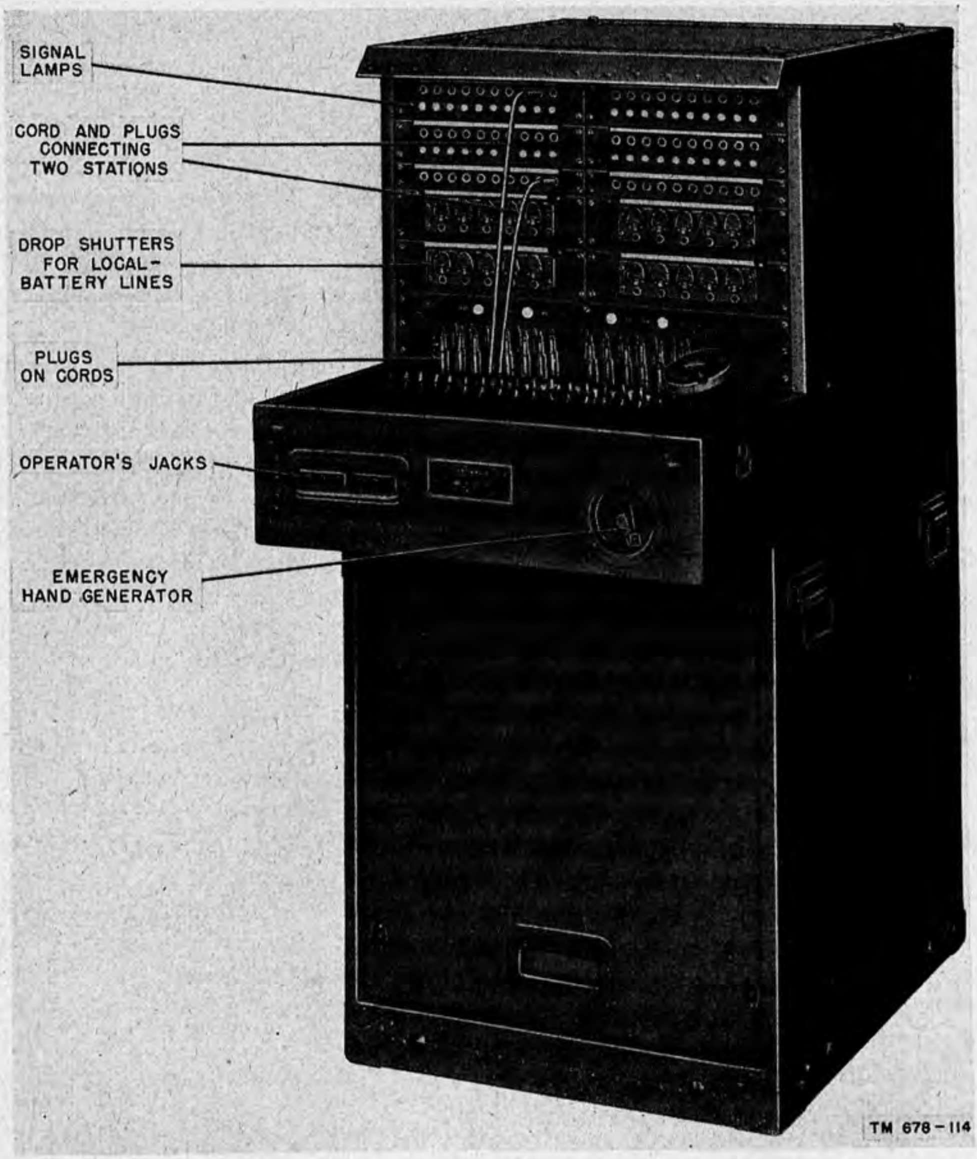


Figure 39. Common-battery manual switchboard.

advantages, and under certain conditions provides better service than the others. Each telephone system therefore has an important place in the military communications network. Both manual and dial systems are used. This technical manual is concerned primarily with the fundamentals of manual systems, but also contains a brief treatment of dial systems. In general, dial systems are less suitable than manual systems for mobile operations and usually are installed only at more permanent locations, such as posts and the larger headquarters in the rear area of a theater of operations.

b. Military field telephone systems usually are manual systems. They may be either of the local-battery or common-battery type.

c. A military local-battery field telephone system usually has rapidly laid insulated wire or cable for its lines and uses sturdy portable central-office equipment. Figure 38 shows an Army local-battery switchboard designed for field service.

d. The common-battery manual telephone system is used most frequently to serve a great number of telephone users located in a relatively small area. It has numerous refinements not found in the simple local-battery system which make possible more efficient and rapid handling of large numbers of calls. Because of these refinements, however, a common-battery central office with its associated lines requires more time for installation and greater attention to maintenance. Common-battery manual systems are used frequently by the Army in higher headquarters and fixed installations. Figure 39 shows an Army common-battery switchboard designed for field service.

e. Dial telephone systems, which are also common-battery, by the use of automatic-switching devices eliminate the errors inherent in human operation of a manual telephone switchboard. A dial central office involves much intricate wiring and complex equipment. Its installation is both time-consuming and costly; it requires great care in maintenance, but, when properly maintained, it provides more rapid and accurate handling of heavy telephone traffic than usually is possible with a manually operated common-battery switchboard.

f. To provide greater flexibility for military operations, practically all common-battery switchboards are designed to permit connections with local-battery switchboards and telephones. The larger local-battery switchboards permit connections to common-battery switchboards, both manual and dial.

39. Summary

a. One-way communication can be effected with a transmitter at one telephone station, a receiver at the other, a battery, and connecting lines.

b. Two-way communication requires at each telephone station at least a transmitter, a receiver, and a means for signaling the called station.

c. For economy and efficiency, telephone stations usually are connected to a switchboard or other switching device in a central office, and intercommunication is effected through it.

d. Telephone central offices are interconnected by trunk lines, permitting communication between telephone stations connected to different central offices.

e. Systems are either local-battery systems, which have local current sources in dry cells for the transmitter and a hand generator for signaling, or common-battery systems, in which current for the entire system is supplied from a single point, the central office.

f. Common-battery systems usually serve a greater concentration of telephone stations than local-battery systems, but heaviest traffic usually is handled best by dial telephone systems, in which dials and automatic electromechanical or electrical means perform all the operations which otherwise would have to be performed manually by attendants.

40. Review Questions

a. Why are telephone switchboards or other switching devices a practical necessity for telephone communication between widely separated telephone stations?

b. What two items of equipment, essential in a telephone set connected to a local-battery switchboard, are not found in the telephone set of a common-battery system?

c. What is the most important difference between a common-battery system and a local-battery system?

d. What is the device that attracts the attention of the switchboard operator to an incoming telephone call at a local-battery switchboard? A common-battery switchboard?

e. During mobile field operations of a small military combat group, why is a local-battery telephone system used most frequently?

f. Give one important technical reason for the general use of manual common-battery telephone systems in the larger villages of the United States.

g. Give at least two reasons why the installation of automatic telephone systems ordinarily would prove impractical in the more forward battle areas during mobile field operation.

h. If the Army should find it necessary to install a new telephone system, with 700 telephone sets, in a very busy permanent supply depot, what type of telephone system would you recommend? Why?

CHAPTER 4

LOCAL-BATTERY TELEPHONY

41. Equipment of Local-Battery Telephone System

The equipment of the local-battery telephone system may be classified as telephone-station equipment, central-office equipment, and interconnecting equipment. The unit of equipment at the telephone station is the telephone set, and the unit of equipment at the central office is the switchboard. The interconnecting equipment is the telephone line. Because the electrical properties of the telephone line are, in general, similar for both the local-battery and the common-battery systems, discussion of the line will be deferred for a later chapter, following discussion of the common-battery system.

42. Telephone Set

In both systems, the *telephone set*, often simply called the *telephone*, is the device supplied the telephone user to initiate and receive telephone calls. In the telephone circuit of figure 28, the group of components at each station comprises a simple telephone set. The group includes the transmitter, the receiver, the hand generator, and the ringer.

a. Principal Circuits of Telephone Set. The components of the telephone set of both systems are connected to provide two principal circuits: the talking circuit in A, figure 40, and the signaling circuit, shown in B. Each one is the telephone circuit of figure 28 modified to represent two local-battery telephone sets connected directly to each other. The circuits of the telephone sets are completed by the telephone line connected to terminals L1 and L2 of the sets.

(1) The *talking circuit* of the telephone set provides an electrical path for the voice current. Its prime components are the transmitter and the receiver. In the local-battery telephone set, it also includes

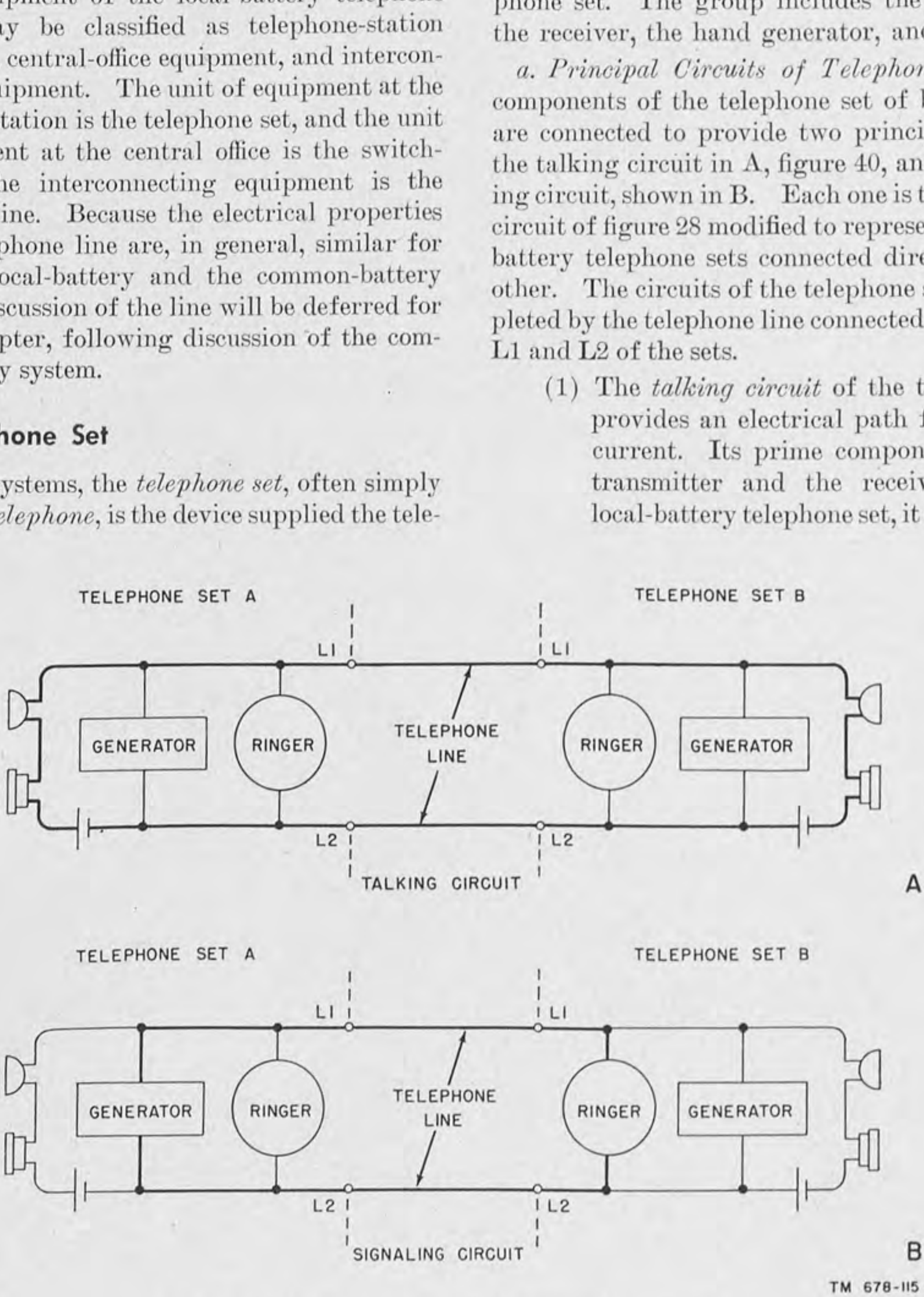


Figure 40. Circuits of local-battery telephone sets.

a battery. In the two-station local-battery system shown in A, the heavy lines show the complete talking circuit, which includes the transmitters, the receivers, the batteries of the two telephones, and the connecting telephone line. Thus, voice currents generated by a person speaking into the transmitter of one telephone have a complete electrical path through the telephone line to the receiver of the other telephone.

(2) The *signaling circuit* of the telephone set provides an electrical path through the signaling device for the signaling current. Its prime component is the ringer. In the local-battery telephone set it also includes a hand generator. In B, the heavy lines show the complete signaling circuit between the two telephones. It includes the generator of telephone set A, the ringer of telephone set B, and the connecting telephone line. Rotation of the

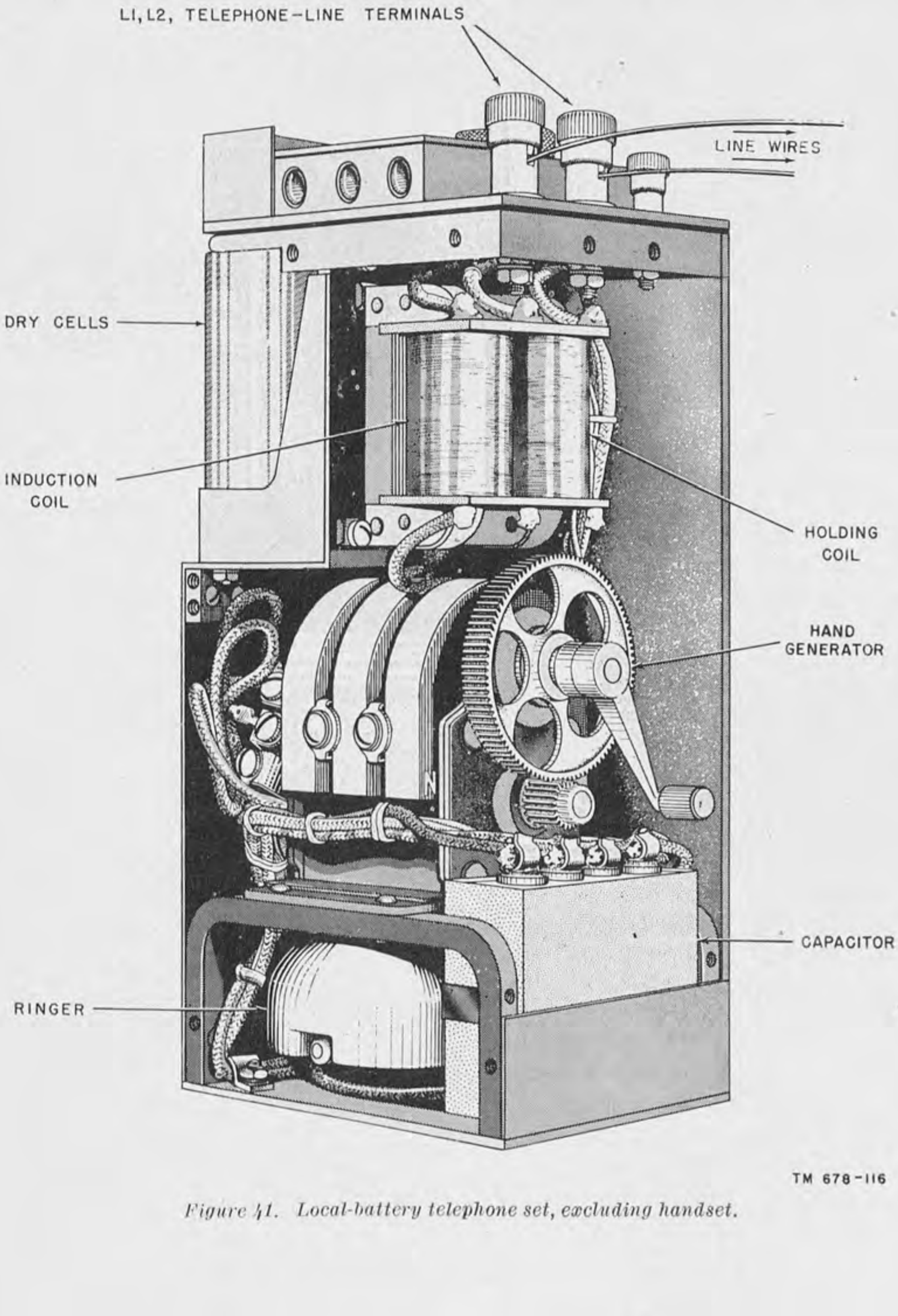


Figure 41. Local-battery telephone set, excluding handset.

crank of the hand generator of telephone A generates an alternating current which is conducted by the telephone line to the ringer of telephone B and causes it to operate. The switches referred to are not shown in the illustration. A similar circuit exists between the hand generator of telephone B and the ringer of telephone A.

b. Components of Telephone Set. The components of a local-battery telephone set, excluding the handset, are shown in figure 41. In addition to the hand generator, the battery, and the ringer, there are an induction coil and a capacitor to improve electrical efficiency and performance.

43. Battery

The function of the *battery* in the local-battery telephone set is to supply the current for the transmitter. The battery consists of two or three dry cells, which obtain their electrical energy from the chemical action of the materials of which the cell is composed. The chemical action during current flow produces an accumulation of gas bubbles around the positive electrode, which insulates the electrode and increases the internal resistance of the cell. This action of the cell is called *polarization*. The manganese dioxide contained in the dry cell neutralizes the polarization, but its action is slow, and a continuous drawing of current causes the emf of the cell to fall rapidly. If the cell is given a short rest, however, the depolarization reaction *catches up*, and the emf increases to nearly its original value. Dry cells therefore are suited particularly for intermittent use. The emf of a new dry cell is about 1.53 volts, and it decreases with age.

44. Handset Switch

a. Function. A handset switch is usually a normally open, momentary (spring-return) switch. When pushed, it connects the transmitter in the talking circuit. When released, the transmitter is out of the circuit, thus conserving the battery when the transmitter is not in use.

b. Push-To-Talk Handset Switch. A, figure 42, illustrates a handset switch of push-to-talk type, frequently used in local-battery telephone sets. It consists of an assembly, or *pile-up*, of flat, spring-metal conductors, separated by insulators, as in B. Welded to the ends of the conductors are contacts made of a special alloy which withstands arcing when the switch is opened and closed. The contacts are closed by rotation of the butterfly nut attached to the short shaft which passes through the plate. When the butterfly nut is released, the spring action of the conductors opens the contacts and restores the switch to its normal, or open, position. The push-to-talk handset switch usually is mounted in the telephone handset between the transmitter and receiver (fig. 42). So located, the telephone user can connect the battery readily when speaking and disconnect it when listening. Figure 43 shows another handset with a push-to-talk switch. When speaking, the switch is pressed downward instead of sideways. On this handset, the receiver unit has been

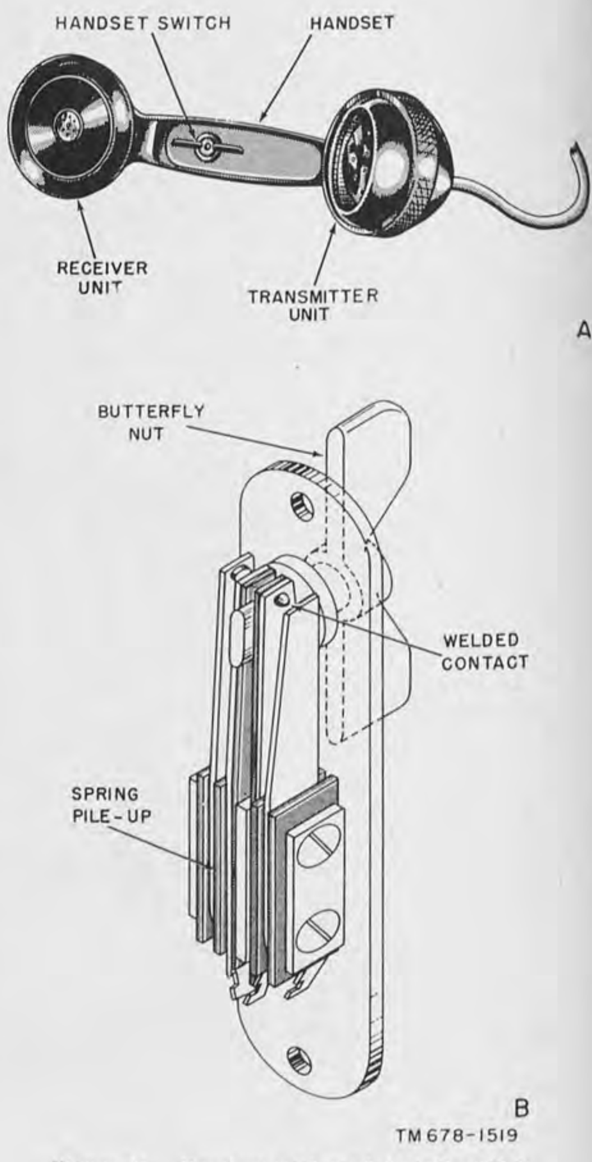


Figure 42. Handset with push-to-talk switch.

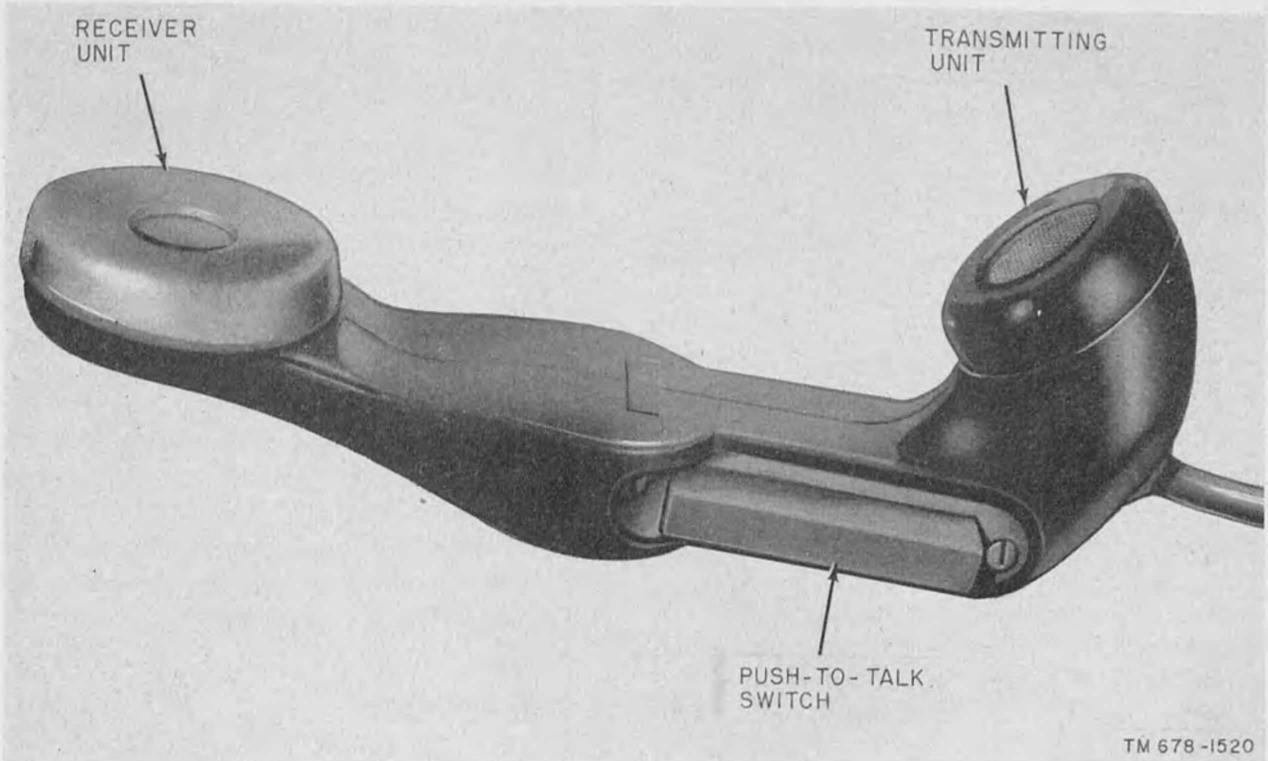


Figure 43. Military handset with push-to-talk switch.

made almost flat to allow the unit to be slipped under a helmet.

c. Circuit with Handset Switch.

(1) Figure 44 shows the talking circuit of two local-battery telephone sets, each of which includes a handset switch. It differs from the circuit of figure 40 in that the transmitters and receivers are in parallel instead of in series. This manner of connecting the components automatically results in a closed talking circuit between the two telephones when either handset switch is closed. This would not be the result if the components were connected in series with each of the transmitters; in the normal position, the spring-metal conductors hold the handset switch open, and the talking circuit would not be completed unless both handset switches were closed at the same time. In use, this could be managed, but it would require, between the persons speaking, a coordination that is unnecessary with the circuit of figure 44.

(2) The heavy lines (fig. 44) show the complete talking circuit between the two telephone sets: the transmitter, the battery, and the handset switch of telephone A and the receiver of telephone B. The handset switch of telephone A is shown

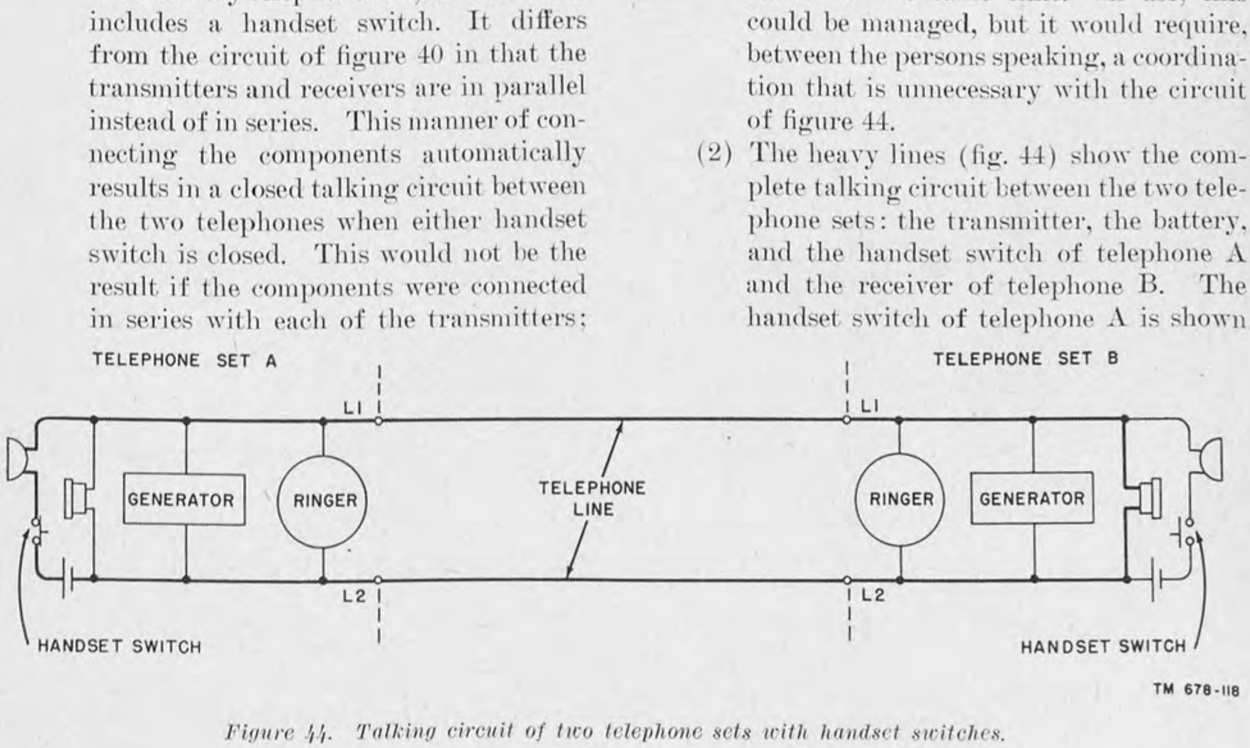


Figure 44. Talking circuit of two telephone sets with handset switches.

in the talking (closed) position, and that of telephone B is in the listening (open) position. (Telephone circuit diagrams usually show the switch in the open position.)

45. Handset

In most telephone sets, the transmitter and receiver units are contained in a single mounting, the *handpiece*, also called the *handle* and the *handset handle*. The combination of handpiece with transmitter, receiver, and connecting cord is called the *handset*. In the local-battery telephone set, the handset usually includes the push-to-talk handset switch. Figure 45 is an exploded view of the components of a local battery telephone handset.

a. Advantages of Handset. The handset provides a convenient support or mounting for the transmitter and receiver. In addition, its design results in an increase in the output of the transmitter. The transmitter is at the proper distance from the mouth of the telephone user when the receiver is against his ear; more of the sound energy of the speakers' voice is directed into the transmitter than might otherwise be the case, and the result is a greater average output of voice current.

b. Structure of Handset. The material of the handpiece is molded bakelite or a phenol plastic. Its ends are designed to contain the transmitter and receiver elements. These are retained by molded bakelite or phenolic plastic *caps*, perforated to pass the sound energy. The transmitter cap is called the *mouthpiece*, the receiver cap the *earpiece*. Connections to the transmitter and receiver are made by silver-plated contact springs, fastened to terminals molded in the plastic. In the local-battery telephone handset, the handle is recessed for mounting the push-to-talk switch in the handle. Metal tubes extending through this handle carry the necessary conducting wires between the transmitter, receiver, and handset switch.

c. Circuit of Handset. The broken lines of figure 46 show the wiring of the local-battery telephone handset. The receiver terminals and the handset switch are connected to terminals in the transmitter end of the handle. A three-conductor cord connects the handset to the telephone set. In practice, the individual conductors of the cord usually are identified by the color of the conductor leads; here (and in most circuit diagrams)

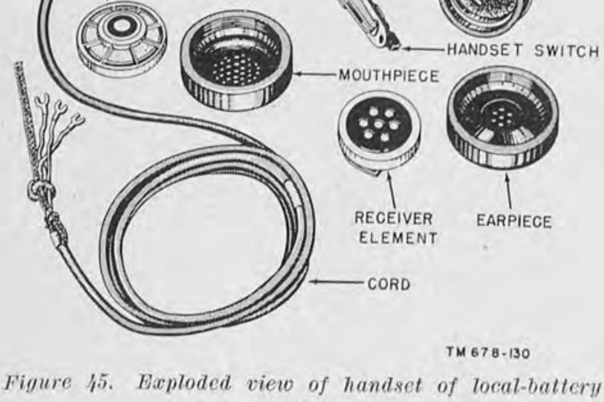


Figure 45. Exploded view of handset of local-battery telephone.

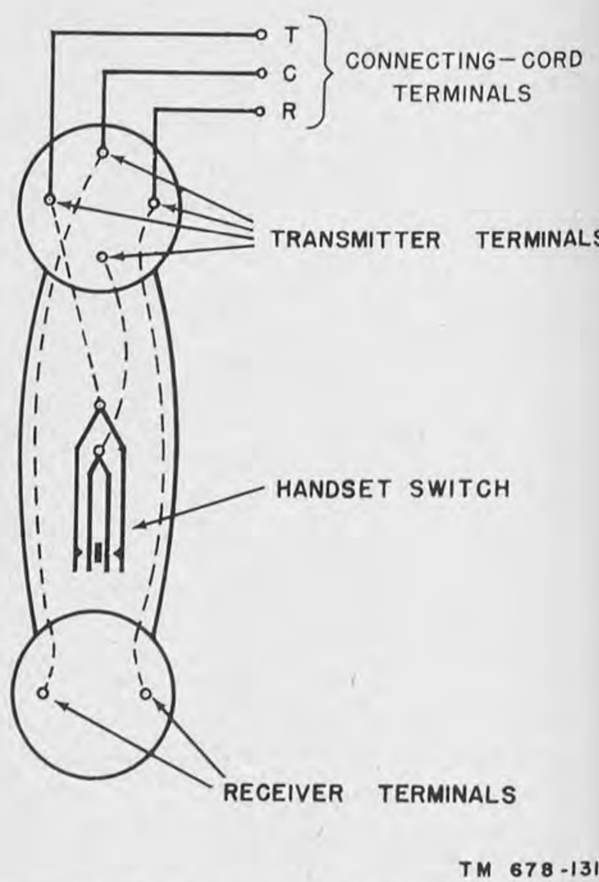


Figure 46. Wiring diagram of handset with handswitch.

they are designated T for transmitter, C for common, and R for receiver.

46. Induction Coil

The circuits of the telephone sets of figures 40 and 44, using dry cells alone, can be used to provide voice conversation only between telephone sets separated by short distances. The range may be extended, however, and performance and efficiency may be improved, by including an *induction coil* in the circuit.

a. Functions. The induction coil performs two functions in this particular telephone set. First, it increases the voltage of the voice current generated by the transmitter. Second, it separates the transmitter and receiver currents so that the direct current of the transmitter circuit does not pass through the receiver (secondary) circuit.

b. Circuit. The circuit of a local-battery telephone set with an induction coil is shown in A and B, figure 47. The induction coil consists of two separate coils which have a common connection and are wound on an iron core. One coil, the *primary winding*, receives the electrical energy; the other, the *secondary winding*, delivers the electrical energy to the circuit. The induction coil separates the circuit of the telephone set into two circuits, the transmitting circuit and the receiving circuit.

(1) The *transmitting circuit* is emphasized by the heavy lines in A. This circuit includes the primary winding of the induction coil, the transmitter, the handset switch, and the battery, all in series. When the handset switch is closed, direct current from the battery is supplied only to the primary circuit.

(2) The *receiving circuit* is shown by the heavy lines in B. This circuit includes the secondary winding of the induction coil and the telephone receiver.

(3) The function of the transmitting and receiving circuits of the telephone set will be considered after the following discussion of the basic principles of the induction coil.

47. Principles of Induction Coil

a. Comparison with Transformer. The induction coil is essentially a *transformer.* This similarity may be noted by comparing the circuit diagrams of the transformer and induction coil in figure 48. Electrically, the action of an induction coil is the same as that of a transformer, and the same basic principles apply to it. The transformer in its simplest form consists of two conducting coils which have mutual inductance between them. The common connection between the windings of the induction coil does not affect the

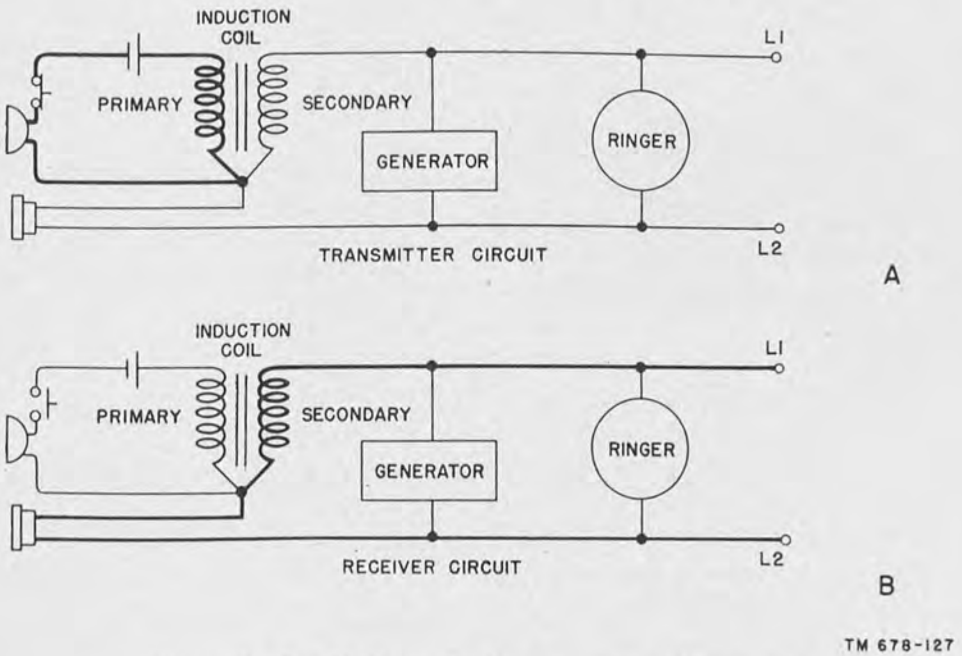


Figure 47. Local-battery telephone set with induction coil.

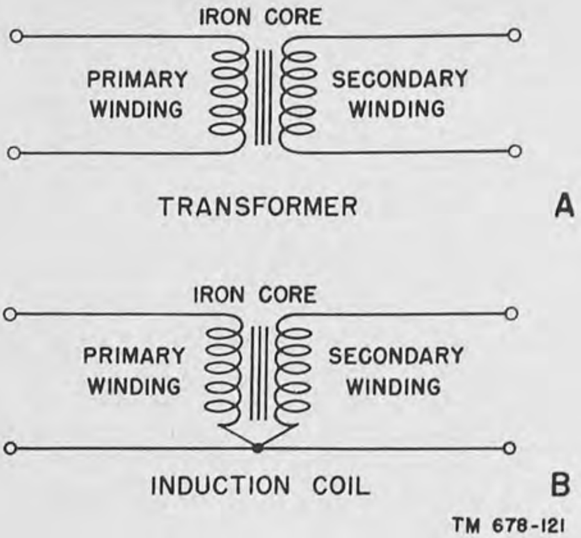


Figure 48. Comparison of transformer and induction coil.

mutual inductance between the coils. As a result of the mutual inductance, a varying current in one winding induces an a-c voltage in the other. The value of the induced a-c voltage depends on the turns ratio and on the rate at which the current changes: the higher the rate of change, the greater the induced voltage. The induced voltage has the waveshape of the changing current. This action of the transformer is explained in detail in TM 11–681.

b. Ideal Transformer. The properties of an *actual* transformer are understood more easily by considering the properties of an *ideal* transformer. An ideal transformer has no electrical losses. None of the electrical energy supplied to it is lost in the production of the magnetic field in the iron core, or lost as heat in the windings; and all the magnetic flux of the changing current in one winding links all the turns of the other winding. Physically this is not possible, of course, and no ideal transformer actually exists; but in performance the actual transformer approaches the ideal transformer so closely that the latter serves very well to explain its action.

(1) Figure 49 shows an *ideal* transformer with an a-c generator connected to its primary winding and a telephone receiver connected as a load to its secondary winding. A-c ammeters and voltmeters are connected as shown, to indicate the primary current, I_P, the primary voltage, E_P, the secondary current, I_S, and the secondary voltage, E_S.

(2) Consider the primary winding to have N_P turns and the secondary winding to have N_S turns. Since the ideal transformer has no electrical losses, all the power supplied to the primary winding is transferred to the secondary winding. The power input to the primary in watts, E_P times I_P, equals the power output of the secondary in watts, E_S times I_S. From this is obtained the relation,

$$\frac{E_S}{E_P}=\frac{I_P}{I_S}.$$

(3) Since all the magnetic flux of the primary winding links all the turns of the secondary winding, the ampere-turns of the primary, I_P times N_P, equal the ampere-turns of the secondary, I_S times N_S. From this is obtained the relation,

$$\frac{I_P}{I_S}=\frac{N_S}{N_P}.$$

(4) Since the ratio of secondary to primary voltage equals the ratio of primary to secondary current (fig. 49), and the ratio of secondary to primary turns equals the same ratio of primary to secondary current, the ratio of secondary to primary voltage also must equal the ratio of secondary to primary turns; or,

$$\frac{E_S}{E_P}=\frac{N_S}{N_P}, \text{ or } E_S=E_P\,\frac{N_S}{N_P}.$$

In other words, the secondary voltage equals the primary voltage times the ratio of the secondary turns to the primary turns. If this ratio is greater than one (if the secondary has more turns than

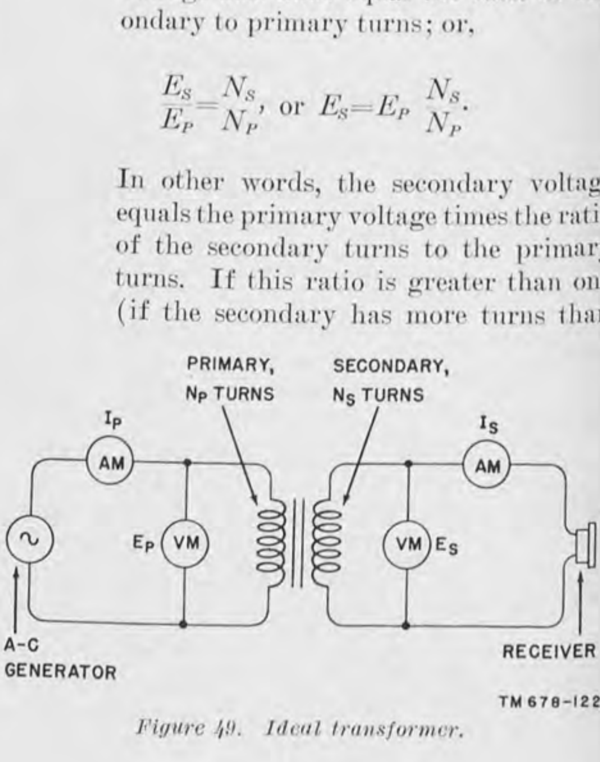


Figure 49. Ideal transformer.

the primary), the transformer is said to *step up* the voltage. If the ratio is less than one, the transformer is said to *step down* the voltage. In many telephone applications, the transformers have ratios equal to one (the primary and secondary have the same number of turns). The primary and secondary voltages of these transformers are the same, and they are used to isolate or separate physically one electrical circuit from another.

c. Actual Transformer. In an *actual* transformer, electrical losses do occur. They include losses caused by the resistance of the winding and the energy taken to provide the magnetic field in the iron core. Also, not all the magnetic flux of the primary winding links all the turns of the secondary winding. In actual transformers such as the induction coil, these losses are very small, however, and can be ignored. The action of the induction coil therefore is very similar to that of the ideal transformer.

48. Induction Coil in Telephone Set

a. Function of Circuit with Induction Coil. Figure 50 shows a circuit of two local-battery telephone sets with *induction coils*. To understand the function of the circuit in providing voice conversation between the two telephones, assume that a person at telephone A is about to speak to a person at telephone B.

(1) Before speaking into the transmitter, the person at telephone A closes the handset switch (fig. 50). This action completes the transmitter circuit, and battery current is supplied to the transmitter through the primary winding of the induction coil. The battery current remains constant; therefore no voltage is induced in the secondary winding of the induction coil, and there is no current in the secondary winding.

(2) This condition changes when the person at telephone A speaks into the transmitter (fig. 50). The sound waves of his speech produce a changing voice current in the transmitter circuit. The changing current induces an a-c (voice-current) voltage in the secondary winding of the same waveform as that of the changing current. As a result of the induced a-c voltage, a current is produced in the closed circuit consisting of the telephone line, the secondary windings, and the receivers of both telephones. The person at telephone B hears in his receiver a reproduction of the original speech sounds. The circuit functions in the same manner for transmission in the opposite direction.

(3) Both receivers are in the voice-current circuit during transmission from either end (fig. 50). Therefore, a person speaking into either transmitter hears his own voice in the receiver at his ear. This sound, reproduced in the receiver of the speaker, is called *sidetone*. The sidetone effect can be reduced by means of an *antisidetone circuit* using an antisidetone induction coil or an autotransformer (par. 59).

b. Common Connection of Induction Coil. The common connection between the primary and secondary windings of the induction coil does not affect its transformer action. The circuit in figure 50 would function just as well if the two windings were separate, as in a transformer. However, the common connection simplifies the circuit for the handset, by permitting reduction of the number of handset *cord conductors* from four to three (fig. 51). The common connection also is used for special circuits such as the antisidetone circuit, and

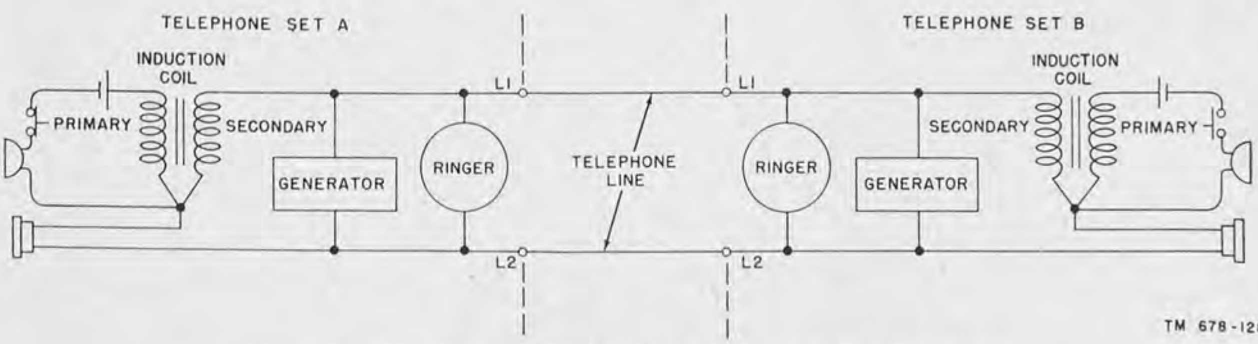


Figure 50. Circuit of two local-battery telephones with induction coil.

that of the common-battery telephone set to be discussed in the next chapter.

c. Effect of Direct Current in Winding of Induction Coil. The circuit in figure 50 prevents the direct current for the transmitter from passing through the receiver. This is desirable, because telephone receivers are not designed to operate with direct current in the receiver-coil winding. The effect on the receiver of direct current in the winding depends on the direction of the current; the direction can be such as to produce a magnetic flux which will either strengthen or weaken the field of the permanent magnet of the receiver. If the direction of the d-c magnetic flux is such that it *aids* the field of the permanent magnet, the pull on the diaphragm of the receiver *increases.* This usually makes the receiver more sensitive in its response to the voice current; but it also may bring the diaphragm into contact with the pole pieces, so that it is prevented from vibrating properly; or the diaphragm even may become clamped to the pole pieces. If the direction of the d-c magnetic flux is such that it *opposes* the field of the permanent magnet, the pull on the diaphragm of the receiver *decreases.* This usually makes the receiver less sensitive to the voice current and lowers its efficiency. Where permanent-magnet receivers are required to operate with direct current in the winding, the practice is to connect them so that the pull of the magnet is *strengthened* by the direct current. This is called *poling the receiver.* The induction coil does away with the necessity of poling the receiver of the local-battery telephone set.

d. Percent Change in Resistance Caused by Induction Coil. The induction coil in figure 50 increases in two ways the voltage of the voice current generated by the transmitter: First, it acts as a step-up transformer (since the secondary winding has more turns than the primary), and, second, it causes a greater *percent change* in the resistance of the transmitter circuit.

(1) To understand the effect of the induction coil in increasing the percent change in the resistance of the transmitter circuit, compare the circuits in A and B, figure 52. In both, the generators and ringers are omitted, since their resistance is relatively much greater than that of the other components. In A, the transmitter of telephone A is in series with all the other circuit components: both receivers, both batteries, the telephone line, and the other transmitter. In B, the transmitter of telephone A is in series only with the battery and primary winding of the induction coil. Now, the primary of the induction coil of the latter circuit has a much lower resistance than the total resistance of the components connected in series in the former circuit. Because of this big difference in the circuits, the change in the resistance of the transmitter of each set, under the action of the sound waves of speech, produces a greater percent change in the total resistance of the circuit in B than in A.

(2) The greater the variation of the total resistance, the greater is the current in the transmitter circuit. This is the same as saying that the amplitude of the voice current is increased (since the frequency of the speech sound wave is the same). As a result, the voltage of the voice current induced in the secondary winding of the circuit with the induction coil, in B,

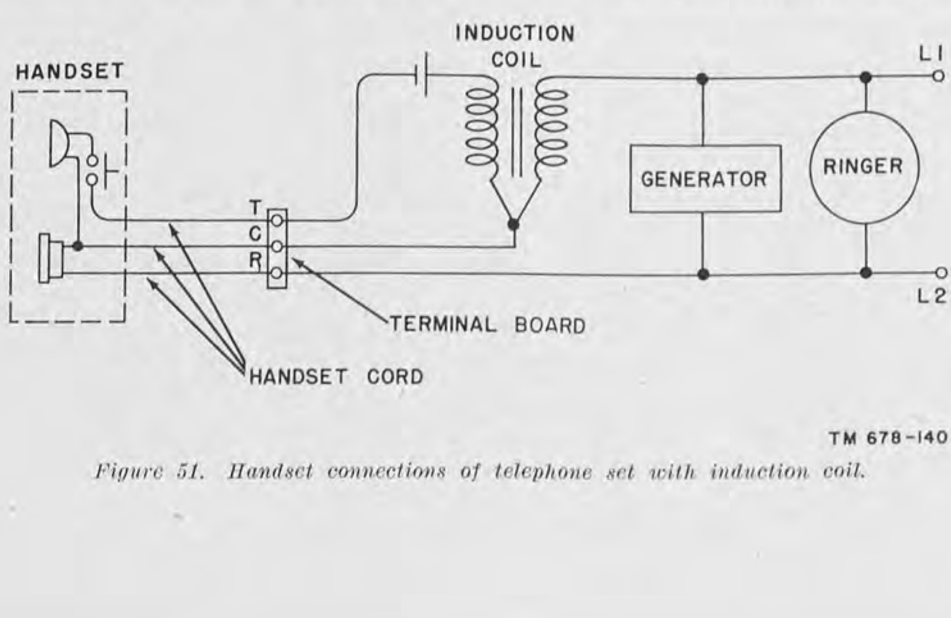


Figure 51. Handset connections of telephone set with induction coil.

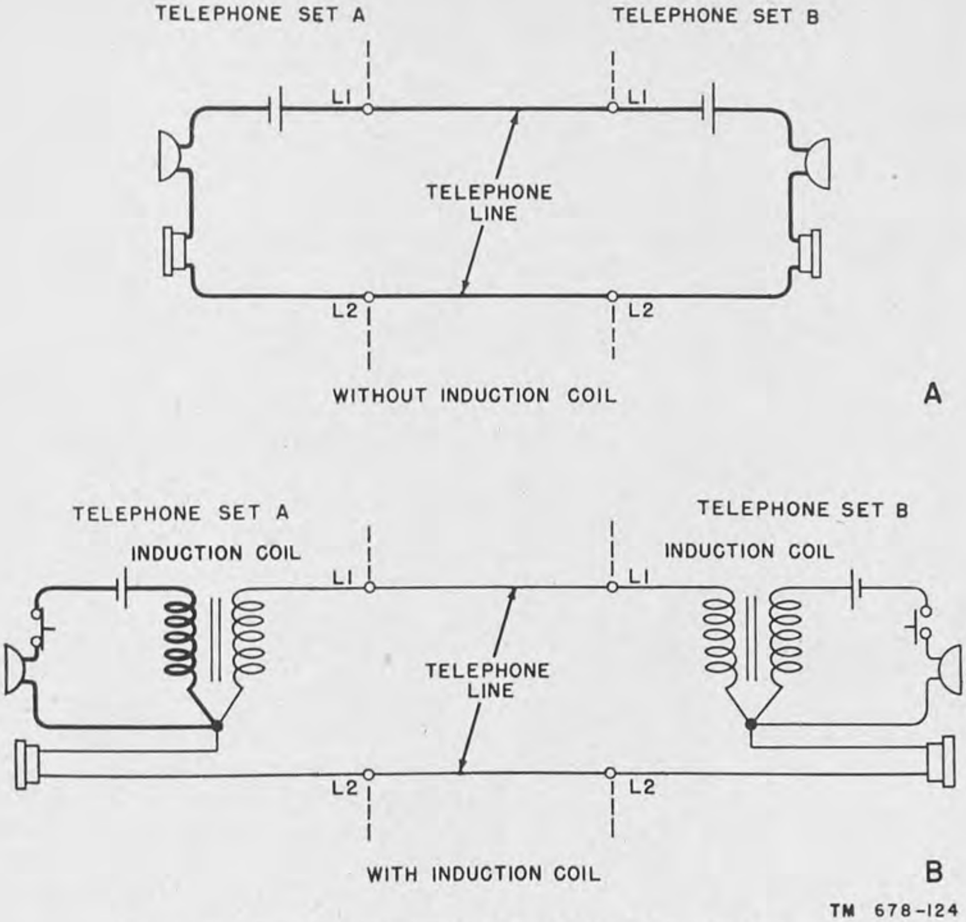


Figure 52. Transmitter circuits with and without induction coils.

is greater than the voltage of the voice current generated by the transmitter in A, the circuit without the induction coil.

e. Advantage in Use of Induction Coil. Because the induction coil, in B, increases the voltage of the voice current generated by the transmitter, it can be used to provide voice conversation over greater distances. The resistance of the talking circuit between two telephone sets becomes greater with increase in the length of the connecting telephone line. Telephone lines have a certain amount of current leakage, and this, too, increases with the length of the line. The greater resistance and current leakage in long telephone lines reduce the voice current in the circuit. The increased voltage produced by the induction coil increases the effective range of practical telephone communications.

49. Structure of Induction Coil

Figure 53 illustrates a typical induction coil, consisting of coils of insulated copper wire wound around a laminated silicon-steel core. The ends of the windings are brought out to terminals mounted on a bakelite insulator. The laminated core minimizes power losses caused by eddy currents induced in the core by the varying voice current. Induction coils are of *closed-core type* and *open-core type.*

a. Figure 53 illustrates an induction coil of the *closed-core type.* The steel core incloses the coils completely, providing a closed magnetic path for the lines of force. Because the magnetic path of this type of coil has less reluctance than that of the open-core type, it is more efficient.

b. An induction coil of the *open-core type* is shown in figure 54. This coil usually has a core made of a bundle of round iron wires which does not provide a complete magnetic path around the coil. Part of the path of the magnetic lines of force passes through the air from one end of the iron core to the other. Because of this, the reluctance of the magnetic circuit is greater, and the magnetic flux less, than that of a closed-core coil with the same current in the winding. The

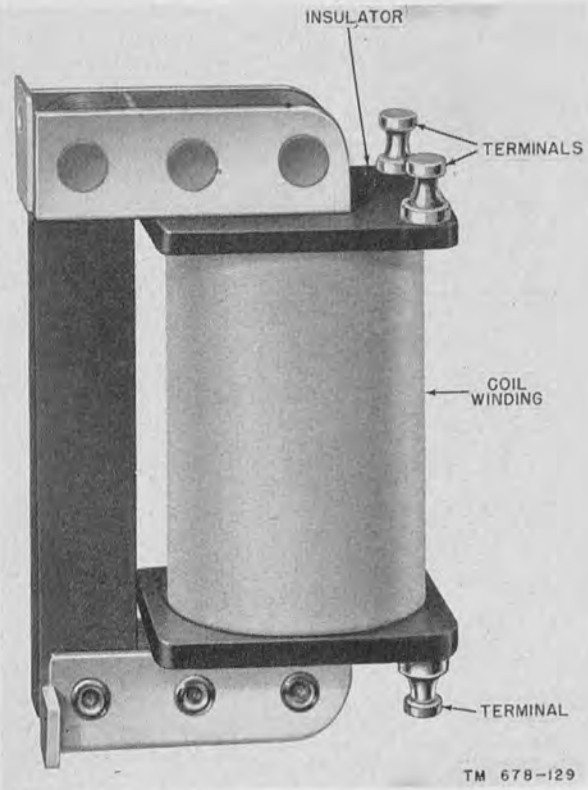


Figure 53. Closed-core induction coil.

open-core coil also has a greater leakage flux; that is, all of the magnetic flux produced by the primary winding does not link the secondary winding. Both of these factors increase the impedance of the coil.

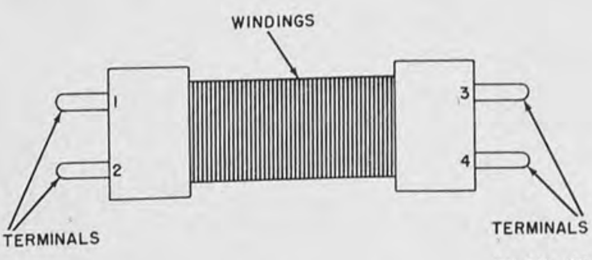


Figure 54. Open-core induction coil.

50. Hand Generator

a. Function of Hand Generator. The *hand generator* enables the telephone user to signal the switchboard when placing a telephone call. It generates an a-c voltage which provides signaling current for operating the signaling device. The signaling device used at the switchboard is the *line drop;* at the called telephone station it is the ringer. The hand generator often is called

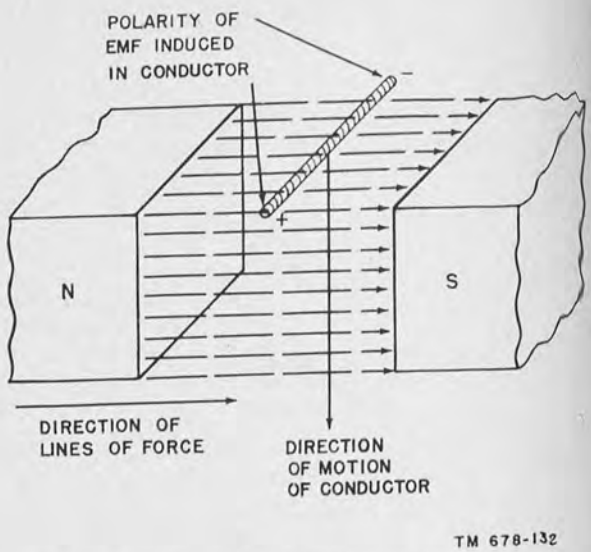


Figure 55. Principle of electromagnetic induction.

the *magneto,* and because it is included in all local-battery telephone sets, local-battery systems sometimes are called *magneto systems.*

b. Principle of Hand Generator. The action of the hand generator depends on the principle of electromagnetic induction, which may be stated as follows: *An emf is induced in a conductor which*

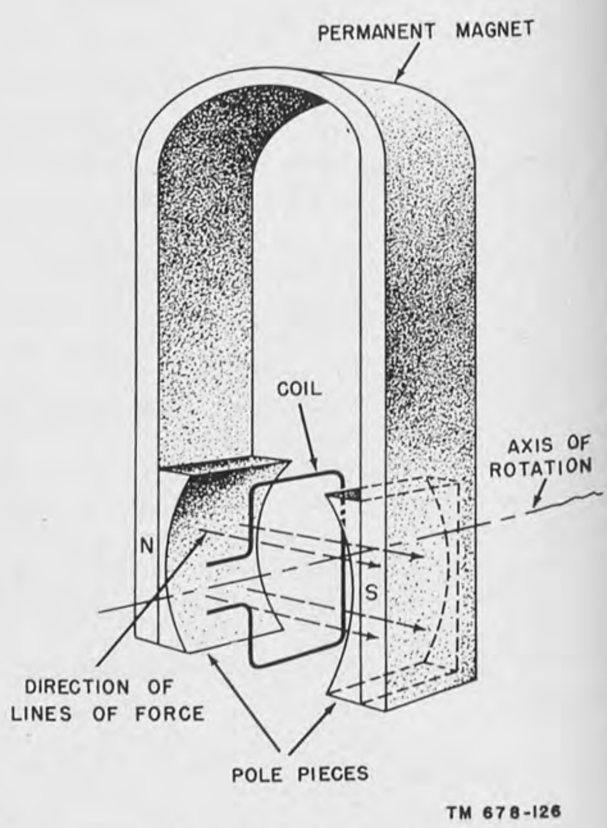


Figure 56. Operating principle of hand generator.

moves in such a way as to cut lines of force in a magnetic field. The induced emf is proportional to the strength of the magnetic field and to the rate at which the lines of force are cut, increasing as the rate at which they are cut increases. The direction of the induced emf depends on the direction of the magnetic field and on the direction of the motion of the conductor through the field. Figure 55 shows this relation. Thus, if the conductor is moving down in a magnetic field extending from left to right (north pole to south pole), the polarity of the induced emf is as indicated.

c. Production of Alternating Current by Hand Generator. Figure 56 shows a conductor that is a single coil of wire fixed to rotate on an axis between the poles of a horseshoe magnet. Attached to the poles of the magnet are *pole pieces* of cast

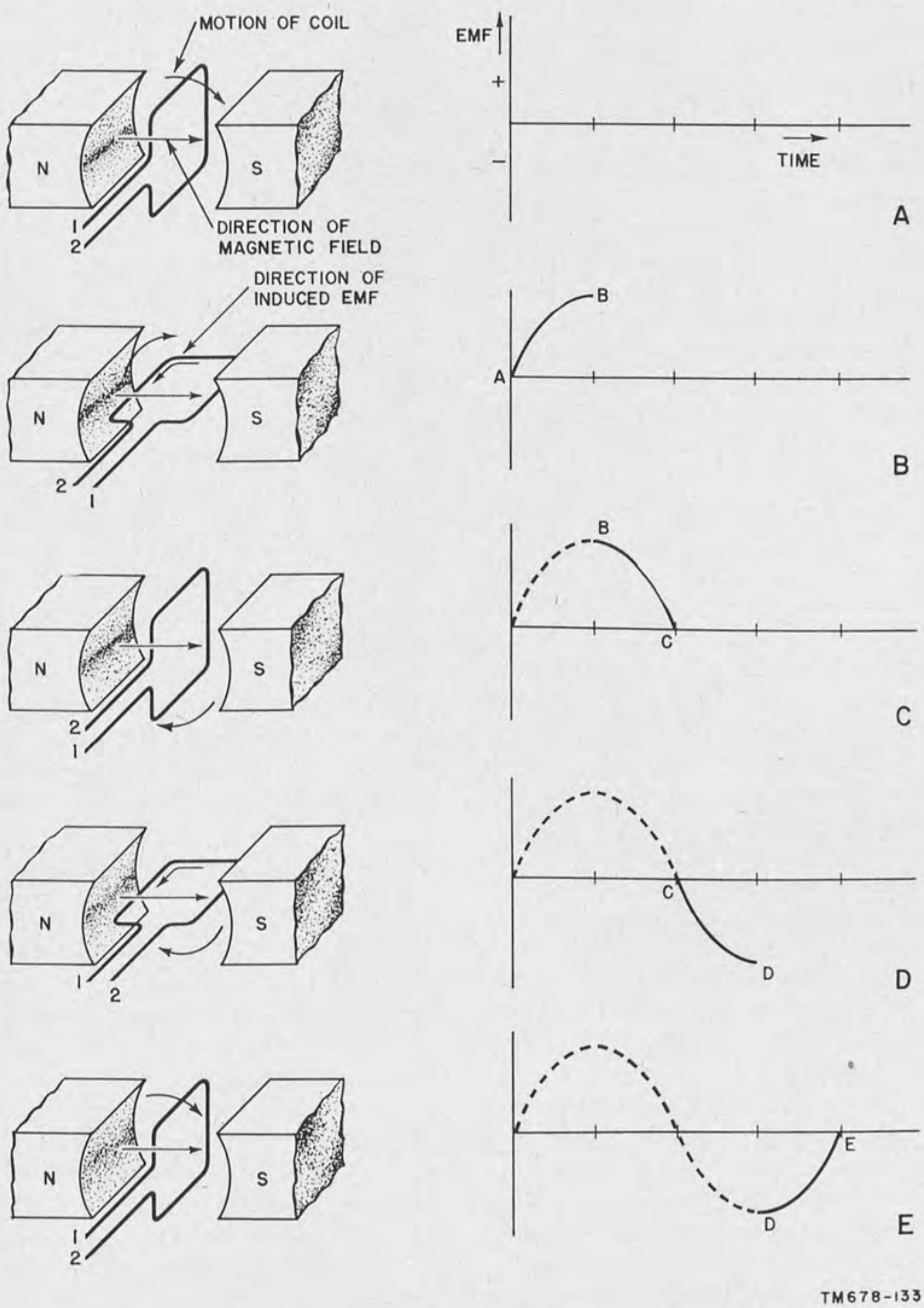


Figure 57. Emf induced by coil rotating in magnetic field.

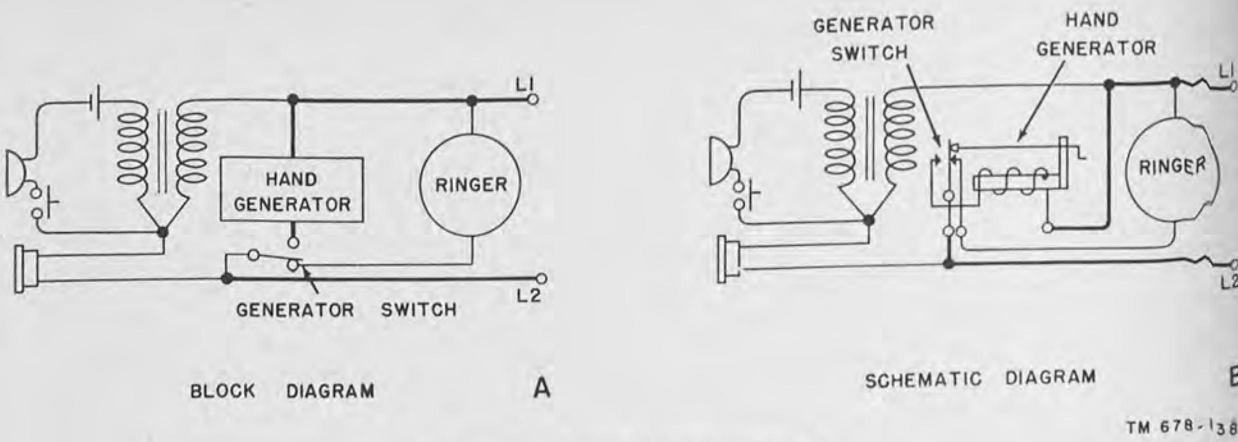


Figure 58. Circuit of hand generator.

iron, used to concentrate the magnetic flux in the space between them. When the coil is rotated, it cuts the magnetic field of the magnet, and an emf is induced in it. Figure 57 shows successive positions of the coil as it rotates between the pole pieces, along with graphs of the waveshapes of the *induced emf* plotted against *time* for the rotation between the successive positions.

(1) When the coil is vertical, as in A, the two sides parallel with the axis of rotation are moving parallel with the lines of force, and are not cutting them; therefore the induced emf is zero. As the coil rotates from this position in the direction of the curved arrow (clockwise), the rate of cutting and, therefore, the induced emf increase until the coil is horizontal, as in B. At this point, the rate of cutting of the magnetic lines of force and, therefore, the induced emf are maximum. As the coil rotates farther, in C, the rate of cutting, and, therefore, the induced emf decrease until the coil is vertical. At this point, the rate of cutting of the magnetic lines and, therefore, the induced emf are zero again. This second vertical position of the coil differs from the first, in that the coil as a whole has undergone a 180° change of position. Terminal 2 is now above terminal 1.

(2) The second half-revolution of the coil repeats what occurred above, except that the induced emf is of opposite polarity to that of the first half-revolution. This is to be expected, because of the reversal of the position of the coil.

(3) Each complete revolution of the coil thus generates 1 cycle of an alternating emf. When the coil is connected through slip rings to a closed, external circuit, this induced alternating emf produces an alternating current in the circuit. A greater induced voltage can be obtained by increasing the number of turns of the coil.

d. Circuit of Hand Generator. In figure 58, A illustrates the generator circuit of a local-battery telephone set, with the hand generator shown as a block. The circuit includes the hand generator and the *hand-generator switch.* In its normal position, the hand-generator switch keeps the hand-generator circuit open and the ringer circuit closed. When the hand generator is used to signal, its operation automatically opens the ringer circuit, preventing signal current from activitating it, and closes the hand-generator circuit, putting the hand generator across the terminals of the telephone set. B shows the same circuit, using the schematic symbol for a hand generator. The symbol includes the hand-generator switch.

51. Structure of Hand Generator

a. Magnets of Hand Generator. The magnetic field in the hand generator illustrated in figure 59 is supplied by *permanent bar magnets* arranged on either side. The magnets are made of alnico, a special steel alloy which has high magnetic retentivity and is capable of providing a strong magnetic field. The magnets are provided with pole pieces located as shown. The rotating coil consists of many turns of fine enamel-insulated wire wound on an iron core. The combination of coil and iron core is called the *armature.*

b. Armature of Hand Generator. Figure 60 shows the construction of the armature of a hand generator. One end of the coil winding is con-

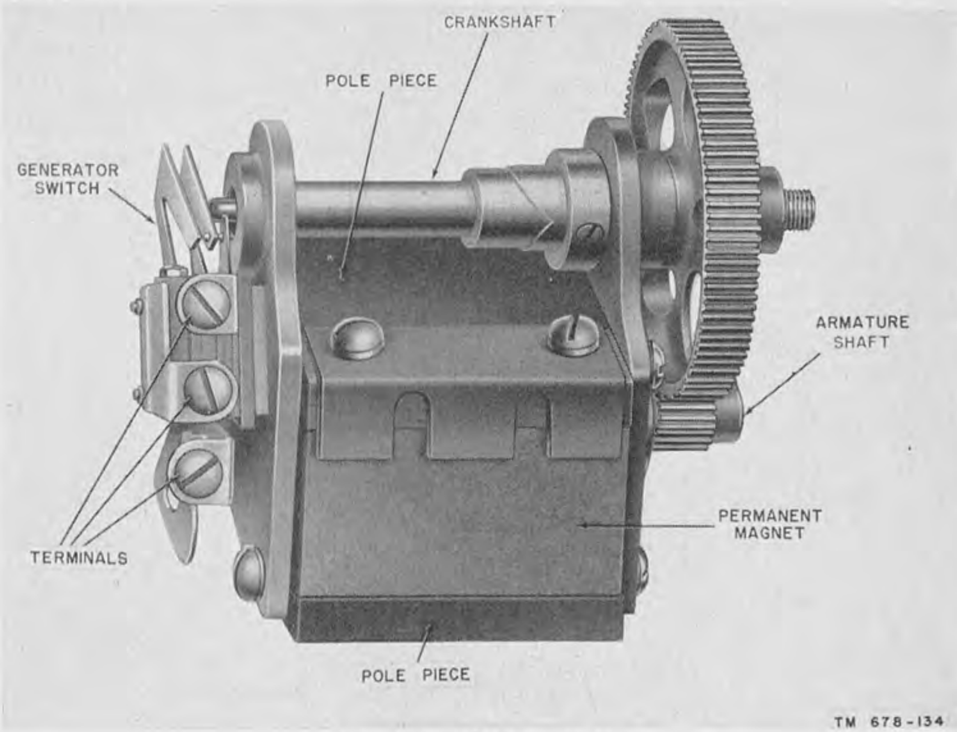


Figure 59. Hand generator.

nected to the armature core and the other end to a pin in the axis of the armature shaft. The pin is insulated from the rest of the shaft. A flat spring (not shown), pressing against the pin, completes the circuit from the armature to one terminal of the hand generator. The frame of the hand generator is in contact with the armature core and acts as the other terminal.

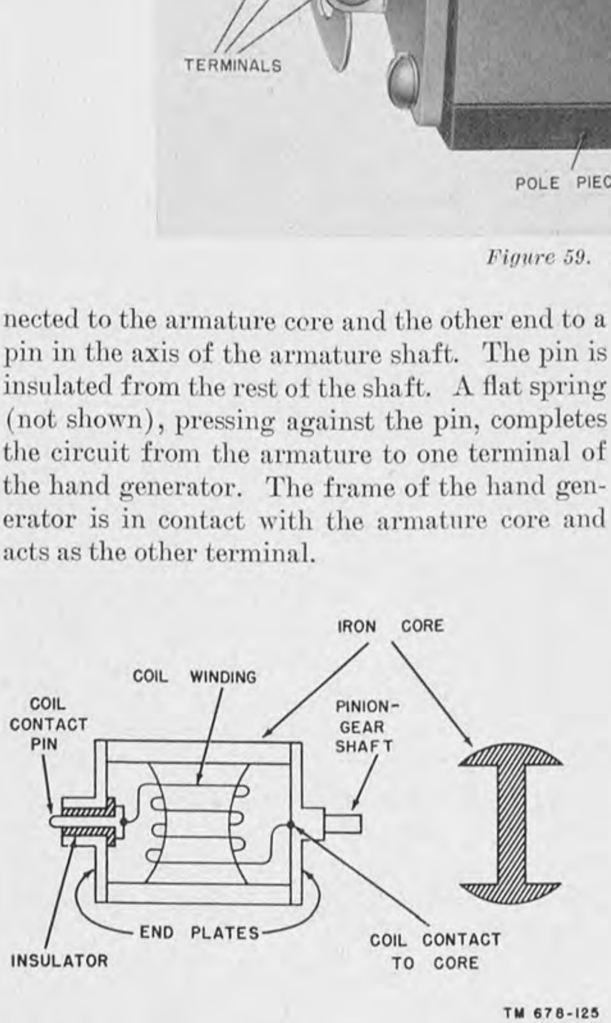


Figure 60. Construction of armature of hand generator.

c. Other Types of Hand Generators. Other types of hand generators have slightly different arrangements for producing the magnetic field. The type shown in figure 41 uses **U**-shaped or horseshoe-shaped permanent magnets fitted over the pole pieces. The number of magnets used varies from two to five, depending on the size of the hand generator. Another type of hand generator has a fixed armature and a rotating magnet.

d. Hand-Generator Switch. The *hand-generator switch* is fastened to one end of the hand generator (fig. 61). It consists of a pile-up of phosphor-bronze springs separated by insulators. The spring assembly includes the terminals of the hand generator and the contact to the insulated pin of the armature shaft which completes the armature circuit. The switch is operated by the motion of the shaft of the hand generator as the crank is turned.

52. Mechanical Operation of Hand Generator

a. Operation of Hand-Generator Switch.

(1) The *crank* is mounted on a crankshaft extending the full length of the hand generator (A, fig. 61). On the *crankshaft*, free partially to rotate, is a *drive gear* which meshes with a *pinion gear* mounted on the shaft of the *armature* below. The drive gear has an extended hub with a matched end which mates with a V-ended *cam* pinned to the crankshaft. A compression spring, coiled about the crankshaft within a *retaining collar* on

the crank, presses against the drive gear on one side and the crank on the other. In the nonoperating position, the pressure of the spring separates the retaining collar and drive gear, mating the cam in its notch and keeping the tipped extension of the crankshaft from touching the hand-generator switch.

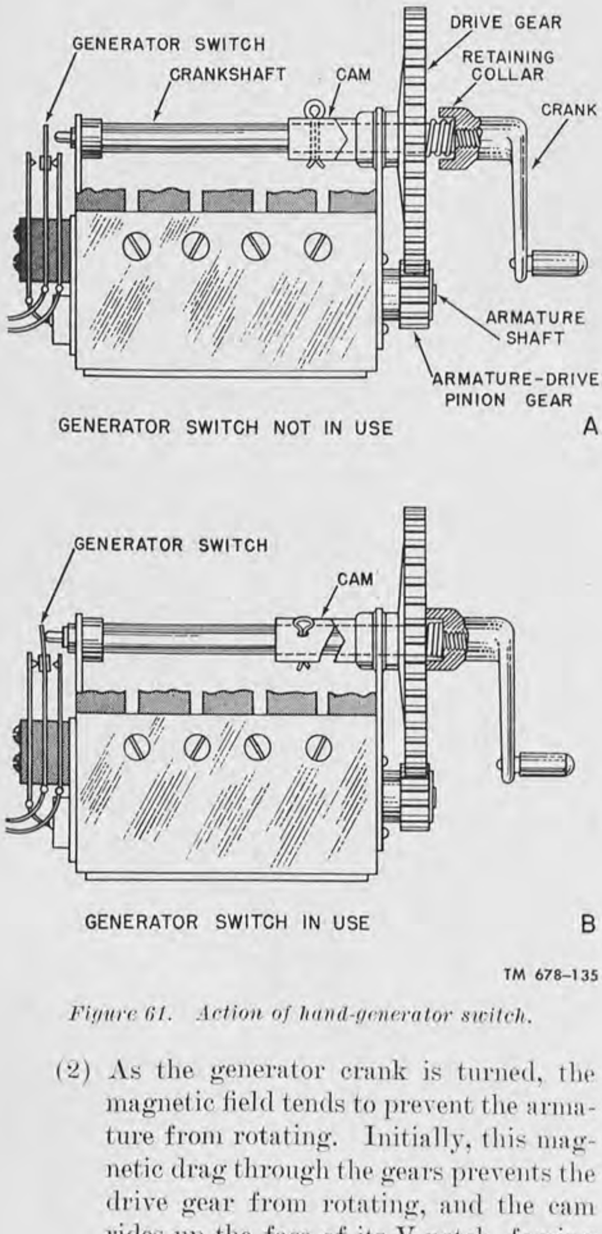


Figure 61. Action of hand-generator switch.

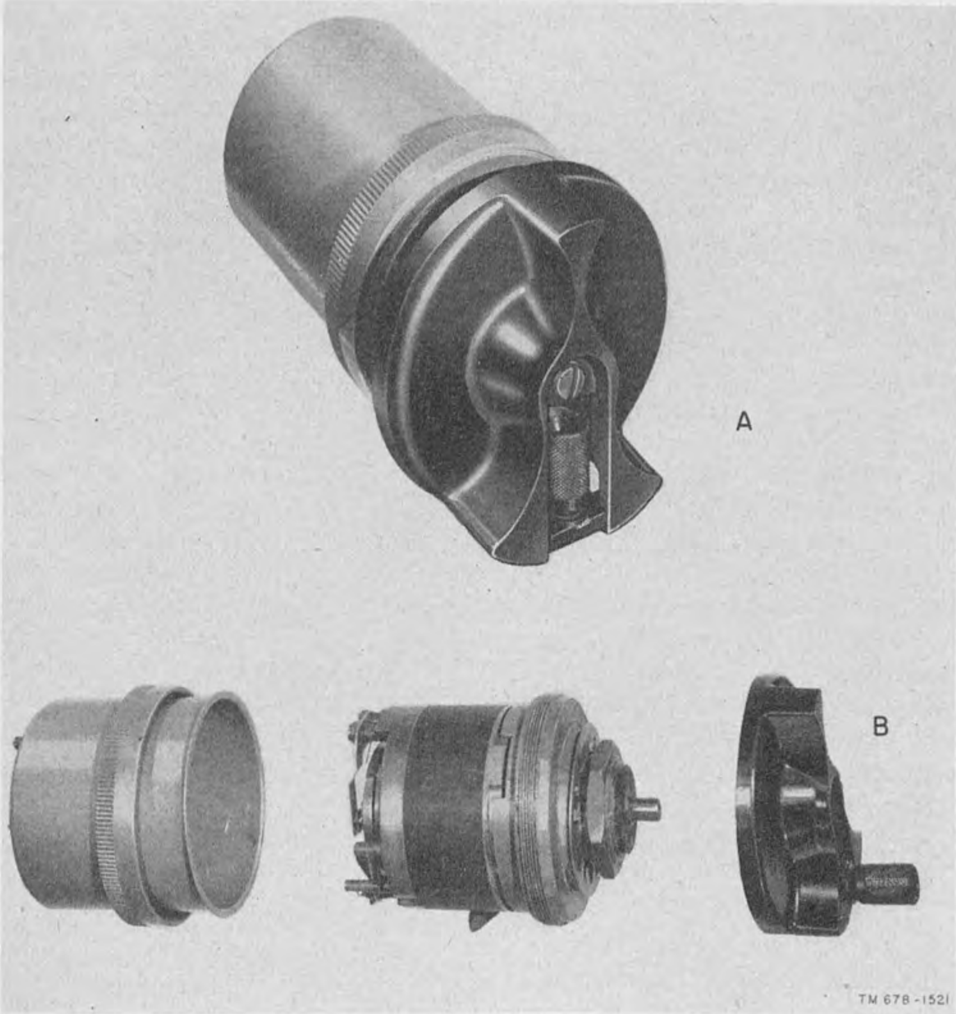
(2) As the generator crank is turned, the magnetic field tends to prevent the armature from rotating. Initially, this magnetic drag through the gears prevents the drive gear from rotating, and the cam rides up the face of its V-notch, forcing the crankshaft to move slightly endwise to the left, as in B. This motion causes the tipped extension of the crankshaft to operate the hand-generator switch, mounted at the left. The retaining collar, by jamming against the drive gear, limits both the motion of the shaft and the travel of the cam up the face of the notch. After it has jammed, further turning of the crank causes the drive gear and armature to rotate. The armature by its rotation in the magnetic field generates the emf for the signaling current. When the crank is released, the compressed spring restores the crankshaft and the hand-generator switch to their nonoperating positions. The pinion gear usually is connected to the armature shaft in such a manner that when cranking has ceased, the armature is free to rotate and aline itself with the field between the poles. This conserves the life of the permanent magnets.

b. Operating Speed of Hand Generator. The hand generators used in local-battery systems develop an emf of approximately 85 to 90 volts at a frequency of 16 to 20 cycles at normal cranking speed. Both the frequency and the generated voltage depend on the speed with which the generator is cranked. Each rotation of the armature produces 1 cycle of alternating current. The gear ratio between the drive gear and the armature pinion gear is about 5 to 1. To produce the required ringing frequency of 16 to 20 cycles with this arrangement, the drive gear must be rotated slightly more than three times per second.

c. A recently designed hand generator which is now being used on many military equipments is shown in figure 62. Electrically, the performance of this generator is comparable to the generator described previously and its functioning is similar. Mechanically, the unit has been modified. The generator is smaller and can be removed from an equipment, disassembled, and serviced with relative ease. When using the generator, the operator has a choice of spinning the dial with his fingers or cranking in the usual manner. The crank is pivoted and can be snapped into a compartment on the face of the dial when it is not being used.

53. Ringer

a. Function of Ringer. The ringer is the signaling device of the telephone set. By sounding, it signals all within earshot that the telephone is to be answered. Usually it is an electric bell which operates on the low frequency of about 20 cycles generated by the hand generator or ringing ma-



A. Unit removed from equipment
B. Unit with cover removed
Figure 62. Hand generator.

chine. (The ringing machine will be described later.)

b. Operating Principle of Ringer.

(1) Figure 63 shows a simplified diagram of the *ringer.* Two electromagnets, coils wound on soft-iron cores, are permanently joined at the upper ends by a soft-iron yoke to form a *horseshoe magnet.* A soft-iron *armature,* pivoted at its center, is placed under the cores of the electromagnets. The armature carries a *clapper rod* and a *clapper* which can vibrate between the two *gongs* (bells). A *permanent magnet* in the form of a shallow **U** is secured by one end to the yoke; its other end is bent around to lie adjacent to, but not touching, the center

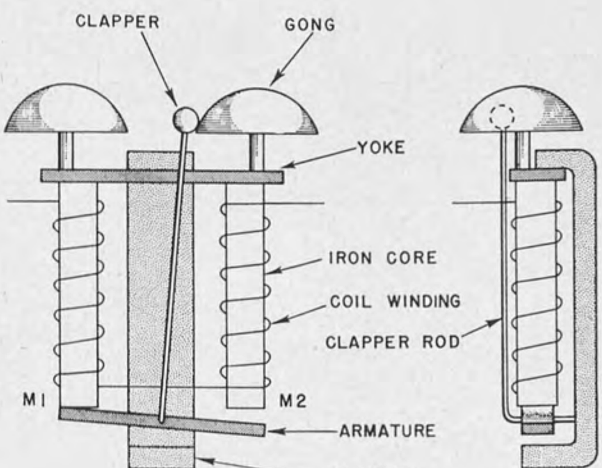


Figure 63. Ringer.

of the armature. The coils of the electromagnet are so wound that when a current passes through them they are magnetized in opposite directions; thus, if the lower end of coil M1 becomes a north pole, the lower end of coil M2 becomes a south pole.

(2) The operating principle of the ringer is illustrated in figure 64. When there is no current in the ringer, the cores and armature are magnetized by the permanent magnet, and the path of the magnetic flux is as shown in A. If the upper pole of the magnet is assumed to be a north pole, the flux of the permanent magnet has a path through the yoke, the cores of the electromagnets, the air gap between the cores and the armature, the armature, and the air gap between the armature and the south pole of the permanent magnet. Since the reluctance of the magnetic path is the same through either core, the magnetic lines of force distribute evenly between them; the magnetic pull of the cores on the armature is equal, and the armature occupies the balanced position shown.

(3) Alternating current through the ringer upsets this magnetic balance. Since the current changes direction each half-cycle, one core alternately is made magnetically stronger than the other. If the current direction for the first half-cycle of ringing current is taken as shown in B, the magnetic flux in core M1 is strengthened, whereas that in core M2 is weakened. This results in an increased pull on the armature by core M1, which attracts the left end of the armature and causes the clapper to strike the right gong.

(4) In the second half-cycle, in C, the current reverses its direction. The magnetic flux in core M2 now is strengthened, and that in core M1 is weakened. As a result, the right end of the armature is attracted by the greater magnetic pull of core M2, causing the clapper to strike the left gong. The continuous change in the direction of the current thus alternately attracts the armature to one core and then the other, causing the clapper to vibrate between the gongs. Because of the initial magnetic field set up by the permanent magnet, such ringers are termed *polarized ringers*.

c. Structure of Ringer. Figure 65 illustrates a

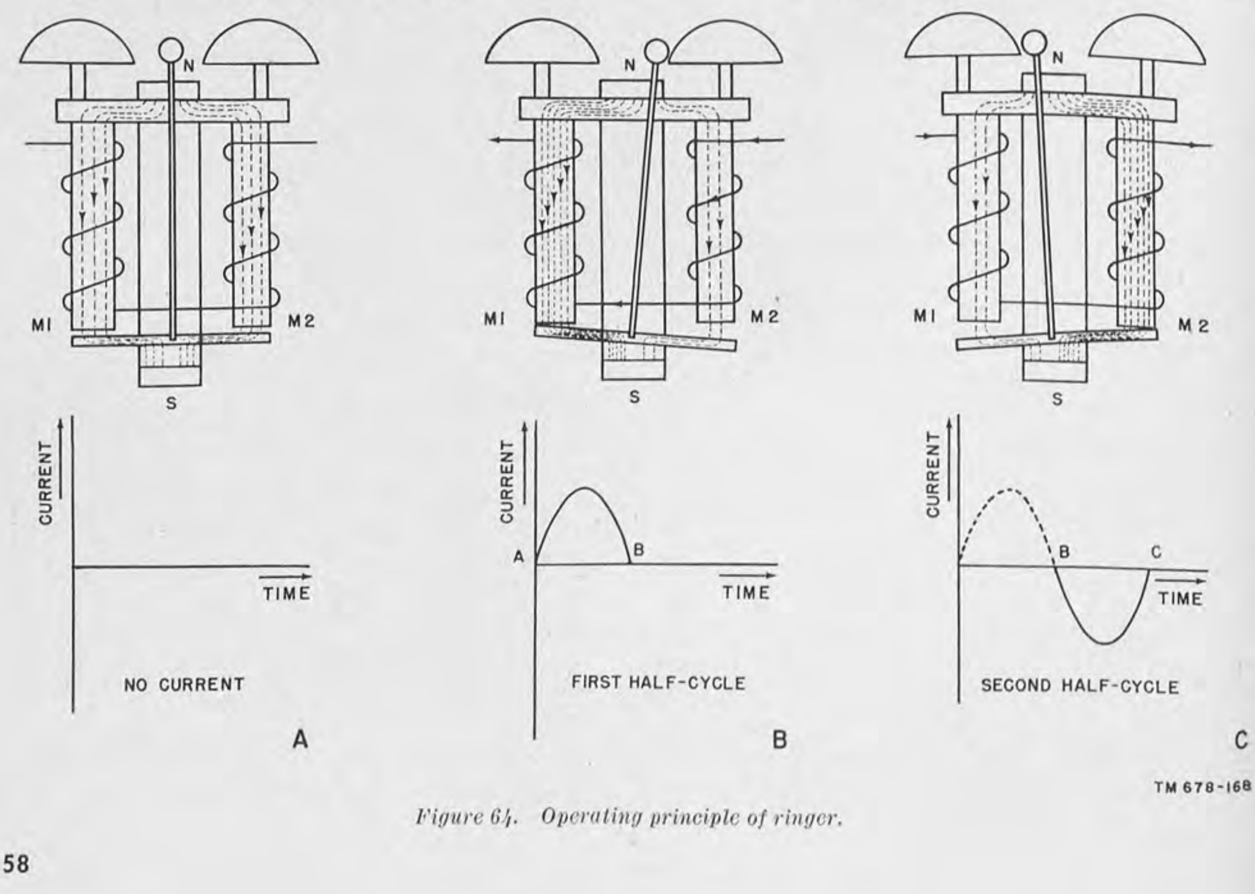


Figure 64. Operating principle of ringer.

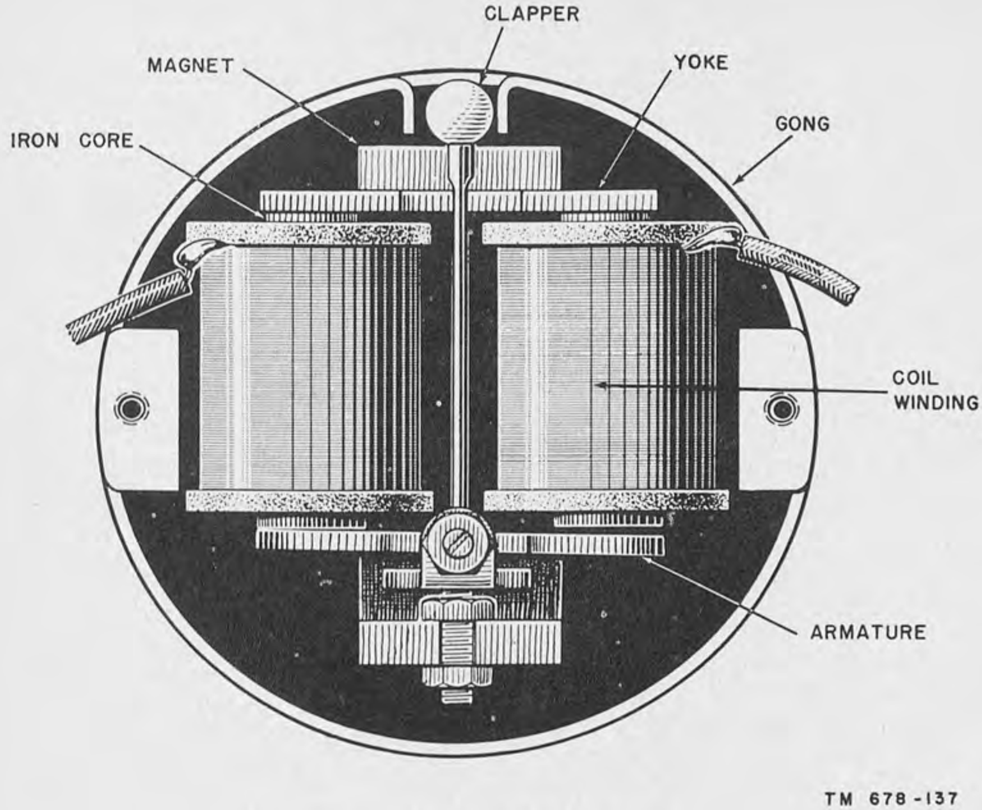


Figure 65. Local-battery ringer.

typical local-battery-telephone ringer. The coils are wound of many turns of fine enamel-insulated wire. Externally, they are wrapped with soft cotton fiber as a protection against mechanical injury, and then impregnated with varnish to keep out moisture. The two coils in series have a d-c resistance of 1,300 ohms and an impedance, at 1,000 cycles, of 18,750 ohms. The yoke, electromagnet cores, and armature are made of soft iron which retains very little magnetism when the magnetizing current or the permanent magnet is removed. The ringer has a single gong with a split section between which the clapper vibrates. The gong and clapper usually are made of brass. The ends of the armature are fitted with brass tips, to prevent residual magnetism from causing them to stick to the core ends.

d. Circuit of Ringer. Figure 66 shows the *ringer circuit* of the local-battery telephone set. It includes the ringer and the hand-generator switch. In the normal position, the hand-generator switch connects the ringer across the terminals of the set.

54. Signaling Circuit

Figure 67 shows the *signaling circuit* of two local-battery telephone sets. It includes the hand generator and the hand-generator switch of telephone A, the telephone line, and the hand-generator switch and ringer of telephone B. To call telephone B, a person at telephone A first turns the crank of the hand generator. This closes the hand-generator switch and puts the hand generator across the telephone line. The hand gen-

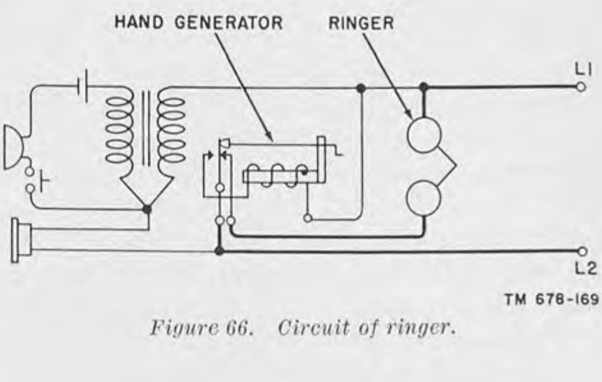


Figure 66. Circuit of ringer.

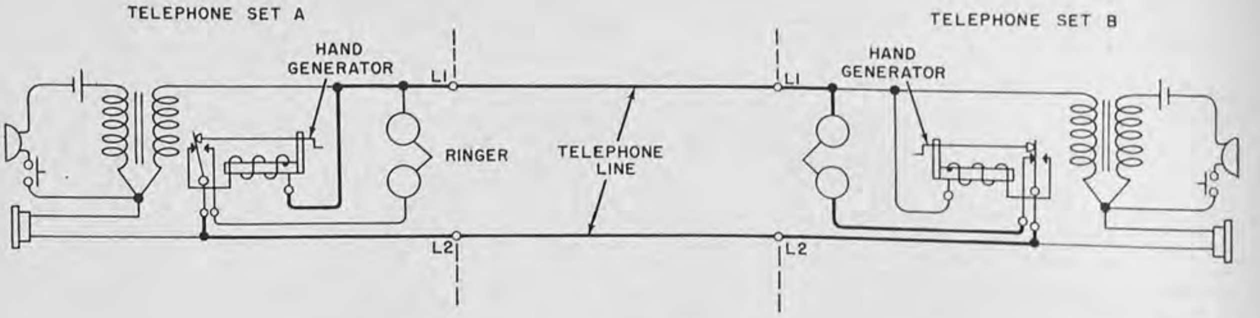


Figure 67. Signaling circuit of two local-battery telephone sets.

erator sends a 20-cycle ringing current to the ringer at B through the connecting circuit provided by the line and the hand-generator switch of B. The sounding of the ringer signals someone at B to answer the telephone. When the telephone is answered, the conversation proceeds. Both ringers are connected across the telephone line during the talking period, but their high impedances prevent the shunting of the voice currents through them. Of course, at the end of the ringing, the hand-generator switch of telephone A opens its hand-generator circuit, leaving the hand generators at each telephone disconnected from the talking circuit. Because each hand-generator switch keeps its hand-generator circuit disconnected at all times except during ringing, it also prevents the shunting of the ringing current through its hand generator when its ringer is activated. The armature of the hand generator has a lower impedance than the ringer; if it were not removed from the line, the shunting of signaling current through it would weaken the response of the ringer.

55. Capacitor

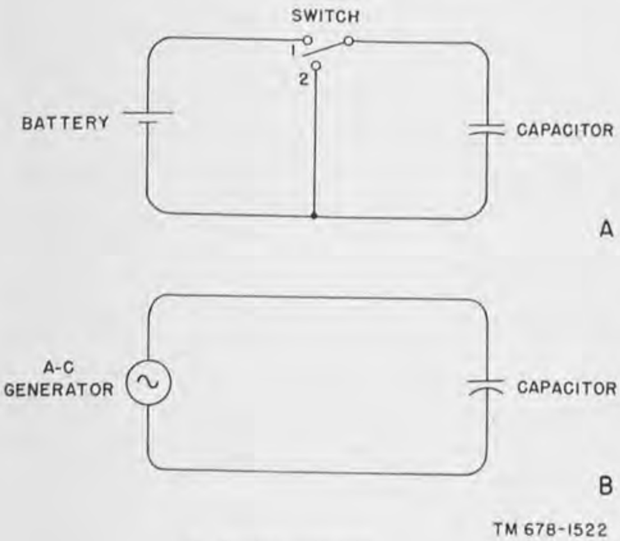
A capacitor is an electric device of many purposes, among which are the coupling of alternating-current circuits and the blocking of direct current. It consists of two conductors called *plates*, or *electrodes*, between which exists, or is inserted, an insulating material called a *dielectric*.

a. Use in Telephone Circuit. In the local-battery telephone set, a capacitor is used to reduce or limit the 20-cycle ringing current through the telephone receiver.

b. Principle. The principle of the capacitor depends on its ability to store an electric charge. When a capacitor is connected to a source of emf, it takes electrical energy from the source and stores it in the form of an electric field, established between the plates. The effect of a capacitor on current in the circuit depends on whether the current has a direct or an alternating source of voltage.

(1) *D-c voltage.* A, figure 68, shows a circuit containing a capacitor, a two-position switch, and a battery. The switch is between positions 1 and 2, and the circuit is open. Now, assume that the switch is thrown to position 1, connecting the battery across the terminals of the capacitor. Instantly, there is a flow of electrons between the battery and the plates of the capacitor. The electron flow constitutes a charging current which makes the voltage across the capacitor equal to that of the battery. As soon as the capacitor voltage equals that of the battery (almost instantaneously) the electron flow stops and the battery supplies no more current to the circuit. The capacitor has taken electrical energy from the battery and is now storing it in the form of an electric field, set up and maintained between its plates. The capacitor can return this stored energy to the circuit. For example, if the switch now is thrown to position 2, the capacitor discharges, releasing its stored energy through the circuit connecting its terminals. The direction of the discharging current is opposite to that of the charging current, and the voltage across the capacitor falls to zero. The *amount of charge* a capacitor will take depends on its capacitance and the voltage of the source to which it is connected. The capacitance is determined

by the size, structure, and materials of the capacitor—that is, the area of its plates, the distance between the plates, and the dielectric material separating the plates. It increases with increase of the area of the plates and with decrease of the distance between them. The effect of the dielectric depends on the insulating value of the material of which it consists. A capacitor having a dielectric with a greater insulating value, such as mica, has a higher capacitance than one of equal dimensions but with a poorer insulating value, such as dry paper. The unit of capacitance is the farad. Since the farad is too large a unit for general electronic use, capacitance usually is expressed in μf (microfarads). (One μf is one-millionth of a farad.) A capacitor takes a full charge almost instantly when a d-c voltage is applied; however, if resistance is connected in series with the battery and the capacitor, the time required fully to charge or completely to discharge the capacitor is increased. Except for the initial charging current, there is no current in the capacitor circuit when a d-c voltage is applied.



A. Direct current.
B. Alternating current.
Figure 68. Capacitor circuits.

(2) *A-c voltage.* B, figure 68, shows an a-c generator connected to the terminals of a capacitor. The generator supplies a sine-wave a-c voltage. Thus, the voltage across the capacitor rises to a maximum and falls to zero first in one direction and then in the opposite direction. During a complete cycle of the generator voltage, this voltage makes one plate of the capacitor positive for one half-cycle and the other plate positive for the next half-cycle. Therefore, in the circuit between the generator and the capacitor, there is a continuously varying flow of electrons first in one direction and then in the opposite direction, which constitutes an alternating current. Although there is alternating current *in the circuit* there is none *through the capacitor.* The *frequency* of the alternating current in the circuit (fig. 68) is the same as that of the a-c voltage of the generator. The *amount* of current in the circuit, however, is determined by the capacitor, which tends to oppose the presence of the current. The opposition of the capacitor to the current is termed *capacitive reactance*, and it depends on the frequency of the applied voltage and the capacitance of the capacitor. The capacitive reactance is higher for lower frequencies and higher for smaller values of capacitance. Because the capacitive reactance is large at the lower frequencies, the a-c current in a circuit is reduced by adding a capacitor to the circuit. A more complete discussion of the capacitor is included in TM 11–681.

56. Structure of Capacitor

Figure 69 shows the structure of one type of capacitor. Each of the two plates is a thin sheet of tinfoil, to which a lead (wire) is attached for the purpose of making connections. The plates are separated by a sheet of waxed paper. To save space, the tinfoil plates and the waxed-paper insulator are formed into a flattened rectangular roll. The roll then is inserted in a metal can which is filled with wax and then sealed to keep moisture out. The connecting wires are brought out to insulated terminals mounted on one face of the can. Figure 70 shows three capacitors used in local-battery telephone circuits; the one with the four terminals is actually three capacitors mounted in one metal can. Other capacitors used in telephone circuits have mica as an insulator

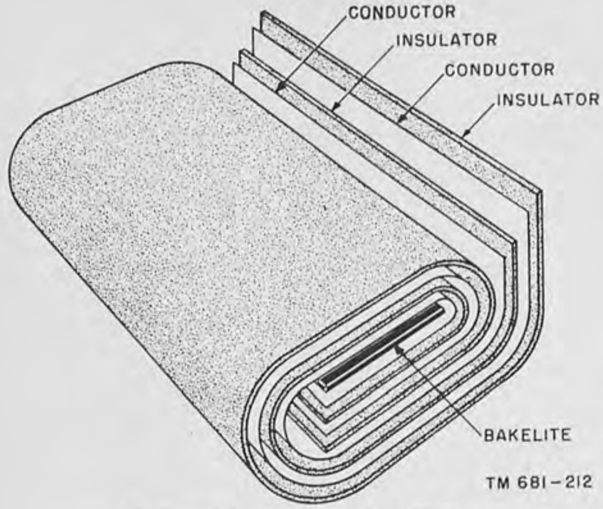


Figure 69. Structure of capacitor.

between the metal coil. They are more stable with changes in temperature than waxed-paper capacitors, their value of capacitance usually is more precise, and they can withstand larger operating voltages.

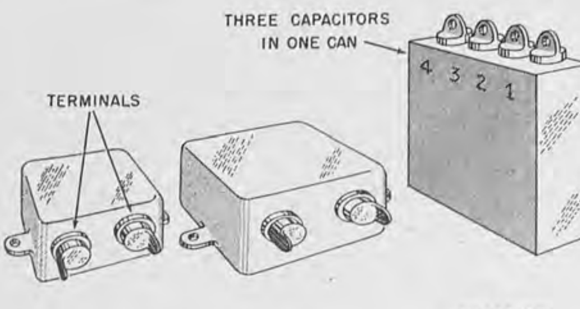


Figure 70. Capacitors.

57. Capacitor in Telephone Circuit

a. Figure 71 shows the circuit of a local-battery telephone set with capacitor C1 in the receiver circuit (heavy lines). This capacitor usually has a capacitance of .5μf. It has a high capacitive reactance at the 20-cycle frequency of the signaling current, but a relatively low capacitive reactance at the 200- to 2,700-cycle frequency (approximately) of the voice current. The high capacitive reactance at the low signaling frequency increases the impedance of the receiver circuit for the signaling current, whereas the impedance for the higher-frequency voice current remains relatively unchanged. Thus, the voice current to the receiver is not affected by the capacitor.

b. If there were no capacitor in the receiver circuit (fig. 71), the circuit of the telephone receiver and the secondary winding of the induction coil would have an impedance lower than that of the ringer. Since the receiver circuit is in parallel with the ringer circuit, it would provide an additional path for the signaling current, so that when a distant telephone set signaled, a large part of the signaling current would be shunted through the receiver circuit. This would reduce the current through the ringer and decrease its volume of sound. Thus, the capacitor, by limiting the amount of 20-cycle signaling current through the receiver circuit, prevents the weakening of the ringer response.

c. In the same way, the capacitor prevents a reduction in the amount of a signaling current transmitted to a distant telephone set (fig. 71). Rotation of the hand generator removes the ringer from the circuit and places the generator in parallel with the receiver circuit. If the capacitor were not in the receiver circuit, part of the signaling current would be shunted through the receiver circuit. This of course would result in less signaling current at the distant telephone set.

58. Sidetone

a. Sidetone is sound transmitted through a local path from the transmitter to the receiver of the same telephone set. This effect was pointed out in connection with the circuit of figure 50 (par. 48). Sidetone results when two telephone sets such as

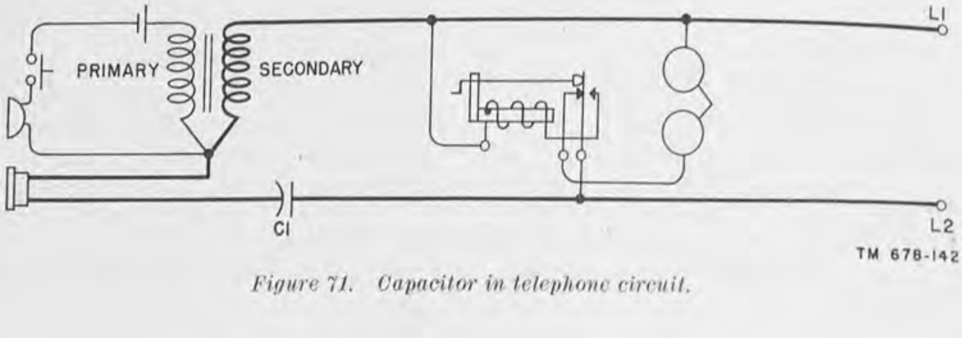


Figure 71. Capacitor in telephone circuit.

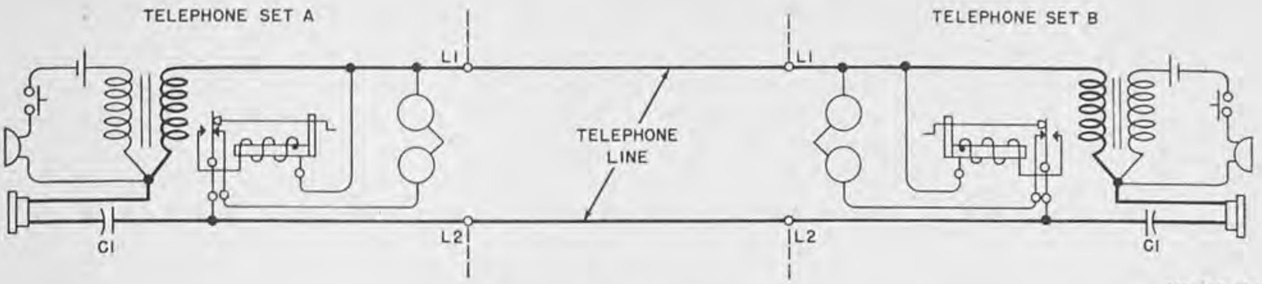


Figure 72. Sidetone circuit.

those of figure 71 are connected as in figure 72. The heavy lines of the latter figure show the mutual path of the voice current in the receiver circuits of the two telephone sets. Both telephone receivers are connected in a series circuit along with the secondary windings of both induction coils, both capacitors, and the connecting telephone line. The voice current produced in this circuit by a person speaking at either telephone passes through both receivers and is reproduced as a sound wave of speech in each one. Persons at both telephones therefore hear their own voices reproduced in their own receivers.

b. Although the receivers in figure 72 are connected in series, the voice current in the telephone set of the speaker is greater than the voice current in the set of the listener. Two factors contribute to make this difference. One factor is current leakage from the telephone line connecting the two telephone sets. Such leakage will be explained in a later chapter. Because of this current leakage, the sidetone in the receiver of the speaker is louder than his words in the receiver of the listener, and the voice of the speaker sounds louder to him than it does to the listener. The other factor is increase of the voice current in the secondary winding caused by the transformer action of the induction coil. This increased voice current, passing through the receiver of the speaker, further increases its output of sidetone.

c. A loud sidetone is undesirable in the telephone set for three reasons. First, when the speaker hears his own voice loudly reproduced by the receiver, he usually lowers his voice. This reduction of the sound input of the transmitter reduces its voice-current output, which in turn reduces the current in the receiver of the distant telephone set. Second, the amplified and comparatively loud tones reproduced in the receiver of the speaker tend to lessen the sensitiveness of the ear of the speaker to the more feeble voice current from the distant telephone set. Third, local room noise is picked up by the transmitter and is heard by the local listener along with the voice of the distant speaker. These surrounding noises, reproduced in the local telephone receiver, both distract the listener and reduce the intelligibility of the words he hears. The effect is particularly objectionable when the telephone is used in unusually noisy locations. Many antisidetone circuits greatly reduce the undesirable effects of sidetone. One, commonly used by the Army in local-battery telephone, will be described.

59. Principle of Antisidetone Circuit

An *ideal* antisidetone circuit is one that prevents the passage of voice currents from the transmitter to the receiver of the same telephone set. However, a path is provided to the receiver for voice currents originating at a transmitter of a distant telephone set. This means that a person talking into a telephone set equipped with an ideal antisidetone circuit cannot hear his own voice in the receiver, but can hear in his receiver the voice of a person at the other end of the line. In actual practice, an ideal antisidetone circuit is not obtainable, and, even if it were, it would not be desirable. There is a good psychological reason for this. It has been found that it is advantageous for the speaker to hear his voice faintly in his receiver, which assures the speaker that his telephone set is in proper working order. In the explanation which follows, the ideal antisidetone circuit will be considered.

a. A, figure 73, shows a d-c Wheatstone-bridge circuit. The four resistors, R1, R2, R3, and R4, called the *arms* of the bridge, are connected to a battery. A galvanometer—a current-indicating instrument—is connected to junction points A and B. Current from the battery is supplied resistor branches R1–R2 and R3–R4; consequently, there is a potential difference (voltage) across

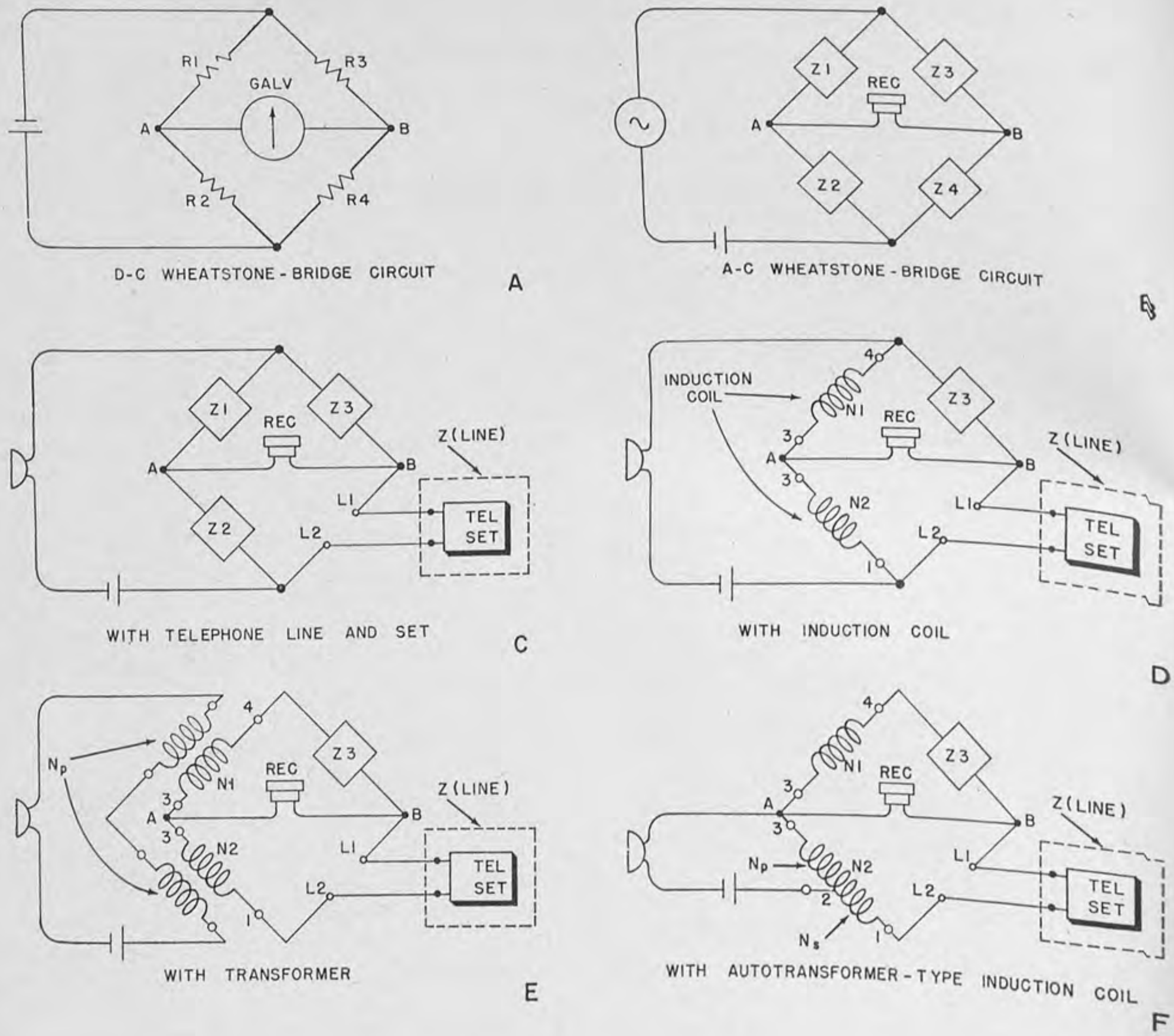


Figure 73. Development of antisidetone circuit.

TM 678-167

each of the resistors. When, in addition, there is a potential difference between points A and B, current passes through the galvanometer and causes it to deflect. The bridge is said to be balanced when there is no potential difference between points A and B, and the galvanometer does not deflect. This occurs when the values of the resistors are such that the ratio of R1/R2 equals ratio R3/R4. Thus, when the bridge is balanced, there is no current through the galvanometer.

b. In B, the resistors are replaced by impedances which, in addition to resistance, have inductive or capacitive reactance; the battery is replaced by an a-c since-wave generator, and the galvanometer is replaced by a telephone receiver. This arrangement constitutes an a-c bridge circuit, which, when balanced, passes no current through the receiver. The a-c voltage supplied by the generator is of fixed frequency. When the bridge is not balanced, there is a potential difference between points A and B, and this produces an alternating current through the receiver and causes sound in it. When the ratio of the impedance, Z1/Z2, equals that of Z3/Z4, however, the bridge is balanced, and there is neither current nor sound in the receiver.

c. In place of the a-c generator, a transmitter and a battery may be used as the source of a-c voltage, as in C. Also, in place of impedance Z4, the impedance of a telephone line and connected telephone set, Z(line), may be used. If Z(line) equals Z4, the bridge still is balanced, because the ratio of impedance Z1/Z2 now equals that of Z3/Z(line). When a voice-current voltage is generated by the transmitter, there is no current through the receiver, and it does not sound, but there is a voice current in each of the impedances of the bridge circuit, one of which is the telephone line and the connected telephone set Z(line). This voice current is reproduced by the receiver of the telephone set, but not by the receiver of the bridge circuit. On the other hand, voice current from the transmitter of the connected telephone set produces a response in the bridge receiver. This response occurs because the bridge is not balanced for a voltage applied between terminals L1 and L2. The bridge arrangement in C can be used as the circuit of a telephone set which eliminates sidetone, provided the condition of balance is satisfied at all voice-current frequencies. In practice, it is impossible to secure an exact balance over the entire range of voice frequencies, because the impedances of the components of the circuit vary with frequency; but, for any given telephone line, the balance can be so adjusted that the sidetone is small. Since the impedance of the transmission line is considered one of the components of the antisidetone circuit, the efficiency of the circuit depends in part on the length of the line connecting the two telephone sets.

d. When transmitting with this circuit, part of the energy of the voice current is wasted in impedance arms Z1 and Z2 as well as in Z3 and Z(line). However, by substituting windings N1 and N2 of a transformer or induction coil, as in D, the loss of energy can be reduced. If N1 and N2 were the windings of an ideal transformer—if they had negligible resistance—no energy would be wasted in them; all the energy would be used in impedances Z3 and Z(line).

e. The induction coil in D can be replaced by one having a separate primary winding, N, as in E. This does not change the bridge action of the circuit, but it permits the voltage of the voice current generated by the transmitter to be stepped up or down effectively in any desired ratio by choice of the proper number of primary turns. Thus, a transmitter of any resistance can be used efficiently. In an actual telephone set, the element Z3—which may consist of a noninductive resistance—is combined physically with the resistance of winding N1.

f. The circuit with the type of induction coil called an *autotransformer* is shown in F. An autotransformer is a transformer, the primary and secondary of which are part of the same winding. An a-c voltage applied across a portion of the turns of the autotransformer induces an a-c voltage in the full winding, because the autotransformer is so designed that the varying magnetic flux in the turns to which the voltage is applied links all the other turns. As in the case of a standard transformer, the primary winding is the one to which the voltage is applied, and the secondary is the one in which the voltage is induced. N1 and N2, in F, are parts of a single winding, with intermediate connections at points 2 and 3. The voltage of the voice current generated by the transmitter is applied across points 2–3, part of winding N2. This part of the winding, N2, is therefore the primary winding, Np, of the autotransformer. The varying voice current in Np induces a voltage in winding N1–N2. This induced voltage is greater than that applied to the primary winding, Np, because winding N1–N2 has more turns than winding Np. The use of an induction coil of the autotransformer type produces a step-up in the voltage of the voice current which appears at terminals 1–4 of secondary winding N1–N2. In this circuit, since the transmitter is connected across the same number of turns (Np) as in the circuit shown in E, the action is essentially the same. Use of the autotransformer, however, does result in a slightly more efficient circuit.

60. Operation of Antisidetone Circuit

a. Figure 74 shows the circuit between two local-battery telephone sets with antisidetone circuits and also the actual relation of the coil windings. The induction coil is of the autotransformer type with a continuous winding wound in the same direction between terminals 1 and 4. The coil has connections on the winding at intermediate points 2 and 3. These connections, together with the end connections, 1 and 4, are brought out to terminals mounted on the coil frame. In the antisidetone circuit the transmitter, handset switch, and battery are connected to terminals 2 and 3. Winding 2–3 is the inner winding, or primary, of the coil. The receiver is connected to terminal 3 and one terminal of capacitor C2. Winding 3–4 is part of the outer winding of the induction coil. The secondary is the complete coil between terminals 1 and 4. The terminal notations of figure 74 are similar to those in F, figure 73. Capacitor C2 is

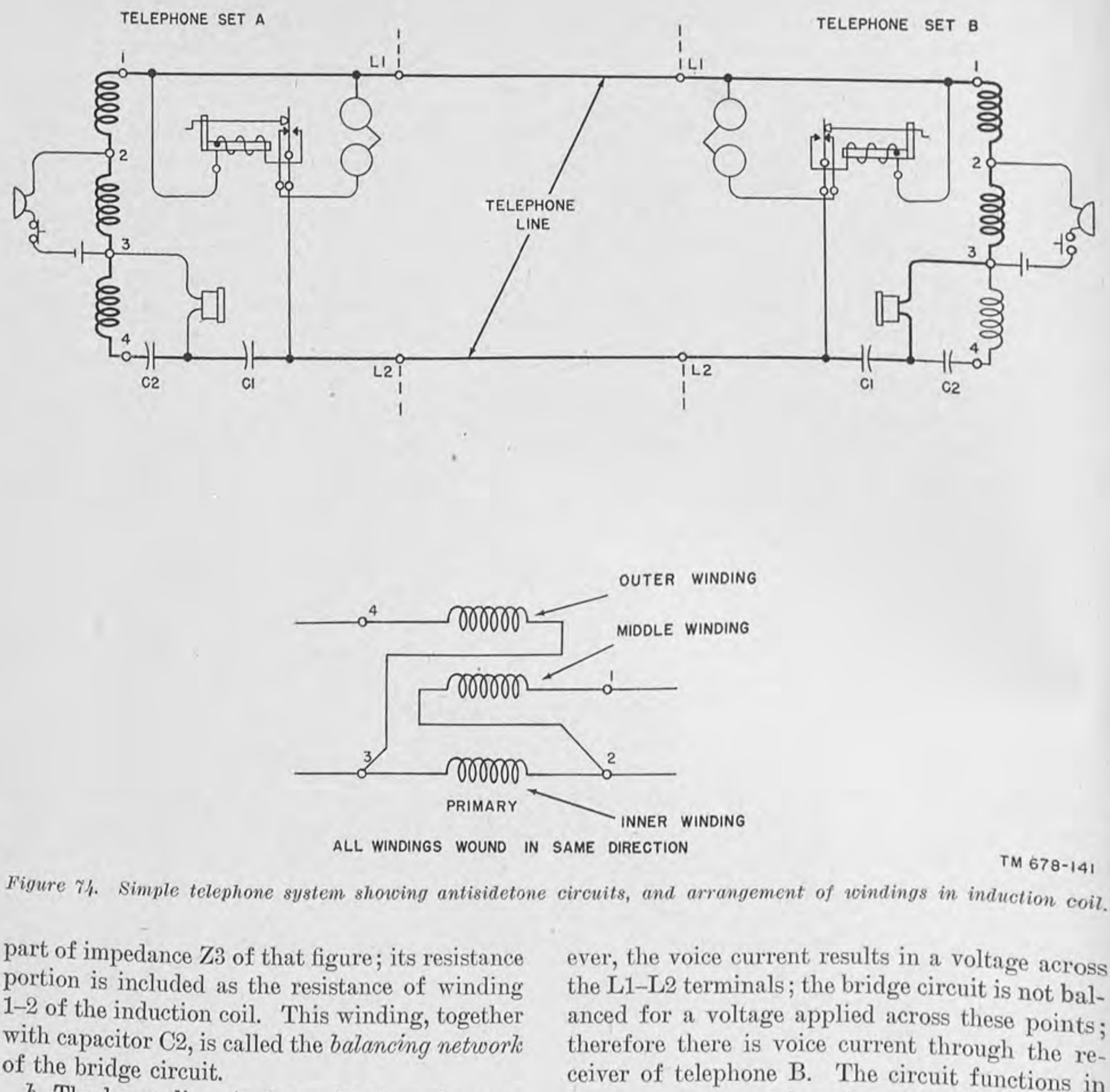


Figure 74. Simple telephone system showing antisidetone circuits, and arrangement of windings in induction coil.

part of impedance Z3 of that figure; its resistance portion is included as the resistance of winding 1–2 of the induction coil. This winding, together with capacitor C2, is called the *balancing network* of the bridge circuit.

b. The heavy lines in figure 74 show the complete talking circuit between the two local-battery telephone sets. A person speaking into the transmitter of telephone A produces a varying voice current in the 2–3 winding of the induction coil. This induces a voice-current voltage across terminals 1–4 which provides a voice current in the circuit of the transmission line and telephone set B. For the voice-current voltage applied to the 2–3 winding, telephoneA, the line, and telephone B form a balanced-bridge circuit for the receiver of telephone A. As a result, the voltage between point 3 and the straight-line plate of capacitor C2 is zero, and there is no voice current through the receiver of telephone A. At telephone B, however, the voice current results in a voltage across the L1–L2 terminals; the bridge circuit is not balanced for a voltage applied across these points; therefore there is voice current through the receiver of telephone B. The circuit functions in the same manner when the transmitter of telephone B provides voice current in the circuit to telephone A, except that the situation is reversed. The receiver of telephone B then is across the balanced-bridge circuit for the voice-current voltage of its transmitter. There is no current through receiver B, but there is current through receiver A. Thus, the antisidetone circuit reduces sidetone by preventing the voice current of the local transmitter from passing through the local receiver.

c. Another explanation of antisidetone action can be obtained by considering the simplified circuits of figure 75. The transmitter and its battery are connected, in A, to terminals 2 and 3 of the

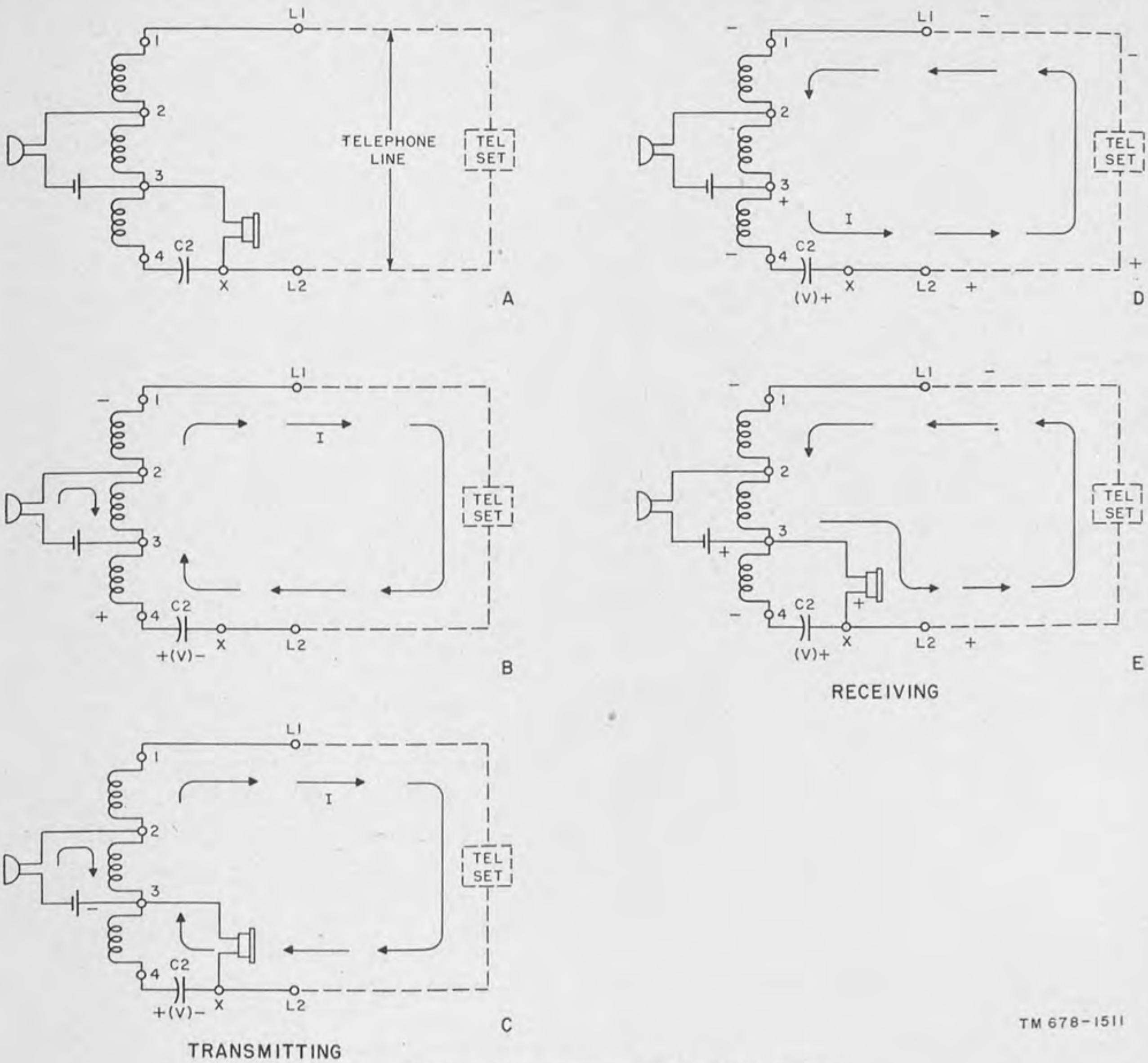


Figure 75. Antisidetone action, functional diagrams.

autotransformer. The secondary of the autotransformer is the complete winding between terminals 1 and 4. The receiver is connected to terminal 3 of the autotransformer and to one side of capacitor C2. Capacitor C2 is necessary to complete the antisidetone action.

(1) *Transmitting.* To show the reason for the location of the receiver in the circuit, assume first that the receiver is omitted, as in B. When a person speaks into the transmitter, a varying voice current is set up in the 2–3 winding of the autotransformer. This action results in a varying voltage between terminals 1 and 4 (the secondary) of the autotransformer. To simplify the explanation, consider an instant of time when the polarity of the induced voltage is as shown, with terminal 1 negative and terminal 4 positive. This voltage causes a current to flow through the external circuit, which consists of the telephone line and the distant telephone set, capacitor C2, and the autotransformer. The direction of current flow through the circuit is from the negative terminal to the positive terminal of the voltage source. As a result of this current, a voltage, V, which has the polarity shown, is developed across capacitor C2. By prop-

erly designing the circuit, the voltage V, can be made equal to the induced emf of winding 3–4 of the autotransformer, but polarities of the two voltages are opposite. Thus, between point 3 on the autotransformer and point X on the diagram there is zero *difference* in potential. If, now, the receiver is connected to these two points, as in C, no current will flow through the receiver, since there is no voltage difference across it. Therefore, by placing the receiver in this location, a person speaking into the transmitter of the ideal antisidetone circuit does not hear his own voice in his receiver. For complete sidetone elimination, it is necessary for the voltage, V, developed across capacitor C2 to be exactly equal to the emf of the 3–4 winding of the autotransformer. This condition seldom occurs in actual practice because certain factors tend to change the voltages. First, the different voice frequency currents transmitted will vary the impedance of the telephone line and distant telephone set in addition to changing the reactance of capacitor C2. Different impedances cause different voltage drops throughout the circuit. Second, if a telephone line with a different impedance is used in place of the original telephone line, the different impedances will change the voltage drops throughout the circuit. Still other changes in voltage in the circuit would occur if the distant telephone were replaced by a telephone the impedance of which is not the same as the original telephone set. Since these conditions exist in practical telephone circuits, it is possible to reduce sidetone but never to eliminate it. However, as explained in paragraph 59, some sidetone is desirable.

(2) *Receiving.* In receiving, as in D and E, the source of voltage is from the circuit of the distant telephone set, which impresses a voltage across terminals L1 and L2. Now, consider an instant of time when the distant telephone applies a voltage across L1 and L2, as in D. The current flow that results from this applied voltage causes a voltage drop, V, across capacitor C2, plus a voltage drop across terminals 4–1 (now the primary) of the autotransformer. The autotransformer winding, 1–4, is now a part of the load (a receiver of voltage); whereas, in transmitting, it was a part of the source of voltage. This means that, in receiving, the voltage of winding 3–4 will have the same polarity as the voltage, V, and the two voltages will aid each other. Thus, in receiving, a potential difference exists between terminal 3 of the autotransformer and point X of the diagram. If the receiver again is connected to these points, as in E, current will flow through the receiver. Current takes the path through the receiver instead of the alternate path X–4–3 (actually a small amount of current does follow path X–4–3) because the impedance offered to the flow of current by the receiver is considerably lower. Therefore, the antisidetone circuit provides a path to the local receiver for voice currents originating at the distant telephone set.

61. Local-Battery Switchboard

a. Purpose. Communication between two telephone stations can be effected through a connecting telephone line, but practical communication among many telephone stations requires that the telephone line from each one be connected to a switchboard. The switchboard allows any two of the stations to be connected to each other.

b. Functions. The switchboard contains circuits and components which permit the following actions:

(1) The calling telephone station is able to signal the switchboard operator.
(2) The switchboard operator can talk and listen to the calling telephone station.
(3) The switchboard operator is able to signal a called telephone station.
(4) The switchboard operator can talk and listen to the called telephone station.
(5) The switchboard operator can interconnect telephone stations connected to the switchboard in the same central office or to those in other central offices.
(6) The called or calling telephone station can notify (signal) the switchboard operator on completion of a telephone conversation.

62. Circuits of Local-Battery Switchboard

The circuits of the local-battery switchboard which perform these functions may be classified as *line* circuits, *trunk* circuits, *cord* circuits, and *common* circuits.

a. Line Circuits. The telephone line from each telephone station is connected to an individual line circuit of the switchboard. Thus, a switchboard with 20 line circuits has connected to it a telephone line for each of 20 telephone stations.

b. Trunk Circuits. The trunk circuit, or trunk, is a switchboard circuit similar to the line circuit. It is connected to the trunk (transmission line) from another switchboard.

c. Cord Circuits. The cord circuits are links used in interconnecting two line circuits, two trunk circuits, or a line and a trunk circuit. The number of cord circuits of a switchboard depends on the amount of telephone traffic the switchboard is required to handle. The telephone traffic is determined by the number of telephone calls originating from the telephone stations served by the switchboard, and the average duration of the calls. Switchboards usually have fewer cord circuits than line circuits, the number depending on the type of switchboard.

d. Common Circuits. Common circuits are circuits that are used with the line circuits or the cord circuits or with both. (A grouping, or transfer circuit, which sometimes is used at large switchboards, will be discussed later.) The four principal common circuits are the operator's telephone circuit, the ringing circuit, the supervisory circuit, and the night-alarm circuit.

(1) The *operator's telephone circuit* permits the switchboard operator to talk with either the calling or the called telephone station. It can be connected to any of the cord circuits by means of a *switchboard lever switch;* therefore it is common to all of the cord circuits.

(2) The *ringing circuit* permits the switchboard operator to ring the called station. Like the operator's telephone circuit, it can be connected to any cord circuits by operating the associated switchboard lever switch; therefore, this circuit is common to all cord circuits.

(3) The *supervisory circuit*, also called the *recall circuit*, is a circuit which enables the calling station to inform the switchboard operator when a telephone conversation is ended. It, too, is common to all cord circuits.

(4) The *night-alarm circuit* is a warning or signaling circuit which causes a bell or buzzer to sound and thus inform the switchboard operator when there is a call to the switchboard from a telephone station. It generally is used for signaling only when the telephone traffic through the switchboard is light, and the operator is not in constant attendance. There is only one night-alarm circuit in a switchboard; therefore it is common to all trunk and line circuits.

63. Components of Local-Battery Switchboard

a. Arrangement of Front of Local-Battery Switchboard. Figure 76 illustrates a local-battery switchboard. It is so designed that the operator can sit comfortably in front for manipulation of its various components. The components are so mounted that they are in complete view and easy reach. Some are on the front *panel* facing the operator, and some are on a shelf called either the *switchshelf* (in front, where the keys are located), or the *plugshelf* (just in the back, where the plugs are located). The operator's telephone set is not part of the switchboard, but is supplied as auxiliary equipment. It contains only the operator's transmitter and receiver, and is connected to the switchboard through the *operator's jack.* A battery mounted in the rear of the switchboard supplies current for the operator's transmitter. The switchboard of figure 76 contains both a hand generator and power-ringing equipment, the latter connected to the switchboard in the rear. The power-ringing equipment, used instead of the head generator for signaling (except in emergencies), automatically provides 20-cycle ringing current. The different types of power-ringing equipment will be discussed later. The type shown in the figure operates on 110-volt, 60-cycle alternating current.

b. Components of Local-Battery Switchboard. The visible components of a local-battery switchboard include line drops, line jacks, cords and plugs, switchboard switches, supervisory or recall drops, and a hand generator. Located within the switchboard are an induction coil, capacitors, and the battery.

(1) The switchboard of figure 76 shows the

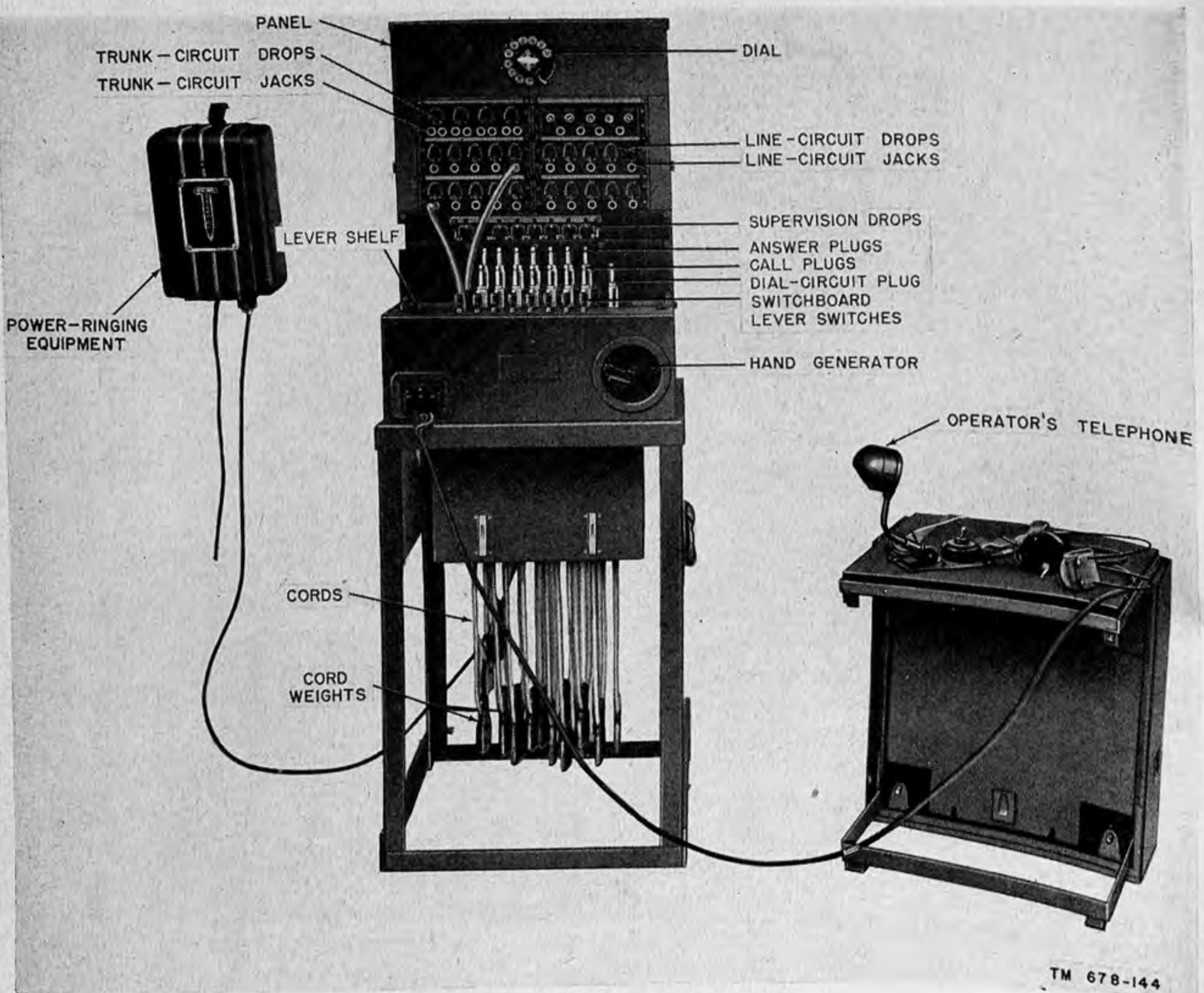


Figure 76. Local-battery switchboard.

relative positions of the components on the panel. This switchboard has 20 *line circuits*, each of which terminates in a line jack mounted on the front panel. A *line-circuit drop*, with its shutter, is mounted above each line-circuit jack. There are four *trunk circuits*, with jacks and associated drops. There are eight *cord circuits*. Two cords and two plugs are connected to each cord circuit. The cords fall downward and are held retracted by pulleys and weights. The free end of each cord passes through the *plugshelf* and terminates in a *plug*. The plugs have a shape permitting easy insertion in the *line* and *trunk jacks*. When not in use, they lie in a double row along the plugshelf, the *answer plug* (of each cord circuit) in back, the corresponding *call plug* (of the same cord circuit) in front. On the *keyshelf* in front of each pair of cord circuit plugs is an associated *switchboard lever switch*. The switch lever stands vertical in the nonoperated position. *Pushing* it toward the panel (away from the operator) connects the operator's telephone circuit to the cord circuit; *pulling* it toward the operator connects the ringing circuit to the cord circuit. Eight *supervisory* or *recall drops*, with their shutters, are mounted on the panel, one opposite each set of answer and call plugs of a cord circuit.

(2) The components just mentioned now will be discussed in connection with the operation of the circuits in which they are

used. (The dial at the top of the switchboard panel and its circuit will be discussed briefly in a later chapter.)

64. Operation of Local-Battery Switchboard

The operation of a local-battery switchboard in completing a telephone call between two telephone stations connected to it is explained with reference to the block diagram of figure 77. This switchboard has six line circuits and three cord circuits. All the various circuits are shown in block form within the switchboard: the line circuits, cord circuits, operator's telephone circuit, ringing circuit, and supervision circuits. Assume that a person at telephone station A, the calling telephone, desires to call a person at telephone station D, the called telephone.

a. The person at telephone station A rotates the hand generator of his telephone set (fig. 77). This provides 20-cycle ringing current through the telephone line to the line circuit of the switchboard (fig. 77). The ringing current operates the line-circuit drop and causes the *drop shutter* to fall. The falling of the drop shutter is a visual indication to the switchboard operator that station A is calling.

b. When the drop shutter falls, the switchboard operator selects the *answer* (back) plug of one of the three cord circuits and inserts it in the line-circuit jack of station A (fig. 78); at the same time, the operator restores the drop shutter to its normal closed position. The operator then pushes the lever switch of the selected cord circuit into the listening position (upward in the diagram). This connects the operator's telephone circuit to the cord circuit, and permits him to talk to the calling telephone and ask for the number of the called telephone. The heavy lines of figure 78 show the circuit at this stage.

c. After the operator is told the identity of the called telephone (station D), he takes the *call* (front) plug of the *same* cord circuit used in answering station A and inserts it in the line-circuit jack of station D (fig. 79). The operator then pushes the switchboard lever switch into the ringing position (downward in the diagram). This connects the ringing circuit to the cord circuit. With the switch in the ringing position, the operator next rotates the switchboard hand generator and provides 20-cycle ringing current through the telephone line to the ringer of station D. (If the switchboard is provided with power ringing, pushing the switch to the ringing position supplies 20-cycle ringing current from

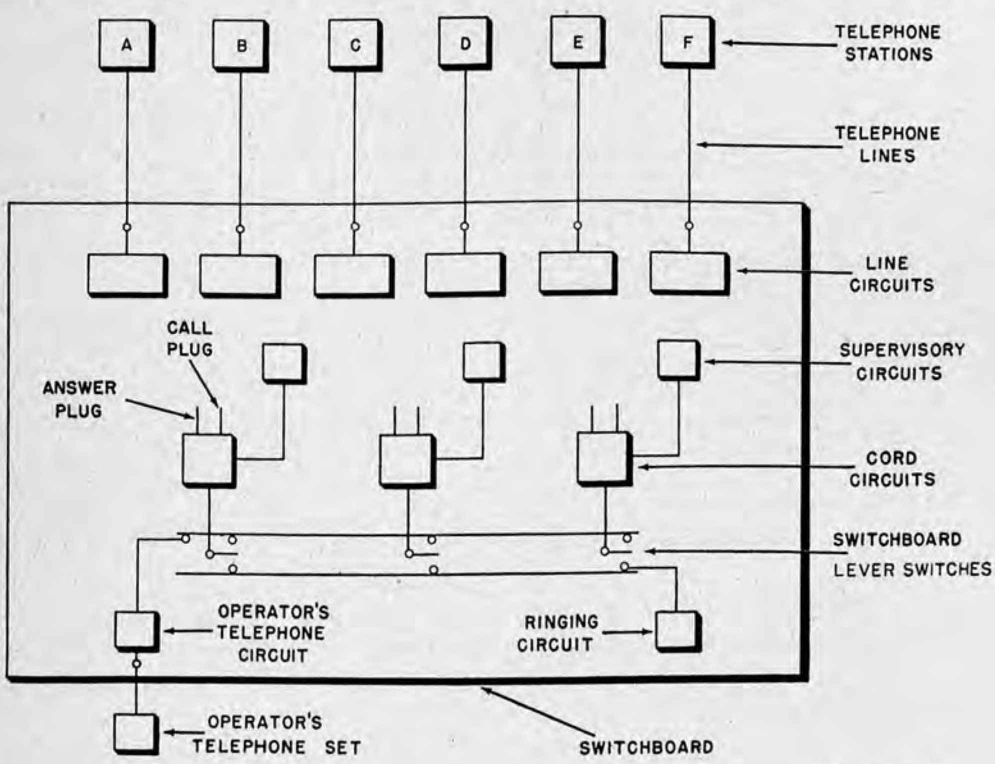


Figure 77. Circuits of local-battery switchboard.

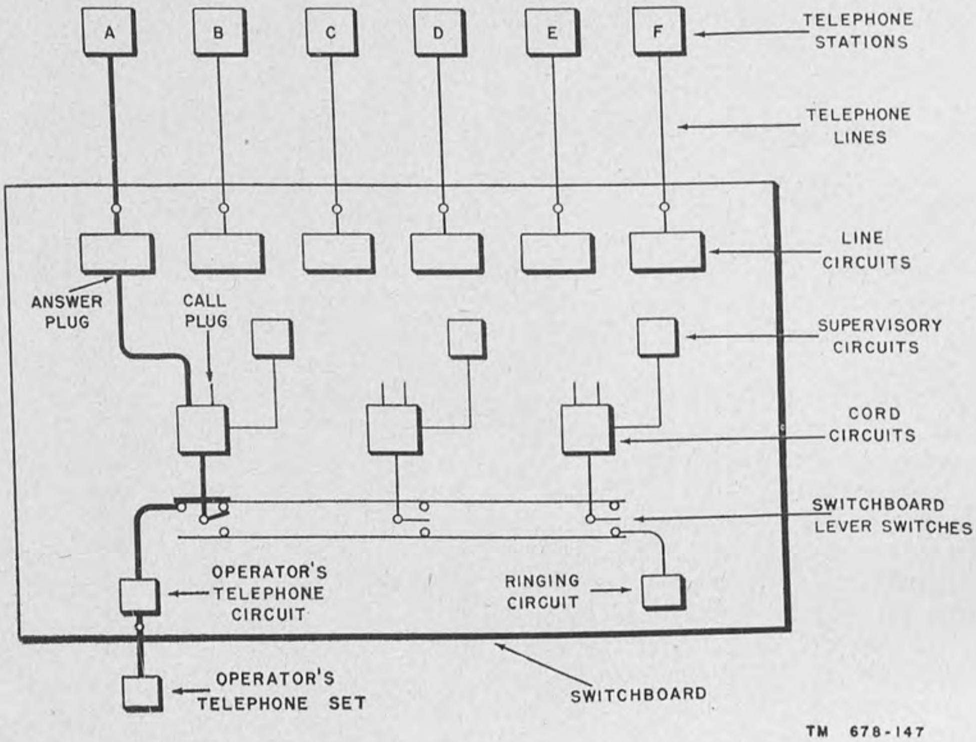


Figure 78. Switchboard connection to station A.

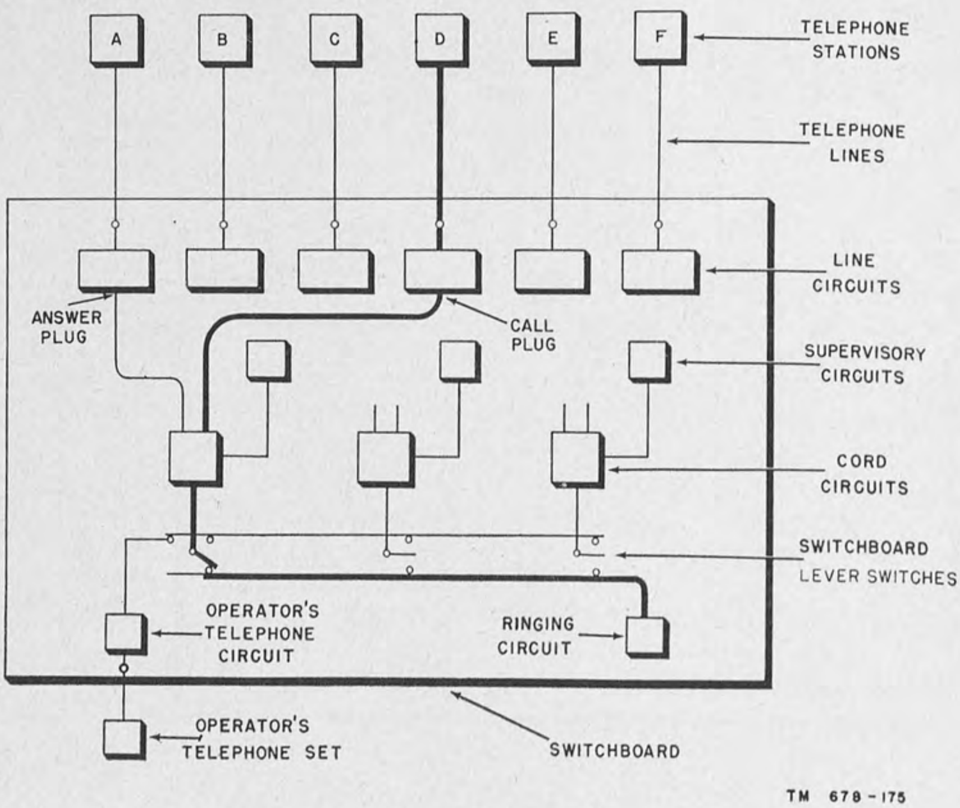


Figure 79. Ringing of station D.

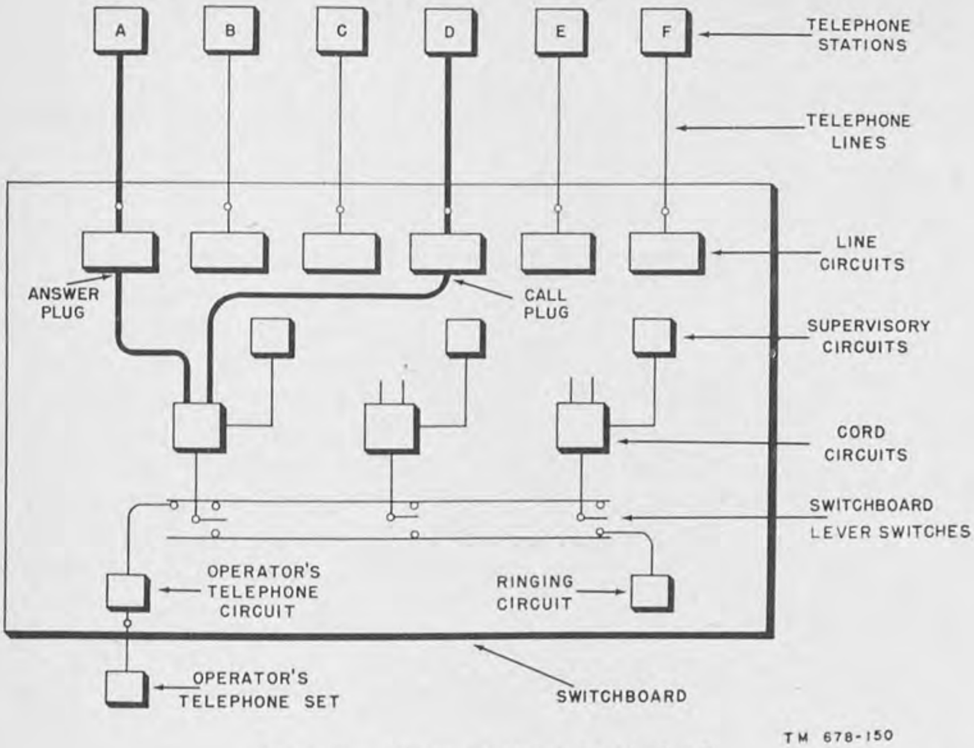


Figure 80. Station A connected to station D.

the power-ringing machine through the telephone line to the ringer of station D; the hand generator need not be used.) After ringing station D, the operator pushes the switch back into the listening position (upward in the diagram) and waits for station D to answer.

d. When station D answers, the operator restores the switchboard lever switch to the normal (vertical) position and the conversation proceeds (fig. 80). When the conversation between the stations is over, either of the persons who have conversed (but usually the caller) rotates the hand generator at his telephone. This provides 20-cycle ringing current through the telephone line and cord circuit to the supervisory drop, causing the shutter of the supervisory drop to fall and indicating to the switchboard operator that the conversation is completed. The operator then listens, or challenges the telephone users; and, finding the conversation is over, he removes the answer and call plugs from the line jacks and restores the shutter of the supervision drop.

65. Switchboard Jack

a. Function of Switchboard Jack. The *switchboard jack* is the switching connector for the line circuits. Each line circuit is connected to a jack, mounted on the front panel of the switchboard. The jack is designed to be used with the plug of the cord circuit; together they form the complete connector.

b. Structure and Operation of Switchboard Jack.

(1) Figure 81 shows a local-battery switchboard jack and its symbol. The jack has two springs, the *tip spring* and the *ring spring*. Each spring bears a contact, and the sleeve provides a third contact. The names, *tip*, *ring*, and *sleeve*, are the same as the names of the parts of the plug with which the jack elements make contact when the plug is inserted in the jack. Local-battery jacks require only two contact points—the tip, on the tip spring, and the ring, on the ring spring; the ring spring and sleeve contact usually are connected.

(2) The jack springs are flexible. They are separated by insulators, and springs and insulators are assembled in a pile-up (fig. 81). The pile-up is fastened to the frame of the jack, the end of which forms the sleeve contact. The jack may be designed to perform additional switching

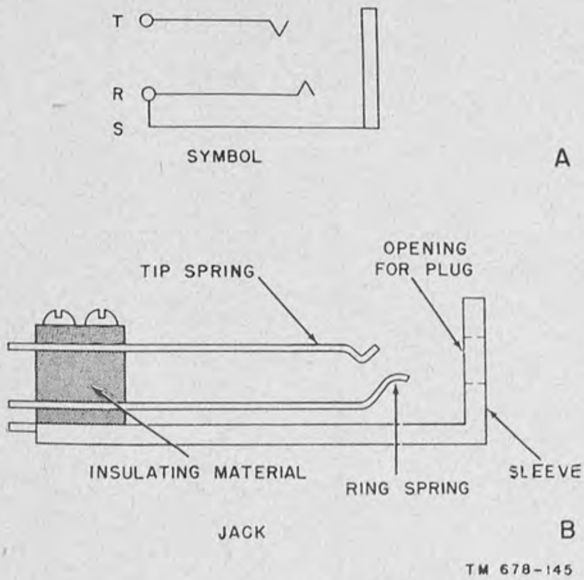


Figure 81. Local-battery switchboard jack.

functions by the addition of other springs to the pile-up. Usually, such added springs make contact with the tip and ring springs by means of welded-on contact points. B, figure 82, shows a jack with two added springs. When the plug is inserted in the jack, the tip and ring springs are pushed away from the normal position and break the contacts. A shows the symbol for this type of jack, with inserted plug.

(3) Figure 83 contains schematic diagrams of local-battery jacks with various spring combinations. A and B show the combinations most frequently found in local-battery switchboards—the single cut-off and double cut-off types. The jack in C breaks one contact and makes another,

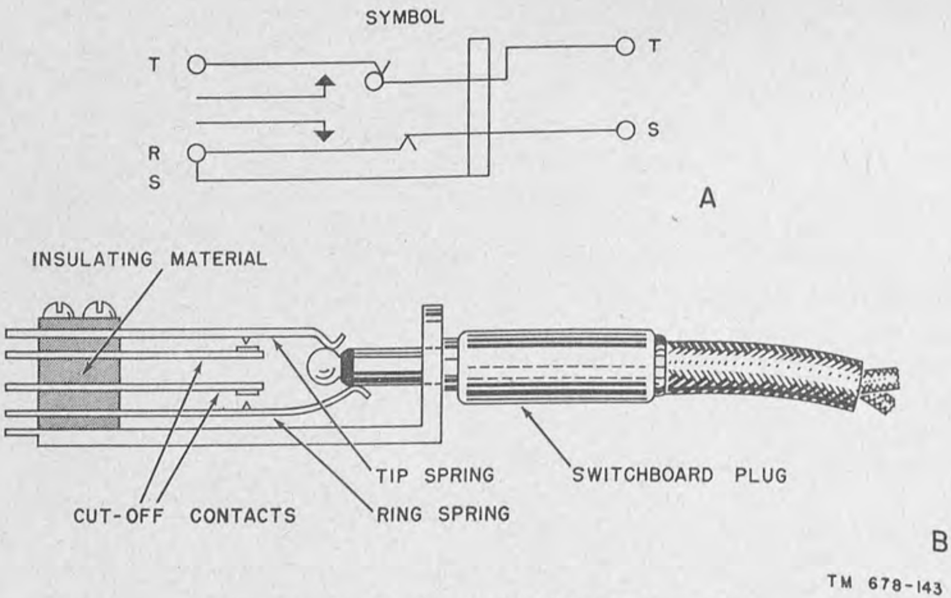


Figure 82. Local-battery jack and plug, with symbol.

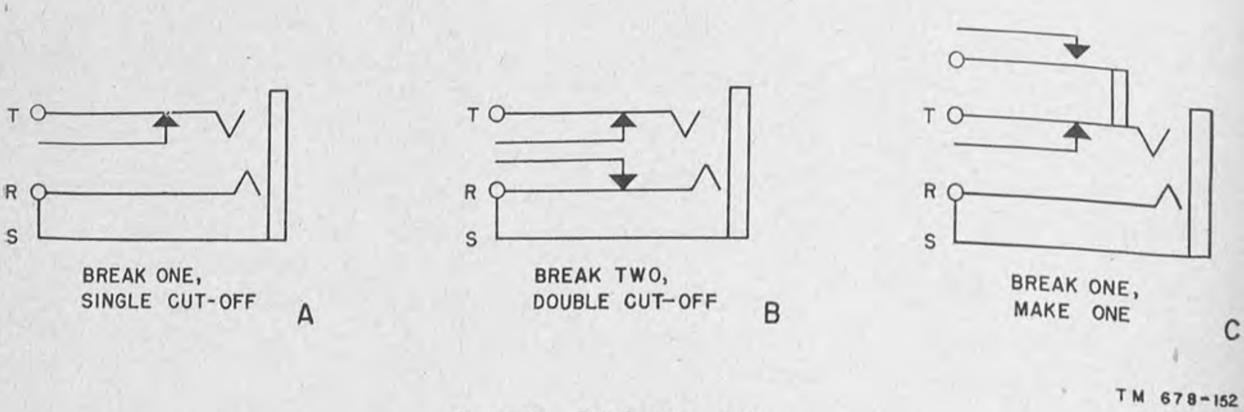


Figure 83. Local-battery jacks.

when the plug is inserted. When the tip spring is forced upward by the plug, an insulator between the tip spring and the upper spring forces the upper spring against the top contact of the jack, making this contact and breaking the lower one. The common-battery plug will be discussed in paragraph 70.

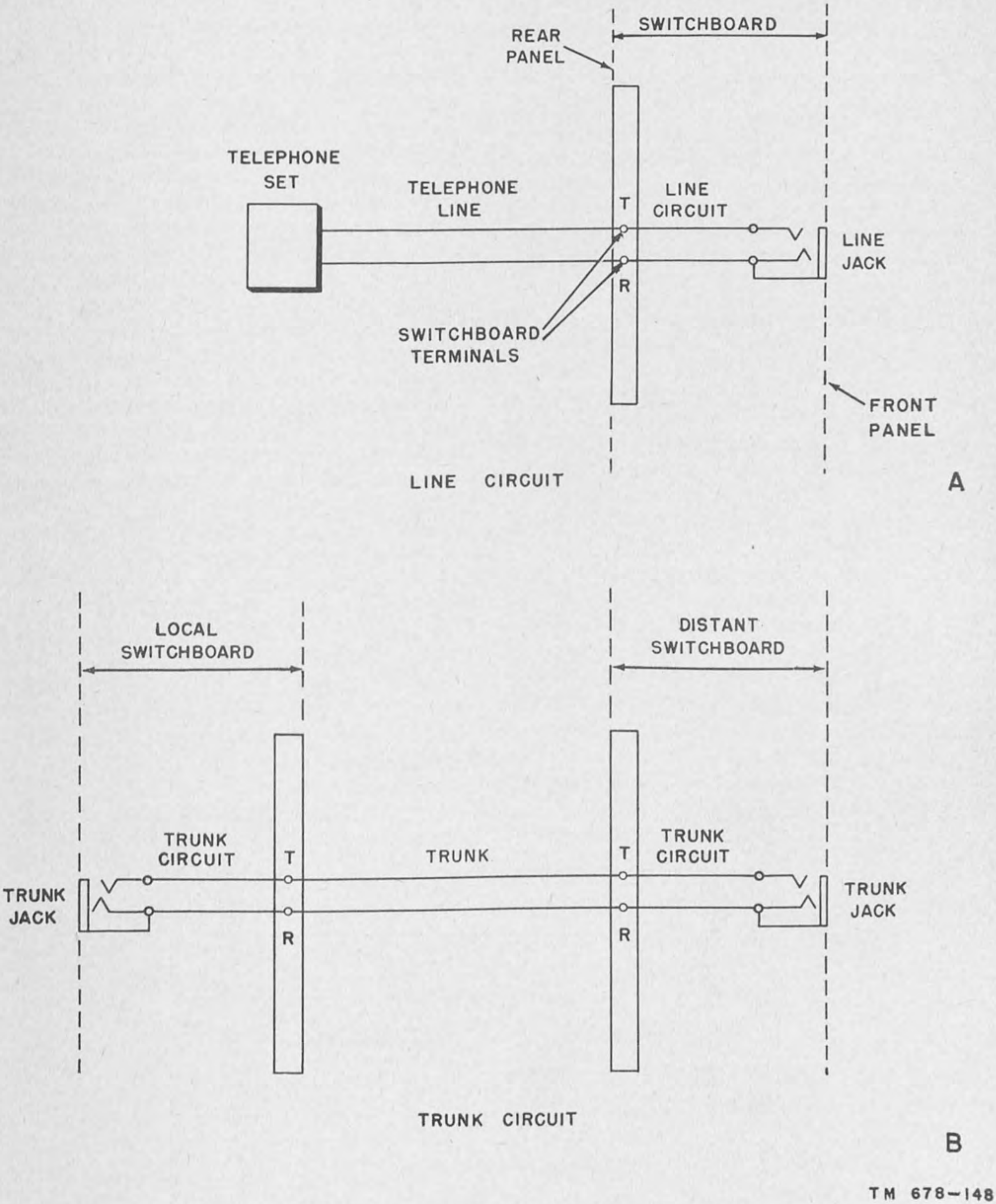


Figure 84. Simple line and trunk circuits.

66. Simple Line Circuit and Trunk Circuit

a. Simple Line Circuit. The *line circuit* in A, figure 84, consists only of the jack and the wire connecting it to the terminals of the telephone line on the back panel of the switchboard. Thus, by means of the line circuit, the telephone station has a direct connection to the front panel of the switchboard.

b. Simple Trunk Circuit. One or more line circuits at each switchboard are used as *trunk circuits.* These trunk circuits are identical with the line circuits, but they serve to connect the switchboard not to a telephone station, but to another switchboard either in the same central office or at a distant central office.

(1) The simple *trunk circuit* shown in B is identical with the simple line circuit in A. In place of the telephone line from the telephone station, however, the *trunk* (transmission line) connects the local and distant switchboards through their terminals on the back panels. As a result, the distant switchboard has a direct connection to the front panel of the local switchboard.

(2) Since the switchboard trunk circuit is exactly like the switchboard line circuit, the following material on the line circuit will apply to the trunk circuit as well. The two circuits vary somewhat in operation, but differences will be noted.

67. Local-Battery Line Drop

a. Function of Line Drop. The local-battery *line-drop* is a visual signal used to secure the attention of the switchboard operator. It is connected to the jack of the line circuit, and it indicates by the fall of its shutter that a telephone station is calling the switchboard. The line drop is mounted directly above the jack of the line circuit with which it is connected or associated. This enables the operator to tell which line is calling.

b. Operation of Line Drop. Figure 85 is a simplified diagram of a local-battery line drop. It consists of an electromagnet and armature and a shutter rod and shutter. The line drop is designed to operate on the 20-cycle ringing current supplied from the hand generator of the local-battery telephone set. When ringing current is supplied to the line drop, the core of the electromagnet is magnetized and attracts the armature. Because the supply is alternating current, the core is magnetized first in one direction and then in the other, as the current varies from zero to maximum in each half-cycle. As a result, the ringing current causes the armature and attached shutter rod to vibrate. However, when the armature is attracted, the shutter rod releases the shutter, allowing it to fall.

c. Structure of Line Drop. Figure 86 shows the structure of a local-battery line drop.

(1) The coil of the electromagnet is made of insulated copper wire wound on a solid iron core. The winding has a resistance which, in different types, varies from 80

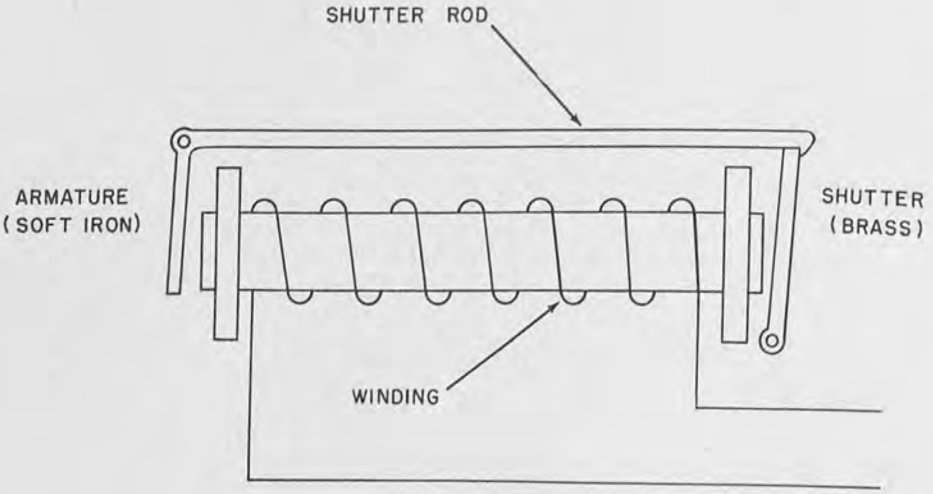


Figure 85. Local-battery line drop.

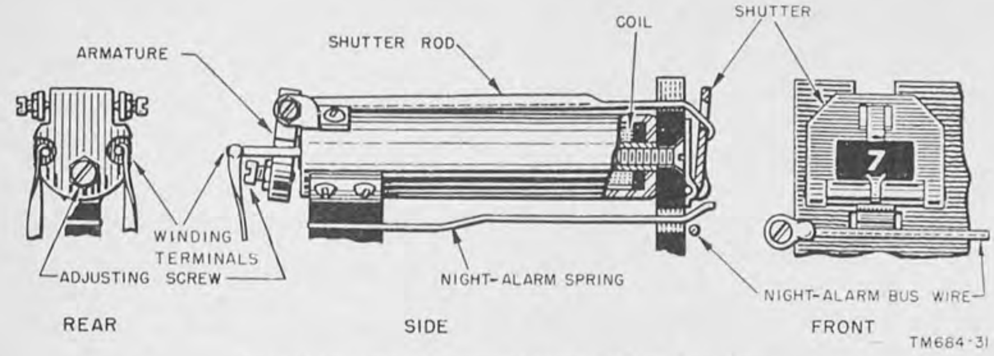


Figure 86. Three views of local-battery line drop.

to 1,600 ohms. The line drop most commonly used has a winding resistance of 350 ohms. The coil and core of the electromagnet are called a *spool*. The ends of the spool are fitted with insulating fiber, and the spool is placed in a soft-iron cup or tube. The cup prevents leakage of the magnetic lines of force, and, by decreasing the reluctance of the magnetic return path, increases the strength of the magnetic field. This makes the drop more sensitive to weak signaling current. The soft-iron cup also acts as a magnetic shield, preventing magnetic interference with adjacent circuits in the switchboard.

(2) The armature hangs between pointed-pivot adjusting screws, provided with locknuts. The adjusting screws determine its range of movement, on one side preventing it from making contact with the core of the magnet and from possibly sticking in an operated position because of residual magnetism. The armature and the terminals are at the rear of the drop. This arrangement permits readjustment and resoldering without disturbing the switchboard operator.

(3) One end of the shutter rod is attached to the armature, and the other end passes through an opening in the shutter. The shutter is made of brass so that it will be unaffected by the magnetic lines of force accompanying the ringing current. When the armature is attracted, the bent end of the shutter rod strikes the upper edge of the opening in the shutter; this forces the shutter outward and causes it to fall. When a drop shutter of this type falls, it must be restored manually by the operator.

(4) Beneath the line drop, from front to back, is the night-alarm spring, and beneath the shutter, in front, is the night-alarm bus wire. When the shutter falls, the weight of the shutter forces the night-alarm spring into contact with the night-alarm bus wire, closing the night-alarm circuit. The night-alarm circuit will be described later.

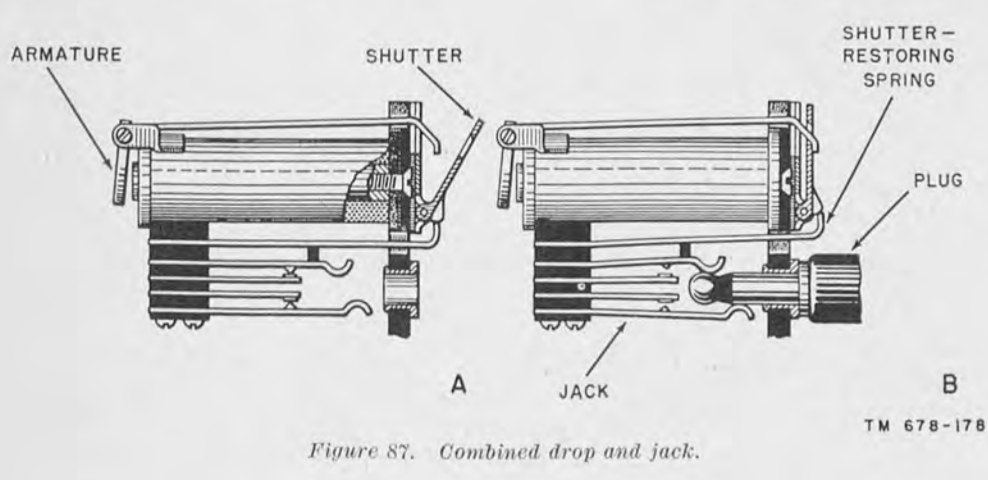


Figure 87. Combined drop and jack.

68. Combined Line Drop and Jack

Because the line drop and the line-circuit jack are associated closely, they usually are constructed in one unit. Figure 87 illustrates a combined drop and jack. The terminals of the drop are connected to separate spring contacts on the jack. After the shutter has fallen, a projection at its bottom rests against the end of a shutter-restoring spring, as in A. This spring is fastened to the tip spring of the jack by an insulated bushing which causes the two springs to move together. When a plug is inserted in the jack, as in B, the tip spring together with the restoring spring is forced upward, causing the restoring spring to push against the shutter and return it to its normal position.

69. Line Circuit With Line Drop

Figure 88 shows a line circuit with its associated line drop. The line drop is connected to the tip and ring springs of the jack, which bear, respectively, the tip and ring contacts of the jack. Thus there is a complete circuit from the distant telephone set, through the line drop. A person at the telephone station desiring to call the switchboard rotates the hand generator of his telephone set. This provides 20-cycle ringing current through the telephone line to the line drop in the line circuit at the switchboard. The ringing current energizes the coil which attracts the armature, causing the drop shutter to fall. The fall of the drop shutter signals the switchboard operator that a telephone station is calling. Because the line drop is just above the line jack, the operator at once identifies the particular line circuit of the incoming call.

70. Switchboard Cords and Plugs

The switchboard cord, with its plug, provides a flexible connector which enables the cord circuit to be connected to any line-circuit jack on the panel of the switchboard.

a. Function.

(1) Most local-battery switchboards have cords and plugs associated in pairs, one cord and plug connected to each end of the cord circuit. The plug which makes the initial connection with a line circuit in response to its signal is called the *answer plug*, because the operator uses this plug in answering a call. The other plug of the pair, with which the operator makes the connection to the line-circuit jack of the called telephone, is designated the *call plug*, because the operator uses it to complete the connection (call the other telephone).

(2) The plug end of each cord rests on a plugshelf just back of the keyshelf. The cord passes downward through an opening in the plugshelf, and is connected

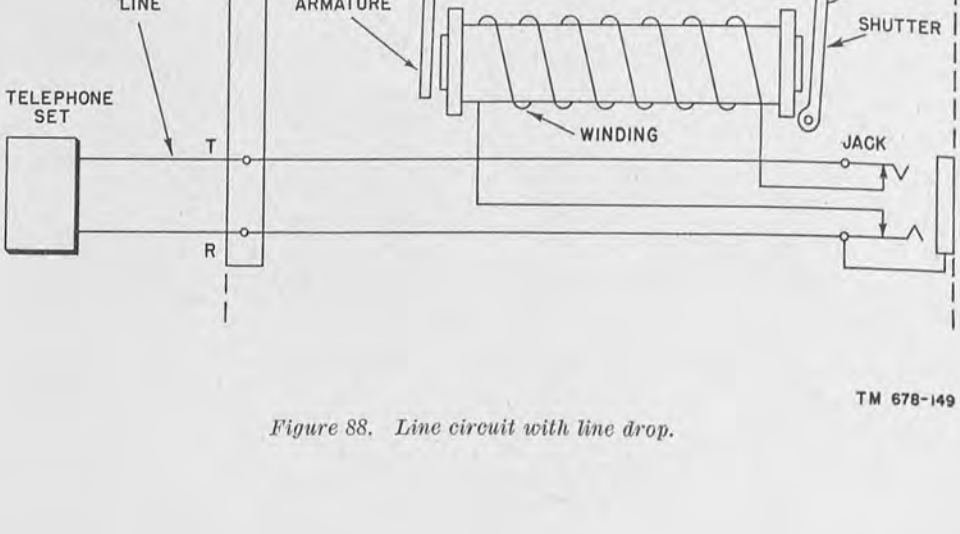


Figure 88. Line circuit with line drop.

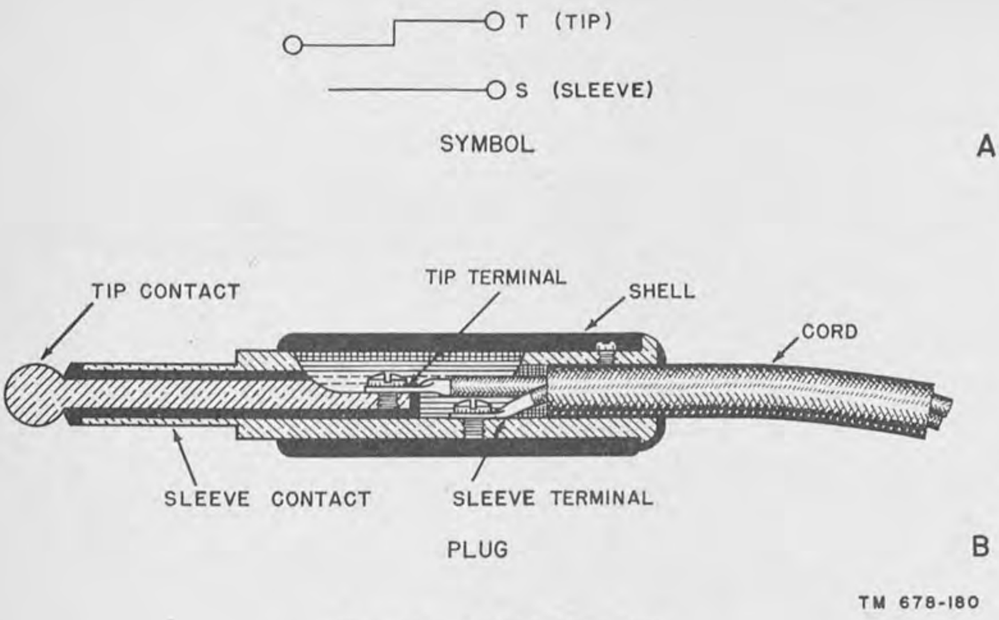


Figure 89. Local-battery plug.

at its other end to terminals on a cord rack mounted on the under side of the switchboard. The switchboard wiring from the other components of the cord circuit is soldered to the cord-rack terminals; the cord conductors are screwed to the terminals, for easy replacement when worn out. A weight mounted on a pulley rides on the cord as it is pulled up and down, keeping it extended and restoring the plug to its place on the plugshelf when the plug is withdrawn from the jack.

(3) One type of local-battery switchboard, called a *monocord switchboard*, uses only one cord and plug for each connection between line circuits. The end of the cord opposite that of the plug is soldered to the terminals of the line-circuit jack. Monocord switchboards have one cord and plug for each line circuit, and therefore have the same number of cords and plugs as line circuits. Connection between line circuits is made by inserting the plug attached to the cord of the line-circuit jack of the calling telephone into the line-circuit jack of the called telephone. The plug of the called telephone is left unused.

b. Structure of Local-Battery Plug.

(1) Figure 89 shows the local-battery plug and its symbol. The plug has two contacting parts, the *tip* and the *sleeve*, separated by an insulator, as in B. They extend toward the back of the plug, where provision is made for connecting the conductors of the cord. The shank of the plug is covered with a removable shell of phenol plastic. When the plug is inserted in the jack, the tip of the plug makes connection with the tip spring of the jack, and the sleeve of the plug makes connection with the sleeve of the jack. The ring spring and sleeve of the jack are strapped together as shown in figure 82.

(2) The contacting parts of the jack have been given the same names as the associated contacting parts of the plug—namely, tip, ring, and sleeve. Use of these terms has been extended further, to designate the associated switchboard terminals and the telephone-line conductors connected to the terminals. Although the present chapter is concerned with local-battery telephony, it is necessary at this point to refer to the common-battery plug (fig. 90), to explain how the names of the three parts were derived. *The common-battery plug*, like the local-battery plug, has a *tip* contact and a *sleeve* contact, but it differs from the local-battery plug in that it has, in addition, a *ring* contact. The ring contact obtains its name from its shape, which is

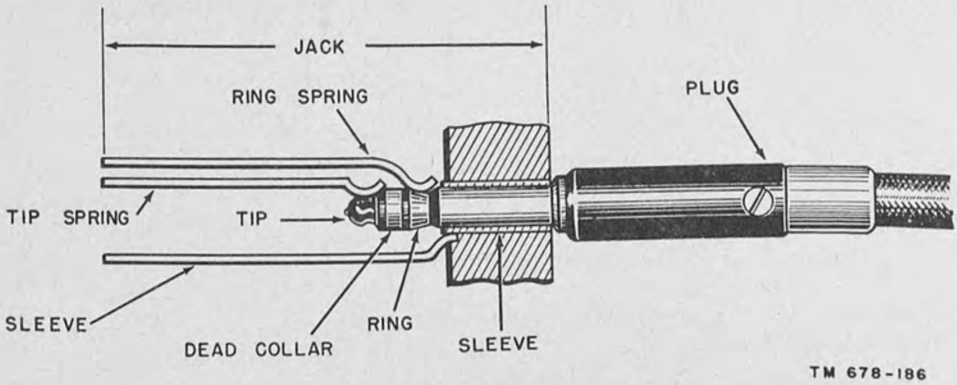


Figure 90. Common-battery plug.

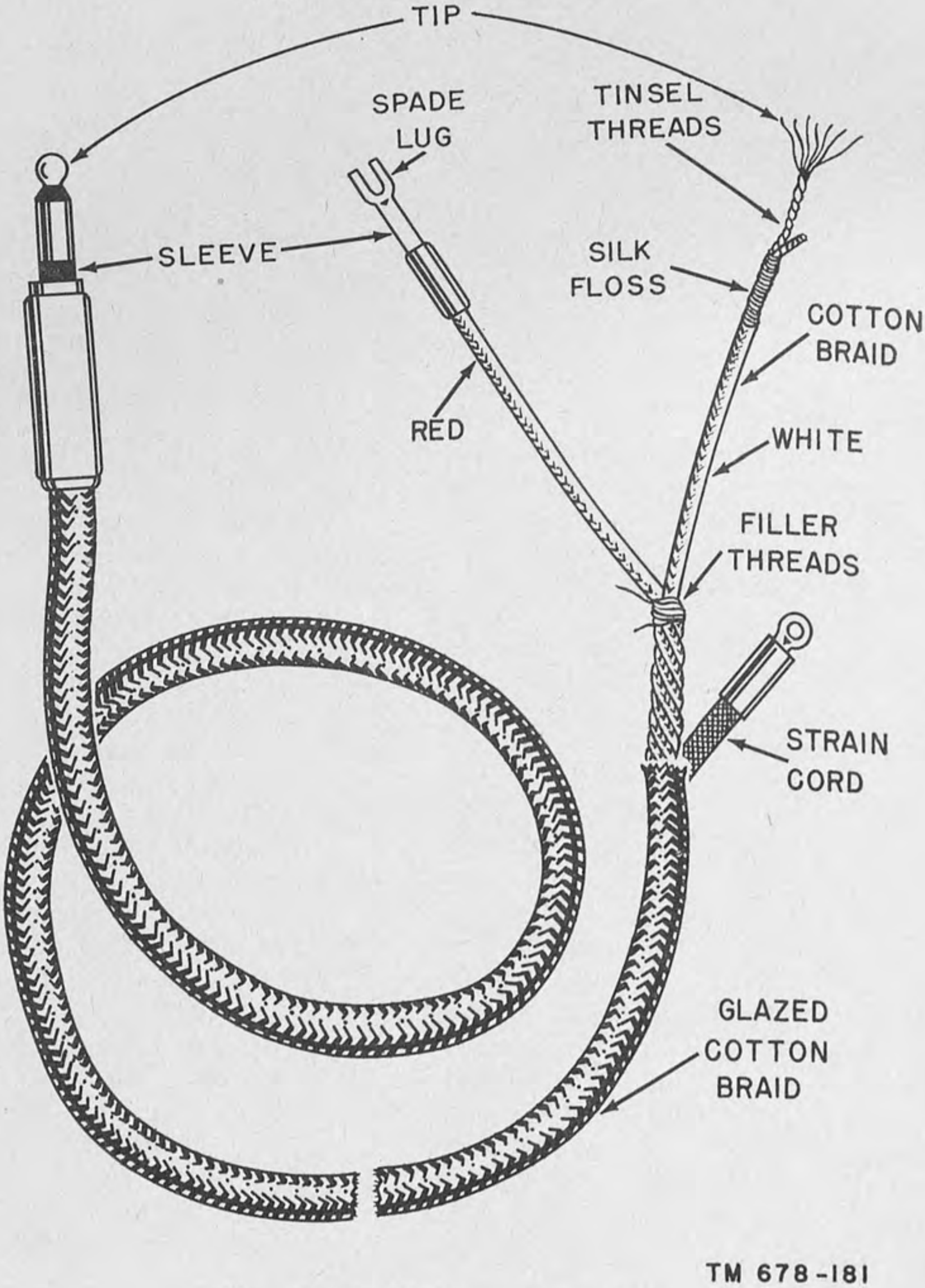


Figure 91. Local-battery cord and plug.

that of a ring, or short collar. It is separated from the tip contact by insulators and another short collar which serves no connecting function and is therefore called a *dead collar*. The dead collar prevents a short circuit between the tip and ring contacts when the plug is inserted. Thus, the names, *tip*, *ring*, and *sleeve*, are applied respectively to the three contacts of the common-battery plug, in order from front to rear. These names, in turn, are applied to the connecting contacts of the *jack:* The tip spring of the jack makes contact with the tip of the plug, the ring spring with the ring of the plug, the sleeve with the sleeve of the plug. Since the two conductors of the telephone line ordinarily terminate in the tip and ring springs in the jack, the terms *tip* and *ring* also are applied to the *line conductors*. Thus, even at a distant point such as the telephone at a telephone station, the telephone-line conductors have their tip and ring sides.

(3) Although the local-battery plug has only two contacts, the two conductors of the

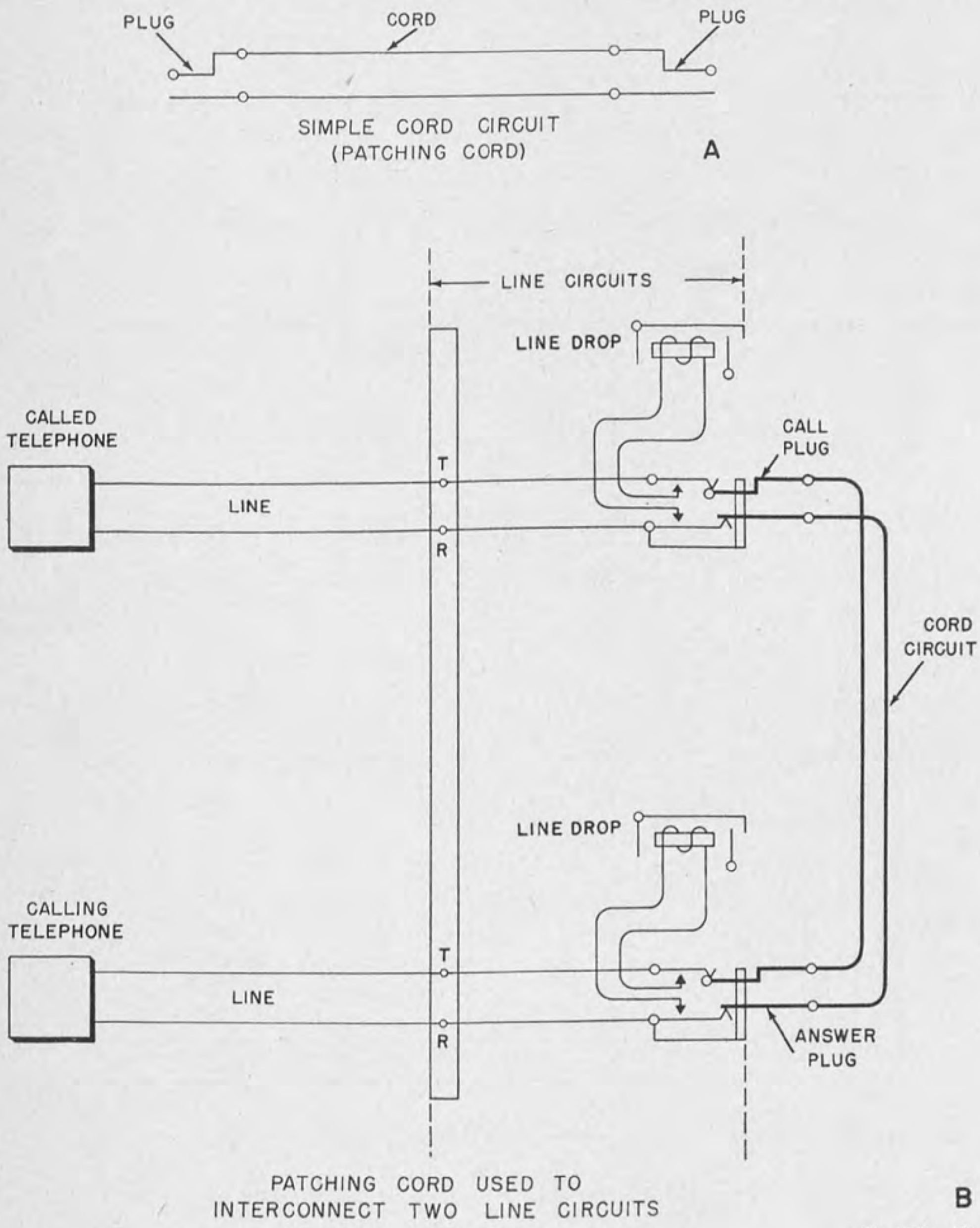


Figure 92. Simple cord circuit.

telephone line retain the same terms, tip and ring, and connection at the switchboard is made to the tip and ring springs of the jack. However, the ring spring of the jack is connected to the sleeve of the jack. When the local-battery plug is inserted in the jack, its sleeve therefore makes contact with both the sleeve and the ring of the jack.

c. Structure of Local-Battery Cord. Figure 91 illustrates a *local-battery cord* with attached plug. The copper tinsel threads used for the conductors reduce the possibility of breaking from the constant flexing they undergo. The cotton-braid insulation is color-coded for ease in identifying the tip and ring connections to the plug. The spade lug is screwed to the terminal of the cord rack, enabling easy replacement of the cord when it becomes worn. The *strain cord* prevents damage to the cord terminals from direct pulls of the cord. It is attached to a hook on the cord rack.

71. Simple Cord Circuit

a. The simplest cord circuit requires only two conductors, the ends of which are terminated with plugs as indicated in A, figure 92. Such a cord circuit is called a *patching cord*. The heavy lines,

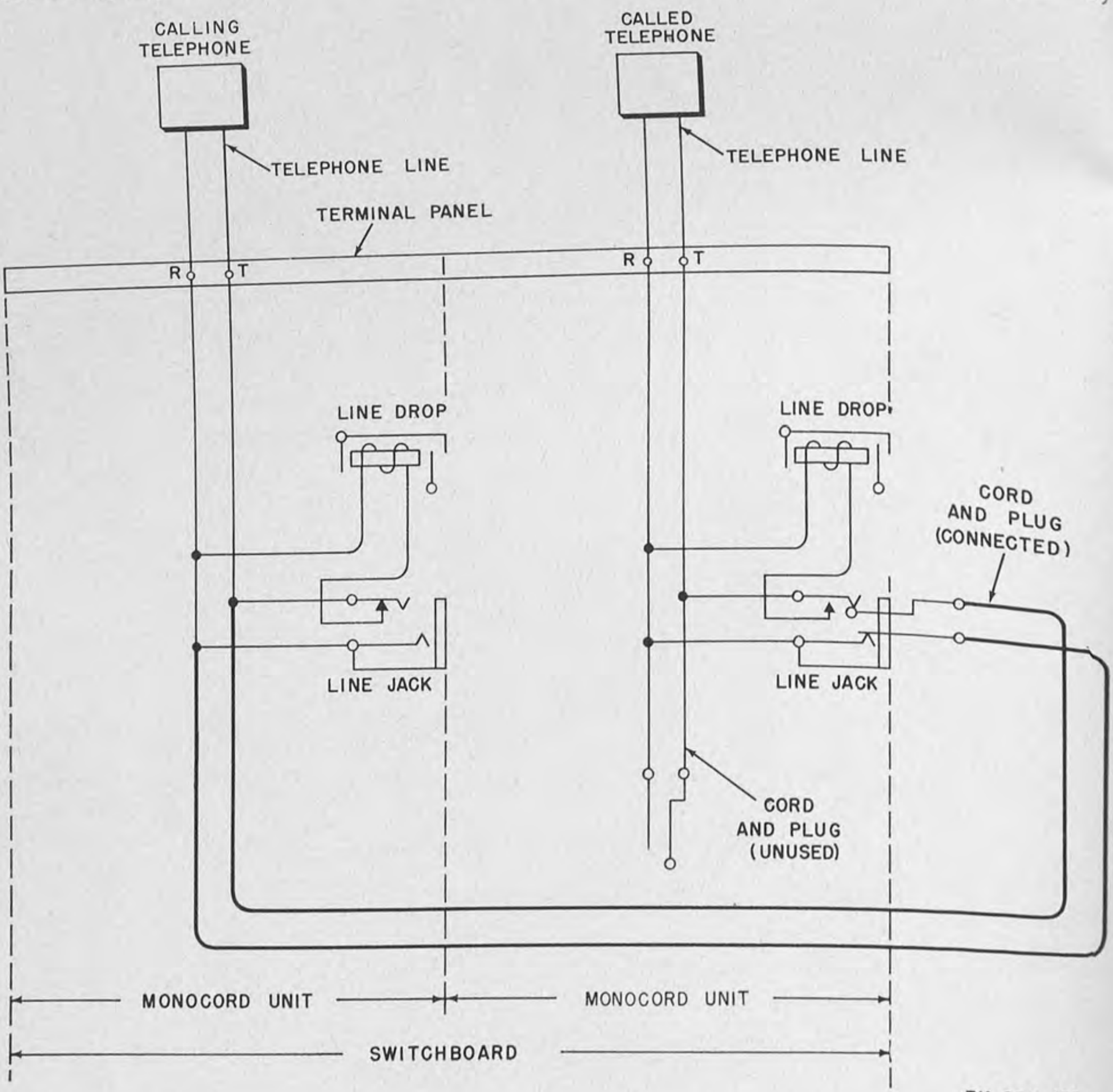


Figure 93. Simple monocord circuit.

in B, show that a patching cord provides a complete connection between two telephones terminated at the switchboard, when one plug is inserted in the line jack of the calling telephone and the other in the line jack of the called telephone. Insertion of the plugs removes both line drops from the circuit by separating the tip and ring springs and thus opening the jack contacts to the line drop.

b. Figure 93 shows a simple *monocord circuit.* Because one end of the cord of the monocord switchboard is connected permanently to the line-circuit jack, the connection between two line circuits is made by inserting the plug of the calling telephone into the line jack of the called telephone. This completes the talking circuit between the two telephones. The line drops in the monocord circuit are connected to single cut-off jacks. When the plug is inserted in the line jack of the called telephone, it opens the line drop circuit for that jack, but the line drop of the calling telephone remains bridged or shunted across the line. This is necessary in order that the calling telephone can signal the end of the conversation to the operator. The signal is given by operating the hand generator at the calling telephone, thus operating the line drop at the switchboard. The line drop, however, has a high impedance to the voice current and little voice current passes through the drop.

72. Operator's Telephone Circuit

a. Neither of the circuits illustrated in figures 92 and 93 is, alone, adequate for proper switchboard operation. The operator can tell by the fall of the drop shutter which station is calling the switchboard, and he can insert the answer plug of the simple cord circuit into the line jack of the calling telephone, but he has no way of talking with the calling telephone to learn the number of the called telephone. In order to permit the operator to talk with the calling telephone, the switchboard is supplied with a talking circuit similar to that of the antisidetone local-battery telephone set discussed in paragraphs 59 and 60.

b. The heavy lines of figure 94 represent a simple *operator's telephone circuit and set.* The circuit includes only the transmitter, receiver, toggle switch, induction coil, capacitor C, varistor, and battery of the local-battery telephone set. It is essentially the antisidetone circuit. The transmitter, receiver, and switch usually are not part of the switchboard, but are considered to be auxiliary equipment, under the inclusive name of the operator's telephone set (fig. 95). Wired in as switchboard components, however, in figure 94, are the induction coil, capacitor C, varistor, and battery. The operator's telephone set is connected

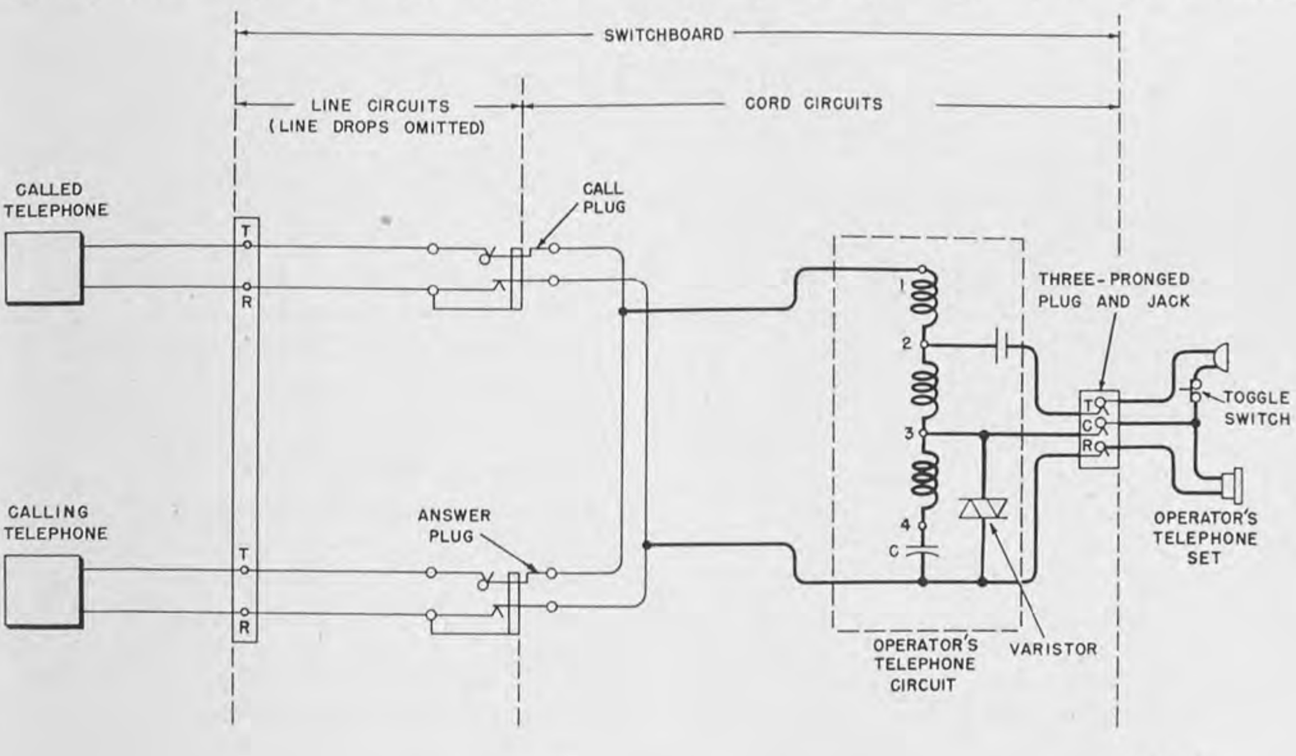


Figure 94. Operator's telephone circuit.

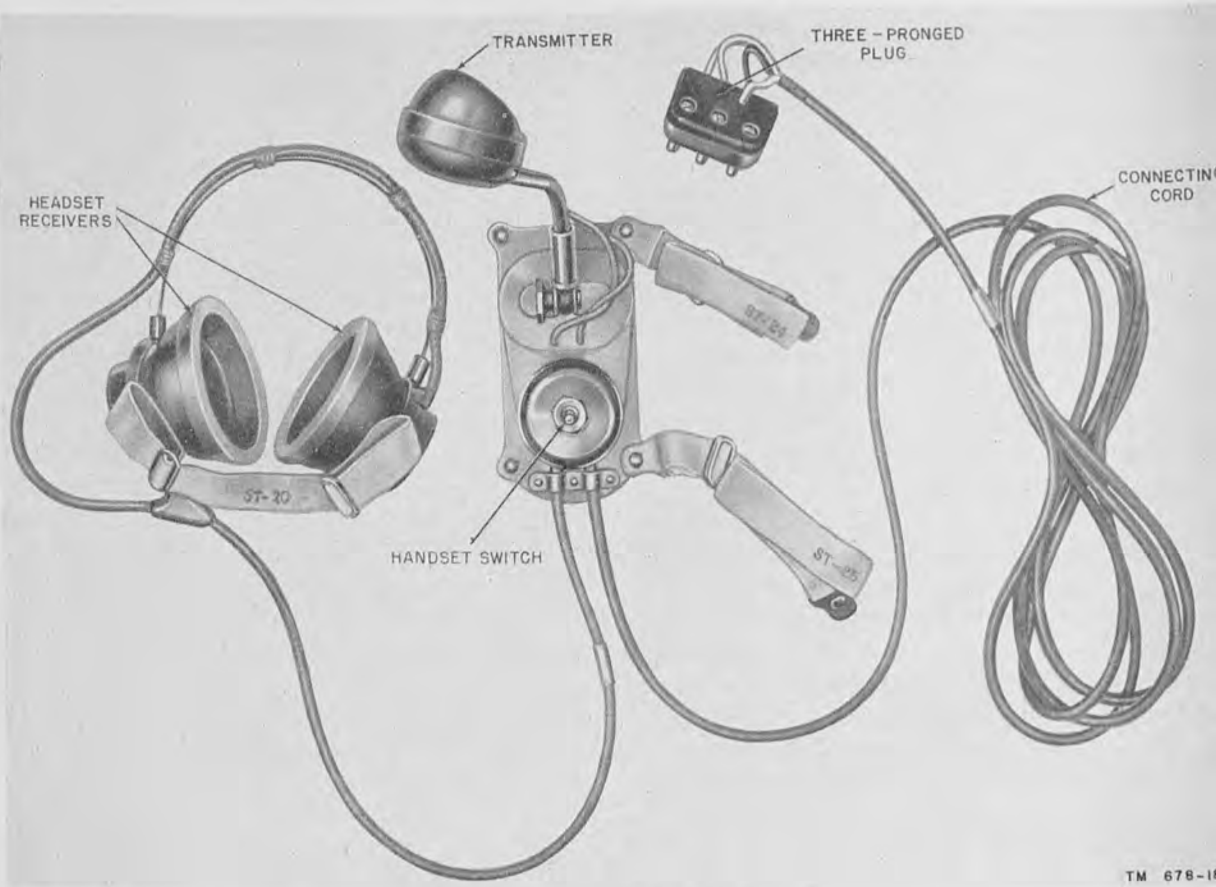


Figure 95. Operator's telephone set.

to these components by a three-pronged plug which fits into the *operator's jack* on the switchboard (fig. 76). The operator's telephone circuit is connected to the cord circuit. When the calling telephone signals the switchboard, the operator inserts the answer plug of the cord circuit in its line jack. This removes the calling-telephone line drop from the circuit, and completes the talking circuit between the calling telephone and the operator's telephone circuit. When the switchboard operator is told the number of the called telephone, he inserts the calling plug of the *same* cord circuit into the line jack of the called telephone. At this stage the calling and called telephones are connected for voice conversation.

c. The varistor which is bridged across the receiver branch of the operator's telephone circuit is used to reduce the intensity of the acoustic disturbances caused by unusually high voltages which suddenly may be impressed on the operator's telephone circuit in the switchboard. The principle of operation is based on the fact that its resistance varies with the applied voltage. When a relatively low voltage of about .1 volt produced by speech at ordinary levels is applied to the varistor, its impedance is relatively high (about 30,000 ohms). Its shunting effect on the receiver therefore is very slight. However, when a considerably higher voltage is applied to the varistor, its impedance is reduced greatly, becoming about 15 ohms at 1.5 volts. Consequently, most of the current is shunted around the receiver, keeping the receiver current at near its normal value, and thus reducing appreciably the acoustic shock which otherwise might result.

73. Ringing Circuit

Although the circuit of figure 94 serves to connect the calling and called telephones for voice conversation, it does not provide means for signaling the called telephone to bring someone to take the call. In order that the switchboard operator may signal the called telephone, the switchboard is provided with a signaling circuit.

a. The heavy lines of figure 96 represent a simplified *ringing circuit*, or *signaling circuit*. The

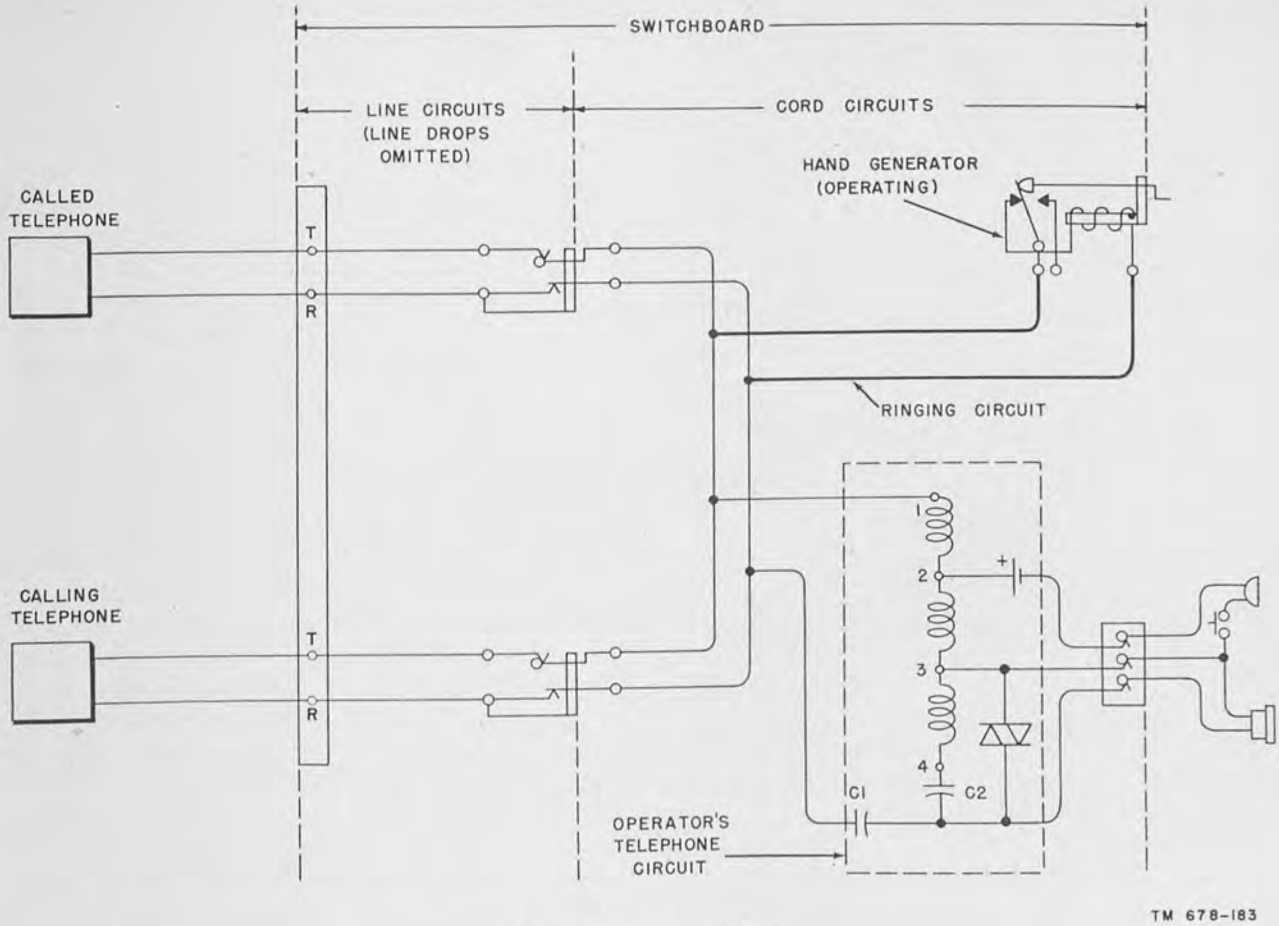


Figure 96. Ringing circuit.

circuit contains a hand generator, with its hand generator switch, connected to the cord circuit. Capacitor C1 is added to limit the 20-cycle ringing current through the operator's telephone receiver. To signal the called telephone, the switchboard operator rotates the crank of the hand generator. This provides 20-cycle ringing current through the call plug of the cord circuit, the line circuit, and the telephone line to the ringer of the called telephone.

b. There is also, in figure 96, a complete circuit for the ringing current through the answer plug of the cord circuit, the line circuit, and the telephone line to the ringer of the calling telephone. The consequent *ring-back* of the calling telephone would be undesirable, for it would reduce the amount of ringing current in the circuit to the called telephone, consequently weakening the response of its ringer. Also, some of the ringing current would pass through the receiver of the calling telephone, causing ringing in the ear of the calling person. Use of a switch, explained in the following paragraphs, prevents such ring-back.

74. Switchboard Lever Switch

The local-battery switchboard may provide either one or two lever switches for each cord circuit, mounted on the keyshelf immediately in front of the cord circuit with which they are associated. If only one switch is provided, it is the *combined listening and ringing switch*, a name frequently shortened to *listen-ring switch*. This switch is associated with the call cord and plug. If there are two switches, they are the *listening switch* and the *ring-back* switch. The ring-back switch is associated with the answer cord and plug.

a. Function. The combined listening and ringing switch performs two functions. Pushed to one position, it permits the switchboard operator to connect and disconnect the operator's telephone circuit to any one of the cord circuits. Pulled to the opposite position, it permits the switchboard

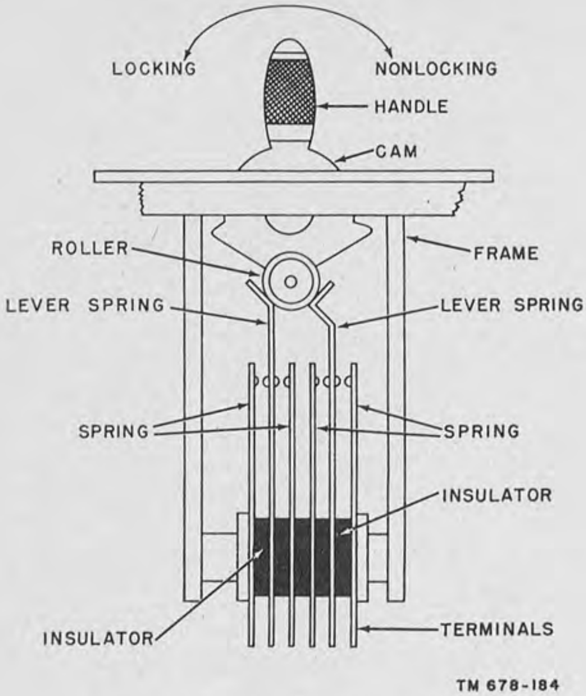


Figure 97. Switchboard lever switch.

operator to connect and disconnect the ringing circuit to any one of the cord circuits.

b. Structure.

(1) Figure 97 shows the structure of a lever switch. It works by cam action. At the top of the cam is the handle; at the bottom is a roller, free to pivot about a pin. Each side of the roller rests against a resilient, conducting lever spring. Just below, on either side of each lever spring, is a conducting spring. These six conductors, separated by insulators, are mounted in a pile-up assembly attached to the frame. There is one welded-on contact on each spring, and there are two on each lever spring. The contacts are of a special alloy that gives maximum protection from the small arcs often formed when such contacts separate and close.

(2) The action of the combined listening and ringing lever switch may be compared with that of a double-pole, double-throw knife switch. In figure 98 the terminals of the switchboard key are marked with the same letters as the related terminals of the knife switch. Pushing either handle to the right connects the same terminals (A to C, and B to D); pushing either handle to the left connects the same terminals (A to E, and B to F).

(3) Switchboard lever switches may be classified as *locking*, *nonlocking*, or a combination of *locking and nonlocking*. When the handle of a locking switch is released, the switch remains in its operated posi-

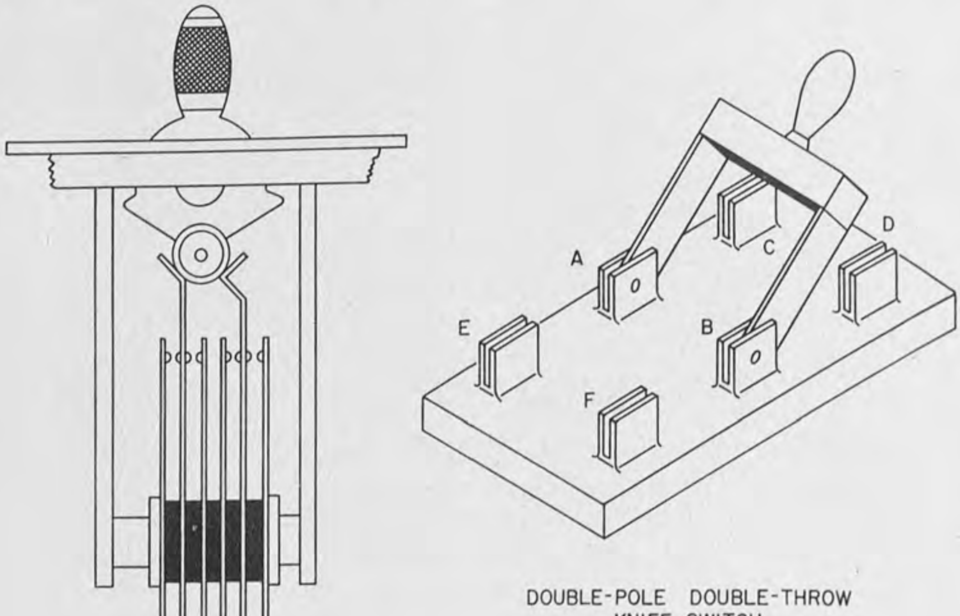


Figure 98. Comparison of lever and knife switches.

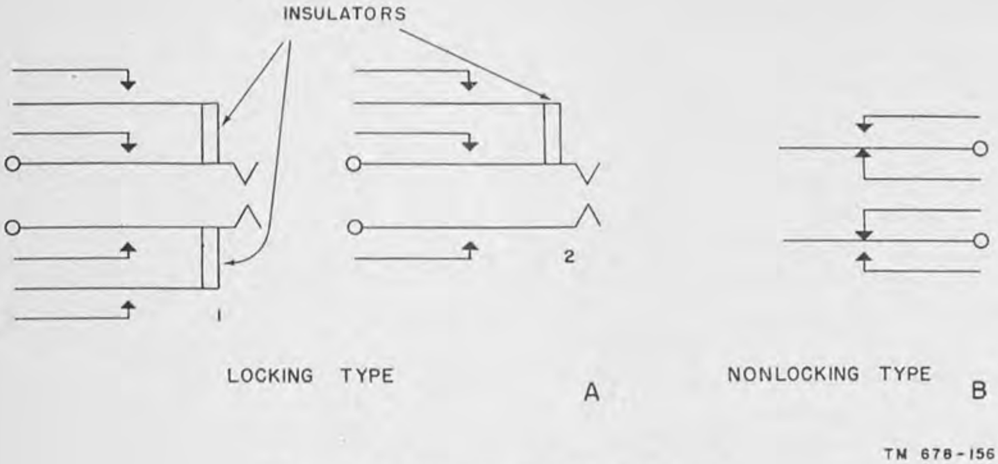


Figure 99. Switchboard lever switches.

tion until it is restored by the operator. When the handle of a nonlocking switch is released, the switch automatically returns to its normal position under the action of the lever spring. Figure 97 shows a switch that is locking in one position and nonlocking in the other—a combined listening and ringing switch. When the handle is pushed to the left, the cam roller, moving to the right, rides upon the tip of the right-hand lever spring in such a way as to lock in that position. The end of the lever spring is shaped so that the pressure it exerts keeps the switch in the desired position until it is restored by hand. When the switch is pushed to the right, the left-hand lever spring exerts pressure which will restore the cam to its original position. Usually, the listening-circuit side of a switchboard lever switch is locking, and the ringing-circuit side is nonlocking.

(4) Many different kinds of switches and spring arrangements are found in telephone switchboards and central-office equipment. Just as in the case of the telephone jack, the addition of auxiliary contact springs to the lever switch permits the use of special circuit features which could not be provided easily with any other type of switch. In figure 99 are schematic diagrams of switchboard lever switches. The center contacts of the locking switch have V-shaped ends, and those of the nonlocking switch are straight. Often, in schematic diagrams, the locking switch has the letter L, for locking, between the two center contacts, and the nonlocking switch has the letters NL, for nonlocking, for quick indication of the type of switch.

75. Need for Switch

Usually, switchboards have only one operator's telephone circuit and one ringing circuit. Since each of these circuits serves all the cord circuits of the switchboard, it must be possible to connect each one to all the cord circuits. To connect them directly without use of switches, as in figure 96, would connect all the cord circuits, resulting in three disadvantages in addition to that of ringback, mentioned previously. The disadvantages described in this paragraph are avoided by use of the switchboard lever switch.

a. One disadvantage that would result from the permanent connection of the telephone operator's circuit to the cord circuits would be a transmission loss, or reduction of voice current, in the circuit between a calling and a called telephone. The loss would occur because of the voice current supplied to the receiver of the operator's telephone set, which also is connected to the circuit.

b. A second disadvantage of such common connecting points would be the provision of paths for voice current from a calling and called telephone on one cord circuit to the calling and called telephones on all the other cord circuits. This would produce cross conversation, or *crosstalk*, between all the calling and called telephones in use at that time. One result of the crosstalk would be to prevent privacy of conversation. More seriously, it would reduce the voice current in the circuit between the two telephones.

c. The third disadvantage would be that when the switchboard operator rang a called telephone, the common connection of the cord circuits would provide paths for the ringing current to all other telephones connected by cord circuits at the switchboard. Thus, ringing current to a called telephone would interfere with all conversations then taking place through the switchboard. More than this, the ringing current to the called telephone would be reduced, so that its ringer would respond very weakly.

76. Cord Circuit With Switchboard Lever Switch

It is convenient to discuss the combined listening and ringing functions of the usual switchboard lever switch as if they were performed by two separate switches, as they are on some switchboards.

a. Listening Switch.

(1) *Functions of listening switch.* The *listening switch*, also called the *listen switch* or *talk switch*, connects the operator's telephone circuit to the cord circuit. A listening switch is provided for each cord circuit. It is mounted on the keyshelf immediately in front of the cord circuit to which it is connected. In the normal (nonoperated) position, the switch contacts are open, and the operator's telephone circuit is disconnected from the cord circuit. When the handle of the switch is pushed to the listening position, the switch contacts are closed and the operator's telephone circuit is connected to the cord circuit. The listening switch is of the locking type, and

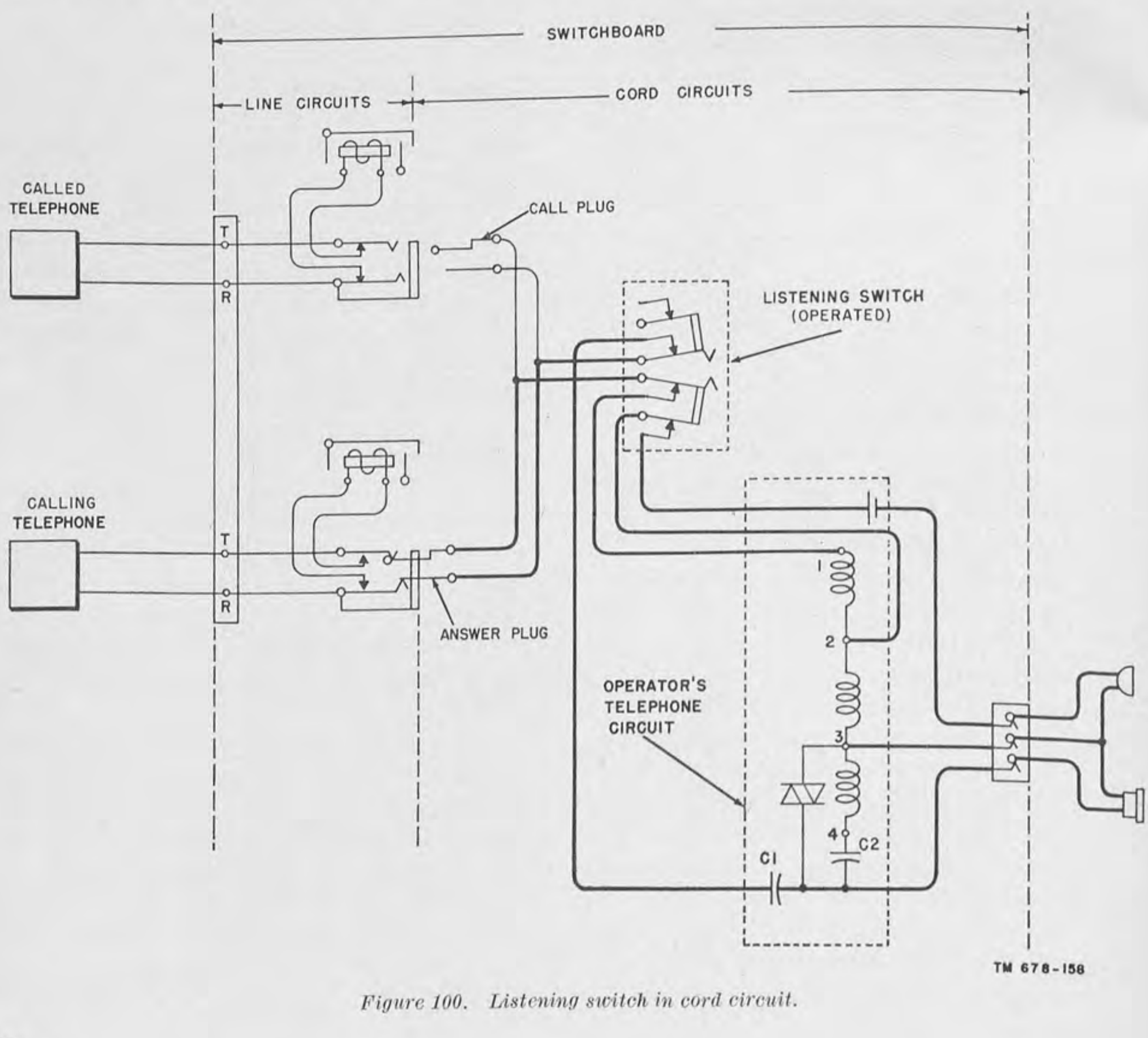


Figure 100. Listening switch in cord circuit.

when pushed to the listening position remains there until restored to normal by the switchboard operator.

(2) *Listening switch in cord circuit.* Figure 100 shows the listening switch in the cord circuit. The switch is similar to that of the diagrams of figure 99, which represents the switch in its normal position. The circuit in figure 100 shows the switch contacts closed—that is, with the switch in the listening position. The plug of the answer cord is shown inserted in the line jack of the calling telephone. With these connections there is a complete voice-current path from the operator's telephone set to the calling telephone (heavy lines). The complete voice-current circuit consists of the operator's telephone set, the operator's telephone circuit, the listening switch, the answer cord and plug, the line circuit, the telephone line, and the calling telephone. The transmitter circuit of the operator's telephone set is connected to a set of contacts on the switch which complete the transmitter circuit when the switch is closed. One set of contacts on the switch is not used in this circuit, and therefore remains unconnected.

(3) *Operation of listening switch.* With the *plug* of the answer cord inserted in the line jack of the calling telephone, the closing of the listening switch enables the switchboard operator to listen to and talk with a calling telephone (fig. 100). If, in addition, the plug of the call cord is in-

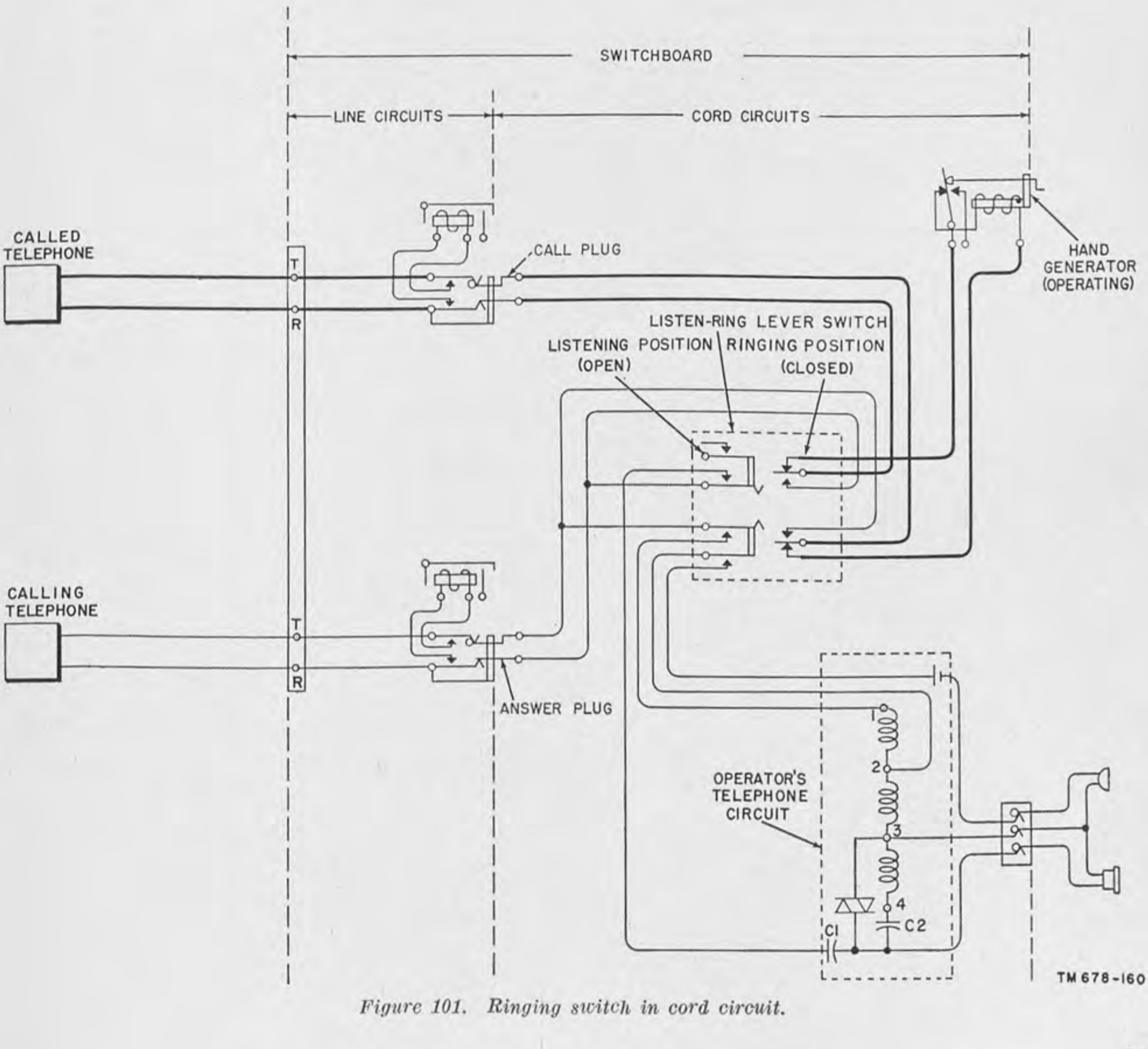


Figure 101. Ringing switch in cord circuit.

serted in the line jack of the called telephone, the switchboard operator similarly can listen to and talk with the called telephone. With this connection, when the lever switch is restored to its normal position, the calling and called telephones can converse without interference by the operator.

b. Ringing Switch.

(1) *Function.* The *ringing switch,* also called *ring switch,* connects the ringing circuit to the call cord and plug of the cord circuit. A ringing switch is provided for each cord circuit. It usually is combined with the listening switch in a single unit, the combined listening and ringing switch. As is now clear, pushing the lever switch in one direction closes the listening contacts; pulling it in the opposite direction closes the ringing contact and opens the listening contacts; restoring it to the central, vertical, normal position opens *both* the listening and the ringing contacts. The ringing switch is of the nonlocking type; therefore, it automatically returns to its normal position when it is released.

(2) *Ringing switch in cord circuit.* Figure 101 shows that the ringing switch in the cord circuit is similar to the one in B, figure 99, where it is in its normal position. The circuit shows the switch contacts closed. The call cord and plug are shown connected to the line jack of the called telephone. With these connections, there is a complete path for ringing-current from the hand generator at the switchboard to the called telephone (heavy lines). The complete ringing circuit includes the ringing circuit of the switchboard, the ringing switch, the call cord and plug, the line circuit, and the telephone line.

(3) *Operation of ringing switch.* The switchboard operator makes use of this circuit to signal or ring the called tele-

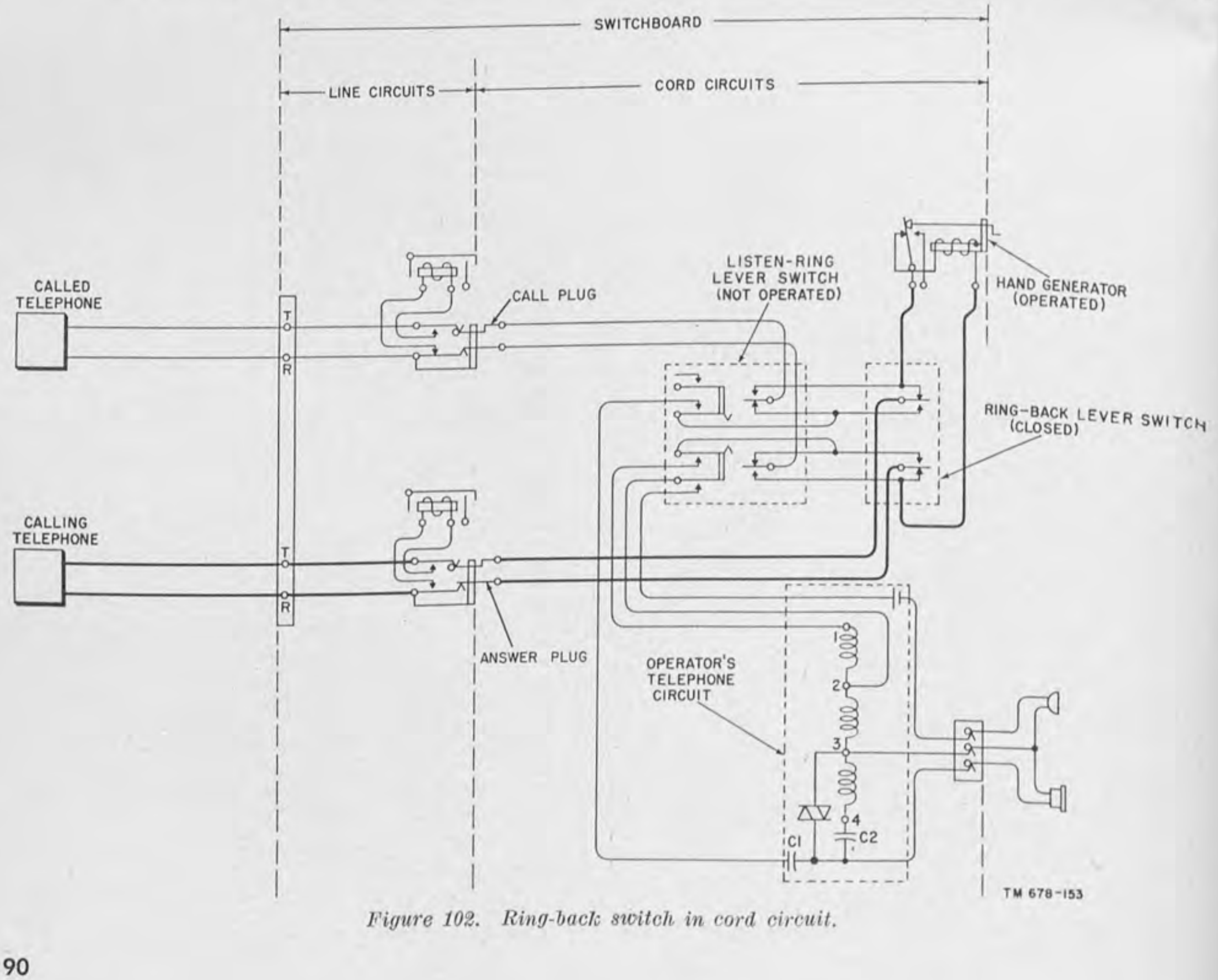


Figure 102. Ring-back switch in cord circuit.

phone (fig. 101). With the call cord and plug connected to the line jack and the ringing switch closed, rotation of the crank of the hand generator at the switchboard supplies 20-cycle ringing current to the ringer of the called telephone. Closing the ringing switch opens the switch contacts to the answer cord and plug, thus keeping the ringing current out of the calling telephone.

77. Ring-Back Lever Switch

a. Purpose of Ring-Back Lever Switch. On many switchboards, between the row of call plugs and the row of combined listening and ringing switches, is a row of *ring-back switches*, one for each cord circuit. The ring-back switch connects the ringing circuit to the answering cord and plug of the cord circuit. It enables the switchboard operator to ring a *calling* telephone through the answer cord and plug *after* a complete cord connection has been made between a calling and a called telephone. Such ringing back of the calling telephone may be necessary either when the calling person, through error, hangs up before his conversation is completed, or when he hangs up while awaiting completion of the connections for a long-distance call. When the ring-back switch is not provided, ringing of the calling telephone requires disconnection of the answer cord and plug from the line jack of the calling telephone, and connection, in its place, of the call cord and plug.

b. Ring-Back Switch in Cord Circuit. Figure 102 shows the ring-back switch in the cord circuit. This switch is similar to the ringing switch and it is connected to the answer cord and plug of the cord circuit. The circuit shows the switch contacts closed; the heavy lines emphasize the

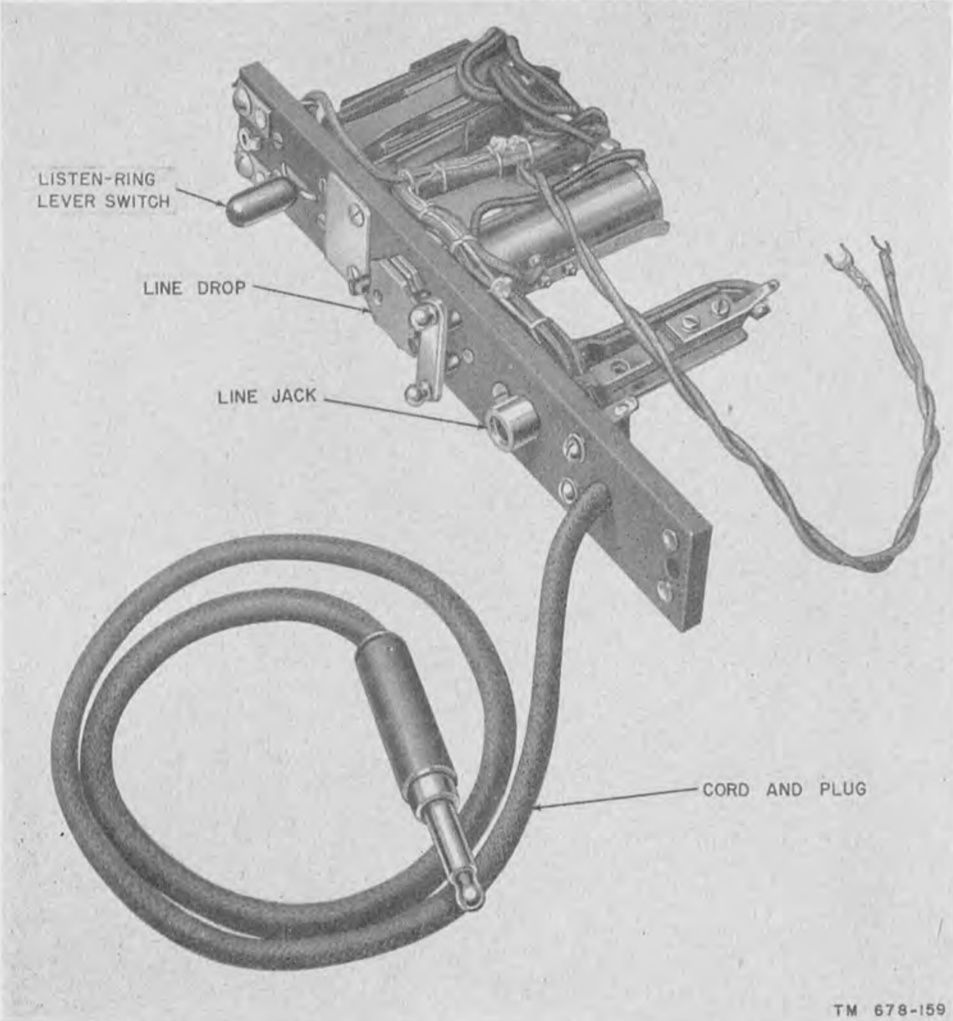


Figure 103. Monocord unit.

complete ringing circuit, from the hand generator at the switchboard to the distant calling telephone. This circuit includes the ringing circuit of the switchboard, the ring-back switch, the answer cord and plug of the cord circuit, the line circuit, and the telephone line.

c. Operation of Ring-Back Switch. The operation of this circuit is similar to that of the ringing circuit, except that the ring-back switch, instead of the ringing switch, is closed. Thus, to ring the calling telephone, the operator merely closes the ring-back switch. This provides a complete path for the ringing current, from the hand generator through the answer cord and plug to the calling telephone. Rotation of the crank of the hand generator then supplies 20-cycle ringing current in this circuit to the ringer of the calling telephone. Note that closing the ring-back switch opens the switch contacts connecting with the called telephone.

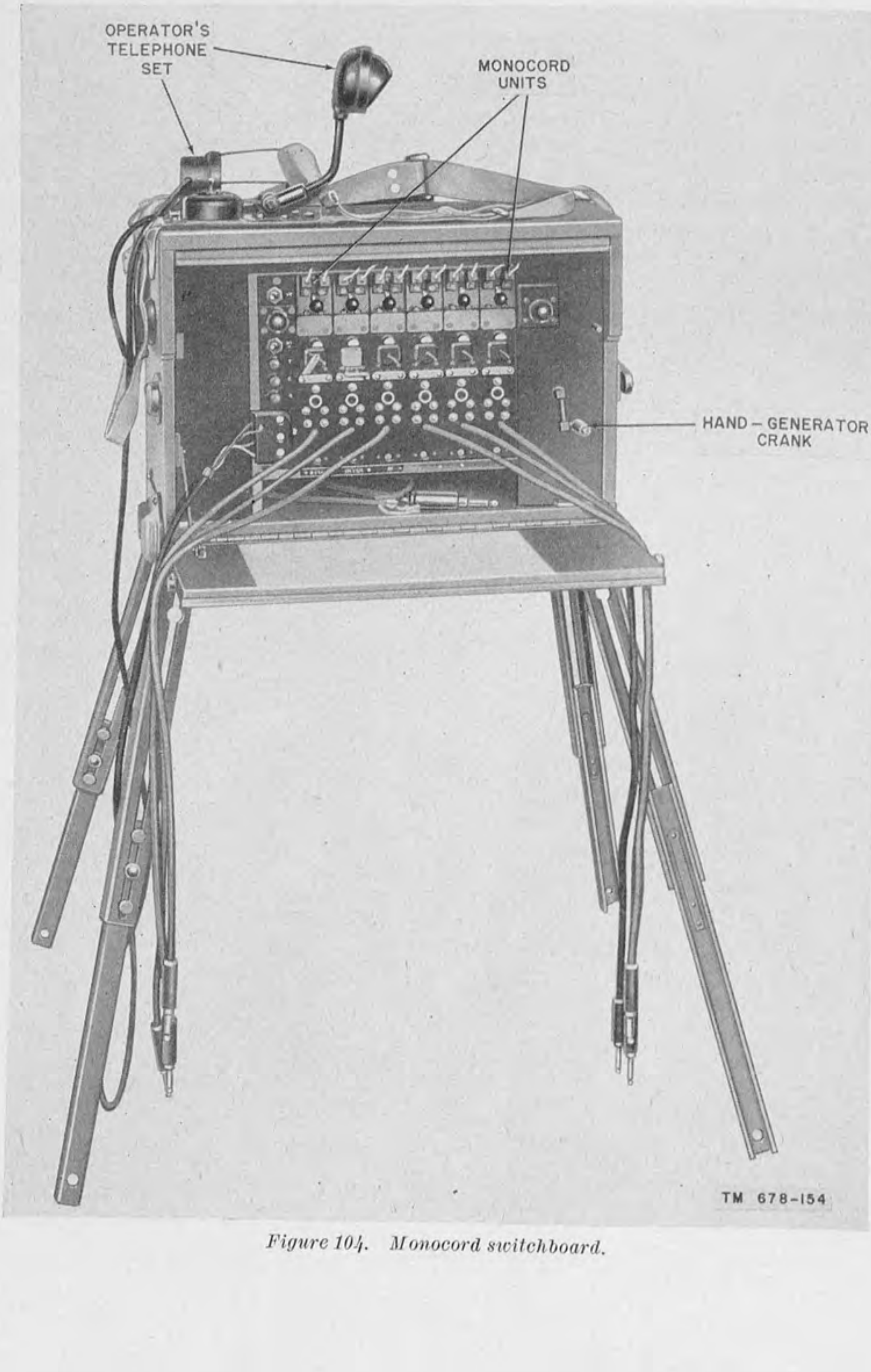


Figure 104. Monocord switchboard.

78. Monocord Circuit With Switchboard Lever Switch

In the monocord switchboard, the monocord circuit is wired as a complete unit containing a cord and plug, line jack, line drop, and combined listening and ringing lever switch (fig. 103). These units are mounted in a switchboard like that of figure 104. The telephone line from each telephone set is connected to a single monocord unit through terminals on the back panel of the switchboard. The switchboard is provided with an operator's telephone circuit and ringing circuit which can be connected to any of the monocord circuits through the combined listening and ringing switch.

a. Listening Circuit in Monocord Switchboard.

(1) *Components of listening circuit in mono-*

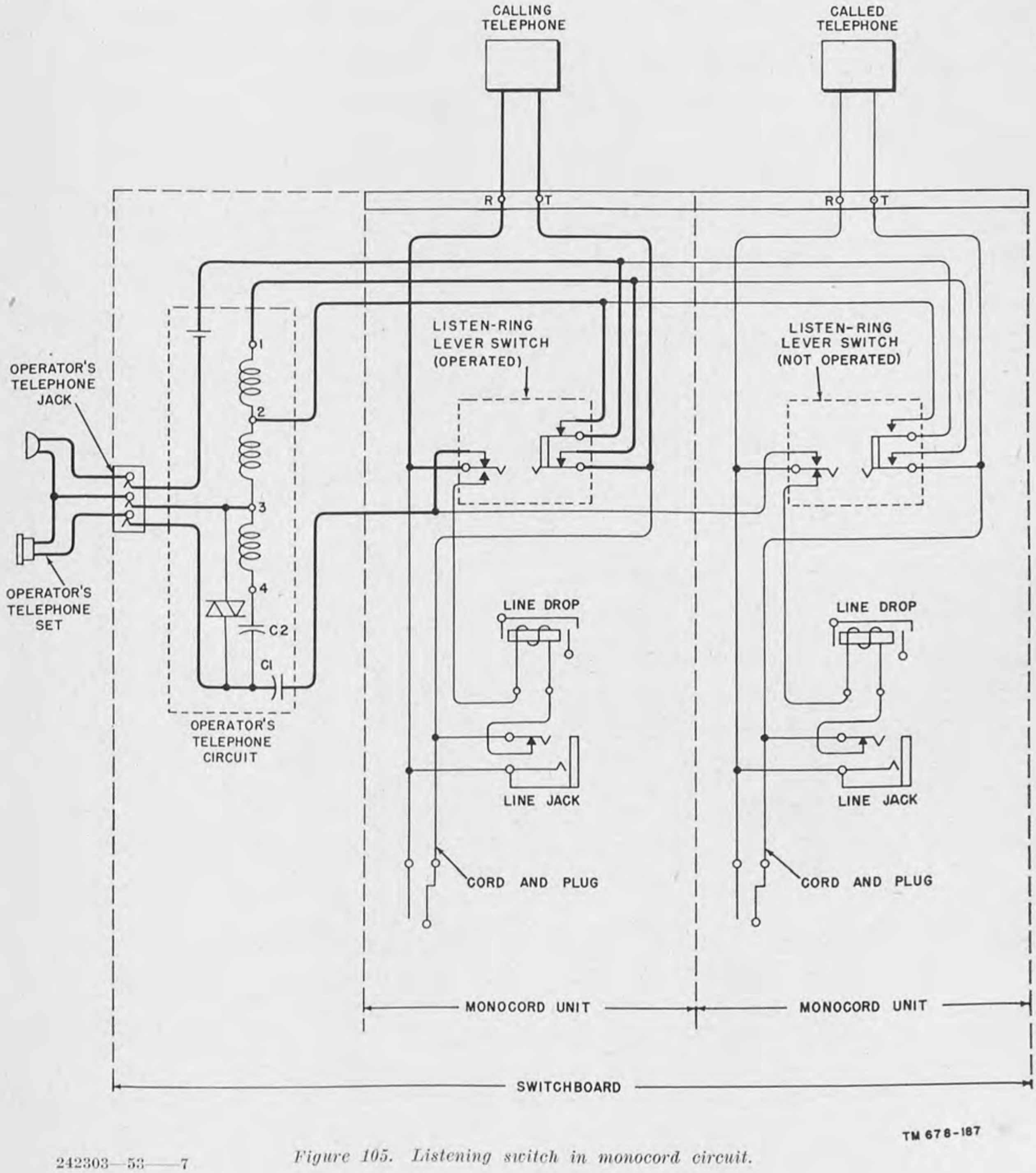


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Figure 105. Listening switch in monocord circuit.

cord switchboard. Figure 105 shows two listening lever switches in two monocord circuits, one in the monocord unit for the calling telephone and one in the monocord unit for the called telephone. Note that the ringing contacts of the combined listening and ringing switch have been omitted for the sake of simplicity. The heavy lines emphasize the listening circuit between the operator's telephone set and the calling telephone. This circuit includes the operator's telephone circuit, the listening switch in the monocord unit of the calling telephone, and the telephone line.

(2) *Operation of listening switch in monocord switchboard.* When the calling telephone signals the switchboard, the operator closes the listening switch in the monocord unit of the calling telephone (fig. 105). This connects the operator's telephone circuit to the monocord circuit through the listening-switch contacts, and provides a complete voice-current path from the operator's telephone set to the calling telephone. The operator now can ask, and be told, the number of the called telephone.

b. Ringing Circuit in Monocord Switchboard.

(1) *Components of ringing circuit in mono-*

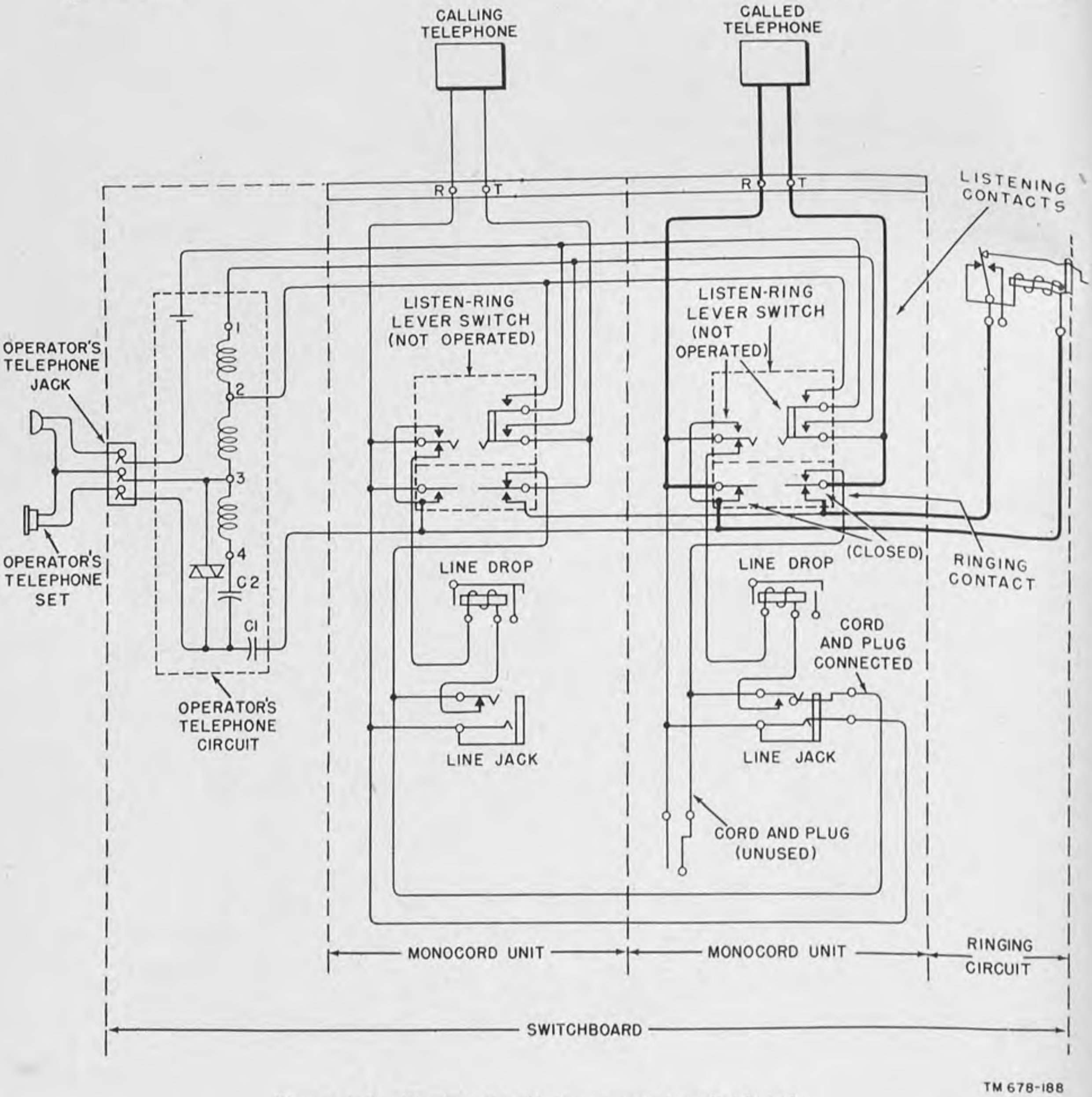

Figure 106. Ringing circuit in monocord switchboard.

cord switchboard. Figure 106 shows two combined listening and ringing switches in the two monocord circuits. Present interest is in the two ringing switches, one in the monocord unit for the calling telephone and one in the monocord unit for the called telephone. The heavy lines emphasize the ringing circuit between the hand generator and the called telephone. This circuit includes the ringing circuit at the switchboard, the ringing switch in the monocord unit of the called telephone, and the telephone line.

(2) *Operation of ringing switch in monocord circuit.* After the number of the called telephone has been ascertained, in the manner described, the plug of the monocord unit of the calling telephone is inserted in the line jack of the called telephone (fig. 106). The listening switch in the unit of the calling telephone is restored to its normal position, and the ringing switch of the called telephone then is closed. This connects the ringing circuit of the switchboard to the monocord unit of the called telephone. With the ringing switch closed, the crank of the hand generator is rotated and 20-cycle ringing current is supplied in the circuit to the ringer of the called telephone. However, before the complete connection is made for conversation between the calling and called telephones, the switchboard operator must wait (listen) for the *reply* of the called telephone. This is done by intermittently releasing the ringing switch and closing the listening switch of the monocord unit of the called telephone. When the called telephone answers, the listening switch is restored to normal position and the conversation proceeds.

79. Supervision

The *supervisory circuit* provides a signal which enables the switchboard operator to ascertain when

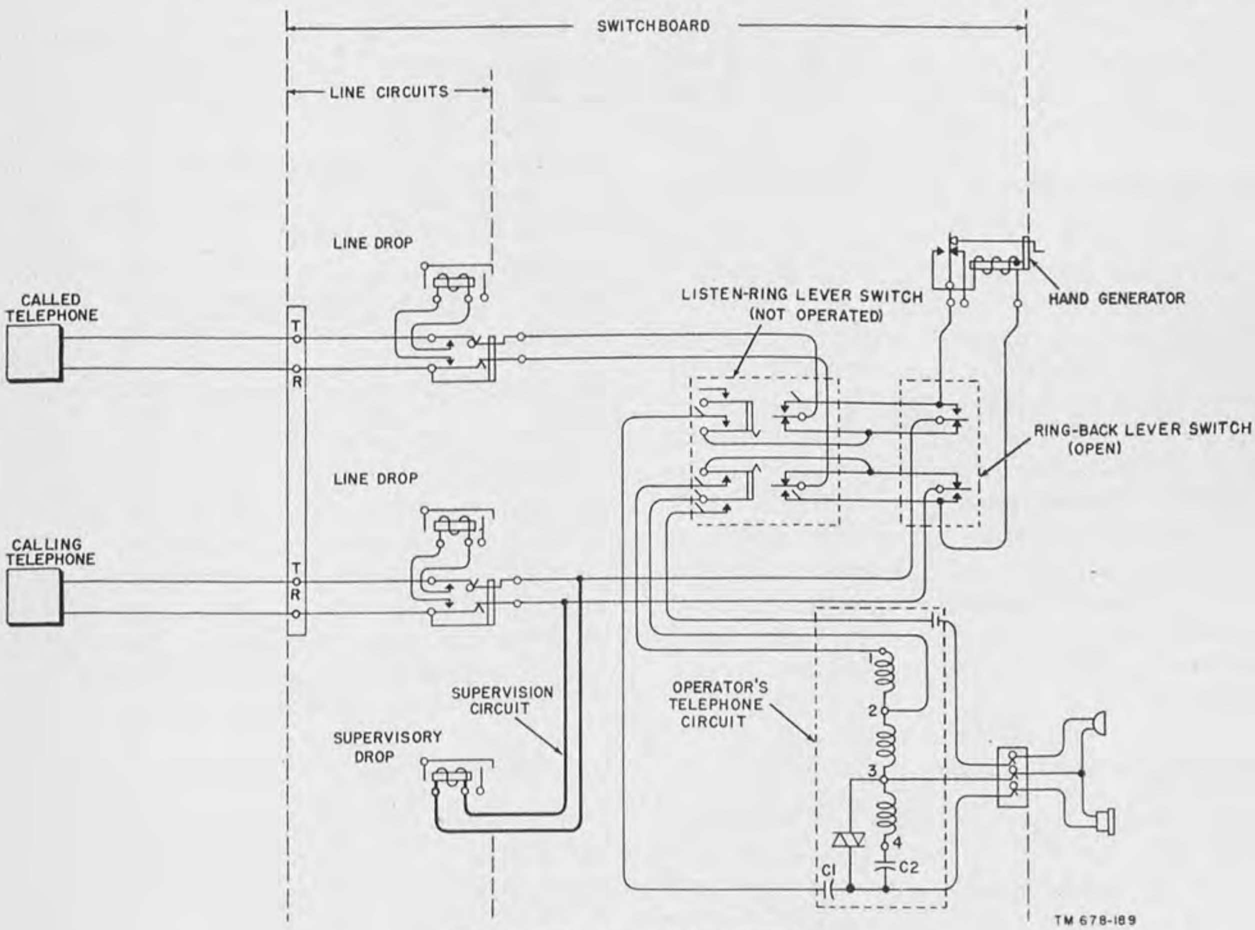

Figure 107. Supervisory circuit.

a telephone conversation is completed. The circuit has a drop and shutter, called the *supervisory drop*, *recall drop*, or *clearing-out drop*, which is similar in construction to the line drop.

a. Supervisory Circuit. The heavy lines of figure 107 show the supervisory circuit. The circuit consists of the supervisory drop connected to the cord circuit during a completed cord connection between a calling and a called telephone. The complete ringing-current circuit between the calling telephone and the supervisory drop includes the calling telephone, the telephone line, the line circuit of the calling telephone, the answer cord and plug, and the supervisory drop. Note that there is also a complete path from the supervisory drop to the called telephone through the cord circuit.

b. Operation of Supervisory Circuit. When a conversation is completed, the calling or the called person rotates the crank of the hand generator of his telephone set (fig. 107). This supplies 20-cycle ringing current in the circuit, which causes the shutter of the supervisory drop to fall, indicating that the conversation on that cord circuit is completed. Because the drop is mounted on the switchboard panel in line with the cord circuit to which it is connected, the operator knows at once which plug to remove.

80. Representation of Common Connections of Cord Circuits

Each switchboard has a number of cord circuits, but there is only one operator's telephone circuit and only one ringing circuit, and these must service all the cord circuits. Since the operator's telephone and ringing circuits are connected to all the cord circuits by the switchboard lever switches, and since this is done by interconnecting the terminals of each switch to which like connections are made from the operator's telephone circuit and the ringing circuit, the cord circuits have common points at each of the switch terminals. In circuit diagrams, such points, connected in common, are indicated by *short, oblique lines* like those in figure 107.

81. Night-Alarm Circuit

The *night-alarm circuit* provides the switchboard operator with an *audible* signal, in addition to the visual signal provided by the fall of the drop shutter. The circuit includes a bell or buzzer which sounds when a calling telephone signals the switchboard. It is used during periods of light telephone traffic when the switchboard does not require constant attendance, as at night.

a. Night-Alarm Circuit. The heavy lines of figure 108 show the night-alarm circuit. The circuit includes a bell in series with a switch, called the *night-alarm switch*, and a battery. The circuit is completed through the night-alarm spring and the night-alarm bus wire of any of the line drops or supervisory drops (fig. 86). The night-alarm springs of all the line drops and supervisory drops are connected in common, so that when any shutter falls it forces the night-alarm spring into contact with the bus wire underneath, closing the circuit.

b. Operation of Night-Alarm Circuit. The night-alarm circuit is set for operation by closing the night-alarm switch, which is similar to the switchboard lever switch except that its spring contacts are opened and closed by a turn-button instead of a lever. Assume that the night-alarm switch is closed (fig. 108). When the switchboard is signaled, the falling shutter of a line drop or supervisory drop pushes the night-alarm spring against the night-alarm bus wire. This closes the night-alarm circuit, and battery current is supplied to the night-alarm bell, summoning the switchboard operator. Before answering the call, the operator restores the drop shutter, thereby opening the night-alarm circuit and stopping the ringing of the bell. The night-alarm bell operates from a 3-volt battery mounted in the switchboard. It has a low resistance, usually about 8 ohms.

82. Miscellaneous Switchboard Circuits

In addition to the circuits already discussed, the switchboard may be provided with additional circuits which give it greater flexibility and efficiency in operation. The number and type of these circuits depend on the amount of telephone traffic the switchboard is designed to handle. Two additional circuits usually found in switchboards are the *transfer circuit*, or *grouping circuit*, and the *generator-switching circuit*.

83. Transfer Circuit

When more than one switchboard is required to handle the telephone traffic, as is usually true in a telephone exchange, the switchboards are grouped together, and the term *switchboard* refers to the group. Each switchboard of the group then is

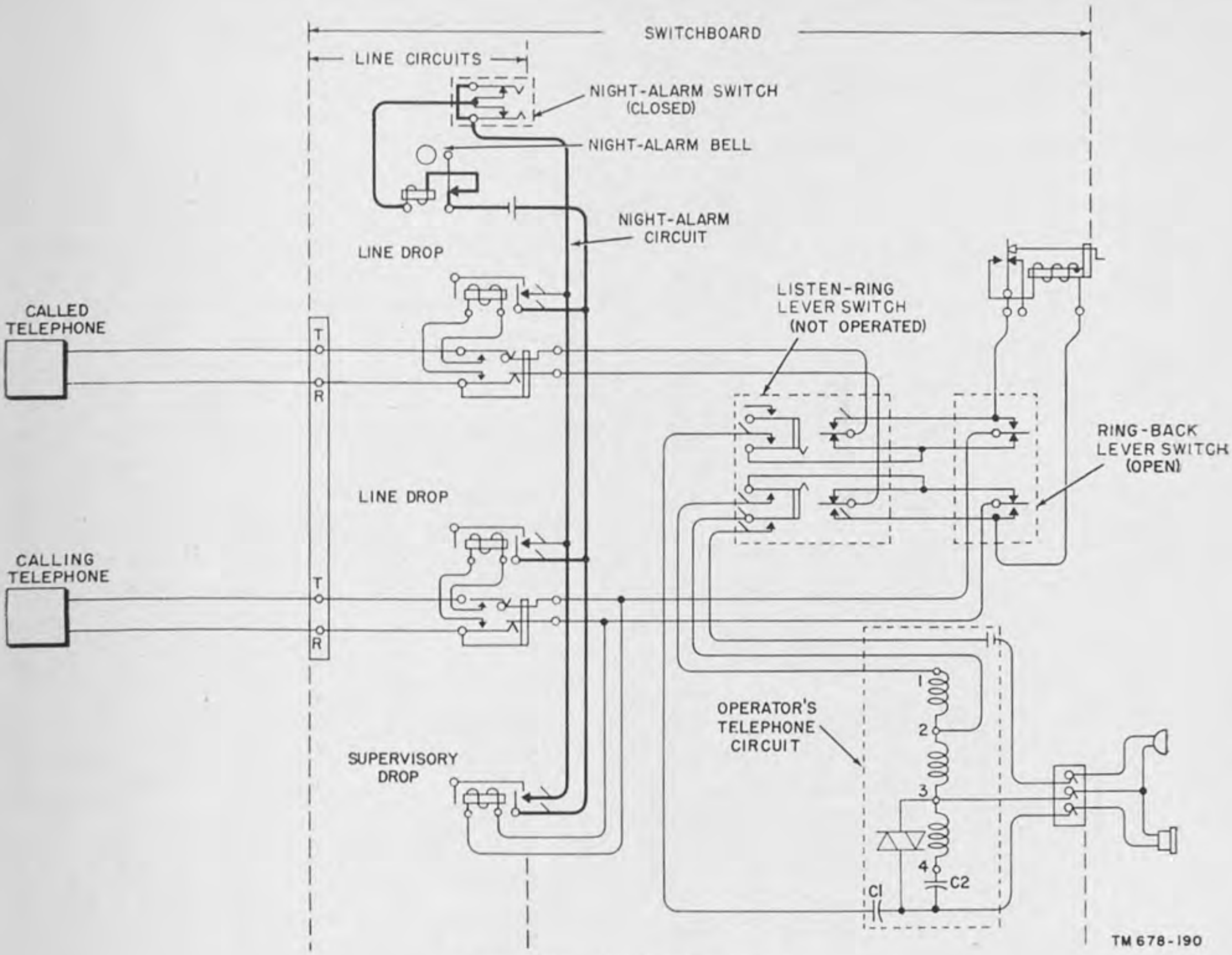

Figure 108. Night-alarm circuit.

called a *position*. When the telephone traffic is light, as it usually is at night, all the positions can be attended properly by a single switchboard operator.

a. Function of Transfer Circuit.

(1) The *transfer circuit*, or *grouping circuit*, interconnects the positions so that the operator's telephone circuit of one position can be used with all the cord circuits of all the positions. This enables the operator to keep his telephone set connected to the operator's jack in one position, without necessarily disconnecting and reconnecting it to complete an incoming call on another position. Since the cord circuits of each position are separate from the line jacks, the cord circuits of one position may be used to complete telephone calls between line jacks of the other positions. Provision is made for this service by equipping the switchboard with cords of greater length than that of the standard cord.

(2) When the cord circuits of one position are all in use, and the transfer circuit is in position, the operator must use the cord circuit of an adjacent position. With the transfer circuit, however, the operator does not have to disconnect his telephone set from the position to which he is connected and then connect it to the operator's jack of the adjacent position, in order to use the cord circuit of the adjacent position.

b. Transfer Circuit. The heavy lines of figure 109 emphasize the transfer circuit of a two-position switchboard. The circuits of each position are simplified by omitting the line drops from the line circuits, and the supervisory drops and ring-back keys from the cord circuits. Also, the operator's telephone circuit is shown in block form. Each position has a transfer circuit with a *trans-*

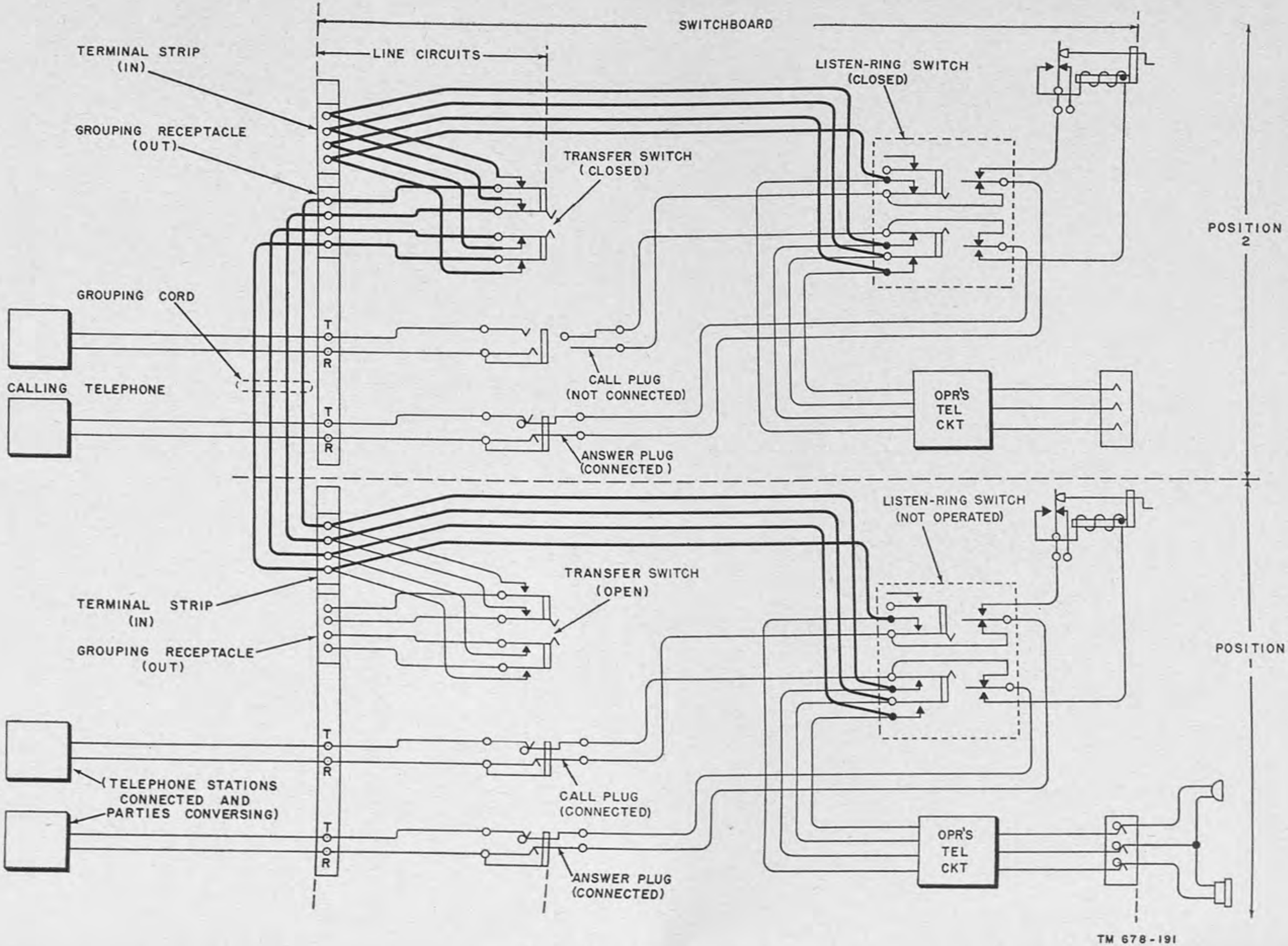

Figure 109. Transfer circuit.

fer switch or *grouping switch*, the spring contacts of which are similar to those of the switchboard lever switch, except that they are operated by a turn button rather than a lever. One set of transfer-switch contacts is connected to a *terminal strip* IN and the other set to a *grouping receptacle* OUT, both usually mounted on the back panel of the switchboard. The IN terminals are connected to those contacts of the listening switch to which the operator's telephone circuit is connected. The two positions are interconnected with a *grouping cord*, which makes connection between the terminal-strip IN terminals of one position and the grouping-receptacle OUT terminals of the other position. The transfer switch and listening switch of position 2 are shown in the closed position. The grouping receptacle of position 1 and its transfer switch provide for interconnection with another position, if required.

c. Operation of Transfer Circuit. The transfer circuit is set for operation by closing the transfer switch of position 2 (fig. 109). This, in effect, connects the operator's telephone circuit of position 1 to the listening-switch contacts of the cord circuit of position 2 through the grouping cord and the transfer-switch contacts. Assume that the transfer switch of position 2 is closed and that a calling telephone connected to position 2 signals the switchboard. The operator answers the call by inserting the plug of the answer cord of position 2. When he now closes the listening switch of that cord circuit, there is a complete voice-current path from the operator's telephone set of position 1 to the calling telephone connected to position 2, as shown in figure 109.

84. Generator-Switching Circuit

Ringing machines, sources of ringing current other than the hand generator, sometimes are provided for local-battery switchboards. They usually are provided as auxiliary equipment.

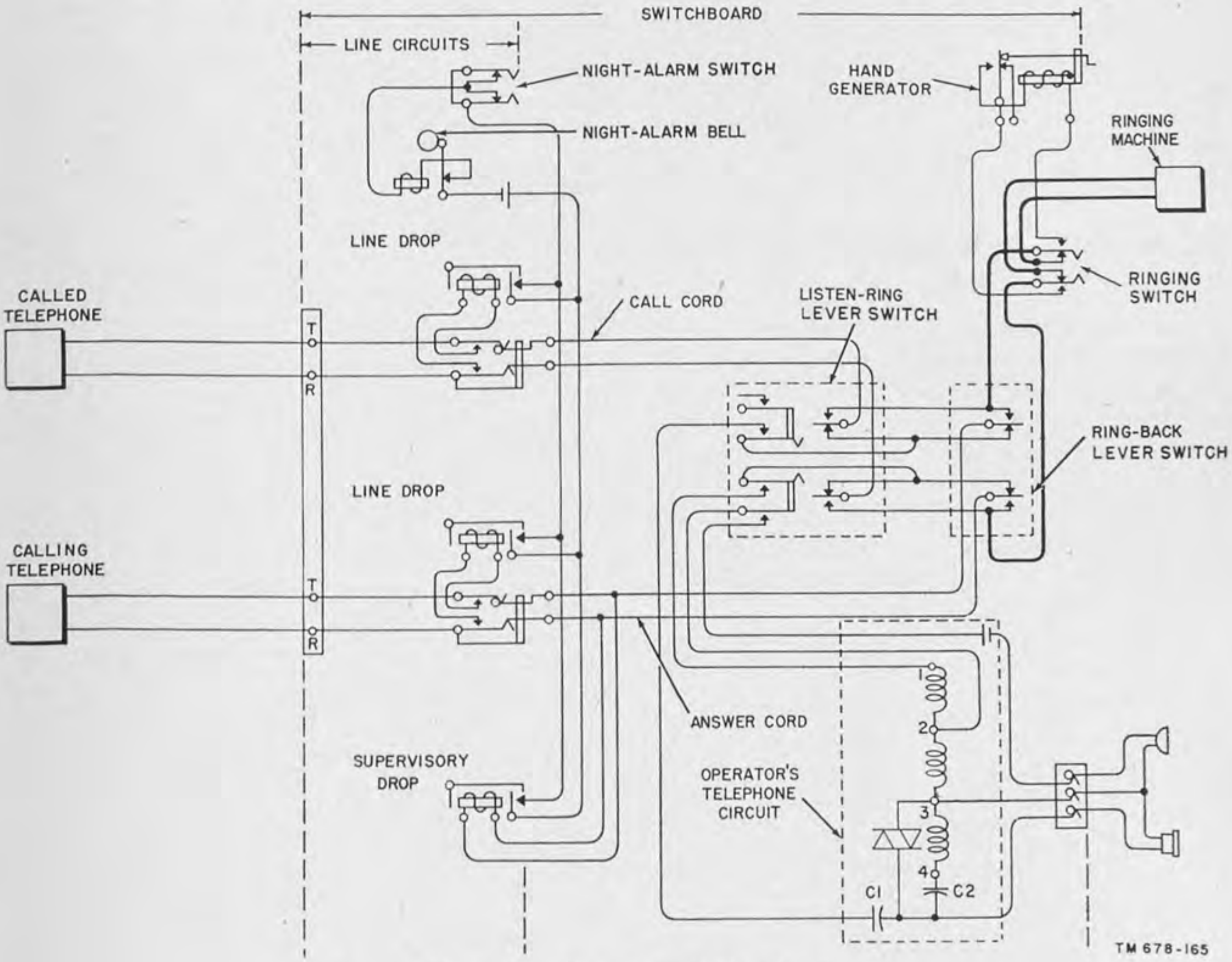

Figure 110. Generator-switching circuit.

a. Function of Generator-Switching Circuit. The *generator-switching circuit* enables the switchboard operator to disconnect the hand generator and connect the ringing machine to the ringing circuit and the ringing switches. With a ringing machine as the ringing source, the operator does not have to rotate the crank of the hand generator to signal a telephone station. Closing the ringing switch automatically provides 20-cycle ringing current from the ringing machine.

b. Generator-switching Circuit. The heavy lines of figure 110 show the generator-switching circuit. The circuit includes a generator ringing switch with spring contacts, similar to that of the switchboard lever switch, operated by a turn-button. One position of the switch connects the ringing and ring-back switches to the hand generator; the other position connects them to the ringing machine. The ringing machine usually is connected to the switchboard through an outlet on the back panel.

c. Operation of Generator-Switching Circuit. When the switch contacts make connection to the hand generator (fig. 110), ringing is performed as has been described previously. When they make connection to the ringing machine, the ringing machine supplies the required 20-cycle current to the ringers of the distant telephone sets.

85. Advantages and Disadvantages of Local-Battery Systems

a. Applications of Local-Battery Systems. Local-battery systems are adapted particularly for telephone communication in areas where the telephone stations are scattered and not numerous. Their design and construction are not suited for the handling of large volumes of telephone traffic. They have a number of advantages over other types of telephone systems (common-battery and dial), however, which make them well suited for field military telephone systems.

b. Advantages. The advantages of local-battery systems are:

(1) The wire or transmission lines, usually called the *outside plant*, can be constructed quickly and cheaply.

(2) The local-battery switchboard is simple in design, positive in operation, easy to repair, and relatively inexpensive to construct.

(3) Transmission of speech is possible over longer lines and, therefore, over lines of higher resistance, since each telephone set has its own battery to supply the voice-current energy.

c. Disadvantages. The disadvantages of local-battery systems are:

(1) The dry cells in the telephone set and switchboard are not an economical source of voice-current energy. Their life is short and they deteriorate even when standing idle. Frequent testing is required for the replacement of exhausted cells.

(2) The voltage of a dry cell varies radically between the time of installation and the time of exhaustion. This drop in voltage produces a progressive decrease in the signal output of the telephone set. Telephone service between local-battery telephone stations is not uniform, because a station with a partly exhausted battery may be connected with one having a fresh battery.

(3) If, by accident, the receiver is left off the hookswitch for an extended period, the battery may become completely discharged and thus of no further use, or it may become so polarized that it would fail to provide sufficient voltage for satisfactory transmission until after a period of rest long enough to permit the battery depolarizing agent to perform its normal function.

(4) The hand generator and battery increase the size of the telephone set.

(5) The turning of the crank of the hand generator for signaling requires effort on the part of the telephone user.

(6) The work of the operator in attending the switchboard is increased, because persons using local-battery telephone sets frequently fail to ring off when their conversations are completed, and this requires the operator to monitor (listen), to determine when to disconnect the cord circuit. Failure of the telephone user to ring off also reduces the availability of the cord circuits, and may hold up the completion of other telephone calls through the switchboard. The work of the switchboard operator is increased still further if the switchboard drops must be restored by hand.

86. Summary

a. The telephone set is the device supplied the telephone user to initiate and receive telephone calls. It has two principal circuits: the talking circuit, which provides an electrical path for the voice current, and the signaling circuit, which provides an electrical path for the signaling current. In the local-battery telephone set the components of the talking circuit are the transmitter, receiver, handset switch, battery, induction coil, and capacitor. The components of the signaling circuit are the hand generator and ringer.

b. The electrical energy for the voice current comes from the battery. A handset switch controls the battery current to the transmitter and thus increases the useful life of the battery. The handset switch, together with the transmitter and receiver, usually is mounted in a handset.

c. The induction coil, which is essentially a transformer, extends the range of the telephone set and improves its efficiency and performance. This it does by—

(1) Separating the transmitter and receiver current so that direct current from the transmitter does not pass through the receiver.

(2) Inducing a higher voice-current voltage in the secondary winding as a result of its step-up action as a transformer.

(3) Increasing the percent change in the resistance of the transmitter circuit.

d. The hand generator is the source of the ringing current. When its crank handle is rotated, approximately 20-cycle ringing current is generated by a coil rotating in a magnetic field produced by permanent magnets. The hand-generator switch removes the generator from the circuit when the hand generator is not in operation, and also removes the ringer from the circuit of the calling station when the hand generator is operated, thereby preventing the generated ringing current from sounding the local ringer.

e. The ringer is a signaling device which operates on a ringing current of approximately 20 cycles. When ringing current is supplied in the ringer, it alternately changes the magnetic field in the cores of the electromagnets of the ringer, which causes the armature and the attached clapper to vibrate between a pair of gongs.

f. Sidetone is the sound of the speaker's voice reproduced in his own telephone receiver. The antisidetone circuit reduces sidetone in the telephone set. It uses an autotransformer induction coil connected with the transmitter, receiver, and capacitors in an arrangement that reduces the sidetone in the receiver to a satisfactory level. Only a small amount of the voice current induced in the secondary winding of the induction coil by the local transmitter then flows through the local receiver. On lines shorter than average, however, the sidetone is greater and the antisidetone effect less.

g. Each telephone station is connected by a telephone line to a switchboard. The switchboard permits the connection for voice conversation of any two telephone stations connected with it, and permits their disconnection when the conversation is completed. A switchboard operator makes the connections through the use of the switchboard line or trunk circuits, cord circuits, and auxiliary circuits.

h. The telephone line is connected to an individual line circuit at the switchboard. The line circuit terminates on the front panel in a line jack. The jack is the switching connector for the line circuit. The line circuit also is provided with a line drop, a visual signal which notifies the switchboard operator when the associated telephone station initiates a call. The line drop is operated by the 20-cycle ringing current from the hand generator of the local-battery telephone set.

i. The cord circuits connect the line circuits or trunk circuits by means of cords and plugs and line jacks.

j. The operator's telephone circuit and the ringing circuit are auxiliary circuits which can be connected to the cord circuit by the listening-ring switch. The operator's telephone circuit may be connected to the cord circuit by the listening switch. With the switch in the listening position, the circuit permits the switchboard operator to talk and listen to calling and called telephones. The ringing circuit may be connected to the cord circuit by the ringing or ring-back switches. The ringing circuit permits the ringing (signaling) of a calling or called telephone either manually with the hand generator or automatically with a ringing machine.

k. The supervisory circuit is an auxiliary circuit associated with the cord circuit. It enables a telephone user to signal the switchboard at the completion of a telephone conversation.

l. The night-alarm circuit is an auxiliary circuit associated with the line circuits and the cord circuits. It provides an audible signal used to summon the switchboard operator to the switchboard during periods of light telephone traffic.

m. The transfer circuit interconnects switchboard positions so that the operator's telephone circuit when connected to one position can be used with each cord circuit of one or more of the other positions.

n. The generator switching circuit enables the switchboard operator to disconnect the hand generator and connect a ringing machine to the ringing circuit and the ringing switches.

87. Review Questions

a. What are the principal circuits of the telephone set?

b. What are the components of a local-battery telephone set?

c. What is the function of the battery in a local-battery telephone set? Why is the dry cell not suitable for long-period supply of continuous current?

d. What is the purpose of the handset switch? Draw a circuit diagram of a simple telephone set with a handset switch.

e. State two advantages of the use of the handset. Draw a circuit diagram of the internal wiring of a local-battery handset.

f. State two functions of the induction coil. How is it similar to the transformer?

g. What is an ideal transformer? Why may the induction coil be compared with the ideal transformer?

h. Draw the circuit of a local-battery telephone set with an induction coil. Use heavy lines to emphasize the transmitter and the receiver circuits.

i. Draw the circuit between two local-battery telephone sets with induction coils, and describe how the circuit functions to provide voice conversation.

j. Draw a circuit showing how the common connection of the induction coil is used to connect the handset to the local-battery telephone set.

k. What are the disadvantages of direct current in the telephone receiver? How does the induction coil keep direct current out of the receiver?

l. State two methods by which the induction coil increases the voltage of the voice current in a local-battery telephone set. What are the advantages of increasing the voltage of the voice current of the telephone set?

m. Name two types of induction coils and state the difference between them.

n. What is the purpose of the hand generator? Why does the local-battery telephone set need a hand generator?

o. What is the electrical principle of the hand generator?

p. How does the hand generator produce an alternating current? What factors determine the strength of the generated voltage?

q. Draw a diagram of the armature of the hand generator, and show how the armature winding is connected to the terminals of the hand generator.

r. What is the hand-generator switch? How is it operated? What is its purpose?

s. What is the approximate frequency and voltage of the ringing current generated by the hand generator at normal cranking speed?

t. Describe the construction of the ringer. What is the purpose of the ringer? How does it operate? What ringing-current frequency is required to operate it?

u. Draw a diagram of the ringer circuit of the local-battery telephone set.

v. Draw a diagram of the complete signaling circuit between two local-battery telephone sets. Explain its operation. What is the function of the hand-generator switch in this circuit?

w. What is sidetone? Why is it undesirable in the telephone set?

x. What is the purpose of the antisidetone circuit?

y. Why is some sidetone desirable?

z. What is an autotransformer? Draw the circuit diagram of the autotransformer-type induction coil of the antisidetone circuit.

aa. Draw the antisidetone circuit of the local-battery telephone set.

ab. Draw the circuit between two local-battery telephone sets with antisidetone circuits, and describe how the circuit operates.

ac. What is a capacitor? What is its purpose in the local-battery telephone set?

ad. What is the action of a capacitor when a d-c voltage is applied to it? An a-c voltage?

ae. What factors affect the capacitance of a capacitor?

af. Why is a switchboard used?

ag. What are the functions of the switchboard?

ah. Name the principal circuits of the switchboard.

ai. Name six components of the switchboard.

aj. What determines the number of line circuits of a switchboard? The number of cord circuits?

ak. Describe how a telephone call between a calling and a called telephone is completed through a local-battery switchboard.

al. What is the purpose of the switchboard jack? What are the names of its contact parts?

am. Draw a diagram of a simple line circuit; a simple trunk circuit.

an. What is the difference between a line circuit and a trunk circuit?

ao. What is the purpose of the local-battery line drop? Describe how it operates. Draw a diagram showing how it is connected in the line circuit.

ap. What is the advantage of the combined drop and jack? How does it operate?

aq. What is the purpose of the cord and plug? What is the function of the answer plug? The call plug?

ar. Name the two contacts of the local-battery plug. How does the local-battery plug differ from the common-battery plug?

as. How many conductors does the local-battery cord have? What are they called? How are the terms derived?

at. What is a patching cord? Draw a circuit diagram showing the use of a patching cord to connect two line circuits.

au. Draw a circuit diagram of a simple monocord circuit, and show how it may be used to interconnect two line circuits.

av. What is the purpose of the operator's telephone circuit? Draw a simplified circuit diagram showing how it is connected to the cord circuit.

aw. What is the difference between the operator's telephone set and the operator's telephone circuit?

ax. What is the purpose of the ringing circuit? Draw a simplified diagram of the ringing circuit, and show how it is connected to the cord circuit.

ay. Describe how the ringing circuit operates.

az. Give two functions of the listen-ring switch.

ba. What is the difference between the locking and nonlocking types of switchboard switches? Draw a diagram of each.

bb. State three reasons why the listen-ring switch is necessary in the cord circuit.

bc. What is the purpose of the listen switch in the cord circuit? Describe the operation of the cord circuit with the listen switch.

bd. What is the purpose of the ring switch in the cord circuit? Describe the operation of the cord circuit with the ring switch.

be. What is the purpose of the ring-back switch in the cord circuit? Describe the operation of the cord circuit with the ring-back switch.

bf. What is the difference between the monocord switchboard and the regular switchboard?

bg. Describe the operation of the monocord circuit with the listen switch; the ring switch.

bh. What is the purpose of the supervisory circuit? Draw a circuit diagram showing the connection of the supervisory drop. What frequency of ringing current is required to operate the drop?

bi. How are common connections indicated in circuit diagrams? Draw a circuit diagram which shows the common connections of the cord circuit.

bj. What is the purpose of the night-alarm circuit? Draw a circuit diagram of the night-alarm circuit. Describe its operation.

bk. What is the purpose of the transfer circuit? Describe its operation.

bl. What is the purpose of the generator-switching circuit? Draw the circuit and describe its operation.

CHAPTER 5

COMMON-BATTERY TELEPHONY

Section I. BASIC PRINCIPLES AND COMPONENTS OF COMMON-BATTERY SYSTEM

88. Introduction

a. The essential difference between *common-battery systems* and the local-battery systems discussed in chapter 4 is in the number and location of the batteries which furnish the power to operate the system. A common-battery telephone system is one in which a centrally located storage battery is used in place of the individual dry cells required at each telephone station of a local-battery system. The single *common battery* serves *all* the stations of the system.

b. As might be expected, many of the components of common-battery systems are identical with, or at least very similar to, the corresponding local-battery components. In this chapter, such components are only briefly treated, and the similarities and differences between them and their local-battery counterparts are pointed out.

c. In order that a single battery may serve all stations in the system, it is necessary that the stations be in parallel with each other as far as dc is concerned, with the battery connected across the line instead of in series with it. It follows from this requirement that certain circuits and components of common-battery systems are different from their local-battery counterparts, and that certain other circuits, not used at all in local-battery systems, are included in a common-battery system. Such circuits, which differ materially from components discussed in earlier chapters, are explained fully here. In presenting the complexities of common-battery systems, the method followed is the same as that in chapter 4, starting with a highly simplified circuit incorporating only the barest essentials, and then adding components and auxiliary circuits one at a time as the need for them is developed. In the interest of clarity, it sometimes will be necessary to postpone the discussion of certain components when they first are mentioned until a later point, and therefore only by a careful reading of the entire chapter can the complete system, its components, and their functions and interrelations be understood.

89. General Features of Common-Battery System

a. Advantages. The use of a single storage battery gives the common-battery system several important advantages over the local-battery system.

(1) The storage battery used in the common-battery system is much more economical to maintain than the dry cells of the local-battery system. Dry cells deteriorate and must be replaced periodically, whereas storage batteries can be recharged when necessary.

(2) The storage battery of the common-battery system gives a voice signal more uniform in amplitude, because it maintains a fairly constant voltage—more constant than the dry cells of the local-battery system.

(3) In the common-battery system, signaling is performed automatically when the receiver is lifted, eliminating the need for a hand generator and manual cranking, and making the equipment of the telephone set much simpler.

(4) In the common-battery system, the operator is signaled automatically upon completion of calls. This reduces the amount of supervision required, and allows a single operator to handle many more lines than is possible in a local-battery system.

(5) Finally, because the single storage battery is located at the telephone central office, inspectors are not required to make periodic visits to the associated telephone stations, as they must do in a local-bat-

tery system, to test dry cells for deterioration.

b. Limitations. In spite of its many advantages, the common-battery system has limitations and disadvantages that must be considered before giving it preference over the local-battery systems in certain applications.

(1) The common-battery system requires line construction of much higher quality than that required for the local-battery system, because current for the operation of the transmitter at the telephone set and supervisory relays at the central office must be supplied over the line.

(2) The lines of the common-battery system must be well balanced electrically, since unbalance in the wires of the outside plant impairs the quality of transmission and the distance over which transmission can be effected.

(3) Switchboard equipment in common-battery systems is much more complex and expensive than local battery equipment performing comparable functions, and it requires a greater time for installation and maintenance.

(4) The resistance of the loop or line to the common battery telephone station limits the distance over which talking and signaling currents may be supplied. Sufficient current must flow to assure operation of the following:

(*a*) The transmitter at the station.

(*b*) The line signal at the central office when the receiver is lifted.

(*c*) The supervisory relay at the central office when the receiver is hung up.

c. Applications. Because of the greater expense involved in the construction and maintenance of the inside and outside plant equipment of the common-battery system, it can be used efficiently only where relatively many stations and much local traffic are concentrated in a small area. In commercial practice, common-battery systems are used in all cities and large towns; in military applications, they often are used in higher headquarters. Local-battery systems are better suited to rural areas, where there are relatively few stations, scattered over a large area; but they also are used for *field* military applications, for they provide better transmission over field wire than does the common-battery system. In general, common-battery systems have greater application in *permanent* installations.

90. Basic Circuits of Common-Battery System

a. Simple Common-Battery Circuit. The essential feature of a common-battery system is emphasized best by comparing the simplest possible common-battery system with the simplest possible local-battery system. The essential difference between the two systems is illustrated in figure 111.

(1) The figure illustrates a very simple local-battery circuit, with hand generators and ringers omitted. The circuit consists of a transmission line terminated at each end by a telephone set. The telephone sets, A and B, are shown in elementary form and consist of a transmitter, a receiver, an induction coil, and a local battery.

(2) For purposes of comparison, an equally simple common-battery circuit also is illustrated. In this diagram, a *common battery* is shown connected across the telephone line, replacing the individual local batteries. Each telephone set consists of a transmitter, a receiver and an induction coil. Reference to the circuits will indicate one outstanding difference: In the local-battery circuit, the receiver and the secondary, S, winding of the induction coil are wired in series and connected across the line; in the common-battery circuit, the transmitter and the primary, P, winding of the induction coil are wired in series and connected across the line. A later paragraph describes more in detail the practical circuits used in common-battery systems.

b. Direct-Current Paths of Simple Common-Battery Circuit. As explained in chapter 3, direct current flows through the transmitter when it is operating. In the simple local-battery circuit, direct current is furnished by the local battery in series with the transmitter and primary winding of the induction coil at each station. In the common-battery circuit, however, direct current is furnished to both transmitters by the common battery, as shown in figure 111. The figure illustrates the direct-current path from the common battery to two telephone sets. It can be seen that, as far as direct current is concerned, the two telephone sets and their associated telephone lines are in *parallel* with respect to the common battery. If

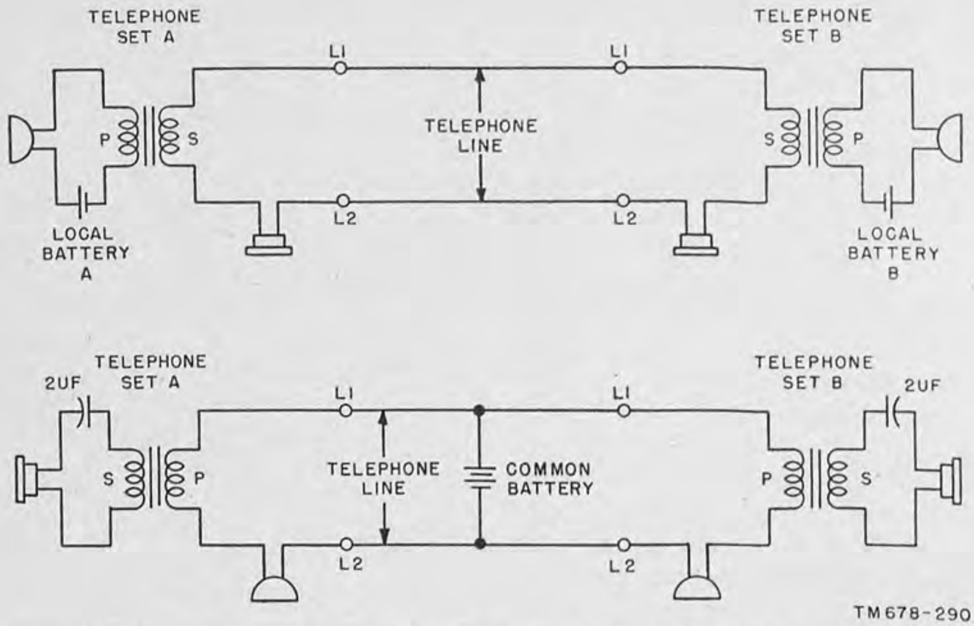

Figure 111. Comparison between simple common-battery and local-battery telephone circuits.

several telephone circuits were connected across the single battery, the direct current which the battery would be required to furnish easily could reach extremely large values. For this reason, the common battery in a common-battery system usually is connected permanently to a battery charger. The function and operation of a battery charger will be explained more fully in a later chapter.

c. Talking Path in Simple Common-Battery Circuit.

(1) It has been shown (ch. 3) that the operation of a telephone transmitter is based on the principle that sound waves, striking the diaphragm of the transmitter, produce corresponding vibrations of the diaphragm. The varying pressure of the diaphragm varies the resistance of the carbon granules, and causes the current to fluctuate about its normal steady value. The resulting *pulsating* direct current therefore can be considered to consist of a steady direct current on which is superimposed a voice-frequency alternating current. The paths of the d-c and a-c components of the transmitter current are not necessarily the same.

(2) The talking path in the simplified common-battery circuit is shown in figure 111. At first glance it would appear that the two telephone sets are in series so far as the talking path is concerned. However, the common battery now must be considered in parallel with the receiver and transmitter of the listening station. Thus, if the person at station A is talking into his transmitter, the voice-frequency currents originating at transmitter A flow through the line until they reach the point where the common battery is bridged across the line. Since the impedance of the battery to the voice-frequency currents is much lower than that of the transmitter-receiver combination of station B, the major portion of the voice-frequency currents will flow through the battery leg. The same situation arises when the voice-frequency currents originate at the transmitter of station B. The battery, by shunting the receiver branch of the listening station, greatly reduces the magnitude of the voice-frequency currents flowing in the receiver.

(3) In order to prevent the common battery from shunting the receiver branch of the listening station, some component must be inserted in series with the battery in the battery leg to increase the impedance of the battery leg to voice-frequency currents. This is accomplished by the use of filter networks (fig. 112). The actual filter networks used in common-battery circuits are either *retardation-coil* or *re-*

peating-coil arrangements, which will be discussed more completely in paragraphs 99 through 113. Although the filters present a relatively high impedance to alternating currents, their d-c resistance is so low that they do not affect materially the direct current from the battery to the telephone stations.

d. Practical Common-Battery Circuits. In the following paragraphs, the simplified circuit explained above will be used as a starting point to outline the need for the various circuits and components used in practical systems. For example, the simplified circuits of figures 111 and 112 show only two telephone stations, and the common battery is bridged across the line. In practice, the system would include many more than two stations, and *any* two stations would be connected through one or more switchboards or central offices. Also, in practice, the common battery is located at a central office, and is connected through a power distributing panel to the switchboard, and through the switchboard to the telephone stations when they are in use. Associated with the switchboard are various circuits required to develop the advantages of efficient operation of which the common-battery system is capable. The switchboard may be regarded as the heart of the system. Although the switchboard serves the same basic function in the common-battery system as in the local-battery system, the common-battery switchboard differs in many of its details from the local-battery switchboards discussed in chapter 4. Therefore, before proceeding with a full discussion of practical common-battery circuits, the common-battery switchboard will be described.

91. Common-Battery Switchboard

a. Function.

(1) As in the case of the local-battery switchboard, the main function of the common-battery switchboard is to permit efficient connection of any two telephone stations connected to it. The switchboard also must provide means for supervision of calls, and must enable the operator to ring the called station. Most ringing is performed by ringing machines and circuits similar to those of a local-battery system. Other ringing systems are described in paragraphs 114 through 121. Signaling from the calling station to the operator is automatic in a common-battery system (par. 93*c*).

(2) The efficient operation of a common-battery system is made possible by the various circuits contained in the switchboard. They include line circuits and cord circuits of various kinds, trunk circuits, ringing circuits, supervision circuits, and various auxiliary circuits.

(3) Although the circuits mentioned above seem to be of the same general types as those in a local-battery switchboard, they actually are different in many respects, primarily because of the difference in battery supply. The structure and operation of the circuits associated with common-battery switchboards, together with their interrelation and the role of the switchboard operator in making connections between telephone stations, are discussed in later sections of this chapter.

b. Types. Common-battery switchboards in general may be classified as *nonmultiple* and *multiple*.

(1) A *nonmultiple switchboard* is one in which each line connecting a telephone station to the switchboard terminates in only *one* line jack. This type of switch-

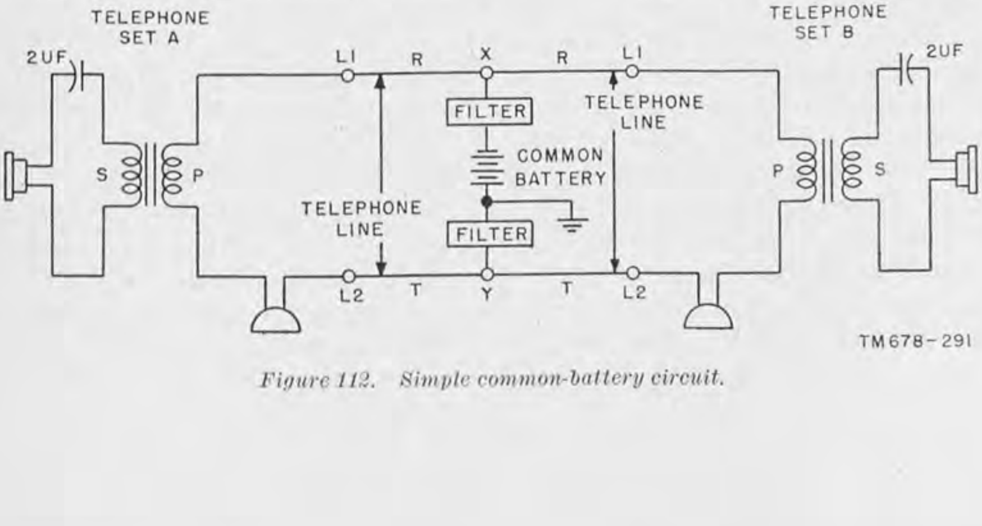

Figure 112. Simple common-battery circuit.

board obviously limits the number of lines that can be serviced by a single operator, or even by several operators. It is obvious that it often might be necessary to connect a calling line terminating on a line jack located at one end of the switchboard to a called line terminating on a line jack at the other end, which would result in a confusing network of cords. For this reason, the use of nonmultiple switchboards is limited to systems that do not require more than three operators to handle the traffic.

(2) A *multiple switchboard* is one in which each line connecting a telephone station to the switchboard terminates in *several* line jacks, connected in parallel or multiple, at different points on the switchboard. This makes it possible for the operator at each position of the switchboard to reach one of the line jacks of any calling or called station connected to the switchboard, greatly increasing the traffic which the switchboard can handle. The discussion which follows will concern itself with the description and operation of a nonmultiple common-battery switchboard. Multiple switchboards and their associated circuits are discussed in paragraphs 129 through 136.

c. Description of Front of Switchboard. In general, the equipment arrangement is similar in all cord-type switchboards, but it is not exactly the same. The switchboard in figure 113 can be used at a small central office.

(1) The illustration shows the vertical portion of the board above the plugshelf, sometimes called the cordshelf, divided into two panels by the vertical separator through its center. The left panel carries 50 line (station) jacks with their associated line lamps, a supervisory pilot lamp, fuse-alarm lamp, and a line pilot lamp. The right panel has, in addition to 50 line jacks and line signals, a single row of jacks and signals to which exchange lines are connected.

(2) The plugshelf holds 15 pairs of cords and 1 single cord. The paired cords are used to complete interconnections. The single cord, when present, is used by the operator to advise a calling station when all the paired cords are in use. This single cord is not standard equipment on all switchboards.

(3) The switchshelf carries the control levers of the listening and ringing switches, the associated supervisory lamp signals, and the switchboard dial. Each pair of cords is associated with a pair of supervisory lamp signals and a pair of switches. The dial is used in completing connections between one of the switchboard stations and a station associated with a dial central office.

(4) The extreme left-hand cord (fig. 113) is the A (answering) cord of the first pair of cords. The cord immediately in front of that cord, toward the operator, is the C (calling) cord of the first pair of cords. The term *answering cord* means that on a station line signal this cord is used in answering the signal, leaving the C cord available for making connections to an exchange if this is required. This association of cords to lines is necessary to proper supervision. Calls to another switchboard station can be completed with the C cord. Answering and calling cords sometimes are referred to as back and front cords, respectively.

(5) The two lamp signals immediately in front of each pair of cords are the supervisory signals associated with these cords. The supervisory signal farthest from the operator is the A cord signal. The signal nearer the operator is the C cord signal. These signals inform the operator when one or another of the connected stations hangs up the receiver, or whether either station jiggles the hookswitch. The supervisory signals are discussed in more detail in later paragraphs.

(6) The switch levers shown on the switchshelf control the associated listening and ringing switches. Each pair of switches is associated with a pair of adjacent cords. Each switch lever may be placed in any one of the following positions: In any selected pair of levers, the lever farthest from the operator, when drawn backward toward the operator, operates the associated switch, which connects ringing power to the ring and tip of the A cord. Pushing the lever away from the operator establishes in the associated

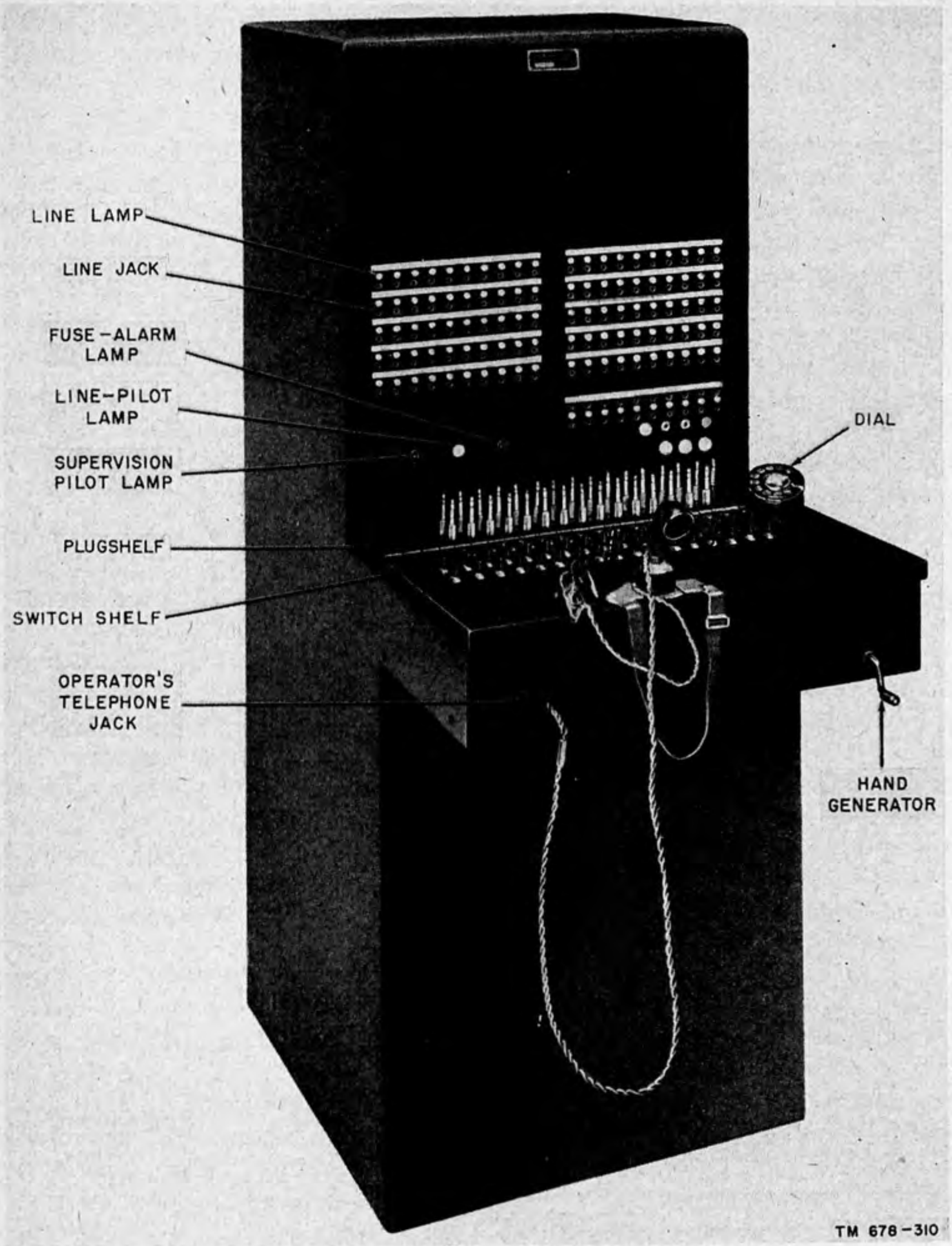

Figure 113. Typical nonmultiple common-battery switchboard.

cord circuit a condition commonly referred to as a *night connection*. When the lever is vertical, the associated switch is in its neutral position. The lever nearer the operator, when moved away from the operator, connects the operator's telephone set to that particular cord circuit, permitting intercommunication among the operator and the stations connected by the cord circuit. When the lever is drawn toward the operator, ringing power is connected to the ring and tip of the C cord. Service at a switchboard sometimes requires that certain extension stations be connected to central-office lines during times while the switchboard is unattended, such as outside of regular business hours, and at night. This service can be provided in the usual manner by connecting the A cord to the extension station and the C cord to the central-office line. The act of connecting the C cord to the central-office line, however, automatically connects a bridge across the ring and tip cord conductors, and thus a signal appears at the central-office switchboard, even when the receiver is on the hookswitch at the extension station. The undesirable condition is corrected when the *night-connection* switch is moved to the operated position. This operation *opens* the bridge across the ring and the tip cord conductors and holds the central-office line *open* until the receiver is removed from the hookswitch at the extension station. This establishes the *night connection*.

(7) The vertical portion of the switchshelf carries the operator's telephone jack and the hand-generator crank. The operator's headset (transmitter and receiver) is corded to a plug. When this plug is inserted in the telephone jack, the headset is connected electrically into the switchboard circuits. Almost every switchboard is equipped with a hand generator. This generator is used for ringing the bells at the stations when the ringing power supply fails or when no other ringing power is available. The hand generator is operated by rotating the hand-generator crank in a clockwise direction. Operating a ringing switch while turning the hand generator crank connects ringing power to the associated cord.

Note. Access to parts of the switchboard apparatus and wiring is gained by removing a panel from the back of the board. Generally, this panel is removed by lifting upward and then drawing outward on the panel. Access to the switches shown on the switchshelf, operator's telephone jack, hand generator, and associated wiring is obtained by unlocking and raising the switchshelf. A special switchboard key is necessary to unlock the switchshelf.

92. Operation of Common-Battery Switchboard

To make clear the main function of the switchboard in relation to the telephone lines and stations connected to it, a brief over-all picture of the operation of a common-battery switchboard is given in this paragraph. A number of important details, omitted here for simplicity, are described fully in later paragraphs. The present discussion covers a cord circuit and the telephone stations which it interconnects through the switchboard.

a. Cord Circuit.

(1) Figure 114 is a simplified diagram of a *cord circuit* in a common-battery switchboard. This circuit consists of two cords,

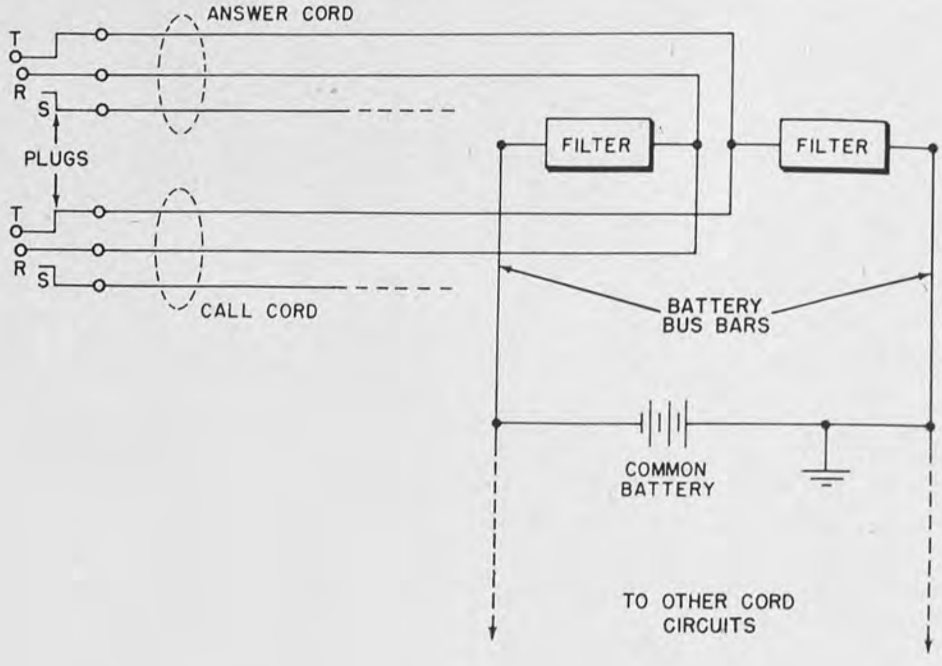

Figure 114. Simplified common-battery cord circuit.

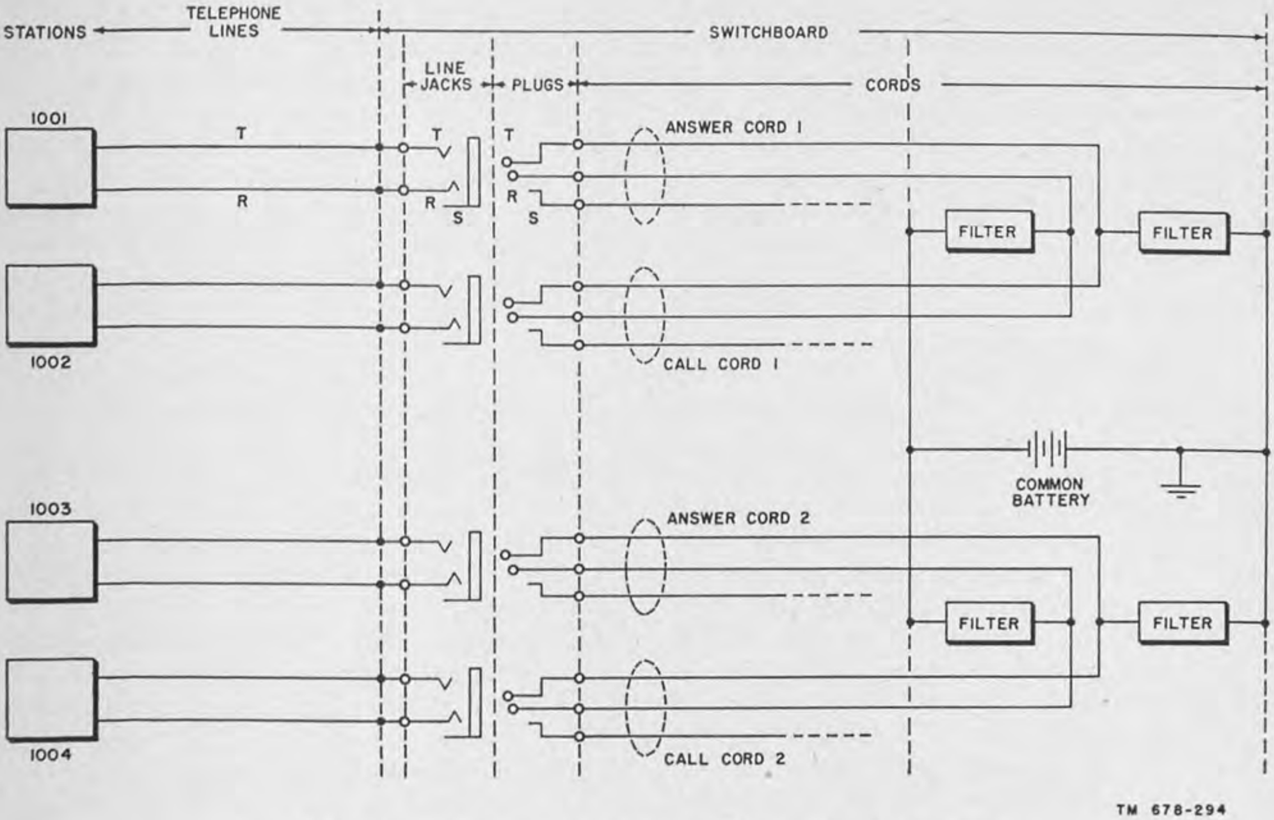

Figure 115. Simplified common-battery cord and line circuits.

an *answer* cord and a *call* cord, each of which contains three conductors: *tip* (T), *ring* (R), and *sleeve* (S). The tip conductors of the two cords are connected, and their junction is connected to the *positive* (grounded) battery bus through a filter network (par. 90*c* and fig. 112). Similarly, the two ring conductors are connected, and their junction is connected to the *negative* battery bus through a similar filter network. The sleeve conductors are shown not connected. Actually, they are used for connection to supervisory circuits, as explained in paragraphs 99 through 113.

(2) Each of the cords is connected at its free end to a plug containing three contacts (fig. 90). The contacts of the plug also are called *tip*, *ring*, and *sleeve*, from which the cord conductors connected to them derive their names. The plug at the end of the answer cord is called the *answer* plug, and is used by the switchboard operator in answering a call originating at the calling telephone station. The plug at the end of the call cord is known as the *call* plug; it is used by the operator to complete the connection to the called telephone station.

b. Line Circuits.

(1) As in a local-battery system, a connection between two telephone stations in a common-battery system is completed by means of a cord circuit through the *line circuits* associated with the two telephone stations. In figure 115, the line circuits are shown as consisting only of *line jacks*, one for each telephone line connected to the switchboard, into which the plugs of the cord circuits may be inserted by the operator. Actually, several kinds of line circuits are associated with common-battery switchboards, all of them including some means for signaling the operator automatically when a station wishes to make a call. Since the present discussion is concerned only with the basic elements of the common-battery system, however, consideration of the line circuits actually used in common-battery switchboards, including such necessary requirements as signaling and supervisory circuits, must

be deferred. Note that the line jacks illustrated have three contacts, also called *tip*, *ring*, and *sleeve*, to correspond to the contacts of the plugs and the conductors of the cords.

(2) The tip and ring contacts of the line jacks are connected by wires to terminals on the rear panel of the switchboard. Since the telephone line from each telephone station is connected to *one* pair of these terminals, each telephone station has a direct connection to a line jack on the front panel of the switchboard. Figure 115 shows four telephone stations (numbers 1001 through 1004), each of which is connected by a separate telephone line to a line jack on the switchboard. Also shown in the figure are two cord circuits, connected through their respective filter networks to the battery bus bars. All of the cord circuits contained in a switchboard are connected in this manner.

c. Tracing a Call Through Switchboard.

(1) The progress of a call from station 1001 (the calling station) to station 1002 (the called station) through the switchboard is traced in figure 116. Again, the operation of the signaling and supervisory circuits is not considered in this introductory simplification. Assume that the operator is informed that station 1001 wishes to place a call. He inserts the answer plug of cord circuit 1 in the line jack connected to station 1001, in A. This causes the tip and ring contacts of the plug to make contact with the tip and ring springs of the line jack, as shown.

(2) The operator switches his telephone set into the cord circuit. He receives the number of the called station, 1002, from the calling station, and inserts the call plug of the *same* cord circuit used in answering the calling station in the line jack associated with station 1002, as in B. He then rings station 1002 and watches for the answer signal. (This is made known to the operator by means of the supervisory circuit associated with the cord circuit, as explained later.) When station 1002 answers the ring, the ringing is stopped.

(3) A talking path now is established between station 1001 and station 1002. The path is from station 1001 over the tip side of the telephone line to the tip contacts of the associated line jack and the answer cord; through the tip conductors of the answer and call cords to the tip contacts of the call plug and the line jack of station 1002; over the tip side of the telephone line of station 1002 to the telephone set of station 1002; over the ring side of the telephone line of station 1002 to the ring contacts of the associated line jack and the call plug; through the ring conductors of the call and answer cords to the ring contacts of the answer plug and the line jack of station 1001; and, finally, over the ring side of the telephone line of station 1001 to the telephone set.

(4) The filters in series with the battery leg prevent the flow of talking current through the battery. Besides preventing the battery from short-circuiting the talking current to the listening station, they prevent the various cord circuits from interfering with each other. For example, suppose a conversation is in progress between telephones 1003 and 1004 by way of cord circuit 2, as in B, in addition to the conversation between telephones 1001 and 1002. If no filters were present in the cord circuits, talking current originating at *any* of the four stations theoretically could flow in the receivers of *all* of the other stations. This, of course, would make impossible a private conversation between only two stations.

(5) With the circuit arrangement shown in B, however, it is possible for any two stations to have a private conversation, without interference from any other conversations that might be in progress by way of the other cord circuits. Thus, for example, if station 1001 wishes to converse with station 1003, the answer cord would be connected to the line jack of station 1001, and the calling cord would be connected to the line jack of station 1003. The cord circuits in the switchboard therefore provide a rapid and efficient means of interconnecting the various lines terminating on the switchboard, each cord circuit accommodating a conversation between any two stations.

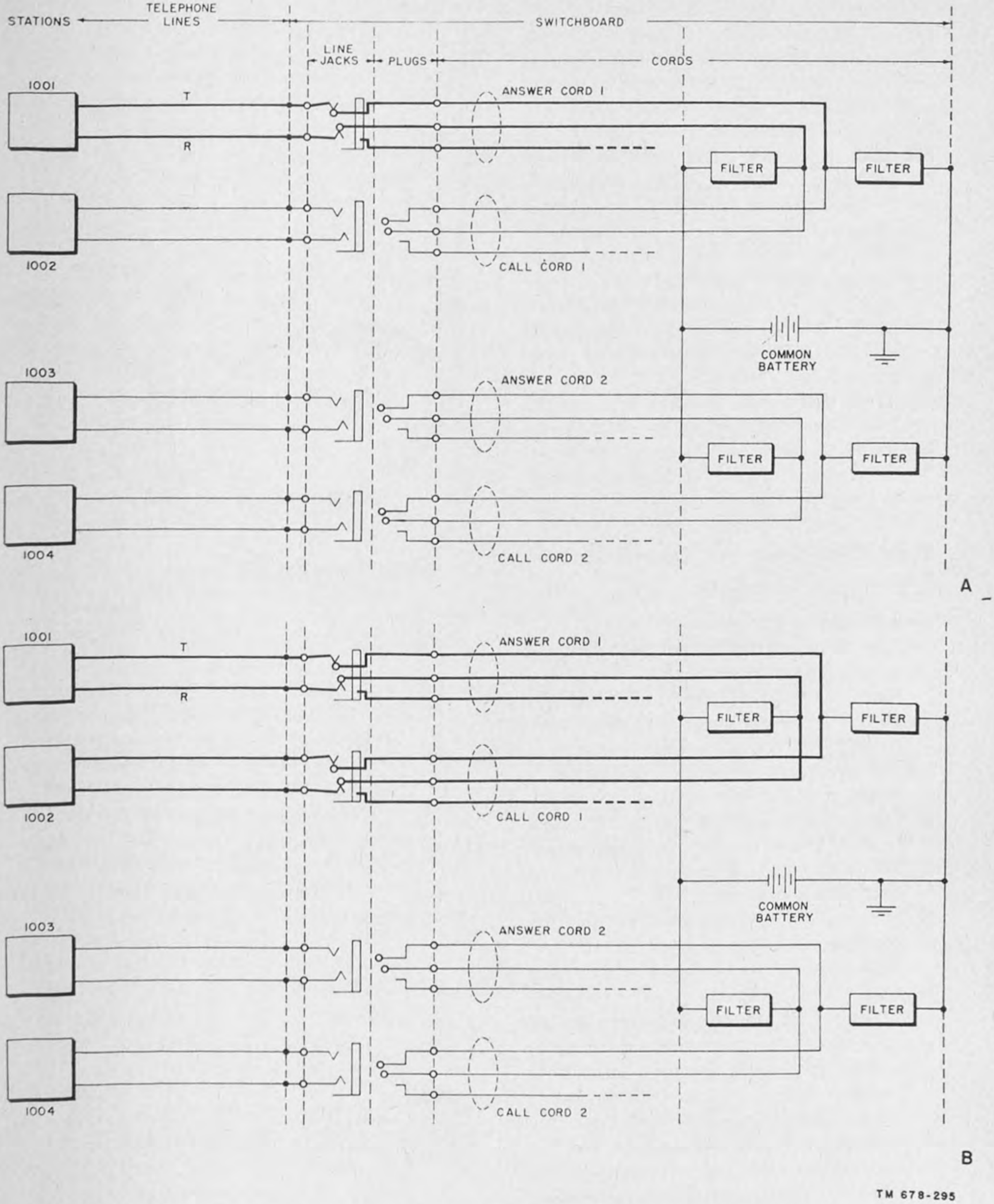

Figure 116. Tracing a call from station 1001 to station 1002.

(6) Figure 113 shows that, although the switchboard has 100 line jacks and lamps accommodating 100 telephone stations, it has only 15 cord circuits and an additional answer cord (located at the extreme right of the plugshelf). This enables the switchboard to handle up to 15 individual calls at any one time, so that this particular switchboard would be used in a common-battery system where the traffic normally would be not more than 15 calls at any one time. The additional answer cord (not found on all switchboards) is used to notify a calling telephone that all the regular cord circuits are busy when that situation arises.

(7) After the various switchboard circuits have been discussed more fully, paragraph 112 will describe in greater detail the progress of a call through a common-battery switchboard.

93. Basic Components of Common-Battery Cord and Line Circuits

a. Common-Battery Cords and Plugs.

(1) The functions of the cords and plugs of the cord circuits in common-battery systems, as explained above, are essentially similar to those associated with local-battery systems. In addition to providing connections between a calling and a called telephone for talking and signaling, however, common-battery cords and plugs provide a means of automatic supervision through their respective sleeve conductors and contacts.

(2) Figure 117 illustrates a common-battery cord connected to a plug. Its general appearance is similar to the local-battery cord shown in figure 91. The common-battery cord, however, instead of having only two conductors, has *three*. As mentioned previously, the conductors of a common-battery cord are the *tip* (white wire), *ring* (blue wire), and *sleeve* (red wire), and they are connected at the free end of the cord to the corresponding terminals (tip, ring, and sleeve) of the plug.

(3) The other ends of the cord conductors are soldered or clipped to individual metal lugs and connected to terminals in the interior of the switchboard which connect the cords to the remainder of their respective cord circuits. The tip and ring of the cord and plug connect the line wires from the telephone stations to the cord circuit by way of the various line jacks.

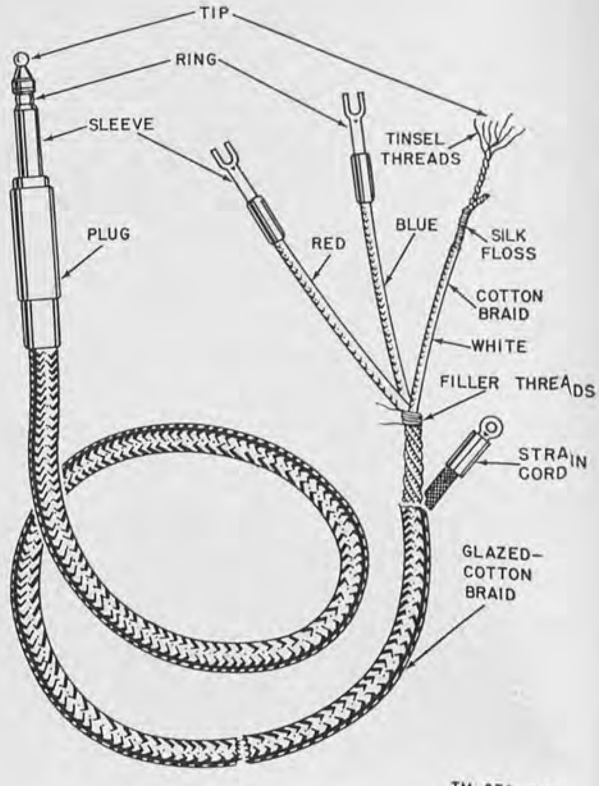

Figure 117. Common-battery switchboard cord and plug.

(4) Each cord conductor consists of fine tinsel threads and is insulated with a layer of silk floss covered by cotton braid of the proper identifying color (white, blue, or red). As in the case of the local-battery cord, a *strain cord* also is provided which has the same function as the strain cord of the local-battery switchboard (par. 70*c*).

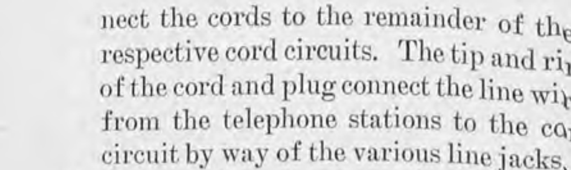

Figure 118. Common-battery line jacks.

(5) The structure of the common-battery plug has been described in detail (par. 70*b*(2)).

b. Common-Battery Line Jacks.

(1) The line jacks shown in figures 115 and 116 are called *simple* jacks. They have three contacts—tip, ring, and sleeve—to correspond to the contacts of the plug and cord. It will be remembered that the local-battery jack has only two contacts—tip and sleeve. The tip and ring contacts of the simple common-battery line jack are spring-type contacts. They make contact with the tip and ring contacts of the plug when a plug is inserted in the jack. The tip and ring wires of the telephone line, with which the jack is associated, are connected to corresponding terminals on the rear of the switchboard, and the tip and ring of the line jack are connected respectively to the same terminals, as explained previously. The sleeve of the line jack is tubular, and makes contact with the sleeve of the plug.

(2) Another type of line jack, called a *cut-off jack*, is illustrated in figure 118. This type of line jack has two *auxiliary* contacts in addition to the regular tip, ring, and sleeve contacts. When no plug is in the jack, one auxiliary contact lies against the tip spring of the jack, and the other against the ring spring. This provides a means of connecting an auxiliary circuit, such as a lamp circuit, to the tip and ring of the jack through the auxiliary contacts, as will be explained later. When a plug is inserted in the jack, as shown in the figure, the tip and ring contacts of the jack are spread farther apart, away from the auxiliary contacts, breaking or cutting off the auxiliary circuit. Although the cut-off jack provides a simple means of connecting an auxiliary circuit to the tip and ring contacts of the line jack, it has a serious limitation. Since the main and auxiliary contacts are contained *within* the jack, they are not readily accessible for adjustment. Special tools must be used, and, even with such tools, adjustments must be made without possibility of observing the effect produced, unless the jack is removed from the panel. A means of overcoming this limitation will be discussed later.

(3) Line jacks are mounted individually or in strips of 10 or 20, according to the type of switchboard in which they are used. The switchboard illustrated in figure 113, for example, has its line jacks mounted in strips of 10.

c. Common Battery Signal Lamps.

(1) The line signal used in common-battery switchboards is usually a small *lamp*, instead of a ring-down drop, the drop-shutter mechanism used in local-battery switchboards (par. 67). A typical signal lamp is illustrated in A, figure 119. It contains two filament terminals, small metal plates extending along opposite sides of the glass bulb, to which the filament wires from inside the bulb are soldered. A small wooden or bakelite block, cemented to the rear end of the lamp, supports and insulates the filament terminals. The glass bulb is tubular in shape to permit easy insertion of the lamp in the switchboard panel. In B, the lamp is shown in the position of a *line lamp*. A lamp of similar type is used for supervisory signaling.

(2) Because the line lamp is associated closely with the line jack, it usually is mounted in the switchboard panel as part

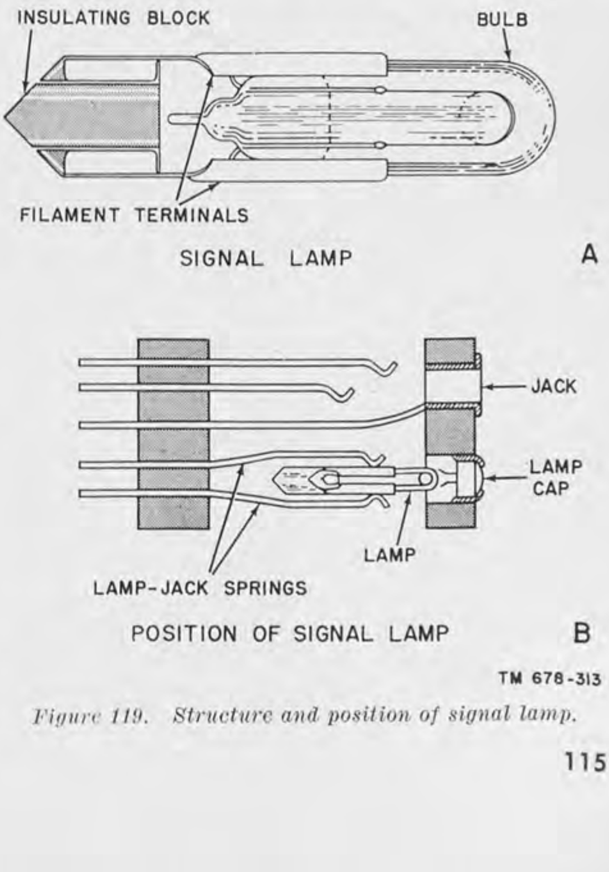

Figure 119. Structure and position of signal lamp.

of the same unit with its associated line jack, as in B. Here, a signal lamp is shown in a two-contact lamp jack below its associated line jack. After the lamp is inserted in its jack, the lamp entrance opening in the panel is closed with a glass *lamp cap*, or *opal*, as shown. The lamp cap may be color-coded to indicate that a particular line shall receive priority in the matter of prompt service or that the station is equipped to dial its own calls. Lamp jacks, like line jacks, are mounted either individually or in strips of 10 or 20, and they are located either directly below or directly above their respective line jacks. The lamps illustrated in the switchboard of figure 113 are located above the corresponding line jacks.

(3) The operation of line lamps in signaling by the calling user is discussed in paragraph 101 in connection with line circuits.

94. Common-Battery Telephone Sets

Telephone sets in a common-battery system contain most of the same components that are in the local-battery telephone sets. The circuits connecting these components, however, differ considerably in the two systems. For this reason, the telephone sets in figures 115 and 116 are shown only in block-diagram form. It is now appropriate to consider the circuits of common-battery telephone sets in detail.

a. Basic Circuit of Common-Battery Telephone Set.

(1) The circuits of common-battery telephone sets may be classified as *sidetone*, or *booster* circuits, *sidetone-reduction* circuits, and *antisidetone* circuits. All three types, however, are understood best by considering first a simpler and more fundamental circuit, basic to them all (fig. 120). Each telephone set contains a transmitter, a receiver, an induction coil, I, with a primary winding, P, and a secondary winding, S, a ringer, RG, a capacitor, C, and a *hookswitch*, H. Each telephone set has a circuit similar to the circuit of a local-battery telephone set shown in figure 71 except for these differences: There is no battery or hand generator in the common-battery set, and the handswitch shown is replaced by a hookswitch in the common-battery set. (In a local-battery system, the hand generator is needed to signal the operator. In a common-battery system, the switchboard operator is signaled automatically by the operation of the hookswitch.) There is also a difference, which will be discussed in paragraphs 114 through 121, in the manner of connecting the ringer and capacitor in the circuit with respect to the transmitter and receiver.

(2) The primary and secondary windings of the induction coil are shown in figure 120 as *separate* windings, without the common connection point shown in figure 71. This representation, although not important for the discussion of the operation of the basic circuit of figure 120, must be used in connection with the explanation of some of the other circuits which will follow.

(3) The theory of operation of the several components of a common-battery telephone set—transmitter, receiver, induction coil, capacitor and ringer—is the

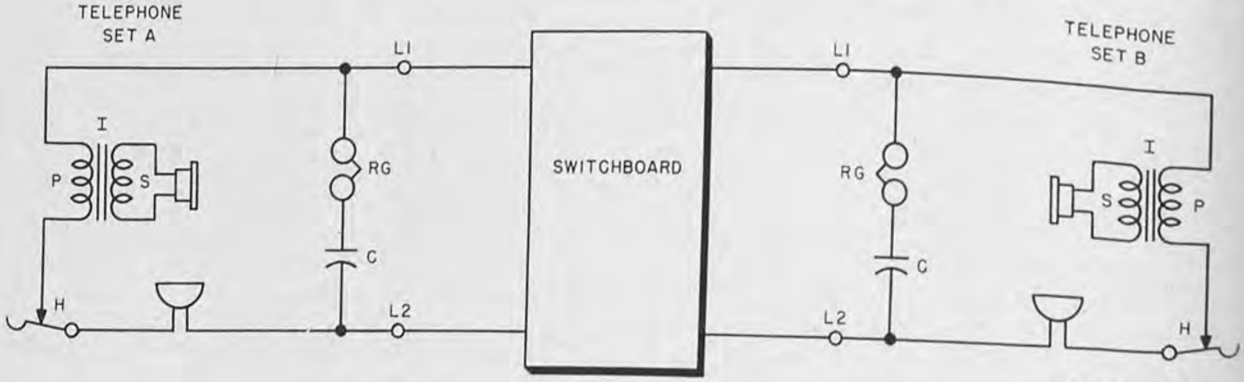

Figure 120. Basic circuit of common-battery telephone set.

same as that of the corresponding components of a local-battery telephone set. Their relation to each other and to the other components of the circuit differ in a common-battery system.

b. Operation of Basic Circuit. The basic simplified circuit of a common-battery telephone set (fig. 120) can be considered conveniently in three parts: the *primary*, or transmitter circuit, the *secondary*, or receiver circuit, and the *ringing* circuit.

(1) The primary circuit of a telephone set, shown in the figure, consists of the transmitter in series with the primary winding of induction coil I, hookswitch H, and line terminals L1 and L2. The hookswitch, as explained in (3) below, closes this circuit whenever the receiver is lifted from its hook or cradle, as when a user lifts it to make or answer a call. The battery at the central office may be considered connected effectively to terminals L1 and L2, on answering a call, by means of the cord circuit, line jack, and telephone line. When the hookswitch contacts are closed, direct current from the common battery flows through the primary winding of the induction coil and the transmitter. Words spoken into the transmitter cause a pulsating direct current to flow through the primary winding of the induction coil and over the line. A similar telephone set, at the calling station, is connected to this set, and the similar pulsating direct current flows through the primary winding of its induction coil. By transformer action, an *alternating* current flows in the secondary winding of the induction coil of the called set and in its receiver, where the sound waves striking the calling transmitter diaphragm are reproduced.

(2) The secondary circuit consists simply of the secondary winding of the induction coil in series with the receiver. It has been explained above that the pulsating direct current in the primary winding of the induction coil of the called set causes an alternating current to flow in the secondary winding and the receiver of the called set. However, by the same transformer action, the pulsating direct current in the primary winding of the induction coil of the *calling* set also causes a corresponding alternating current to flow in the secondary winding and the receiver. of the calling set. This results in the production of an appreciable amount of *sidetone* (par. 58) so that the speaker hears his own voice in his own receiver. This undesirable effect is minimized by the use of circuits described below (pars. 95 through 97).

(3) Because the battery of a common-battery system is located at the central office, and is therefore always in the circuit, some means must be provided for *making* the circuit when a conversation is to be started, for *keeping* it closed while the telephone sets are in use, and for *breaking* it when the telephone conversation is over. This function is performed by a *hookswitch* in series with the primary circuit (fig. 120). The receiver in a common-battery telephone set hangs on the *hook* of the hookswitch when not in use, and its weight keeps the hookswitch contacts normally *open*. Removal of the receiver causes the hookswitch contacts to close. Unlike the handswitch of the local-battery set, which may be the type that is pushed for talking and released for listening, the hookswitch contacts of a common-battery set remain closed during the entire conversation.

c. Ringer Circuit. The ringer circuit of the basic common-battery telephone set consists of a ringer in series with a capacitor, usually of $.5\text{-}\mu f$ capacity. The combination is connected directly across the line, between terminals L1 and L2. (In the basic local-battery circuit of figure 72, the ringer alone is connected across the line, and the capacitor is in series with the receiver and the secondary winding of the induction coil.) The capacitor, in the common-battery set, blocks the flow of direct current through the ringer, but permits the flow of ringing current. The ringer does not shunt the primary circuit of the set appreciably so far as talking current is concerned, because the impedance of the ringer path to voice frequencies is much greater than that of the primary winding of the induction coil. Ringing in common-battery systems is discussed more completely in paragraphs 114 through 121.

95. Common-Battery Sidetone (Booster) Circuit

a. Arrangement. The basic circuit of a common-battery telephone set has been found (par. 94*b*) to produce considerable sidetone in either receiver. A more efficient circuit which, although it also produces sidestone, represents a considerable improvement over the basic circuit of figure 120 is the so-called *booster* circuit (fig. 121). It contains the same components as the telephone set shown in figure 120, but they are arranged differently. In this circuit, the receiver and the secondary winding of the induction coil are connected in series between the junction of the ringer and capacitor at A and the upper hookswitch contact, which is electrically the same as B when the hookswitch contacts are closed. Although this arrangement permits some direct current to flow through the ringer and the receiver, the high resistance of these components makes the amount small.

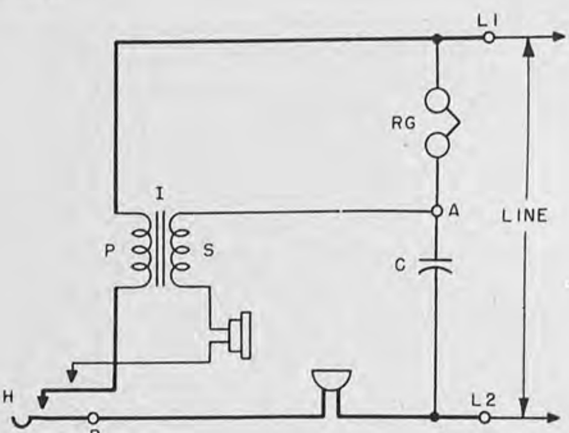

Figure 121. Arrangement of common-battery sidetone circuit.

b. Transmitting Circuit. When hookswitch H is closed, d-c voltage from the central office battery is applied to the components of the telephone set shown in figure 121. Application of this d-c voltage produces a d-c current flow in two paths. One current path (path 1) is through the primary of induction coil I, hookswitch H, and the transmitter. The other d-c path (path 2) is through ringer RG, the secondary winding of the induction coil, the receiver, the hookswitch, and the transmitter. The amount of direct current flowing through path 2 is less than that through path 1 because of the higher ohmic resistance of path 2.

(1) When a voice-frequency sound activates the diaphragm of the transmitter and disturbs the position of the carbon granules in the transmitter, the current in the two paths varies in accordance with the frequency and amplitude of the sound wave. As a result, a voice-frequency component of current is developed through path 1 and the line, with voice-frequency voltages appearing across the transmitter and the primary winding of the coil. Little voice current flows through path 2, because the voice current through this path is limited by the high impedance of the ringer as compared to the impedances of the receiver and secondary winding. However, voice current in the primary winding through path 1 induces, by transformer action, a voice current in the path comprised of the secondary winding, the receiver, the hookswitch, the transmitter, and the capacitor.

(2) The connections to the primary windings of the induction coil are made so that the primary and secondary currents are in phase with each other. As a result, the primary and secondary currents combine in the common impedance presented by the transmitter, and the resultant voice current sent out over the line is boosted to a higher level. Also, the increased secondary current produces a larger local receiver current, and a high level of sidetone is obtained.

c. Receiving Circuit.

(1) When the circuit is used for receiving, its operation is slightly different from that described above. Suppose that a voice current is being received from the line and enters the circuit through terminals L1 and L2 (fig. 121). This current will pass through path 1, and will induce a voice voltage across the primary winding and across the transmitter, the diaphragm of which is now at rest. The received current will not enter path 2 because of the high impedance of ringer RG. Because of this condition, it might at first appear that no output would be obtained from the receiver unit. However, this is not the case, because of inductive coupling between the windings

of the induction coil. By transformer action, the primary current produced by the received signal induces a voltage into the secondary circuit consisting of the secondary winding, the receiver, the hookswitch contacts, the transmitter, and capacitor C. Voice current flowing through the receiver unit provides reception of the incoming signal.

(2) Again, a booster, or regenerative action is produced by the in-phase connections of primary and secondary windings of the induction coil, and these currents add in the common impedance presented by the transmitter.

d. Circuit Efficiency. The over-all performance of the booster circuit is characterized by high efficiency. The chief disadvantage of the circuit is the presence of a high level of sidetone.

96. Common-Battery Sidetone-Reduction Circuit

a. Arrangement. A circuit that reduces the amount of sidetone produced in the receiver of its telephone set is the *sidetone-reduction* circuit (fig. 122). It is like the booster circuit of figure 121, except that here the transmitter is connected in series with the primary winding of the induction coil on the *opposite* side of the hookswitch contacts, as shown.

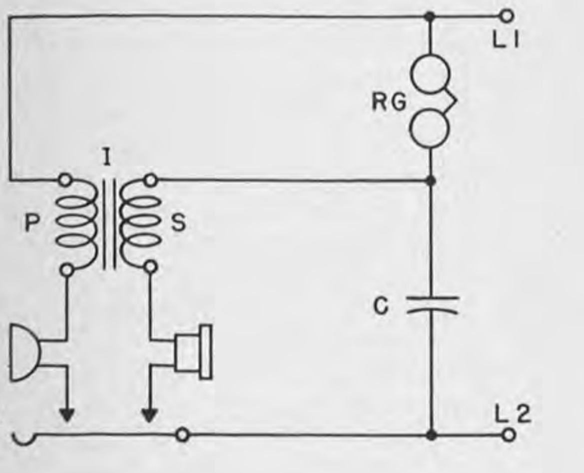

Figure 122. Common-battery sidetone-reduction circuit.

b. Operation.

(1) Since the resistance of the primary circuit of figure 122 is approximately the same as that of the sidetone circuit described in paragraph 95, both the direct current from the central office battery and the voice-frequency currents corresponding to the sound waves striking the diaphragm of the transmitter are similar to those in the sidetone circuit. In this circuit, however, because of the different location of the transmitter with respect to the receiver, all of the voice current originating in the transmitter flows in the primary winding of the induction coil, and only by induction in the receiver circuit. The impedance of the ringer to voice-frequency current is so high that negligible current flows through the circuit comprised of the ringer and capacitor or the ringer, secondary winding, and receiver.

(2) The current fluctuations in the primary winding of the induction coil induce a corresponding alternating emf in the secondary winding. The primary and secondary currents are in phase because of the transformer connections, but little reinforcement of currents occurs because there is no impedance common to primary and secondary circuits. As a result, sidetone is reduced.

(3) Although the sidetone-reduction circuit is effective in reducing the amount of sidetone, it lacks the desirable feature of the sidetone circuit—that of causing a higher voltage to be impressed on the line by booster action. For this reason, *transmission* with the sidetone-reduction circuit is less efficient than with the booster circuit discussed in the preceding paragraph.

97. Common-Battery Antisidetone Circuit

a. Arrangement. As already explained, a high level of sidetone is undesirable in telephone receivers. It produces interference when the set is operated in noisy locations, and usually makes the user lower his voice when he hears his spoken words reproduced loudly by his own receiver, thus reducing the output of his transmitter to the line. Both of the common-battery sets discussed in paragraphs 95 and 96 produce sidetone. An antisidetone circuit which reduces sidetone to a very low level is illustrated in figure 123. The actual circuit

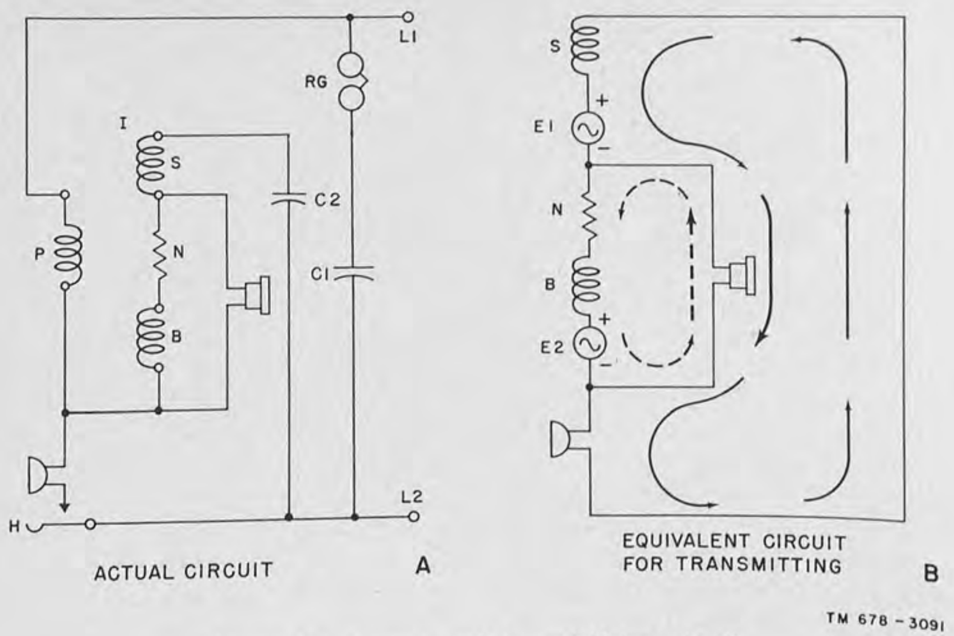

Figure 123. Common-battery antisidetone circuit.

diagram, in A, shows a three-winding induction coil. The primary circuit consists of a single primary winding, P, in series with the transmitter. The secondary circuit consists of two secondary windings, S and B, with a resistor, N, connected between them. The receiver is connected across the series combination of the resistor and secondary winding B, as shown.

b. Operation of Circuit.

(1) The operation of the antisidetone circuit shown in A can be understood by referring to its equivalent circuit for transmitting, in B. Voice currents originating in the transmitter flow in the primary coil, P, inducing voltages in both secondary windings. These voltages are represented in B by the a-c generators—E1 for the voltage induced in winding S, and E2 for winding B. Voltage E1 causes a current to flow through the parallel combination of the receiver shunted by winding B and resistor N, through the transmitter and back to winding S through the capacitor (omitted from B, since it is practically a short circuit to voice-frequency currents). A portion of this current, of course, flows through the receiver in the direction shown by the unbroken arrows. At the same time, voltage E2 causes a current to flow in the series circuit consisting of the receiver, resistor N, and winding B, in the direction of the broken-line arrows. The two currents through the receiver flow in opposite directions. By proper choice of the resistance of resistor N, the current caused by E2 is made exactly equal to the current through the receiver caused by E1. The two currents thus cancel, or *balance*, each other through the operation of *balancing winding* B, and no sidetone is produced.

(2) Actually, the circuit shown in figure 123 gives a perfect balance at only *one* frequency in the voice-frequency range. However, sidetone is reduced greatly over the entire telephone frequency range with this circuit. It is only one of several antisidetone circuits that have been developed in recent years.

(3) In receiving from a distant station, the operation of the receiver circuit in figure 123 is similar to that in figure 121, and is not affected by the antisidetone feature.

98. Summary of Basic Principles and Components

a. Common-battery systems use a centrally located storage battery in place of the individual dry cells at the telephone stations in local-battery systems. The common battery is actually an *auxiliary* source of power, the main source being either a motor-generator set or a rectifier system.

b. The common battery gives a common-battery system certain advantages over a local-battery system, including automatic signaling and simpler supervision and maintenance. However, they can be used efficiently only where the traffic is heavy enough to warrant the relatively high construction and installation costs.

c. The two important paths in a common-battery system are the direct-current path, for which the two telephone stations are in parallel with respect to the common battery, and the talking path, which does not include the battery. Filter networks are used to prevent the battery from short-circuiting the listening station.

d. Common-battery switchboards, like local-battery switchboards, are used to permit efficient connection of any two telephone stations connected to the switchboard. However, because of the difference in battery supply, there are differences between the circuits contained in common-battery switchboards and those in local-battery switchboards.

e. Nonmultiple common-battery switchboards are arranged so that each incoming telephone line terminates in only one line jack on the switchboard. This restricts the use of such switchboards to systems where no more than three operators are required to handle the traffic. The switchboard contains all the signal, supervisory, and pilot lamps, the line jacks, the cords and plugs, and the various switches and relays necessary for efficient operation.

f. Common-battery cords have three conductors—tip, ring, and sleeve. Common-battery plugs have corresponding elements to which the conductors of the cord are connected. Cords normally are plugged; one, the answer cord, is used in answering a calling station; the other, the call cord, for completing the call to a called station.

g. Simple common-battery jacks have three contacts—tip, ring, and sleeve, corresponding to the three conductors of a common-battery cord. Cut-off jacks have two or more auxiliary contacts associated with the tip and ring contacts. The auxiliary contacts either can be made or broken by the movement of the jack springs.

h. Line signals in common-battery systems are line lamps, mounted on the panel of the switchboard above or below their associated line jacks. Supervisory signals are lamps associated with the cord circuits.

Section II. MAJOR COMMON-BATTERY SWITCHBOARD CIRCUITS

99. Telephone Relays

a. Application of Relays to Telephony. As explained in paragraph 89, one of the imporant advantages of common-battery systems over local-battery systems is the provision for automatic signaling and supervision. This is made feasible by the use of a control device called a *relay*. The principles of relays are explained in this paragraph before proceeding to a detailed discussion of the switchboard circuits which they control.

b. Definition of Relay. A relay, as used in telephone circuits, is an electrically operated *switch* by means of which *one* switchboard circuit can be made to control the operation of one or more *other* switchboard circuits; in some cases the use of a relay enables a circuit to regulate or control its own operation. The basic operation of a relay is similar, therefore, to that of a manually operated switch (par. 64), except that a relay is *automatic* in its operation.

c. Structure of Typical Relay.

(1) Although there are many different types of relays, differing in the details of their construction, operation, and application, the principle of operation is the same for all, and structural features are similar. Consider therefore what might be called a *typical relay*, illustrated in figure 124.

(2) The essential components of any relay include an *armature*, the motion of which opens and closes the circuit or circuits to be controlled, and one or more *windings*, through which the control current flows. The *core* on which the windings are placed is composed of a magnetic material such as silicon steel or permalloy. The number and types of the windings depend on the particular function of the relay.

(3) Associated with the armature are an *armature spring* and one or more *contact springs*. Each spring has one or more *contacts* made of pure silver, some silver alloy, or alloys of platinum or other metals. The contacts are arranged to be either *open* normally, as in figure 124, or

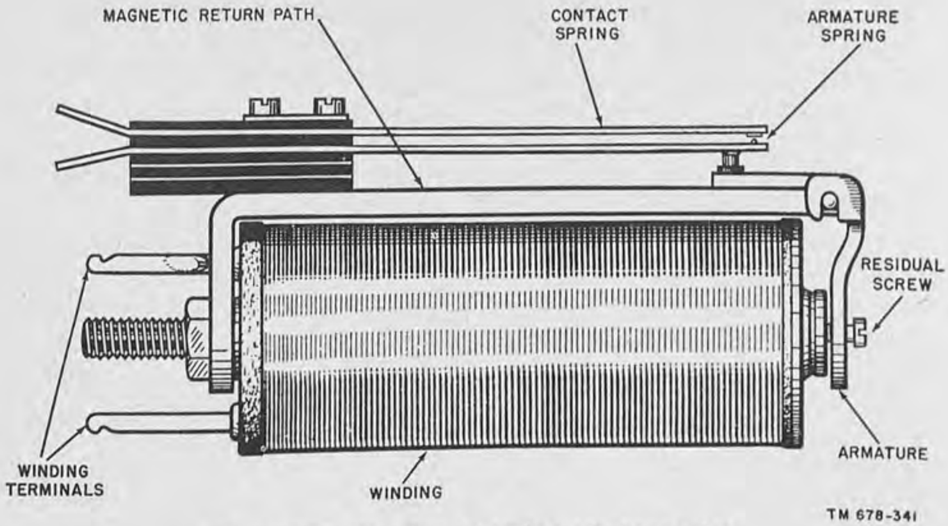

Figure 124. Structure of typical telephone relay.

closed normally; or, in relays with several contacts, some contacts may be open normally and others may be closed normally.

(4) In the armature of some relays (fig. 124) there is a small setscrew, called a *residual screw*. It is used to prevent the armature from sticking to the core because of its residual magnetism, and can be adjusted for proper operation as required.

(5) To protect them from mechanical injury, and also to keep out dust and dirt, relays usually are provided with covers (not shown in the figure), often made of a nonmagnetic material so that they do not interfere with the operation of the relays. Some newer types of relays are sealed *hermetically* in an atmosphere of dry, inert gas, such as neon or argon. This protects them from the harmful effects of moisture, ice, fungi, acid, salt spray, and sand, and assures continuously uniform performance under varying conditions. They are becoming popular in military applications of equipment, especially for foreign service.

(6) Telephone relays are mounted at the rear of the switchboard, either singly or in groups, depending on their particular function, or on the circuits with which they are associated. Relay covers may be designed to cover only one relay or several relays of a group.

d. Operation of Relays.

(1) A relay is really an electromagnet when current flows through its winding. The magnetic field around the core causes the armature to be attracted to the core. As it moves on its pivot, the armature causes the armature spring to be pushed up, moving the contact springs to open or close the various circuits controlled by the relay. When the circuit of the relay winding is broken, the magnetic field collapses, permitting the armature to spring back to its original position and restoring the relay contacts and springs to their normal position.

(2) The number and arrangement of contact springs and contacts which a relay may have depend on its application in a particular circuit, and on the power available to move the armature and the springs. The force with which the armature is attracted is proportional to the strength of the magnetic field, which, in turn, depends on the number of ampere-turns of the electromagnet. This can be made large by using either a winding of many turns and a small current, or a winding of fewer turns and a large current.

(3) When a relay is connected in series with other circuit components, the current available to operate the relay depends on the total resistance of all the components in series, and tends to be relatively small. The winding (or windings) of the relay therefore should have a relatively *low* resistance but a sufficient number of turns to operate the relay properly. When re-

lays are connected directly across the battery, however, it is necessary to *increase* the resistance of the windings in order to limit the current to a safe value. This usually is done by adding some German silver wire, or some other high-resistance wire, to the regular relay windings.

100. Classification of Relays

Although the relay shown in figure 124 may be considered representative, there are so many different types of relays that it would be impractical to discuss each one individually. For the purposes of this manual, however, it will suffice to consider some of the ways in which relays differ as to the arrangement of their contacts, their windings, and their current requirements.

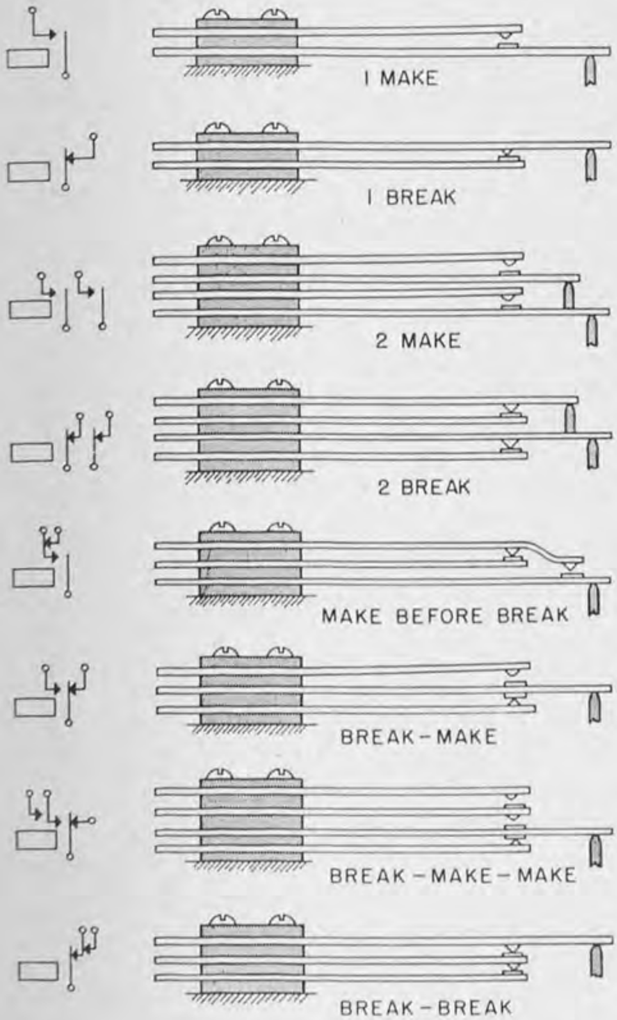

Figure 125. Arrangements of relay contacts.

a. Relay Contact Arrangements.

(1) Relays may be classified according to the contact arrangements they contain. These arrangements depend on the number and kinds of contacts; whether contacts are made, broken, or switched; the order in which the contacts open or close; and the speed with which the contacts operate (discussed below). Some of the more common contact arrangements of relays are illustrated in figure 125, together with the symbols used to denote the arrangements in schematic diagrams of telephone circuits.

(2) In each symbol, the rectangle represents the magnet core, with the windings omitted. In complete circuit diagrams, the windings generally are included, and their connection to the controlling circuit is shown. The relay armature generally is shown in the *normal* position—that is, the position in which the spring places it when no current flows in the operating winding.

(3) In some relays, the contact springs are constructed so that the movement of the armature is continued for a short distance after the contacts meet. This provides a wiping action that tends to make the contacts self-cleaning, insuring good electrical connection. Most modern relays are constructed with *twin contacts*—two contacts mounted on separate arms of each contact spring, so that they operate almost independently of each other. The circuit therefore is completed through one of the contacts even if the other is not functioning properly because of dust or grit on its surface.

(4) Twin contacts also provide higher current-carrying capacity than a single contact. A pair of twin contacts, if properly adjusted, can accommodate almost *twice* the current that a single contact can accommodate.

b. Relay Windings. The number and types of windings (fig. 126) with which a relay may be provided depend on the function the relay is required to perform. The windings usually are of enamel-coated wire and the successive layers are separated by layers of thin insulating paper to keep the turns spaced. Enamel covering is used in preference to silk or cotton because it occupies less space and is more impervious to moisture. The five representative winding arrangements are as follows:

(1) A *single-wound relay*, shown in A, figure 126, contains only one winding around a magnetic core. This is the simplest possible type of relay winding, and the relay illustrated in figure 124 is of this type.

(2) A *double-wound relay*, shown in B, contains two separate windings, both wound in the same direction. The second winding is placed directly over the first.

(3) A *parallel-wound relay*, in C, also contains two windings, but they are wound *simultaneously* around the core, instead of consecutively as in B.

(4) A *tandem-wound relay*, in D, also contains two separate windings, but they are at opposite ends of the core.

(5) A *noninductive-wound relay*, in E, has two different kinds of windings. One is like the winding of a single-wound relay. A second winding starts out in the same way as the first, but is doubled back on itself in the opposite direction, as shown. This causes it to act like a noninductive shunt, and it is used in supervisory relays (to be discussed later) to bypass voice currents around the main winding.

c. Current Requirements of Relays. Relays also differ in the relative values of current required to operate them. All telephone relays are designed to operate, release, or nonoperate on certain definite values of current. Most of them are designed to operate on the *lowest* value of current flowing in the circuit in which they occur. The current required for the operation (or release) of some relays is more critical than for others. In certain cases, relays may be designed to have a definite *time delay* in operating or releasing. A partial classification of relays with respect to current requirements is given below.

(1) A *marginal relay* is one that operates when the current through its winding reaches a specified *operate* value, and releases when the current decreases to a certain lower *release* value. Marginal relays also may be designed to have a specified *nonoperate* value of current. They usually are designed to operate only on a relatively *high* current value, and to *remain* operated even when the current is

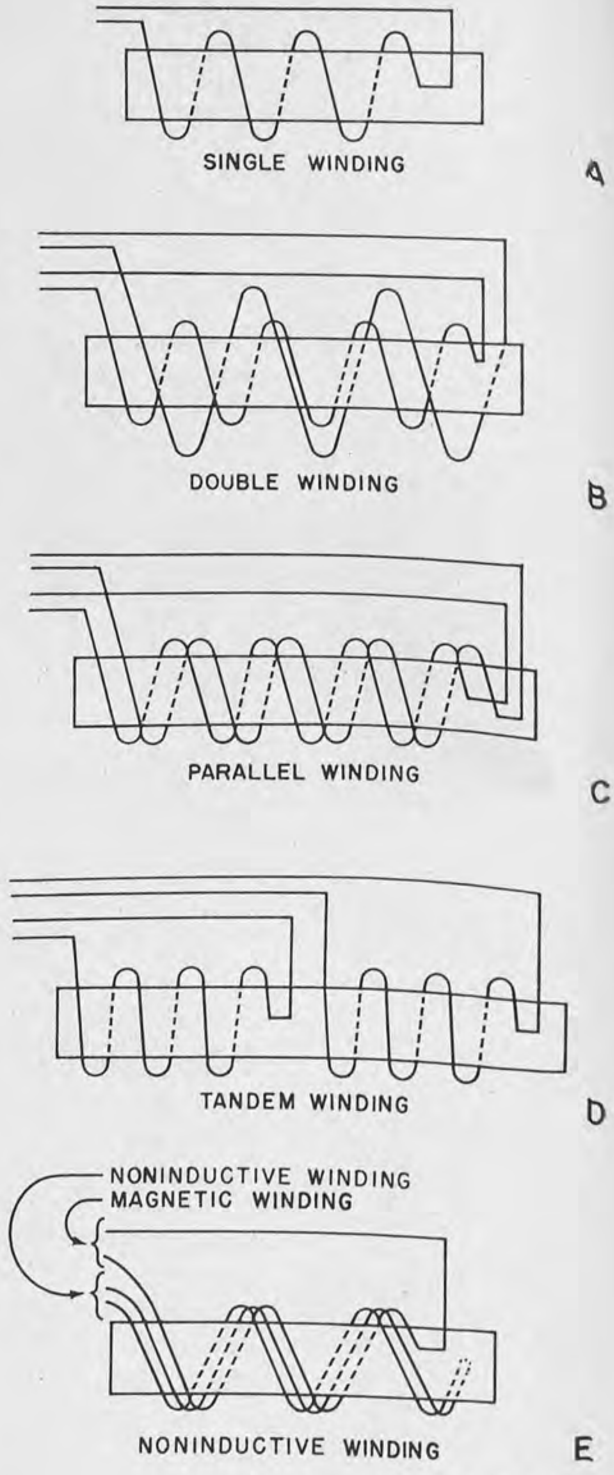

Figure 126. Types of relay windings.

reduced considerably. When the current eventually reaches the release value, the relay releases. However, although a marginal relay remains operated during the interval when the current is diminishing from the operate value to the release value, it is *unoperated* while the current is *increasing* from the release to the operate value. It is necessary to know both the operate and release values (or, in certain cases, the nonoperate value) of current in order to design a circuit in which a marginal relay is to be used.

(2) A *slow-operate relay*, as its name implies, is one that has a certain time delay in operating. This means that the armature of the relay is not attracted immediately to the electromagnet when its electrical circuit is closed. A relay may be made slow to operate by placing a copper collar around the end of the core near the armature. This, however, also makes the relay somewhat slower in releasing. The speed of operation of a relay is reduced also when the number of contacts and contact springs is increased.

(3) A *slow-release relay* also has a time delay, but for *releasing* rather than operating. This means that the relay armature is not released immediately when the circuit of the electromagnet is broken. A relay may be made slow to release by placing a copper collar around the end of the core *away* from the armature.

(4) A *polarized relay* is one that is sensitive to the *direction* as well as to the magnitude of the current flowing in the control circuit. Polarized relays usually are designed to operate on current in one direction, but to remain nonoperated on current in the opposite direction. They have either a permanent magnet or a constantly energized electromagnet serving the same purpose, which exerts a fixed pull on the armature. Current in one direction *aids* the magnetic field and increases the pull on the armature, causing the relay to operate. Current in the opposite direction weakens the magnetic field and decreases the pull on the armature, causing the relay to remain nonoperated. So-called two-position polarized relays are designed to permit release of one set of contact springs and operation of another set when the direction of current is reversed. Three-position polarized relays provide the same type of operation, but, in addition, also provide a *neutral* position for the armature when *no* current is flowing.

(5) An *alternating-current relay* is one that can operate an alternating current. Since an alternating current has a zero value every half-cycle, the magnetic field produced by an alternating current in a coil, besides alternating in direction, also has a minimum value at corresponding points in the cycle. At and near instants of zero current, the armature will spring away from the core unless some special provision is made to hold it in the operated position. This can be done in several ways. One method consists of using an armature of such mass that its inertia will keep it attracted to the core while the current is going through its zero value. Another method consists of using two windings on separate cores and connecting them so that the respective currents are out of phase with each other. Since both windings affect the pull on the armature, and since the two currents do not reach their zero values at the same time, there is always a pull on the armature when alternating current is flowing in both windings. Still another type of alternating-current relay has a split pole piece, and one of the two parts is surrounded by a copper sleeve which acts as a single-turn short-circuited winding. Alternating current in the winding induces a corresponding current in the copper sleeve. The induced current, however, is out of phase with the current in the main winding, so that it does not reach its zero value at the same time as the current in the main winding: Consequently, there is always enough pull on the armature to hold it in the operated position, when current is flowing in the winding.

(6) A *differential relay* has two windings with the same number of turns but wound *oppositely* on the core. Such a relay may be designed to operate when only *one* winding carries current; when both windings carry current in opposite directions, so that they produce *aiding* magnetic fields, since the windings themselves are in opposite directions; or when the wind-

ings carry currents in the same direction, so that they produce *opposing* magnetic fields. If *equal* currents flow in the same direction through both windings, the magnetic fields exactly neutralize each other, causing the relay to remain non-operated.

(7) A *differential-polar relay* is one that uses a split magnetic circuit consisting of a permanent magnet and two windings. It is actually a combination of differential and a polarized relay and acts like both at the same time.

d. Functions of Relays. The selection of a relay is dictated by the job the relay must perform in a given circuit. Telephone relays may be classified conveniently as to their function in switchboard circuits. Several types of relays—line relays, cut-off relays, supervisory relays, and trunk relays—and the circuits in which they operate are discussed in the following paragraphs.

101. Common-Battery Line Circuits

A line circuit provides the necessary connection between a telephone line and the cord circuits of a switchboard. Practical line circuits also must provide for signaling the switchboard operator when a call is coming in or has been terminated. Several additional components, omitted from the simplified line circuit shown in figures 115 and 116, are needed for this purpose. Three types of line circuits used in common-battery switchboards are discussed below.

a. Series Lamp Line Circuit.

(1) Figure 127 shows a fairly simple line circuit, called a *series lamp line circuit*. Instead of a simple line jack, this circuit uses a *cut-off jack* (par. 93*b*). The lower (ring) auxiliary contact is connected to one terminal of a signal lamp, the other terminal of which is connected to the *negative* terminal or bus of the central office battery. The upper (tip) auxiliary contact and the sleeve of the jack are connected to a common ground wire to which the positive terminal of the office battery also is grounded.

(2) It should be remembered for this and subsequent discussions that line wire terminals L1 and L2 are connected by a transmission line to the telephone set of the station with which the line circuit is

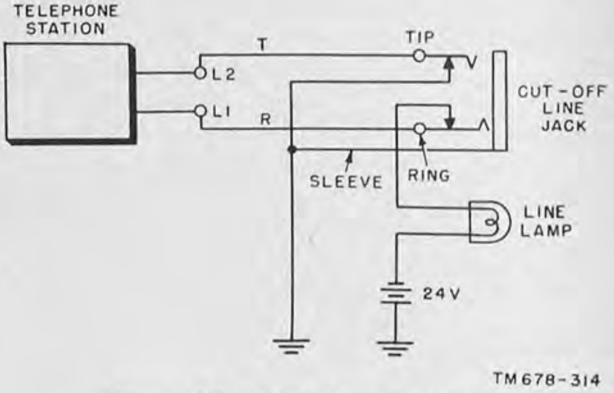

Figure 127. Series lamp line circuit.

associated. When the handset is resting in its cradle or on the hook, the hookswitch contacts are *open*, and consequently the line circuit also is open. When a person at the calling station removes his handset from the hook, the hookswitch contacts *close* automatically and complete a series circuit from the office battery through the line lamp, ring contacts of the jack, to line terminal L1, ring (R) side of the line, to the station transmitter circuit, the tip (T) side of the line to line terminal L2, tip contacts of the line jack to ground. The lamp lights, indicating to the operator that the person at the calling station wishes to place a call. In answering this signal, the operator inserts the answer plug of an idle cord circuit in the jack. This operation spreads the tip and ring springs farther apart, opening the cut-off contacts and thus breaking the lamp circuit. The signal lamp therefore is extinguished.

(3) The lamp in a series lamp line circuit, before the operator answers the line signal, is in series with the telephone line and the transmitter of the calling station. This, of course, means that the voltage available across the lamp is only the *difference* between the terminal voltage of the battery and the voltage drop in the line and transmitter. In lines of different lengths, however, the voltage drops also will be different. Consequently, the voltage available for the lamp in the line circuit of a relatively *short* line is considerably greater than for the lamp in a line circuit of a relatively *long* line. Because of this, lamps having different re-

sistances and different current and voltage ratings must be used for lines of different lengths. This is objectionable because maintenance personnel must be careful to avoid using the wrong lamps in the various line circuits. For this reason, series lamp line circuits generally are confined to lines where the circuit resistance is such that the line lamp signal brilliance is satisfactory.

b. Series Relay Line Circuit.

(1) The main disadvantage of the series lamp line circuit is overcome by the *series relay line circuit* (fig. 128). It contains one more component than the series lamp line circuit of figure 127—a single-wound relay. The relay winding occupies the position of the lamp in the series lamp line circuit of figure 127. The lamp in the series relay line circuit is connected in a series circuit with relay contact A. Thus, the current in the lamp (when the lamp circuit is closed) is *independent* of the current in the line, and consequently only *one* type of line lamp is necessary in switchboards using this type of line circuit, regardless of the length and resistance of the various lines. Furthermore, the operation of the relay is not affected by differences in the lengths of the lines, because this type of relay can be constructed to operate through a fairly wide range of current.

(2) When the handset is off the hook at the telephone station, a series circuit is completed. This circuit is from the battery, line relay winding, cut-off contacts, ring

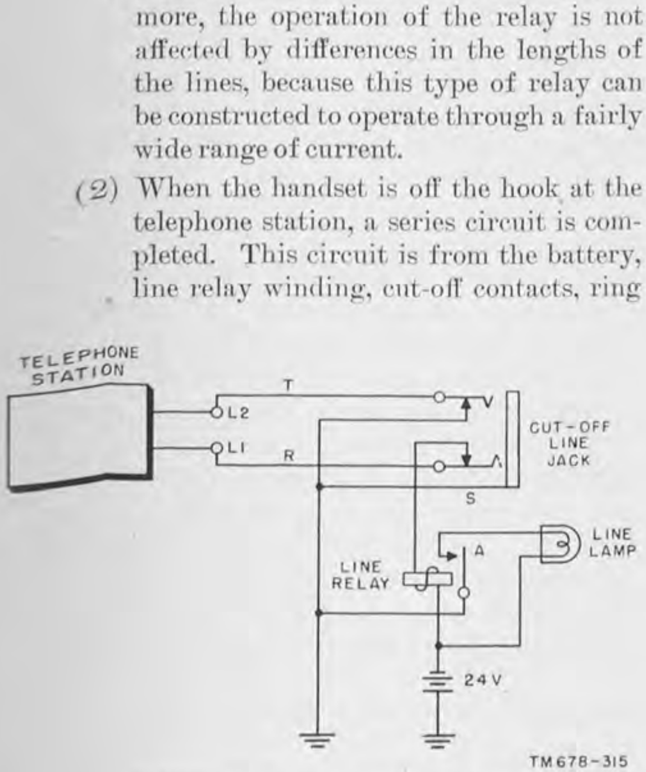

Figure 128. Series relay line circuit.

side of the line, station transmitter circuit, tip side of the line, cut-off contacts to ground, the ring cut-off contact, and the ring side of the line. The current through the relay winding magnetizes the core, attracting relay contact A and closing the lamp circuit. As in the series lamp line circuit, when the operator inserts the answer plug in the jack, the cut-off contacts are opened, breaking the relay circuit. This, in turn, releases the armature, breaking the *lamp* circuit and extinguishing the lamp.

c. Cut-Off Relay Line Circuit.

(1) A serious disadvantage of both the series lamp and series relay line circuits results from the fact that they involve the use of cut-off jacks. As mentioned earlier (par. 93*b*), the jack springs and auxiliary contacts are contained *within* the jack, making them inaccessible for periodic adjustment. A line circuit that overcomes this disadvantage is the *cut-off relay line circuit* (fig. 129), which uses a *cut-off relay* in place of the cut-off contacts of a cut-off jack, and a simple jack instead of a cut-off jack. The cut-off relay winding (fig. 129) is connected between ground and the jack sleeve, which, of course, no longer is grounded as in figures 127 and 128. Although a relay has only *one* armature, the symbol used for the cut-off relay shows two armatures, to indicate that *two* separate contacts are broken when this relay operates (fig. 125). The rest of the circuit resembles the series relay line circuit of figure 128.

(2) Actually, there is only *one* common battery at the central office. In telephone circuit diagrams, however, it is customary to show a separate battery symbol for each part of the circuit in which the battery is involved, and a separate ground symbol for each wire that is connected to the grounded positive terminal of the battery. This is done to keep to a minimum the number of crossing lines in the diagram.

(3) When a person at the telephone station removes his handset from the hook, the hookswitch contacts close and complete a series circuit from the battery, through

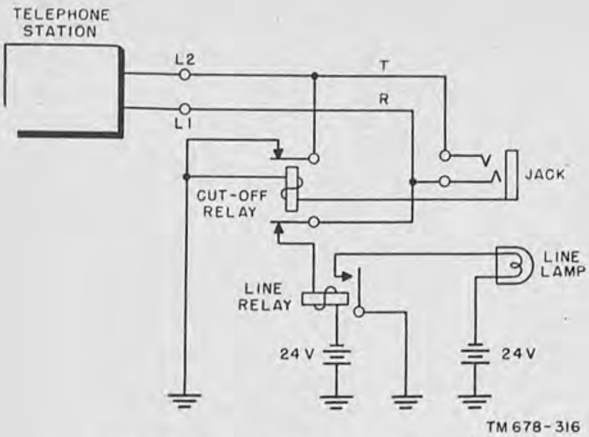

Figure 129. Cut-off relay line-circuit.

the relay winding, cut-off relay contacts, ring side of the line, station transmitter circuit, tip side of the line, cut-off relay contacts to ground. The contacts of the cut-off relay remain in their normal, closed position, but the current through the winding of the *line* relay causes it to operate. This closes the lamp circuit, and the lamp lights.

(4) The operating circuit of the cut-off relay, when the operator inserts an answer plug in the jack, is illustrated in figure 130. The sleeve of the plug is connected to the negative terminal of the office battery through a current-limiting resistor. Insertion of the plug in the jack completes a series circuit from the negative battery terminal, through the resistor and the

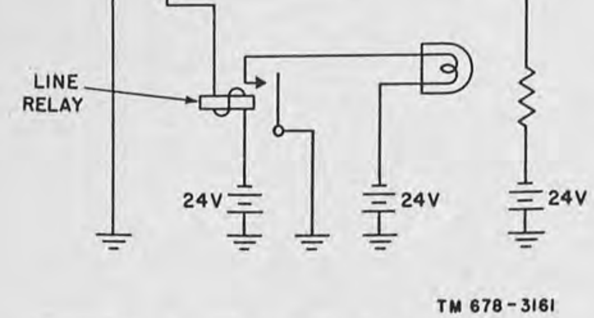

Figure 130. Operation of cut-off relay line circuit.

sleeve contacts of the plug and jack, through the winding of the *cut-off* relay, and back to ground. The cut-off relay now operates, opening *both* its contacts, as shown. This, in turn, breaks the circuit of the line relay, restoring its armature to the normal position shown, and breaking the lamp circuit. This extinguishes the line lamp.

(5) Figures 129 and 130 show the upper contact of the cut-off relay directly connected to ground. In the usual circuit of this type, this contact actually is connected to ground through a second, noninductive winding of the *line* relay. This, however, does not alter the operation of either the cut-off or the line relay.

(6) Because the line and cut-off relays can be mounted in the rear of the switchboard, or on a separate rack outside the switchboard, the contact springs can be adjusted when necessary without interfering with the work of the operator. This makes the cut-off relay line circuit more convenient from a maintenance standpoint than either the series lamp or the series relay line circuit.

102. Common-Battery Cord Circuit

The cord circuit enables the operator to connect a calling or called line to the office battery, and provides a voice-frequency path between the calling and called telephones. This function is shown by the simplified cord circuits of figures 114 to 116, which also show, in block form, the filters required to prevent the battery from short-circuiting the voice-frequency currents. Practical cord circuits, like practical line circuits, are a little more complicated than the simplified versions shown in the introductory figures. They differ in the kind of networks used as filters. Also, they must provide for several additional functions, such as connection of the operator's telephone to either the calling or the called line; connection to interconnected local-battery systems; and signaling the operator of the termination of a call. Several actual circuits which meet these requirements are discussed in the following paragraphs.

103. Retardation-Coil Cord Circuits

a. Simple Circuit. One type of cord circuit which provides the necessary high impedance to

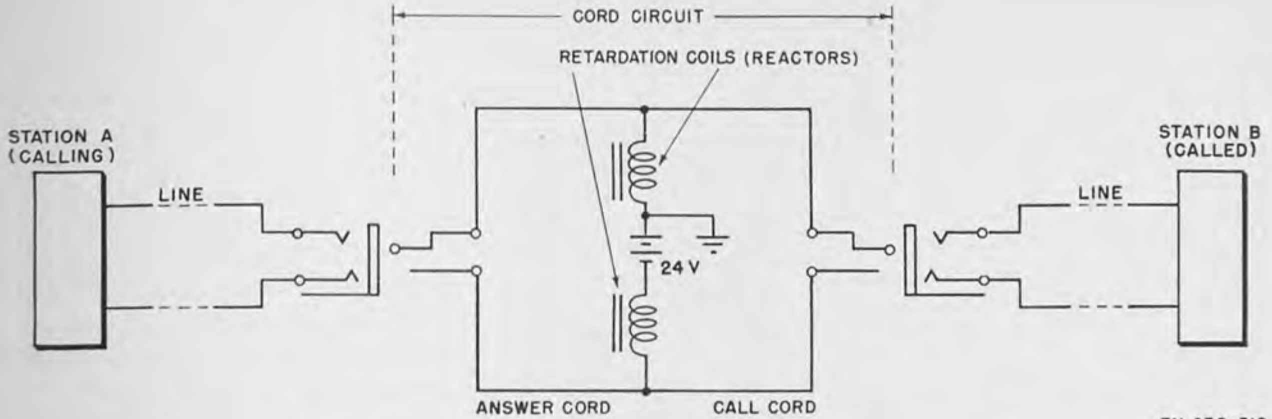

Figure 131. Retardation-coil cord circuit with retardation coils in common-battery leg.

voice-frequency currents in the battery leg is the *retardation-coil cord circuit.* A simple form of such a circuit (fig. 131) contains two *retardation coils*, one on either side of the battery in the battery leg. Since the impedance of the coils to direct current is small, they do not interfere seriously with the flow of direct current from the battery to either telephone station. Their high impedance to voice-frequency currents, however, prevents the battery leg from shunting the two stations, thereby permitting the voice currents originating in the transmitter of station A to flow in the receiver of station B, and vice versa.

b. Limitations of Simple Circuit.

(1) The simple retardation-coil cord circuit described in *a* above, although it provides the necessary filtering action, operates satisfactorily only when the telephone lines which it interconnects have approximately the same length and resistance. When the lines have *different* resistances, the transmitter connected to the line having the *larger* resistance receives less direct current from the battery, whereas the transmitter connected to the line having the *smaller* resistance receives *more* direct current.

(2) This can be explained by an equivalent d-c circuit (fig. 132) of the system under discussion. The resistance of the line connecting station A to the switchboard (line A in the figure) is assumed to be 200 ohms, and that of the line connecting station B to the switchboard (line B) is assumed to be 50 ohms, as shown. The two lines are shown connected in parallel at the 30-ohm retardation coils.

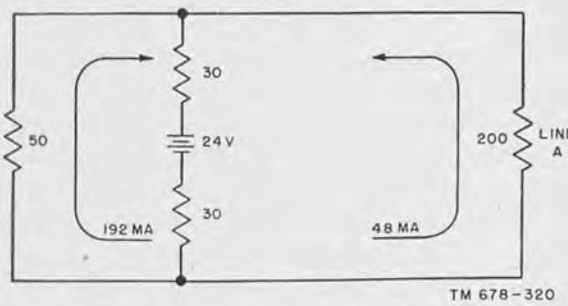

Figure 132. Equivalent d-c circuit of simple retardation-coil cord circuit.

(3) The currents in the two lines now can be calculated. The equivalent resistance of 200 ohms in parallel with 50 ohms is 200 times 50/(200 plus 50), or *40 ohms*. Adding this to the combined resistance of the two retardation coils gives a total circuit resistance of 40 plus 60, or *100 ohms*. The total current from the battery, therefore, is 24/100, or .24 ampere, or *240 milliamperes.*

(4) The IR drop across the two retardation coils is .24 times 60, or *14.4 volts*. This leaves 24 minus 14.4, or 9.6 volts across both lines A and B. The current in line A and transmitter A, therefore, is 9.6/200, or *48 milliamperes*, whereas the current in line B and transmitter B is 9.6/50, or *192 milliamperes—four times* as much. It is apparent that the direct currents in the two transmitters in such a circuit are in *inverse* ratio to the line resistances. Thus, station A, having a line resistance four times that of station B, receives only one-quarter as much current. As a result, transmission from station B to sta-

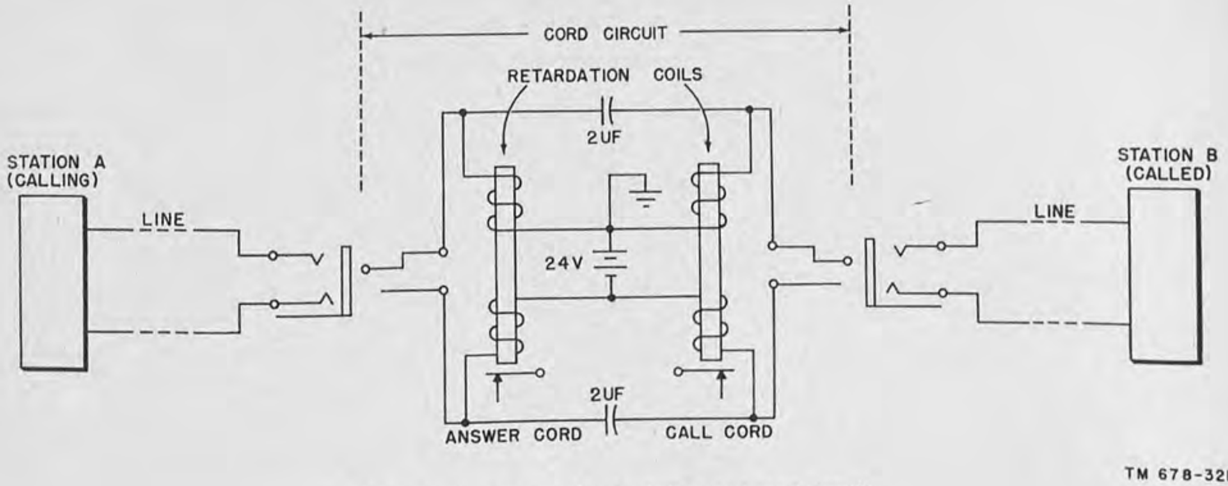

Figure 133. Improved retardation-coil cord circuit.

tion A is much better than transmission from station A to station B.

c. Improved Retardation-Coil Cord Circuit.

(1) An *improved retardation-coil cord circuit* that operates more satisfactorily than the circuit in figure 132 is illustrated in figure 133. Instead of using two retardation coils in series with the battery in the *battery leg*, the improved circuit uses two *sets* of retardation coils in series with the common battery. One coil of one set is connected between the *tip* conductor of the answer cord and the positive terminal of the battery, and the other coil of that set is connected between the negative terminal of the battery and the *ring* conductor of the answer cord. In the second set, one coil is connected between the tip conductor of the *call* cord and the positive battery terminal, and the other coil is connected between the negative battery terminal and the ring conductor of the call cord, as shown. Actually, the two windings of each set are wound on a single core in such a way as to produce an inductive winding. Usually, a two-winding relay is substituted for each set, as indicated by the armature symbol below each core in the figure. This is used for supervisory purposes, and will be explained later. In order to prevent the direct currents flowing in the two lines from interfering with each other—and to bypass voice currents around the retardation coils—capacitors, usually of 2-μf capacity, are connected in the cord circuit, as shown.

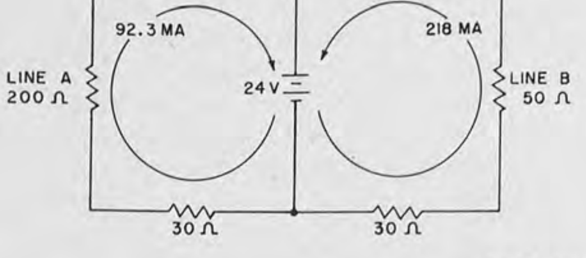

Figure 134. Equivalent d-c circuit of improved retardation-coil cord circuit.

(2) Figure 134, the equivalent d-c circuit of figure 133, illustrates the way in which the improved circuit provides a more equal distribution of direct current to the two lines. Again, the resistance of line A and station A is assumed as 200 ohms, and that of line B and station B is assumed as 50 ohms; the d-c resistance of each retardation coil again is assumed to be 30 ohms, but now there are *four* such resistances, as shown.

(3) Neglecting the internal resistance of the battery, the voltage available across each half of the cord circuit—across two coils and the line resistance in series—is the full battery voltage, 24 volts. The total resistance of the branch containing line A is 200 plus 60, or *260 ohms;* hence, the current in line A is 24/260, or *92.3 milliamperes.* Similarly, the total resistance of the branch containing line B is 50 plus 60, or *110 ohms;* hence, the current in line

B is 24/110, or approximately *218 milliamperes.* Thus, line B still receives more direct current than line A; but, instead of a current ratio of 4 to 1, as was obtained with the simple retardation-coil cord circuit of figure 131, there is now a current ratio of *less than 2.5 to 1.* This, of course, means that the operation of the two transmitters is more nearly equal, as is desired.

(4) This improved type of retardation-coil cord circuit (fig. 133) is used extensively in small common-battery switchboards. Each cord circuit has its own set of retardation coils and capacitors, and the only part common to the various cord circuits of the switchboard is the battery. Since the coupling between the different cord circuits is practically zero, there is no crosstalk between them. The direct-current path from the battery to the calling station includes the set of retardation coils connected in the answer cord, and the direct-current path to the called station includes the set connected in the call cord. The talking path, however, does *not* include the retardation coils or the battery, but is established from one line to the other by way of the capacitors, which have low impedance to voice currents, and therefore do not appreciably reduce the amplitude of the voice currents.

104. Repeating-Coil Cord Circuit

a. Structure of Repeating Coil.

(1) Another type of cord circuit, used in the larger common-battery switchboards, is the *repeating-coil cord circuit.* It uses *repeating coils* in place of the retardation coils used in retardation-coil cord circuit. Before discussing the circuit itself, a brief description of a typical repeating coil differs in structure from a retardation coil chiefly in the shape of its core and the number of its windings.

(2) The repeating coil used in a repeating-coil cord circuit consists of a toroidal (doughnut-shaped) core, wound around by four separate windings (fig. 135). The core is made by winding a continuous iron wire in the shape of a coil. The

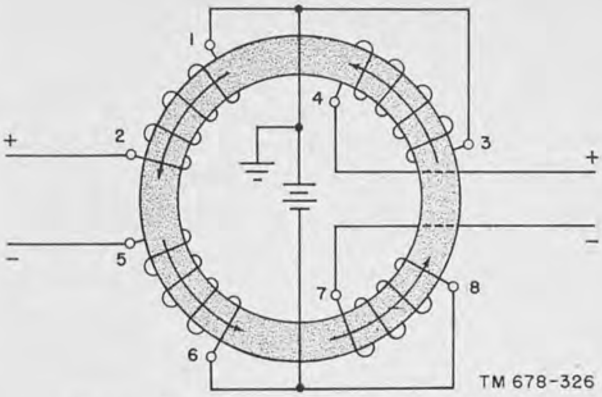

Figure 135. Connections of repeating coil.

core and its windings are inclosed in a pressed steel shell, and the shell is filled with an insulating material. The ends of the windings, which are brought out to terminal lugs on the outside of the shell, are numbered 1–2, 3–4, 5–6, and 7–8, respectively. The windings are indicated in schematic diagrams by either of the symbols shown in figure 136.

(3) As shown in the wiring diagram of figure 135, the four windings are divided into two sets; one set, consisting of windings 1–2 and 5–6, is connected in series with the battery in the *answer* cord; the other set, consisting of windings 3–4 and 7–8, is connected in series with the battery in the *call* cord. Direct current therefore is supplied to a calling station through windings 1–2 and 5–6 and the answer cord, plug, and jack, and to a called station through windings 3–4 and 7–8 and the call cord, plug, and jack. With the windings connected as shown, the magnetic flux produced in the core by the direct current in each winding is in the same direction around the doughnut-shaped core. The resultant flux, there-

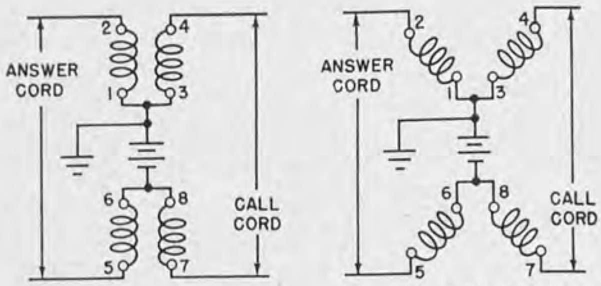

Figure 136. Repeating coil, schematic diagrams.

fore, is continuous, and is the sum of the fluxes produced by the individual winding currents, in the direction indicated by the arrows in figure 135.

b. Operation of Repeating-Coil Cord Circuit.

(1) A repeating coil transfers voice-frequency energy from one station to another by transformer action. It acts like a highly efficient 1-to-1 transformer. Its operation can be understood by referring to figure 137, which shows a repeating-coil cord circuit ready for connection, by means of plugs and jacks at either end, to telephone stations A and B. After the plugs are inserted in the respective jacks, and while the conversation continues, direct current is supplied by the battery to both transmitters through the respective windings of the repeating coil, in the direction shown by the long solid arrows in figure 137.

(2) Now assume that a person at station A is speaking into the transmitter, causing voice-frequency currents to originate there. Also assume that the direction of the voice current at a given instant is such that it flows from the transmitter to the cord circuit over the *tip* (T) side of the line. The voice current reaches terminal 2 of the repeating coil, and flows through winding 1–2, the battery, winding 5–6, and back over the ring side of the line, as indicated by the *shorter, solid arrows* in the figure. Since windings 1–2 and 5–6 are coupled magnetically to windings 3–4 and 7–8, a voltage is induced in windings 3–4 and 7–8. This voltage causes a corresponding induced voice current to flow through windings 3–4 and 7–8, equal in magnitude but in the *opposite* direction to the current in the other windings, as indicated by the *short broken arrows*. This, in effect, causes *two* voice currents to flow through the battery; but, since they are equal in magnitude and opposite in direction, the resultant voice current through the battery is zero. This not only prevents the battery from shunting the receiver of the listening station, but also prevents cross-talk between the various cord circuits of the switchboard.

(3) The net effect of the action of the repeating coil is to form a continuous path for voice-frequency currents from station A to station B (or from B to A) without including the battery. Thus, a current flows through winding 1–2 from terminal 2 to terminal 1, through winding 3–4 from terminal 3 to terminal 4, to station B over the tip side of line B, and back over the ring side of line B to terminal 7, through winding 7–8 to terminal 8, through winding 5–6 from terminal 6 to terminal 5, and back to station A. This permits the person at either station to hear the conversation originating at the other station.

(4) Although the directions in which the windings of the repeating coil are wound on the core are such as to cause their fluxes to be in the same direction through the core when *direct* current flows through them, the fluxes produced by *alternating* current in the windings *cancel*, and their resultant is zero, as explained in *a* (3) above. This can be understood by considering the directions of the voice-frequency current in the four windings of the repeating coil shown in figure 137 and tracing them in figure 135. The voice-frequency current through wind-

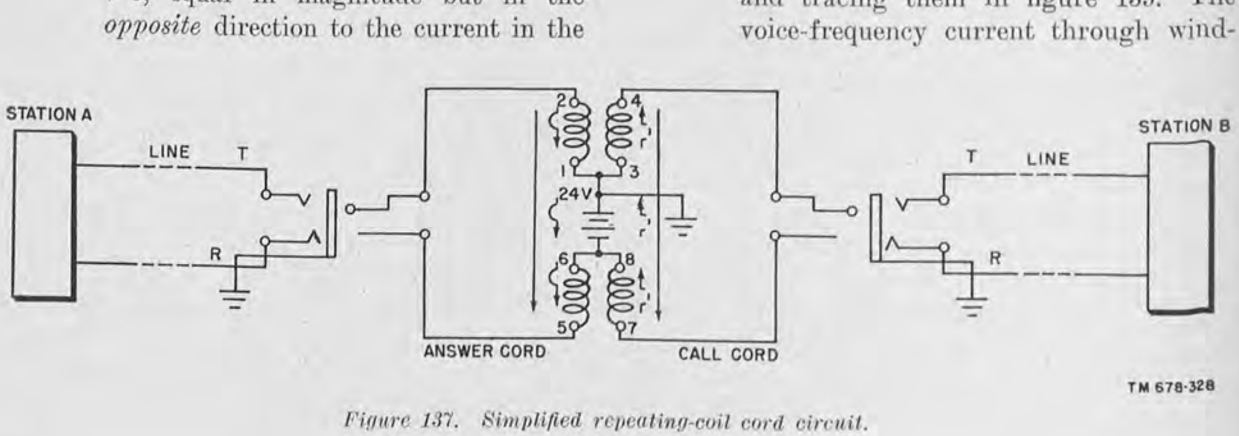

Figure 137. Simplified repeating-coil cord circuit.

ing 1–2 in the direction shown in figure 137 sets up a flux in the *same* direction as the one in which the arrow (fig. 135) within coil 1–2 is pointing; but the current in winding 3–4 (fig. 137) sets up a flux in the *opposite* direction to the one in which the arrow within winding 3–4 (fig. 135) is pointing. The two fluxes therefore cancel each other. Similarly, the fluxes produced by the voice-frequency current in windings 5–6 and 7–8 (fig. 137) cancel each other. Thus, the series combination of windings 1–2 and 3–4 and that of windings 5–6 and 7–8 behave like noninductive pairs of windings, causing the impedance of the two pairs of windings to be negligibly low to voice-frequency currents. This, in turn, permits the two pairs to serve as a path for alternating current between the two stations, without causing reduction in the amplitude of the current, and eliminates the need for capacitors between the tip conductors and ring conductors of the answer and call cords.

105. Operator's Telephone Circuits

Either of the common-battery cord circuits described in the preceding paragraphs fulfills the essential *electrical* purpose of a cord circuit. Both enable the operator to connect any two telephone lines to the office battery, and both provide a talking path between the two telephones in use. Neither type of circuit, however, permits the user of the calling telephone to tell the operator the number of the telephone he wishes to call. For the system to be practical, it must be possible for the operator to listen or to talk to either telephone. For this purpose, an *operator's telephone circuit* for the entire switchboard is provided. In effect, this connects the operator's telephone set across the line from any calling telephone—either before or after the called telephone is connected—forming an additional voice-frequency path in parallel with the cord circuit. There are several types of operator's telephone circuits. They differ in the circuits associated with the operator's telephone set. The operator's set generally is connected to the switchboard by means of a plug and jack. A lever switch enables the operator to switch his telephone into or out of any cord circuit. The operator's set differs from the user's set in that it has no ringer or hookswitch contacts. The function of the ringer is performed by switchboard lamp signals, and that of the hookswitch by the operator's plug, jack, and lever switch. Two operator's circuits commonly used in common-battery switchboards are described in paragraphs 106 and 107.

106. Operator's Circuit in Retardation-Coil Cord Circuit

a. A type of operator's telephone circuit commonly associated with retardation-coil cord circuits, and the method by which it is switched into such a cord circuit are illustrated in figure 138. This particular circuit is a sidetone circuit, and is used in many smaller common-battery switchboards. It is connected to the tip and ring of the cord circuit by means of a *listening lever switch* (also called a *talking lever switch*), as in a local-battery cord circuit. In figure 138, the listening switch is shown in the position in which the operator's circuit is disconnected from the cord circuit.

b. The receiver of the operator's telephone circuit is connected to the two *sleeve* contacts of a *double plug* (fig. 138). When the plug is inserted in the double jack, the receiver is connected across the cord circuit through capacitor C1 and secondary winding S of induction coil I at the contacts of the listening switch. Thus, when the listening switch is thrown to the listen position, the operator can hear what is being said at either telephone station. Capacitor C1 blocks direct current from the receiver path, making it unnecessary to pole the receiver.

c. The transmitter of the operator's circuit is connected to the two *tip* contacts of the double plug (fig. 138). When the plug is inserted in the jack, the transmitter is connected in series with primary winding P of induction coil I, and with a *two-branch parallel* combination. One branch consists of the office battery in series with a high-resistance *choke coil*, L; the other contains only a capacitor, C. The choke coil serves two purposes: It limits the direct current in the transmitter to the proper value, and helps to prevent the voice-frequency currents originating in the transmitter from passing through the battery. The capacitor, because of its low impedance to alternating current, bypasses the voice-frequency currents from the battery branch. Thus, the d-c path consists of the battery, choke coil L, transmitter, and primary winding P; the talking path consists of the

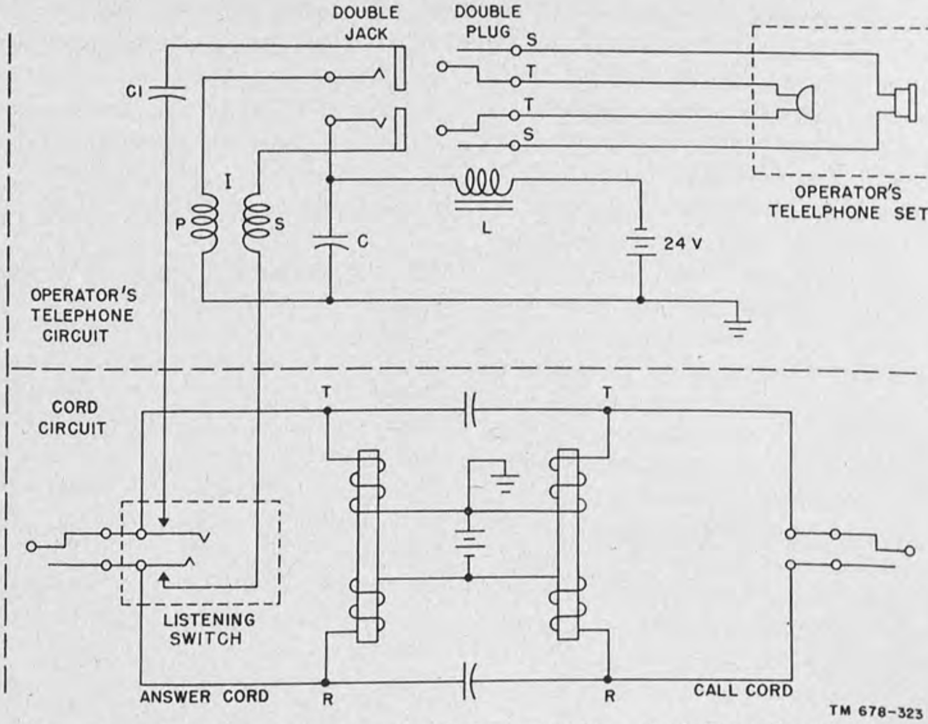

Figure 138. Operator's telephone circuit connected to retardation-coil cord circuit.

transmitter (the source in this case); capacitor C, and primary winding P. The primary circuit is closed simply by the insertion of the double plug in the jack (unlike the receiver circuit, which requires manipulation of the listening switch), and it remains closed as long as the plug remains in the jack. The listening switch, however, must be in the listening position for the voice currents originating in the operator's transmitter to flow in the receivers of the telephones connected by the cord circuit, since these currents reach the cord circuit by way of the secondary winding of the induction coil.

107. Operator's Circuit in Repeating-Coil Cord Circuit

a. The operator's telephone circuit used with a repeating-coil cord circuit is usually an *antisidetone* circuit (fig. 139). The primary circuit

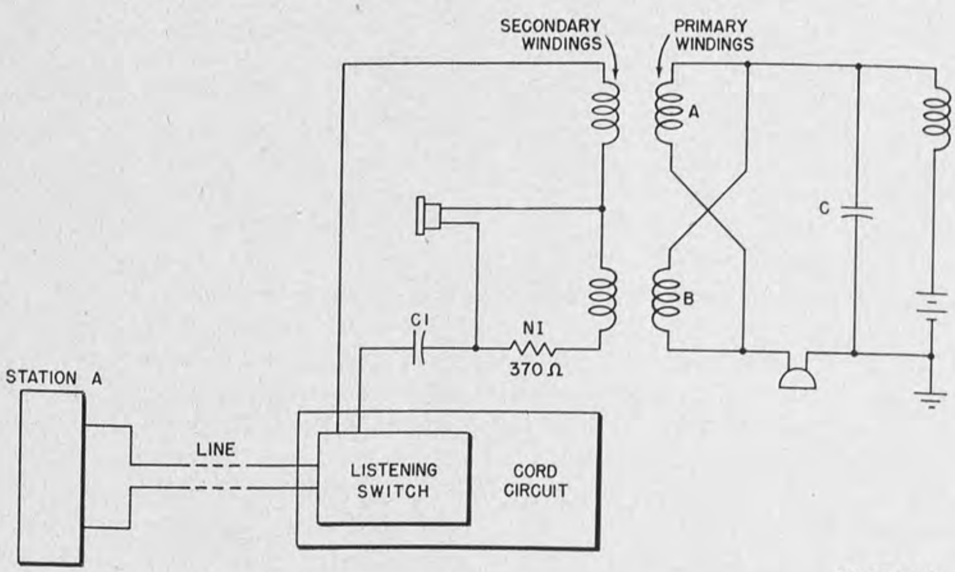

Figure 139. Operator's telephone circuit associated with repeating-coil cord circuit.

differs from the antisidetone circuit of figure 123 in that it contains an induction coil with two primary windings, A and B, connected in *parallel*, instead of in series. This method of connection greatly increases the voltage that is induced in the secondary windings of the induction coil. In this illustration, the connection of the operator's circuit to the cord circuit has been simplified by omitting the operator's plug and jacks, and showing the listening switch and the cord circuit as blocks.

b. This type of operator's telephone circuit differs from that of figure 138 in the manner of connecting the receiver in the secondary circuit. Figure 139 shows the receiver connected across *half* of the secondary winding, in series with a noninductive resistance, NI, of approximately 370 ohms. This value is comparable to the resistance of the average line to a telephone station. When this circuit is connected to a line (through a cord circuit), it acts as a balanced bridge, and no voice current originating in the operator's transmitter flows in his own receiver. The voice current in the primary induces equal voltages in the two halves of the secondary. Both halves of the secondary are in series with a resistance of 370 ohms; consequently the induced voltages cause equal currents to flow in each half of the secondary. (Capacitor C1 is practically a short circuit to voice-frequencies.) A part of each current may be considered to flow in the receiver, but in opposite directions. The resultant current in the receiver, therefore, is zero, and the voice current flows only in the circuit formed by the two halves of the secondary, the line, capacitor C1, and the 370-ohm resistor.

c. Currents originating in the transmitters of the telephone stations, however, do flow in the operator's receiver. For these currents, the operator's receiver is in parallel with half of the secondary winding and the 370-ohm resistance in series, but this parallel combination is now in series with the other half of the secondary winding as far as the source is concerned. Since the receiver resistance is only about 75 ohms, most of the line current flows through the receiver.

d. This type of operator's circuit may be used also with a retardation-coil cord circuit. Of course, like the operator's circuit of figure 138, it is connected to the switchboard by means of a plug and jack, and to the cord circuits by means of the listening lever switch.

108. Supervisory Signals

a. The term *supervision* may be considered to include everything that the operator must do between the original signal from the calling telephone and the restoration of the switchboard to its original condition following the completion of a call. In order to perform the necessary operations at the right times, he must know when a user wishes to make a call, whether the called telephone has answered, when either user wishes to talk to the operator (for instance, to report a wrong number), and when either or both users have hung up their receivers.

b. The line lamps (par. 101) which inform the operator of an incoming call go out as soon as a cord circuit is connected to the calling line circuit. At this point, an additional set of signals, called *supervisory lamps* and associated with the cord circuits rather than the line circuits, comes into service. Hence, the term *supervision* usually is restricted to operations performed by the operator *after* a talking path has been established between the calling and the called stations. These lamps are located on the plugshelf of the switchboard (fig. 113) and they signal the operator when either the calling or the called person replaces his receiver on the hook or removes the receiver when answering a call. A separate lamp is associated with each cord of all cord pairs. Each supervisory lamp is controlled by the hookswitch at the associated telephone station, remaining lighted as long as the hookswitch contacts are *open* (handset on hook), and going out when the hookswitch contacts are *closed* (handset removed from hook). When either person hangs up, the lamp associated with the cord connected to the associated line jack lights again. Thus, when both lamps are lighted, this informs the operator that the call is finished, so that he may disconnect the plugs from the line jacks, or clear the connection.

c. Two of the circuits by which the supervisory signals are connected into common-battery cord circuits are discussed in the two paragraphs following.

109. Supervision in Retardation-Coil Cord Circuit

a. A type of supervisory circuit generally used in connection with a retardation-coil cord circuit is shown in figure 140. Two tandem-wound re-

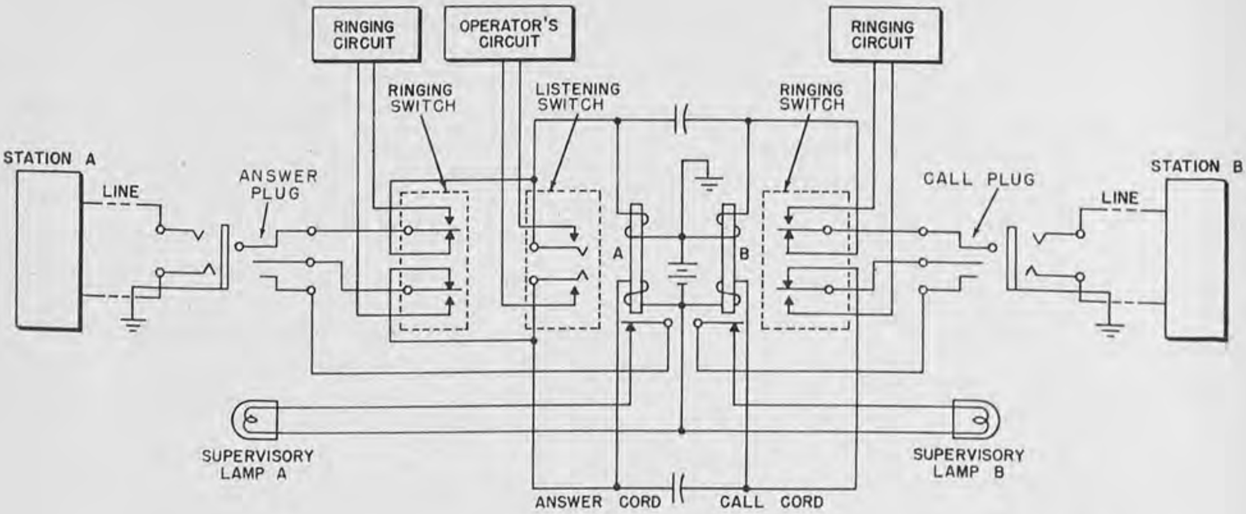

Figure 140. Supervisory circuits in retardation-coil cord circuit.

lays, A and B, are used in place of retardation coils, but they perform the functions of retardation coils as well as those of relays. The circuit also includes supervisory lamp A, associated with the answer cord and station A, and supervisory lamp B, associated with the call cord and station B. One terminal of each lamp is connected to the negative terminal of the office battery, and the other terminal of each lamp is connected to the break contact of the corresponding supervisory relay. The armature of each relay is connected to the sleeve contact of the corresponding plug—relay A to the sleeve of the answer plug, and relay B to the sleeve of the call plug.

b. When either plug is inserted in a line jack, its sleeve makes contact with the sleeve contact of the jack, which is grounded (fig. 140). This grounds the relay armature contact, completing the circuit of the supervisory lamp. Remember, however, that the lamp circuit remains closed only so long as no direct current is flowing through the relay winding, permitting the armature to remain in its normal (nonoperated) position. This condition, in turn, is met only when the hookswitch contacts at the associated station are *open* (receiver on its hook). This is true because, with the plug in its line jack, the hookswitch controls the flow of direct current to the station, and, thus, through the relay winding (par. 103*c*). The operation of the supervisory circuit is explained best by following the sequence of events when a user initiates a call.

c. Assume that station A wishes to call station B (fig. 140). When the handset is removed from the hook, the hookswitch contacts close and the line lamp associated with station A lights, informing the operator that station A is calling. (The line circuits and line lamps, the operation of which were explained in paragraph 101, are omitted for simplicity in figure 140.) The operator inserts the answer plug of a cord circuit in the line jack of station A, causing the line lamp to be extinguished. At the same time, since the line circuit, which includes the windings of supervisory relay A, is closed through the tip and ring contacts of the plug and jack, the relay operates. The armature moves away from the contact, breaking the circuit of supervisory lamp A, and consequently this lamp does not light at this time.

d. The operator throws the listening lever switch to the listening position, connecting his telephone circuit through the answer cord to station A. He then asks for the number of the called station. Upon receiving the number, he inserts the *call* plug of the *same* cord circuit used in answering station A into the line jack of station B, the called station. The operator then throws the ringing switch to the position which connects the ringing circuit to the tip and ring of the call plug and jack, signaling station B. (For the present, the ringing circuit is shown only in block form, and will be explained more completely later.)

e. When the ringing switch is returned to its normal (ringing stopped) position, but *before someone at station B removes his handset from the hook*, the hookswitch contacts at station B are open so that no current flows through supervisory relay B, and its armature is therefore in the normal (unoperated) position shown in figure 140. The circuit of supervisory lamp B therefore is closed (*b* above), since the sleeve of the plug is grounded by the sleeve contact of the jack, and lamp B lights. Now, when someone at station B removes the handset from the hook in answer to the ringing signal, the hookswitch contacts are closed, closing the circuit through the windings of supervisory relay B. The operation of this relay *breaks* the lamp circuit and thus extinguishes supervisory lamp B.

f. During the time the conversation is in progress, both supervisory lamps remain extinguished. When the conversation is completed, both handsets are replaced on their hooks. This reopens the hookswitch contacts at both stations, breaking the d-c circuit of both supervisory relays. Both armatures are restored to their normal positions, closing both supervisory lamp circuits and *relighting* both lamps. When the operator sees the two lamps go on, he knows that the call has been completed, and removes both plugs from the respective line jacks, extinguishing both lamps again, and making the cord circuit available for another call.

110. Supervision in Repeating-Coil Cord Circuit

a. The supervisory circuit discussed in paragraph 109 is feasible in conjunction with a retardation-coil cord circuit, because relays can be substituted for the retardation coils. However, the repeating-coil associated with a repeating-coil cord circuit has only *one* core, and this a circular one, so that it obviously could not be used as two *separate* relays in conjunction with the two supervisory lamps required for supervision, even if its core had ends to which an armature would be attracted. For this reason, two separate relays—one in the answer-cord circuit and the other in the call-cord circuit—must be provided to control the operation of the supervisory circuits used in conjunction with a repeating-coil cord circuit.

b. Figure 141 shows the supervisory circuits associated with a repeating-coil cord circuit. Supervisory relay SR1, associated with the answer cord, is connected between terminal 5 of the repeating coil and the lower spring contact (ring) of the listening switch; similarly, supervisory relay SR2, associated with the call cord, is connected between terminal 7 of the repeating coil and the ring of the call plug (when the ringing switch is in the position shown). Note that in this circuit each relay has a *make* contact instead of a break contact as in the supervisory relays shown in figure 140. Supervisory lamps SL1 and SL2 have one terminal commonly connected to the negative terminal of the battery and the junction of the contacts of the two relays. The other terminal of each lamp is connected to the sleeve of the corresponding plug through an 83-ohm resistor, as shown. A 40-ohm resistor is connected from the armature of each relay to the junction of the corresponding supervisory lamp and 83-ohm resistor.

c. When either plug is inserted in its line jack, with the hookswitch contacts at the station *open*,

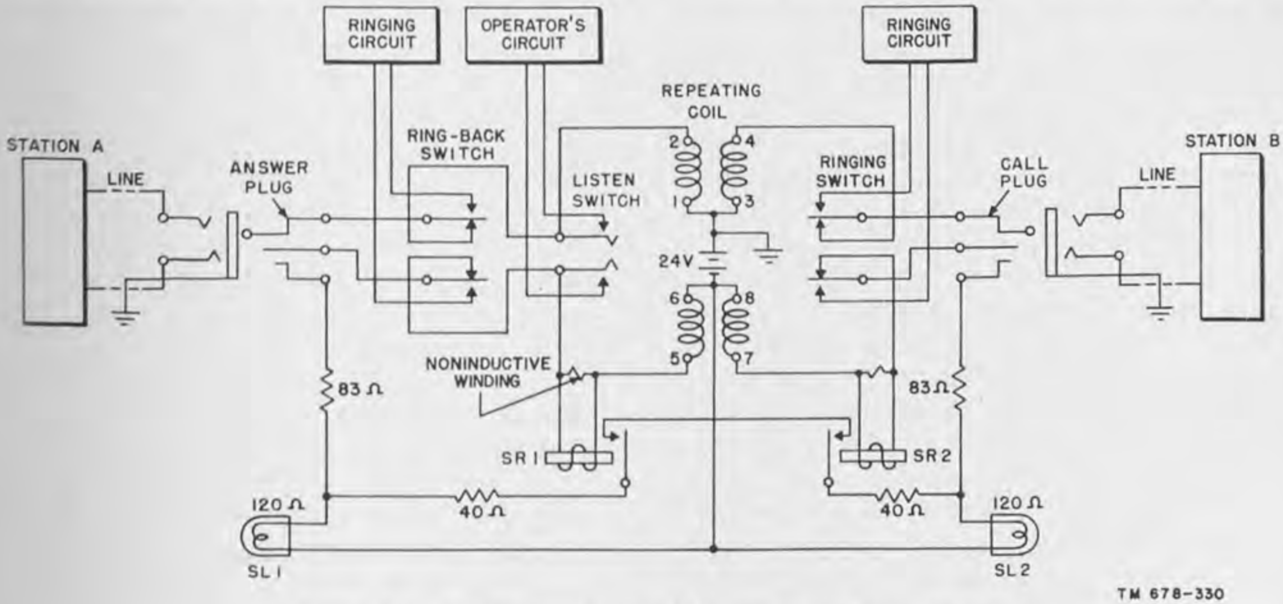

Figure 141. Supervisory circuits in repeating-coil cord circuit.

and the ring and ring-back switches in their normal positions (fig. 141), the grounded sleeve of the jack grounds the sleeve of the plug and completes a series circuit consisting of the battery, the supervisory lamp, and the 83-ohm resistor. The supervisory lamp lights, as it does under similar conditions in the circuit discussed in paragraph 109. When a person at either station removes his handset from the hook, the closing of the hookswitch contacts causes direct current to flow through the windings of the corresponding half of the repeating coil and the associated supervisory relay, and over the tip and ring sides of the line by way of the cord, plug, and jack. The supervisory relay operates, pulling the armature against the make contact, and completing the path of the 40-ohm resistor so that it is in *parallel* with the lamp.

d. The effect of the 40-ohm resistor (fig. 141) is to place a low resistance across the lamp when the supervisory relay is operated, dropping the voltage across the lamp to less than the value necessary to light the lamp. If the relay armature were connected to the lamp directly instead of through the 40-ohm resistor, the lamp would be shorted out completely when the relay is operated, and the entire battery voltage would appear across the 83-ohm resistor. Note, however, that the lamp resistance is 120 ohms, three times that of the 40-ohm resistor. Since the effective resistance of this parallel combination is 30 ohms, a part of the battery voltage appears across the lamp. When the supervisory relay is operated, one-quarter of the current through the relay armature passes through the lamp. This is not enough to light the lamp, but is enough to keep its filament warm so that it will relight almost instantly when sufficient current again flows through it.

e. Since the supervisory relays (fig. 141) are in the *talking* path as well as the d-c path, there must be provision for making their impedance to voice-frequency currents low, so that they do not reduce the amplitude of these currents. This is accomplished by connecting a *noninductive winding* across the relay winding, as shown. Its resistance is made low enough to reduce the equivalent impedance of the relay to voice-frequency currents, but not so low as to short-circuit the relay winding and prevent its proper operation.

f. This method of shunting the supervisory lamp can be used in conjunction with a retardation-coil cord circuit (without the additional relays, of course). It is superior to the method discussed in paragraph 109 because the sleeve circuit never is opened, and because the lamp lights more quickly when the hookswitch contacts at the associated station are opened again.

g. The reader should trace the progress of a call from station A to station B with the aid of figure 141 as a means of reviewing the operation of the supervisory circuit just discussed.

111. Universal Cord Circuit

a. Function of Universal Cord Circuit. A third type of cord circuit, called a *universal cord circuit*, is provided in many military switchboards. Such a circuit, one form of which is shown in figure 142, is needed in switchboards that serve both common-battery and local-battery lines. The universal cord circuit supplies battery voltage to the common-battery lines but not to the local-battery lines. The circuit is called *universal* because it provides a talking path between two common-battery lines, between two local-battery lines, or between a common-battery and a local-battery line in either direction.

b. Connection to Two Common-Battery Lines. First, the operation of the universal cord circuit (fig. 142) between two *common-battery* lines and stations will be examined.

(1) *Incoming call.* When the handset of a common-battery calling station is removed from the hook, the line circuit is closed through the hookswitch contacts, as explained previously. (The line circuits are not shown in figure 142.) The line lamp lights, signaling the operator that the person at the calling station wishes to make a call. The operator inserts answer plug AP of the universal cord circuit in the line jack, and the sleeve of the plug makes contact with the sleeve of the jack. Remember that, in a common-battery line circuit, the sleeve of the line jack is *grounded*, either directly or through the winding of a cut-off relay (in a cut-off relay line circuit). The insertion of the plug therefore completes the following circuit: from the negative terminal of the battery (fig. 142), through the winding of a relay B and supervisory lamp SL1, and back to ground through the sleeve of the plug and jack. Lamp SL1 lights, and relay B operates, causing a sequence of events.

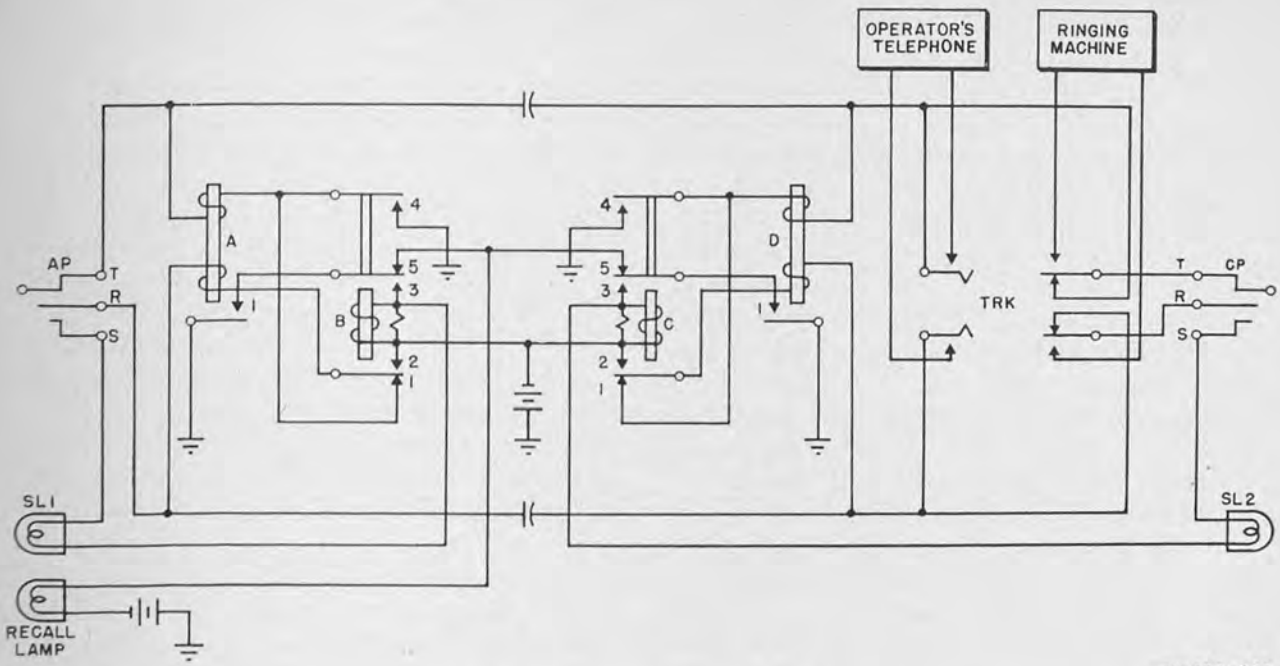

Figure 142. Universal cord circuit.

First, ground is connected to the *tip* of the answer cord and plug through make contact 4 of relay B and the upper winding of relay A. At the same time, the negative battery is connected to the *ring* side of the answer cord and plug through make contact 2 of relay B and the lower winding of relay A. Direct current flows through the windings of relay A, which is wound so that the two magnetic fields *aid* each other, and over the tip and ring sides of the line to the calling station. Relay A operates, closing make contact 1 of relay A, and placing ground on contact 3 of relay B (this contact was *made* by the operation of relay B). This, however, also grounds the side of lamp SL1 which is connected to contact 3, shorting out the lamp, and causing it to go out. Relays B and A, however, remain energized. Since contact 5 of relay B also has been broken, there is no return to ground for the *recall lamp*, and consequently it does not light at this time.

(2) *Outgoing call.* Upon receiving the number of the called station in the usual manner, the operator inserts call plug CP of the same cord circuit (fig. 142) into the line jack of the called station (not shown). The sleeve of the plug is grounded by the sleeve of the jack, completing the circuit from the battery through supervisory lamp SL2 and the winding of relay C. Lamp SL2 lights and relay C operates, causing ground to be connected to the tip side of the call cord and plug through make contact 4 of relay C and the upper winding of relay D, and the negative battery to be connected to the ring side of the call cord and plug through make contact 2 of relay C and the lower winding of relay D, in a manner similar to the operation explained in (1) above. However, since the hookswitch contacts at the called station are still *open*, no complete circuit exists as yet through the windings of relay D, and therefore it still does not operate. The operator now rings the called station, using the talk-ring lever switch, TRK. When the called telephone answers, the circuit of relay D is completed through the hookswitch contacts, causing it to operate. The operation of relay D short-circuits lamp SL2 in the same manner that the operation of relay A short-circuits SL1. Supervisory lamp SL2 therefore is extinguished.

(3) *Completion of call.* When the call is completed, the talking path is broken at

the hookswitch contacts of the first person to hang up. This restores relay A or D (eventually both), and causes the associated supervisory lamp to relight. When both persons have hung up, the operator removes the plugs from the jacks, restoring relays B and C, and extinguishing both supervisory lamps.

c. Connection to Two Local-Battery Lines. Now, the operation of the universal cord circuit (fig. 142) between two *local-battery* lines and stations will be explained.

(1) *Incoming call.* Assume that a person at the calling telephone has signaled the operator that he wishes to make a call. When the operator inserts answer plug AP of the universal cord circuit into the line jack, relay B does *not* operate, because the sleeve of the jack in a local-battery line circuit is *open* (not grounded). The two windings of relay A, therefore, remain connected in *series* through contact 1 (normal position shown) of relay B, and the series combination remains bridged across the tip and ring of the answer cord for later supervision. Lamp SL1, of course, does not light, because the sleeve of the jack is open.

(2) *Outgoing call.* The operator asks for and receives the number of the called station. He inserts call plug CP (fig. 142) of the same cord circuit into the line jack of the called station and rings the station until someone answers. Relay C does not operate for the reason given in (1) above; hence, the two windings of relay D, like those of relay A, remain connected in series with each other, and the combination remains bridged across the tip and ring of the call cord. The talking lever switch is kept in the *talk* position at all times except during the actual ringing, so that the operator may know when the call is answered; no other supervisory signal is provided (lamp SL2 does not light, for the same reason that lamp SL1 remains out).

(3) *Completion of call.* When the conversation is completed, ringing current is sent over the line by either user. If the calling station is the one that rings off, relay A operates, completing the circuit of the *recall lamp* (fig. 142) through contact 1 of relay A and contact 5 of relay B, which has remained in its normal position. Similarly, if the called station rings off, relay D operates, completing the circuit of the recall lamp in the same way. The lighting of the recall lamp signals the operator that the call is finished, so that he can remove the plugs from the line jacks, thus restoring the cord circuit to its normal condition.

d. Connection Between a Common-Battery and a Local-Battery Line. The operation of the universal cord circuit between a common-battery line and station and a local-battery line and station in either direction also can be traced by reference to figure 142.

(1) *Call from common-battery station to local-battery station.* When a call is made from a common-battery station to a local-battery station, the operation of the answer-cord circuit is identical with that described in *b*(1) above. The connection is completed to the local-battery station in the manner described in *c*(2) above.

(2) *Call from local-battery station to common-battery station.* When a call originates at a local-battery station, the operation of the answer-cord circuit is identical with that described in *c*(1) above. The connection is completed to the common-battery station in the manner described in *b*(2) above. Referring to figure 142, the reader should trace the progress of a call from a common-battery station to a local-battery station, and vice versa. This will serve as an excellent means of reviewing the operation of the universal cord circuit.

112. Sequence of Operation of Major Switchboard Circuits

Still more circuits are required to complete the presentation of common-battery systems: ringing circuits and systems, so far merely indicated in block form; trunk circuits; various auxiliary circuits, such as pilot circuits and night-alarm circuits; and multiple switchboards. Before proceeding with these topics, however, all of the major circuits so far discussed separately are assembled in one diagram (fig. 143), and the progress of a call will be traced step by step, from start to finish. Figure 143 shows nine stages in the progress of a call, with the active parts of the circuit at each stage emphasized by heavy lines to facilitate tracing. At each stage, the entire circuit is reproduced, however, including the circuits of both telephone sets, both line circuits (both of the series-relay type, as an example), the cord circuit (a retardation-coil cord circuit in this case), and the supervisory circuits necessary to enable the operator to handle the call.

a. Normal Condition of All Circuits. A of figure 143, shows the telephone sets and the switchboard circuits in their normal condition. Both receivers are still on their hooks, the cord circuit is idle, and all lamps and relays are in their unoperated condition.

b. Operation of Line Circuit No. 1. When the person at calling station A removes his receiver from the hook, as in B, the hookswitch contacts close. Battery B1 (which, of course, is the office battery), sends current through the series circuit consisting of line relay LR1, the ring side of the line, the primary winding of induction coil P, the transmitter, and back to ground over the tip side of the line. The relay winding is connected to the ring side of the line through the ring spring contact of line jack LJ1, and the tip spring contact of LJ1 returns to ground. Relay LR1 operates, closing the circuit of line lamp LL1, and thus lighting the lamp.

c. Operator's Response to Line Signal. The operator responds to the line signal by inserting the answer plug of an idle cord circuit into the line jack, LJ1, associated with the lighted line lamp, LL1, as shown in C, figure 143. This spreads the springs of the jack, as shown, and breaks the cut-off contacts. This, in turn, breaks the circuit of relay LR1, restoring the relay and thereby extinguishing the line lamp LL1. Although battery B1 is removed from the line by this operation, there is still a d-c path over the line to the transmitter of station A from the common battery, CB (actually the same battery as B1), through the windings of supervisory relay SR1 (which also acts as a retardation coil), and through the tip and ring of the answer cord and plug and line jack LJ1, as shown by the heavy lines in C. The current through the windings of supervisory relay SR1 causes it to operate, breaking the circuit of supervisory lamp SL1. This keeps lamp SL1 *unlighted* at this stage in the operational sequence.

d. Operator Asks for Number of Called Station. The operator now throws the listening lever switch, LK, to the listening position, shown in D. This connects the operator's telephone set across the cord circuit and enables him to obtain the number of the called station from the person at station A. The switch may be left in this position until someone at station B eventually answers (see *e* through *h* below).

e. Operator Connects to Line Jack of Called Station B. Upon receiving the number of the called station, B, and if the called line is not busy, the operator inserts the *call* plug on the same cord circuit in line jack LJ2 of station B, as in E. This breaks the cut-off contacts of the jack, as shown. At the same time, since the circuit of supervisory relay SR2 is not complete (the hookswitch contacts at station B are still *open*), relay SR2 is unoperated at this point. The contact therefore is *closed*, and the circuit of supervisory lamp SL2 is completed by the contact of the sleeve of the plug with the grounded sleeve of line jack LJ2, and therefore lamp SL2 lights, as shown.

f. Operator Rings Called Station B. Next, the operator pulls ringing switch RK to the ringing position, in F. This connects the ringing generator (which may be similar to those described in ch. 4) to the tip and ring of the call plug and line jack LJ2, and, at the same time, breaks the talking path of the call cord. Ringing current, therefore, flows only through the ringer of station B (not through either station A or the operator's telephone). This signals the called station, and the ringing switch is thrown alternately to the ring and talk positions until someone at station B answers. Note that the circuit of supervisory lamp SL2 remains closed during this operation, and SL2 consequently remains lighted.

g. Station B Answers. When someone at station B removes the receiver from the hook, the hookswitch contacts close, as in G. When the ringing switch is momentarily in the *talk* (normal) position, there is completed a series circuit from the common battery through the windings of supervisory relay SR2, the tip and ring contacts of the call plug and line jack LJ2, the tip and ring sides of the line, and the transmitter and primary circuit of station B. Relay SR2 operates, breaking the circuit of supervisory lamp SL2, and extinguishing SL2. This informs the operator that station B has answered and that ringing need not be continued, and consequently he lets the ringing switch remain in its unoperated position.

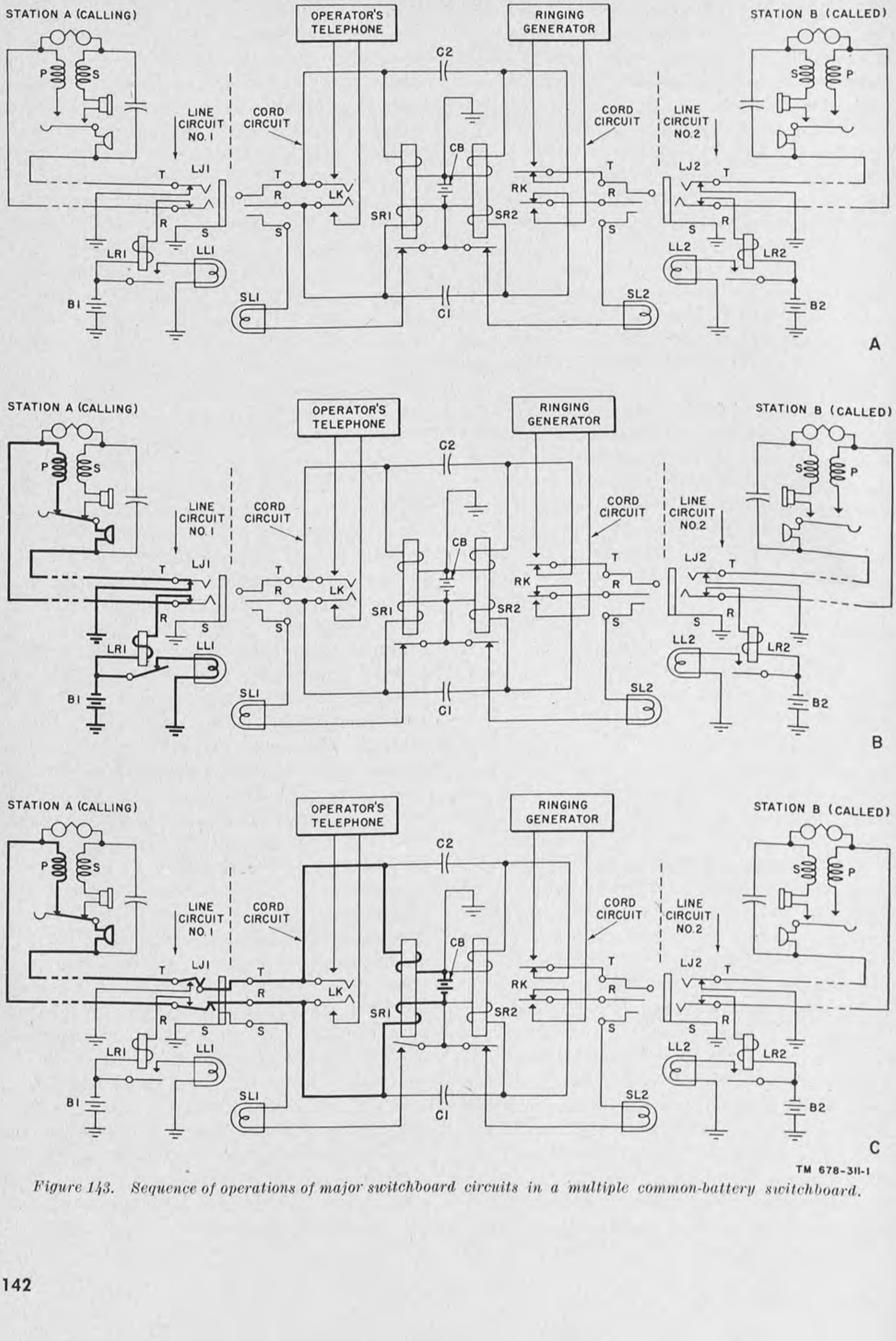

Figure 143. Sequence of operations of major switchboard circuits in a multiple common-battery switchboard.

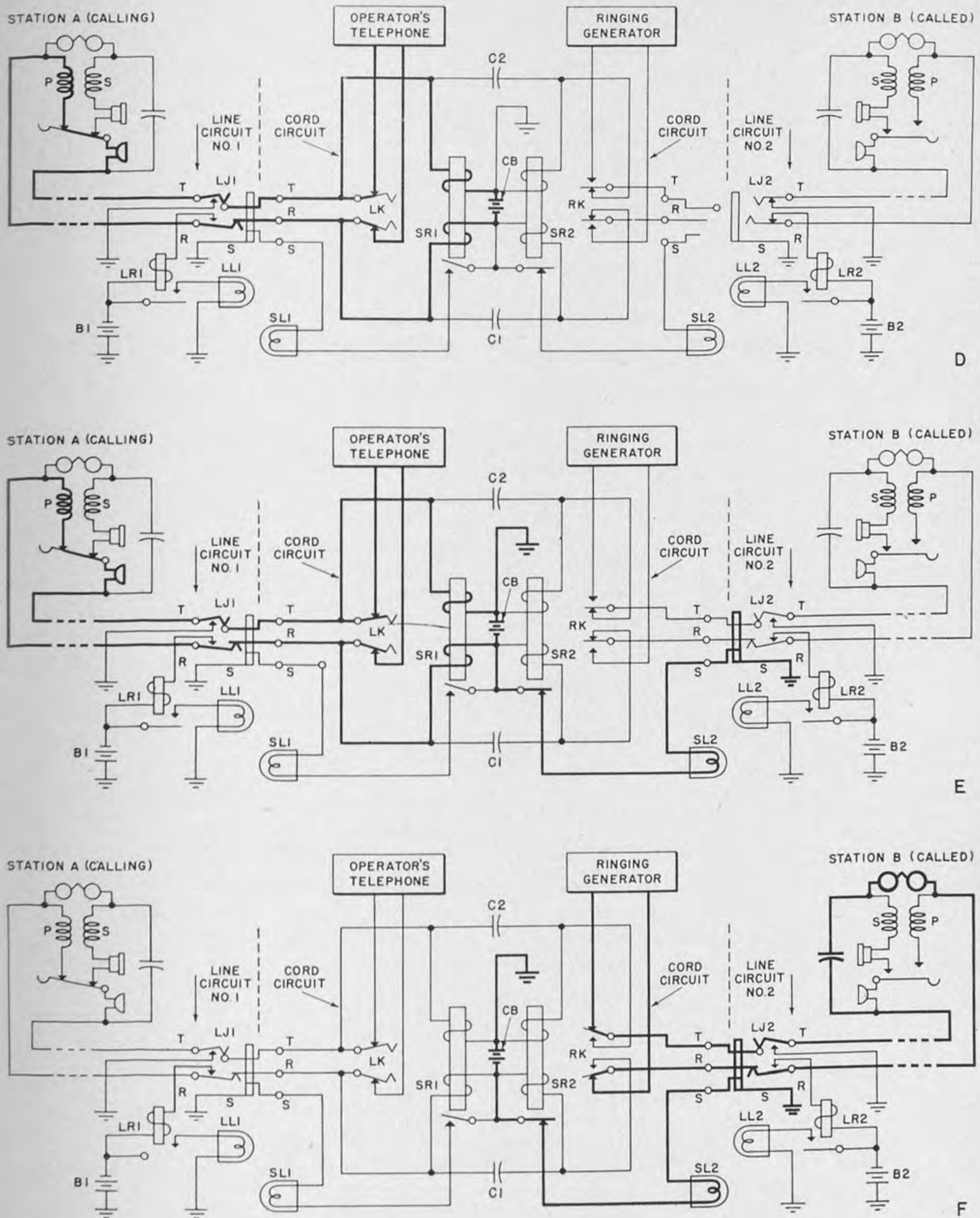

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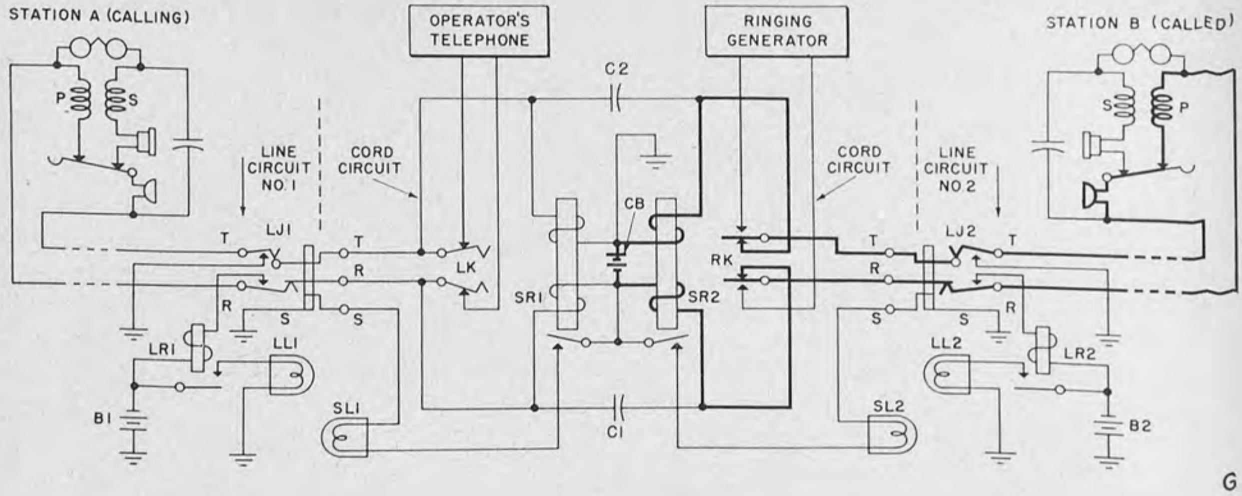
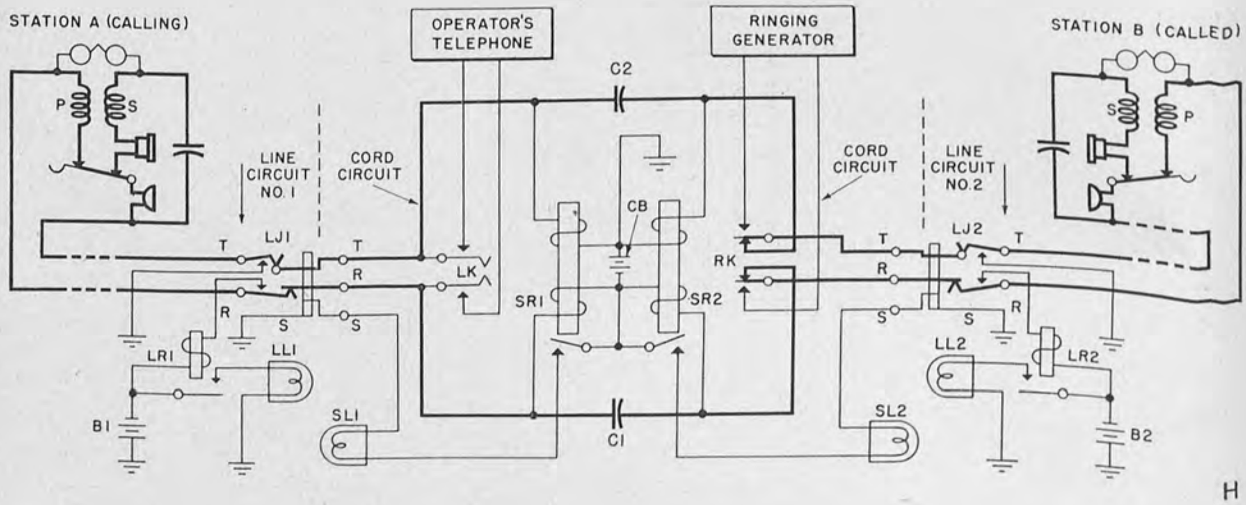
Figure 143—Continued.





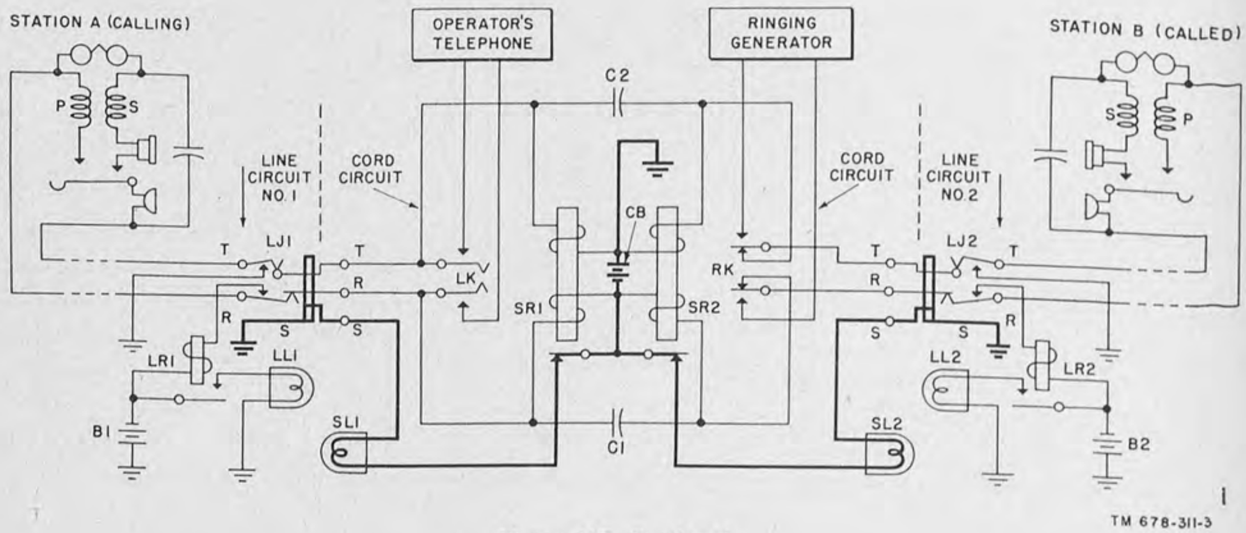


Figure 143—Continued.

h. Conversation Between Stations A and B Proceeds. Stations A and B now are connected to one another through the cord circuit, in H, and the conversation between them proceeds. Of course, direct current still is flowing from the common battery to the transmitters of both stations, but only the *talking* path is emphasized in H. Since the listening switch has been restored to the normal position, the operator's telephone is disconnected from the cord circuit. While the conversation is in progress, all the associated lamps—LL1, LL2, SL1, and SL2—are unlighted. *A lighted supervisory lamp, therefore, will signal the operator that the circuit requires attention.*

i. Circuit Restored to Normal. When the conversation is completed, both receivers are replaced on their hooks, as in I. This breaks the circuit at both hookswitch contacts so that no direct current flows through either line. Supervisory relays SR1 and SR2 release, restoring the respective armatures to the normal position and closing the contacts. This completes the circuits of both supervisory lamps SL1 and SL2, causing them to light. The operator thus is informed that the conversation has been completed, so that he may clear the connection by removing the plugs from the respective jacks. The circuit now has been restored to its normal condition as in A. The reader should trace the operational steps in the progress of a call originating at station B.

113. Summary of Switchboard Circuits

a. Relays are electrically operated switches used to control the operation of switchboard circuits. They are used in switchboards in conjunction with certain line, supervisory, trunk, and auxiliary circuits.

b. Telephone relays may be classified according to the number and kinds of windings they contain, the number and sequence of contacts they provide, and the mechanical features of operation they exhibit.

c. Common-battery line circuits are of three general types: the series lamp line circuit which uses a lamp connected through the auxiliary contacts of a cut-off jack; the series relay line circuit which includes a relay in addition to the lamp and cut-off jack; and the cut-off relay line circuit which substitutes a cut-off relay for the auxiliary contacts of a cut-off jack. All line circuits are designed to provide an automatic line lamp signal when the hookswitch contacts at the calling station are closed by removing the handset from the hook.

d. Cord circuits in common-battery switchboards are designed to prevent the branch containing the common battery from shorting out the receiver of the listening station. This is done by using retardation coils in a retardation-coil cord circuit, or by using repeating coils in a repeating-coil cord circuit. In the former, relays are used as retardation coils to provide automatic supervisory signals; in the latter, separate relays, called supervisory relays, must be used.

e. Supervisory lamps are extinguished automatically at the proper time in one of two ways: opening the circuit of the lamp by the operation of the supervisory relay, or shunting the lamp with a resistor of much smaller resistance than the lamp. The latter method has the advantage of keeping the lamp filament warm, although extinguished, so that it lights more rapidly when required.

f. A universal cord circuit is supplied in some switchboards to accommodate both common-battery and local-battery lines. It can be used to interconnect two common-battery lines, two local-battery lines, or one common-battery line and one local-battery line in either direction.

Section III. RINGING IN COMMON-BATTERY SYSTEMS

114. Single-Party Ringing

a. The signaling of a *called* telephone is effected in much the same way in common-battery systems as in local battery systems, so long as there is only *one* telephone on each line. Each telephone set contains a ringer (par. 53) which operates when connected to 20-cycle ringing current. This current is supplied by a centrally located ringing machine, which may be similar to those described in chapter 4. The operator can connect the ringing machine to the called telephone line by throwing the ringing switch (RK, fig. 143) associated with the cord circuit in use. Ringing current flows only so long as the ringing switch is held in the ringing position.

b. The ringing circuit of a common-battery telephone set differs slightly from that of a local-battery set. In a local-battery set (fig. 74) the ringer is connected across the line, and the capacitor is in series with the receiver, where it serves to reduce the low-frequency ringing current flowing to the receiver. In a common-battery set, the capacitor is in series with the ringer, and the combination is connected across the line.

c. Common-battery switchboards (fig. 113) may be equipped with hand generators like those used in local-battery systems (par. 51), but these are only for emergency use.

115. Party-Line Ringing Systems

The simple ringing system described in the preceding paragraph is feasible only when each telephone station has exclusive use of the line connecting it to the central switchboard. However, under certain conditions, two or more telephone stations often are connected to the same line. In such a case, the ringing system must make it possible for the ringing signal to indicate which of the several stations on the line is called—preferably without the others even hearing the signal.

a. Party Lines. The term *party line* generally is used, in both commercial and military telephone systems, when referring to a telephone line to which two or more telephone stations are connected. In such a case, although each station on the line can listen to any conversation taking place over the line, the line is available to only one station at a time for the purpose of initiating or receiving calls. Usually the number of stations connected to the same line is indicated by calling it a *two-party* line or a *four-party* line, as the case may be. Party lines are not confined to common-battery systems but, since the larger and busier systems are often common-battery, it is here that the need for party lines is encountered most frequently and the expense of the better ringing systems more often is justified. Unless one of several special arrangements described in this section is used, the ringers of all the stations on the line, each in series with its capacitor, are connected in parallel with each other, across the line. If ringing current is sent over such a line, it causes the ringers of all stations on the line to ring at the same time.

b. Code Ringing. One method for signaling the individual stations connected on the same line is called *code ringing.* Each station is assigned a code signal, such as one ring or two rings, and the person at any individual station responds only when he hears the correct number of rings. However, although code ringing is used in local-battery party lines, out of necessity, it has certain disadvantages. First, the person at each station must listen whenever the line is rung in order to determine whether he is being called, which is annoying. Also, nothing except a sense of honor prevents a person from listening in to the conversation of any of the other stations on the same line. For these reasons, code ringing seldom is used on common-battery party lines.

c. Lock-Out System. A lock-out system, as its name implies, makes a party line available to only one station at a time. Not only is the called station the only one to hear its own ringing signal, but the other stations are disconnected from the line when that station is making a call. This system, therefore, insures privacy and secrecy, and it is used extensively in European and other foreign countries for that purpose. In general, the initial and maintenance costs involved in the lock-out system are too great to make it applicable to party-line ringing.

d. Selective Ringing. Ringing on common-battery party lines generally is accomplished by using one of several systems of *selective ringing.* Such a system provides for the signaling of only one station of a party line at a time, the ringers of the other stations remaining silent. It does not afford as much secrecy as the lock-out system, but it is much superior in this respect to code ringing. One great advantage of a selective ringing system is that it requires only minor changes in the equipment of the telephone stations, and only little additional equipment at the central office. The succeeding paragraphs will discuss three common systems of selective ringing: *ringing to ground, ringing with pulsating current, and harmonic ringing.*

116. Ringing to Ground

a. Arrangement of Ringers. Ringing to ground is used on two-party lines and derives its name from the manner in which the two ringers are connected in the system. In a one-party line, such as the one illustrated in figure 143, the ringer, in series with its capacitor, is connected between the tip and ring sides of the line. Figure 144 shows the arrangement of the two ringers in a system of ringing to ground. One ringer, RG1, in series with its capacitor, is shown connected between the *tip* side of the line and *ground*, and the other ringer, RG2, in series with its capacitor, between the *ring* side of the line and *ground.*

b. Operation of Ringing Circuit.

(1) Figure 144 also shows the arrangement of the ringing generator and two ringing switches, A and B, in relation to the two

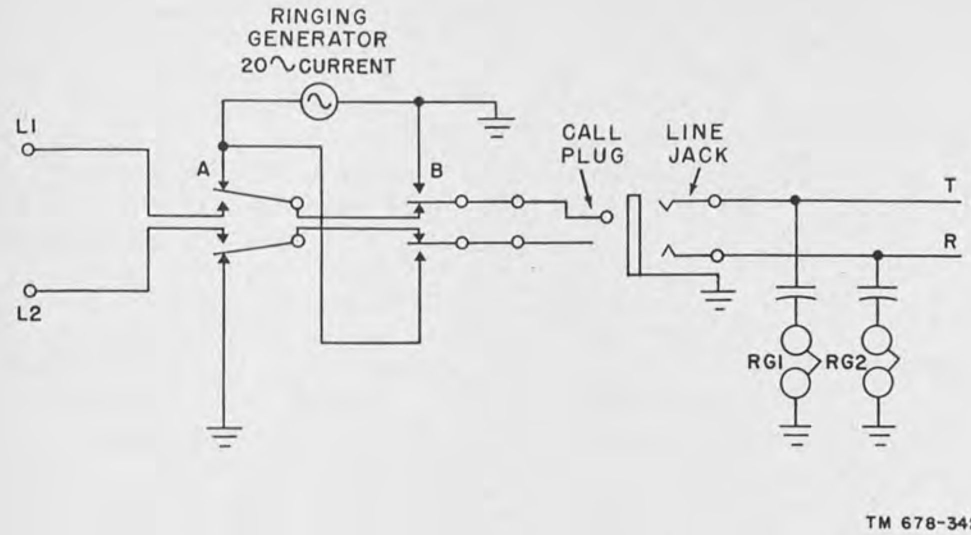


Figure 144. Arrangement for ringing to ground on a two-party line.

ringers. The ringing generator supplies 20-cycle alternating ringing current. One terminal of the ringing generator, the lower ringing contact of switch A, and the upper ringing contact of switch B are connected to ground. The other terminal of the ringing generator, the upper ringing contact of switch A, and the lower ringing contact of switch B are connected to a common tie point. This arrangement permits the operator to select which of the two ringers is to be energized.

(2) Now assume that the call plug is inserted in the line jack, preparatory to ringing one of the stations. When switch A is thrown to the *ringing* position (fig. 144) but switch B is left in the *talking* position (as shown) the ungrounded side of the ringing generator is connected to the tip side of the line (through the upper contact of switch B and the tip of the plug and jack), and ground is placed on the *ring* side of the line (through the lower contact of switch B and the ring of the plug and jack). Since ringer RG1 is connected through its capacitor between the tip side of the line and ground, the generator is connected across RG1 and its capacitor, and consequently RG1 rings.

(3) Now, if the operator wishes to ring the other station, he restores switch A (fig. 144) to the talking position and throws switch B to the ringing position. This connects the ungrounded side of the ringing generator to the *ring* side of the line (through the lower ringing contact of switch B and the ring of the plug and jack), and ground is placed on the *tip* side of the line (through the upper ringing contact of switch B and the tip of the plug and jack). This connects ringer RG2 in series with its capacitor across the ringing generator, and therefore RG2 rings.

(4) With this arrangement, consequently, only one ringer at a time is energized. When RG1 is energized, RG2 is shorted, since both ends of the series circuit are grounded; also, when RG2 is energized, RG1 is shorted. When both ringing switches are in the normal (talking) position, the two conductors of the call cord, L1 and L2, are connected through the upper and lower normal contacts of switches A and B, respectively, and the tip and ring of the plug and jack are connected to tip and ring of the line. Ringing to ground generally is used on military party lines for emergency or temporary service.

117. Ringing with Pulsating Current

a. Biased Ringer.

(1) Before discussing the operation of the system of ringing with pulsating current (alternating current plus direct current), the theory of operation of the special

ringer that makes the system possible first must be understood. This ringer is called a *biased ringer* (fig. 145). It is a polarized ringer, similar to the one described in paragraph 53, but contains an adjustable *biasing spring* attached to one

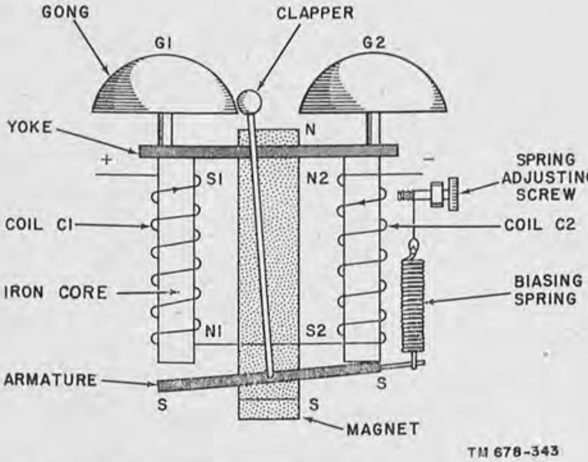


Figure 145. Structure and operation of biased ringer.

end of the armature. The biasing spring is adjusted by means of the spring-adjusting screw to keep the armature *normally* in a definite position. Thus, with the spring attached to the right side of the armature and extending upward to the adjusting screw, as in the figure, the *clapper* (or tapper) rests close to gong G1 in the normal position.

(2) Now assume that pulsating direct current, which flows in only *one* direction but varies in amplitude because of its alternating component, is flowing in coils C1 and C2 in the direction indicated by the arrows on the wires of the coils. Since the current is always in the same direction, the magnetic flux in each core is always in the same direction, as shown by polarity markings S1 and N1 in coil C1, and N2 and S2 in coil C2. Both ends of the armature are always *south* magnetic poles, because of the position of the armature in relation to the permanent magnet.

(3) During the portion of the cycle when the current is small, the upward pull exerted by the biasing spring on the right side of the armature (fig. 145) is greater than the combined upward pull exerted by the electromagnet (coil C1) on the left side of the armature and the downward push at coil S2; the clapper therefore remains in the position shown on the drawing. As the current increases, the electromagnetic forces increase, until eventually they become *greater* than the pull of the spring, causing the left side of the armature to move upward and the clapper to strike gong G2.

(4) After reaching its maximum value, the current starts to decrease. The forces acting on the armature become weaker, and the clapper eventually moves back and strikes gong G1 again. Thus, as the current alternately increases and decreases around its average (direct component) value, the clapper strikes gongs G2 and G1 alternately.

(5) If pulsating current is passed through the coils of the ringer in the *opposite* direction, iron cores C1 and C2 are magnetized with polarities opposite to those shown in the figure. Thus, the lower end of coil C2 becomes a *north* pole and attracts the right end of the armature, aiding the biasing spring. This is true in spite of the fluctuations in the current, since only its magnitude changes whereas its direction is always such as to aid the spring. The clapper therefore is held stationary and the ringer does not ring.

(6) If two ringers of this kind are biased in *opposite* directions, a pulsating current in one direction will operate one ringer, and a pulsating current in the opposite direction will operate the other. Therefore, if some means for changing the direction of the current is provided, the ringers will operate independently of each other, providing a means of two-party selective ringing.

b. Operation of Two-Party Ringing System.

(1) Figure 146 shows the arrangement for accomplishing two-party ringing with pulsating current. Ringers RG1 and RG2 are connected similarly, each having one terminal connected to the *tip* side of the line and the other connected to ground. The two ringers are biased in opposite directions, so that RG1 responds to pulsating current flowing from tip to ground, and RG2 to pulsating current

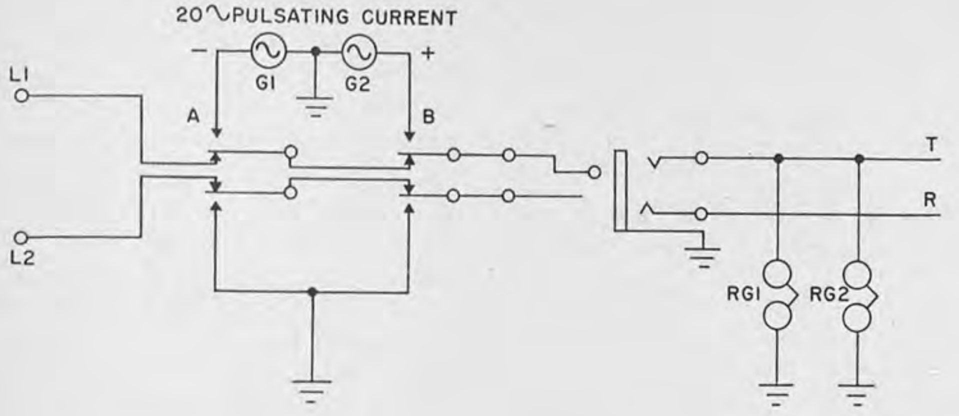


Figure 146. Two-party ringing with pulsating current.

from ground to tip, as indicated by the polarity signs (fig. 146). No capacitors are used with the ringers.

(2) Two ringing generators, G1 and G2, with opposite polarity, and two ringing switches, A and B, are used in the system. Each generator supplies 20-cycle pulsating direct current. If the call cord is inserted in the line jack, and ringing switch A is thrown to the ringing position, the ungrounded (negative) side of generator G1 is connected to the tip side of the line through the upper ringing contact of switch A, the upper normal contact of switch B, and the tip of the call plug and jack. The grounded side of G1 is connected to the ring side of the line through the grounded lower ringing contact of switch A, the lower normal contact of switch B, and the ring of the plug and jack. Generator G1 therefore sends pulsating current *down* through *both* ringers, from tip to ground. However, since only RG1 has been biased to respond to current in this direction, only RG1 operates during this time.

(3) When switch A is restored to its normal position, and switch B, instead, is thrown to the ringing position, the ungrounded (positive) terminal of ringing generator G2 is connected to the tip side of the line through the upper ringing contact of switch B and the tip of the plug and jack. The grounded side of G2 is connected to the ring side of the line through the grounded lower ringing contact of switch B and the ring of the plug and jack. Generator G2 therefore sends pulsating current *up* through *both* ringers, from ground to tip. Since only RG2 has been biased to respond to current in this direction, only RG2 operates. Note that the ring side of the line is grounded when either ringing switch is manipulated. Also, the portion of the cord circuit to the *left* of the ringing switches remains disconnected from the line during ringing.

c. Limitations of Ringing with Pulsating Current. As explained above, both ringers of a two-party ringing system using pulsating current are connected between the *tip* side of the line and ground. Since pulsating current has a d-c component, capacitors cannot be connected in series with the ringers because a capacitor blocks direct current. This makes the extension of this system to four-party ringing impractical (unless certain changes are made), since the two additional biased ringers would have to be connected between the *ring* side of the line and ground. But, in a common-battery system, connecting a ringer without a series capacitor between the ring side of the line and ground furnishes a complete d-c path for the line lamp (fig. 127) or line relay (fig. 128) when the plug is *out* of the jack, regardless of whether the hookswitch contacts at the station are open or closed. This would cause the line lamps to be lighted permanently and therefore would prevent a user from signaling the operator when a call is to be made. For this reason, four-party ringing by this method is applicable only to local-battery systems. In this application, the arrangement of the ringing switches must be changed to avoid grounding the ring side of the line, because this would short out the ringers connected between the ring side of the line and ground.

118. Four-Party Ringing, Using Relays and Pulsating Current

a. Arrangement of Ringers for Four-Party Ringing. A ringing system which is used commercially for four-party ringing with pulsating current is shown in figure 147. Essentially, it combines the principles of the two systems described in paragraphs 116 and 117. In this system, the four telephone stations which constitute the four-party line are connected between tip and ring of the line. The telephone set at each station contains a *relay* which is connected in series with a capacitor between tip and ring of the line, as shown. The relay operates on 20-cycle ringing current, and has a single make contact. All ringers are of the biased type described in the preceding paragraph. Ringers RG1 and RG2 are connected between the ring side of the line and the armature spring of their respective relays, and ringers RG3 and RG4 are connected between the tip side of the line and the make contact of their respective relays, as shown. Also, the ringers are biased so that ringers RG1 and RG3 respond to pulsating current in one direction, and ringers RG2 and RG4 respond to pulsating current in the opposite direction, as indicated by the polarity markings at the ringer symbols.

b. Ringing a Selected Station.

(1) The ringing switches associated with this selective ringing system (fig. 147) consist of a *master switch*, S, and four *plunger switches*, designated J, M, R, and W. The letters indicate the particular station that can be signaled when a specific plunger switch is operated. The mechanical arrangement of the plunger switches is such that only one switch can be operated at a time; once placed in the operated position, it remains there until another plunger switch is operated, when it is released automatically.

(2) Master switch S is shown in the drawing in its normal position; it must be in the *operated* position when any station on the line is to be signaled. Reference to figure 147 shows that the windings of all four station relays are connected, each in series with a capacitor, across the ring (R) and tip (T) of the line, and that operation of the master switch, S, connects the 20-cycle, a-c generator G3 across

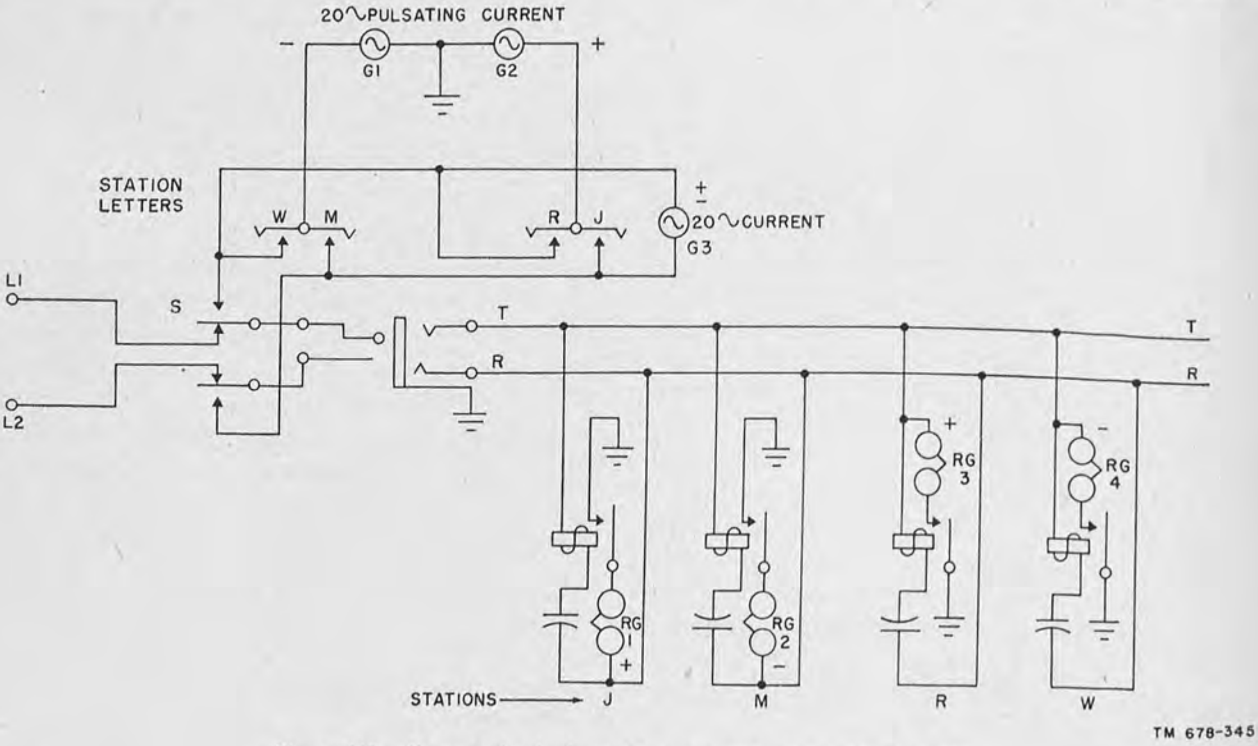


Figure 147. Four-party ringing with pulsating current, using relays.

the line. Since the station relays operate on alternating current, all four relays will operate when switch S is operated.

(3) The figure also shows that a minus (−) or plus (+) symbol appears adjacent to the ringer in each of the four stations. These symbols are used to indicate the polarity of the ringing current to which the particular ringer will respond. The plus (+) symbol at station J, for example, indicates that its ringer will respond when a current of positive polarity flows from the ring (R) side of the line, through the ringer coils and the operated (closed) contacts of the station relay to ground. The circuit that will provide this ringing medium starts at the ungrounded (+) side of ringing generator G2, operated contacts of plunger switch J, lower, operated contacts of switch S, ring (R) side of the line (the call cord plug is assumed connected to the line jack), windings of station J ringer coils, operated contacts of the station relay to ground, and returns to the grounded side of generator G2. The ringer at station M also is connected between the ring side of the line and ground, but in a manner such that it will not respond to a current of positive polarity. However, station M will respond if plunger switch M is operated. Operating switch M will restore switch J automatically and connect the ungrounded (−) side of generator G1 to the circuit comprising the operated contacts of switch M, lower, operated contacts of switch S, ring (R) side of the line, windings of station M ringer coils, operated contacts of the station relay to ground and back to the grounded side of ringing generator G1. In both instances, at this time, a ringing current is flowing in the ringers of both of the stations, M and J, and response or no response is determined only by the polarity of the current. Similar reasoning can be applied to stations R and W. In this case, the tip (T) side of the line is used instead of the ring (R) side.

(4) Each station relay is connected, in series with a capacitor, across the ring and tip of the line. The capacitor blocks the flow of line direct current through the relay winding, and thus prevents a permanent line signal when the line is not in use.

119. Four-Party Ringing, Using Gas Tubes

Figure 148 illustrates a circuit utilizing another method of providing four-party selective ringing. It is essentially the same circuit as the one in figure 147, but it uses *cold-cathode gas-filled tubes* in place of the relays. As will be shown, this eliminates the need for series capacitors, as well as for the third generator used for energizing the relays in the system of figure 147. The arrangement of the master ringing switch, the plunger switches, and the two pulsating-current generators is identical with that in figure 147.

a. Principles of Gas Tubes. Before discussing the operation of the system shown in figure 148, it is necessary to understand the structure and operation of a gas tube. It consists of a glass bulb or an envelope filled with an inert gas, such as neon or argon, and contains three electrodes—an anode, a control anode, and a cold cathode—the symbols of which are designated in figure 148. When a potential of 75 volts (this voltage varies with the particular type of tube used) is applied between cathode and control anode, with cathode negative, the gas in the tube is *ionized* into positively and negatively charged particles, and the tube conducts current from cathode to anode. Current can flow *only* from cathode to anode, and *only* when the anode is *positive* with respect to the cathode.

b. Operation of System with Gas Tubes.

(1) The relation of the four ringers to their respective gas tubes is shown in figure 148. One terminal of each ringer is connected to the *anode* of its associated tube: the other terminal is connected to the *control anode* through a 150,000-ohm resistor, the function of which is to limit the current flowing from cathode to control anode. When proper conditions exist, the tubes associated with ringers RG1 and RG2 conduct current through the ringers *to* ground, from the tip and ring sides of the line, respectively. Similarly, the tubes associated with ringers RG3 and RG4 conduct current *from* ground through the ringers to the tip and ring sides of the line, respectively.

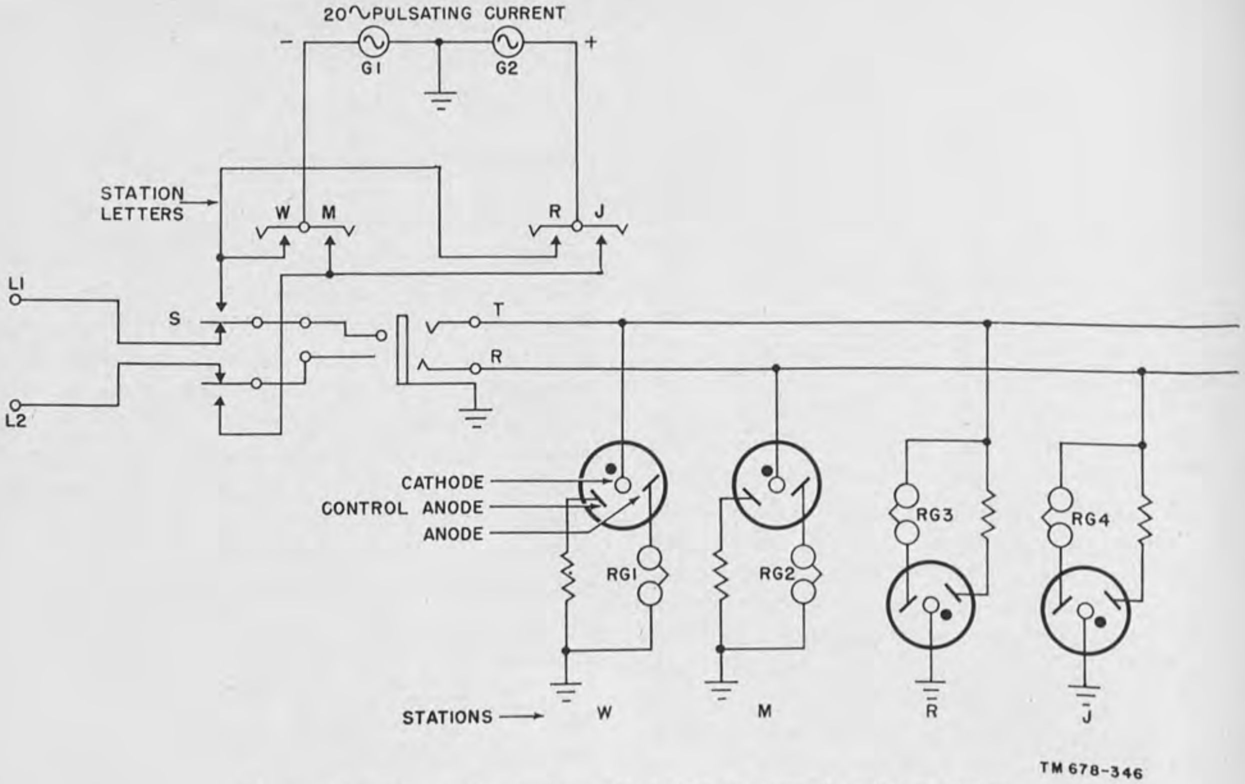


Figure 148. Four-party ringing with pulsating current, using gas tubes.

(2) When signaling station W, the call plug will be in the line jack, and master switch S and plunger switch W both will be in the operated position. This condition establishes a circuit from the minus (−) terminal of ringing generator G1, operated contacts of switch W, operated contacts of switch S and the tip side of the line to the cathode of station W tube. At the same time, the plus (+) terminal of generator G1 is connected through ground and the 150,000-ohm resistance to the *control anode* of the same tube, thereby placing a positive potential on that element; also, a potential of similar polarity is placed on the *anode* of the tube through the ringer coils. When the applied potential rises to approximately 75 volts, the gas within the tube *ionizes*, thus establishing conducting paths between the *cathode* and the *control anode* and between the *cathode* and the *anode*. Current will flow through the 150,000-ohm resistor and through the ringer to ground. These currents will flow and the ringer will operate until the applied voltage falls below approximately 60 volts. At this potential, ionization is discontinued and therefore current flow is cut off. Cut-off will continue until the applied potential again reaches approximately 75 volts and another cycle is begun. Since direct current flows in the ringer coils, the ringer armature will change its position in relation to the coil cones and will remain in the new position as long as the current flows. When the current is cut off, the tensioned ringer biasing spring pulls the armature back to its original position. This armature movement causes the clapper ball to strike the two ringer gongs alternately each time the current flows. The frequency at which the applied potential rises to 75 volts and then falls below 60 volts is 20 times per second, which, of course, is the frequency of the ringing generator voltage.

(3) Reference to figure 148 shows the ringer equipment for station W to be connected between the tip side of the line and ground. But station R also is connected

to the same points. The ringer at station R will not ring because its tube will not ionize, since, at the time, Station W is being signaled, a negative potential is connected to the anodes of the R tube and, as explained above, tube ionization takes place only when the anode potential is positive in relation to the cathode.

(4) Similar reasoning applied to stations J and M explains selective ringing between those two stations. Stations J and M are connected between the ring side of the line and ground and are signaled from ringing generator G2.

(5) The use of gas tubes gives the four-party selective ringing system certain advantages not obtained with relays. The tubes require little or no maintenance, and operate satisfactorily for a long period of time. Also, since capacitors are not needed, and since the tubes are much smaller in size than relays, the telephone set can be made more compact.

120. Harmonic Ringing

a. Type of Ringer Used in Harmonic Ringing. *Harmonic ringing* is a third method of providing four-party selective ringing. The ringer associated with this system is of different design from the biased ringer discussed previously. The armature, instead of being pivoted so that it can rotate about its center, is moved by a spring on the clapper rod—actually a reed which vibrates at some natural vibration frequency. The clappers in the four ringers used on a four-party line are made to have different weights, so that all of their vibration frequencies are different.

b. Ringing Machine Used in Harmonic Ringing.

(1) The ringing machine or generator used in harmonic ringing is designed to provide alternating currents of four different frequencies. The most commonly used frequencies are 16⅔, 33⅓, 50, and 66⅔ cycles (respectively, the fundamental, second, third, and fourth harmonics of 16⅔ cycles) in one type of generator; or, in another type, 30, 42, 54, and 66 cycles (the fifth, seventh, ninth, and eleventh harmonics of 6 cycles). The selection of the particular frequency for ringing at any given time is controlled by plunger switches similar to those used in pulsating-current ringing. Ringing current is sent over tip and ring of the line by means of the master switch.

(2) In this system, all four ringers are connected directly across the line, between tip and ring. As a result, each time the line is rung, regardless of the frequency used, *all* of the ringers receive ringing current. However, only that ringer which is designed to respond to the particular frequency will ring each time, the others remaining silent. Although this system is used commercially, its high maintenance costs and servicing requirements limit its use in military party lines.

(3) The system using 30 cycles as its lowest frequency is preferred, since it is more definite in responding only to the proper frequency. In the system based on 16⅔ cycles, it is possible for ringers timed to the higher frequency to respond falsely to a lower frequency which is an exact submultiple of its own frequency. In the 30- to 66-cycle system, no ringing frequency is an exact submultiple of any other.

121. Summary of Ringing Systems

a. Ringing signals may be provided in a common-battery system by a centrally located ringing generator that is switched into the circuit by the operator.

b. A party line is one to which two or more stations are connected. Code ringing may be used to signal the stations individually, but selective ringing requires special circuits and components.

c. There are three methods of selective ringing: ringing to ground, ringing with pulsating current, and harmonic ringing. The first two methods are used in military systems.

d. Ringing with pulsating current requires the use of biased ringers. Its use in four-party lines requires the addition of relays or gas tubes.

Section IV. COMMON-BATTERY TRUNK CIRCUITS

122. Functions of Trunk Lines and Trunk Circuits

a. The basic function of a *trunk line* (also referred to as a *trunk*) in a common-battery system is exactly the same as in a local-battery system—to interconnect two switchboards, either in the same central office or in different offices. This is necessary to enable a user whose telephone set is connected to one switchboard to converse with another user whose telephone is connected to a different switchboard.

b. A *trunk circuit* serves to connect a trunk transmission line to the other circuits of a switchboard, just as a line circuit is used to connect a telephone line to the other circuits of a switchboard. Thus, every trunk transmission line is connected to a trunk circuit at each end, one at each of two switchboards. The trunk circuit is terminated by a jack, into which the operator may plug a cord circuit.

c. Assume that telephone station 1, connected to switchboard A, is to be connected to telephone 2, connected to switchboard B (fig. 149). The sequence of connections is as follows: telephone set 1, line 1, line circuit 1 in switchboard A, a cord circuit in switchboard A, trunk circuit in switchboard A, the trunk transmission line leading to switchboard B, trunk circuit in switchboard B, a cord circuit in switchboard B, line circuit 2 in switchboard B, line 2, and telephone set 2.

d. In discussing the local-battery system (ch. 4), it has been explained that the trunk circuit at either end of a trunk transmission line is identical with the line circuits of a local-battery system. This is not true in a common-battery system. Because of the location of the common battery, certain differences are necessary to effect proper operation of trunk lines. For instance, provision is made to insure that the batteries of two interconnected switchboards do not oppose each other. Other differences arise because of the signaling and supervision requirements involved.

123. Types of Common-Battery Trunks

The term *trunk* commonly is used interchangeably with *trunk line*. As used in this chapter, however, it designates an entire trunk system, including both the trunk transmission line and the trunk circuits at each end of the line. The term *trunk circuit* is used to designate only the trunk jack and associated equipment at the switchboard. Of course, the operation of a trunk is related to the type of trunk circuit at each end of the system.

a. Types of Common-Battery Trunk Circuits. Common-battery trunk circuits may be classified as *automatic* or *ring-down*.

(1) An *automatic trunk circuit* is one that provides the switchboard operator at the called end of the trunk with an automatic signal when the calling operator inserts the call plug of his cord circuit in the trunk jack at the calling switchboard. No other manual operation is required on the part of the calling operator to signal the called operator.

(2) A *ring-down trunk circuit* (again referring to the trunk circuit at the *called* switchboard) is one in which the calling operator must *ring* the called operator, after inserting the plug in his trunk jack. This requires an additional operation on the part of the calling operator.

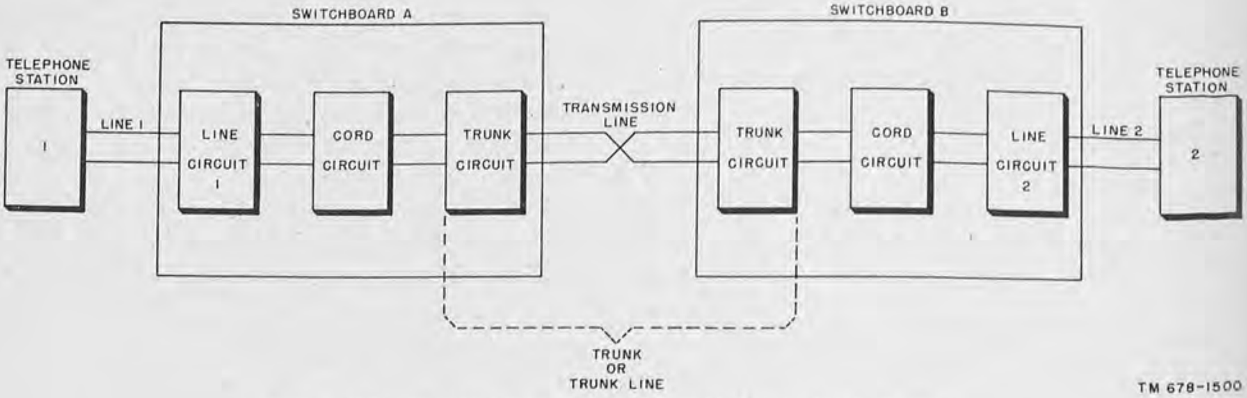


Figure 149. Simple telephone system with trunk, block diagram.

b. Types of Common-Battery Trunks. Trunks may be classified according to whether signaling (automatic or ring-down) is possible in one or both directions, and according to the equipment which the trunks interconnect.

(1) A *one-way trunk* is one in which the trunk circuit at only *one* end is equipped with a signal, either automatic or ring-down, the other having simply a trunk jack. Such a trunk can be used only for *receiving* calls at the end equipped with a signal, and only for *sending* calls at the other end. It usually is called an *outgoing* trunk for the switchboard where only a trunk jack appears.

(2) A *two-way trunk* is one in which either switchboard may initiate or receive calls. Two-way trunks may be automatic both ways (an automatic trunk circuit at both ends), ring-down both ways, or automatic one way and ring-down the other way.

(3) On large switchboards, trunks may be used to interconnect one *position* (par. 129) with another. They are called *interposition trunks*, and they resemble those used to interconnect two switchboards.

124. Two-Way Ring-Down Trunk

Associated with each trunk circuit in a switchboard is a *trunk jack*, similar to the line jacks associated with line circuits, and a *trunk signal*. The trunk signal serves the same purpose in the trunk circuit as a line lamp in a lamp circuit. The trunk signal may be either a lamp signal or a *drop signal*. (For the structure and operation of drop signals, refer to par. 67.) Both trunk jacks and trunk signals are located on the front panel of the switchboard, usually apart from the line jacks and lamps.

a. Trunk Circuits with Drop Signals.

(1) Figure 150 shows the schematic diagram of a two-way ring-down trunk in which the trunk circuits at both ends of the line are provided with *drop* signals. Each trunk jack is a cut-off jack, and the drop is connected in series with a capacitor to the auxiliary contacts of the jack. Assume that the operator at switchboard A wishes to call switchboard B. To signal the operator of switchboard B, operator A inserts the call plug of his cord circuit (the one normally used in answering the calling station) in the trunk jack corresponding with the trunk to switchboard B. This separates the springs of the jack, and disconnects the drop at switchboard A from the line. Operator A then sends ringing current over the trunk line (tip and ring) to energize the drop of the trunk circuit at switchboard B. The drop shutter falls, notifying operator B of a call coming in from A. When operator B inserts the answer plug of an idle cord circuit in his trunk jack in answer to the drop signal, the separation of the jack springs removes the drop from the line, permitting its restoration to the normal position. Operator B then can receive the number of the called station from operator A, as though he were answering a calling station connected to the same switchboard, and complete the call in the usual manner.

(2) The capacitor (fig. 150) is connected in series with the drop winding to prevent the flow of direct current over the trunk until the called operator answers. This keeps the supervisory relay in the cord circuit of the calling switchboard *unoperated* (pars. 108 to 110) and the supervisory lamp *lighted*, until the called operator answers.

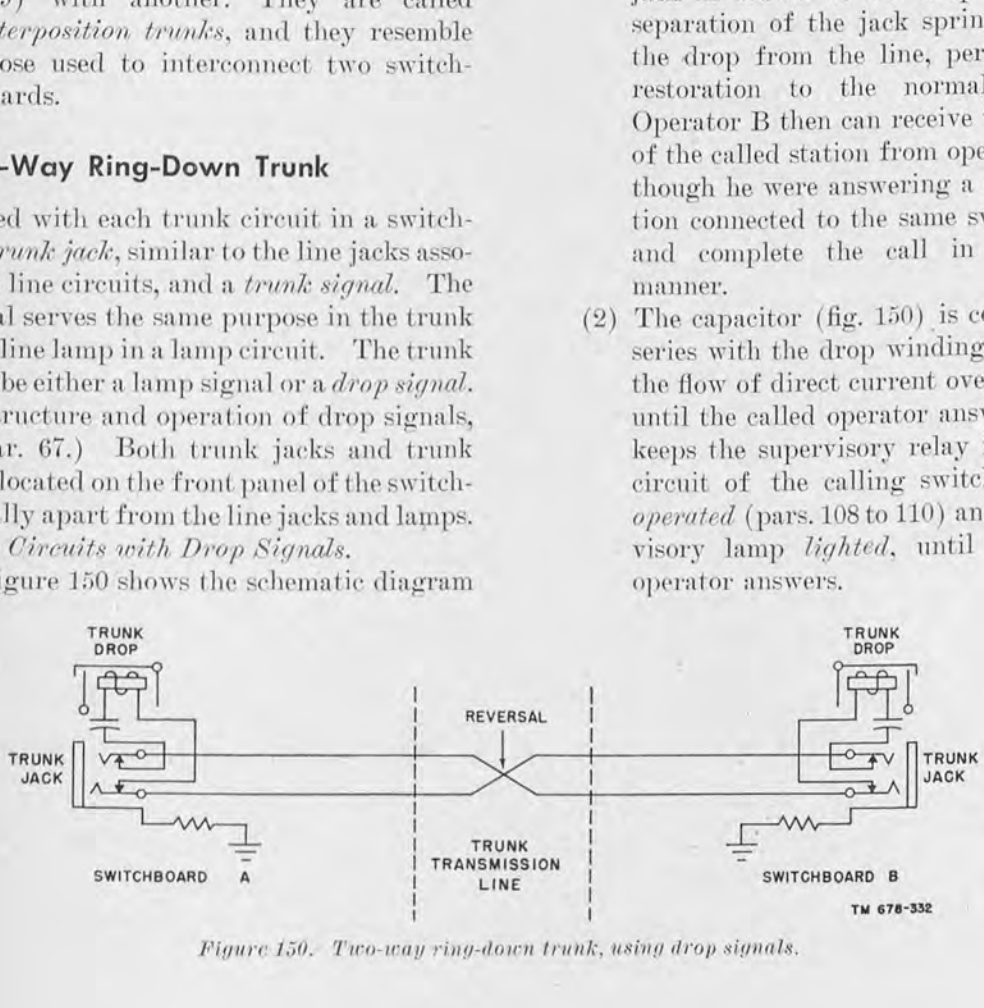


Figure 150. Two-way ring-down trunk, using drop signals.

(3) A *reversal* of the trunk line is shown in figure 150. This connects the tip of one jack to the ring of the other, and vice versa. If this were not done in a common-battery trunk of this type, when both plugs were in their respective trunk jacks the batteries at the two switchboards would be connected to the trunk line, through their respective cord circuits, with the *same polarity*, and thus would *oppose* each other. This would reduce the direct current through the supervisory relays to such an extent that they would not operate. As it is, with the reversal of the trunk line as shown, the two batteries are effectively in *series* so far as the supervisory circuits are concerned, permitting proper supervision. The reader can verify this statement by assuming any type of common-battery cord circuit to be connected to both ends of the trunk in figure 150, and tracing the d-c path through the supervisory relays.

(4) Although the reversal of the trunk line, as explained above, insures proper operation of the supervisory circuits, it has certain disadvantages. On short trunks, since the total voltage of the two batteries in series is approximately *48 volts*, the direct current through the cord circuits is approximately twice as great as when one battery is involved, and the current rating of the components in the cord circuits must be higher. Furthermore, because each switchboard has its own ground point, there are two grounds of different potential as far as the trunk line is concerned, tending to produce *noise* on the line. This effect is explained more fully in paragraph 186.

b. Trunk Circuits with Lamp Signals.

(1) Figure 151 shows a trunk similar to that of figure 150, but with the trunk circuits provided with *lamp signals* instead of drop signals. Instead of the ring-down drop, a *ring-down relay* is connected through a capacitor to the auxiliary contacts of each jack. An additional winding, called a *holding winding*, is wound on the same core, as shown. The purpose of this winding, as will be shown, is to keep the ring-down relay operated—and the signal lamp lighted—until the trunk call is answered. A cut-off relay is connected between the sleeve of each trunk jack and ground, and a signal lamp is connected between the negative terminal of the battery (to which the armature spring of the cut-off relay also is connected) and the make contact of the ring-down relay.

(2) When the operator at calling switchboard A sends ringing current over the trunk, the ring-down relay of the trunk circuit at called switchboard B is energized. It operates, completing the circuit of the trunk lamp and lighting the lamp at the called switchboard. At the same time, since the holding winding of the ring-down relay is in *parallel* with the lamp (when the armature of the cut-off relay is in the unoperated position shown), it is energized by direct current

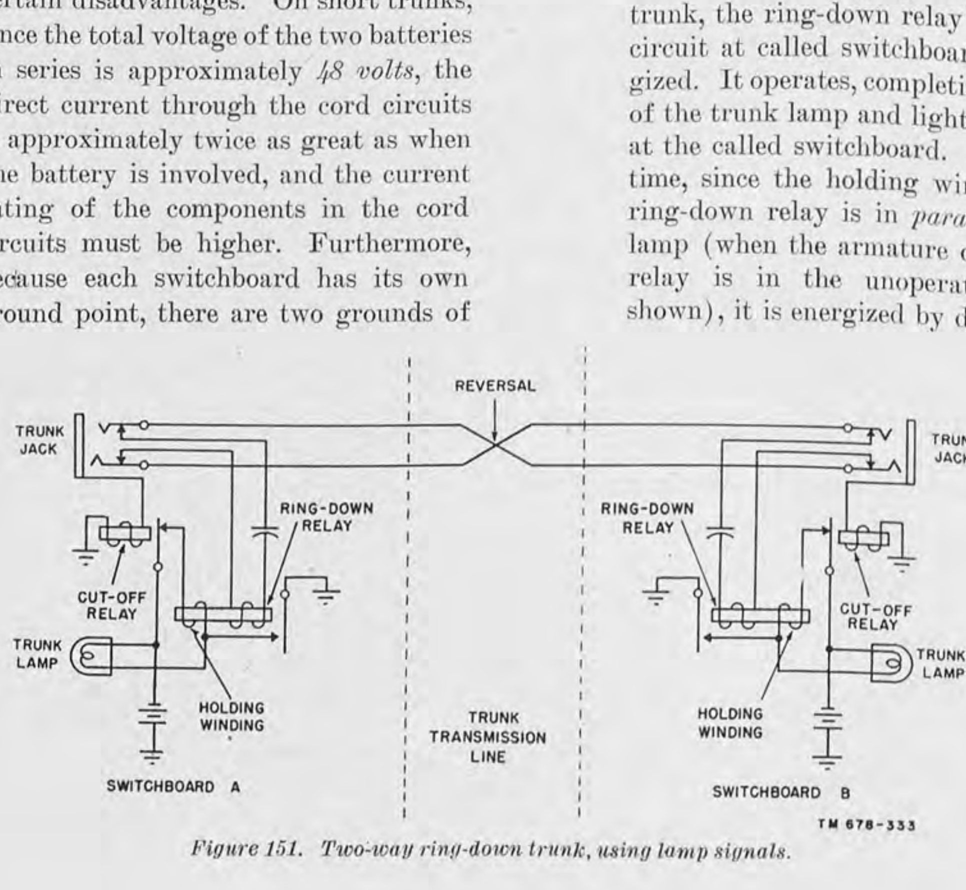


Figure 151. Two-way ring-down trunk, using lamp signals.

and thus keeps the armature of the ring-down relay in the make position, even when the ringing is stopped. This keeps the trunk lamp lighted.

(3) When the operator at called switchboard B inserts the answer plug of an idle cord circuit in answer to the lamp signal, the separation of the jack springs disconnects the main winding of the ring-down relay from the line. However, since the holding winding would remain energized—unless its circuit were broken in some way—the lamp would remain lighted. This is prevented by the operation of the cut-off relay. Its circuit is completed when the called operator inserts his answer plug in the trunk jack, because the sleeve of the plug is connected to the negative terminal of the office battery at the called switchboard. The operation of the cut-off relay instantly breaks the circuit of the holding winding, releasing the armature of the ring-down relay and extinguishing the trunk lamp. The call is completed by the called operator in the usual manner.

125. Two-Way Automatic Trunk

a. Arrangement of Trunk Circuits. Figure 152 shows the schematic diagram of a simple, *two-way automatic trunk.* The trunk circuit at each end of the system resembles a series-relay *line* circuit (fig. 128), except that the *tip* cut-off contact of both jacks is *not* wired to ground in the automatic trunk circuit. The negative terminal of the battery at switchboard A is connected through the winding of its trunk relay to the ring of its trunk jack, and through the reversed trunk line to the *tip* of the trunk jack at switchboard B. The negative terminal of the battery at switchboard B is connected similarly to the ring of its trunk jack and to the tip of the trunk jack at switchboard A. Thus, when the trunk is in the normal condition (no plugs in the jacks), tip *and* ring of *both* jacks are connected to a negative battery terminal through a relay winding.

b. Operation of Trunk.

(1) When the operator at the calling switchboard inserts the call plug of his cord circuit in the trunk jack at the calling switchboard, the separation of the jack springs disconnects from the line the relay of the trunk circuit at the calling switchboard. The grounded (positive) terminal of the battery at this switchboard is connected by the call plug to the tip of the calling trunk jack, and, because of the trunk line reversal, to the *ring* of the trunk jack at the *called* switchboard. This completes the circuit of the trunk relay at the called switchboard (through the ring cut-off contact of the jack). This relay operates, closing the circuit of the associated trunk lamp, and lighting the lamp.

(2) When the operator at the called switchboard inserts the answer plug of an idle cord circuit in his trunk jack, the separation of the jack springs breaks the ring-

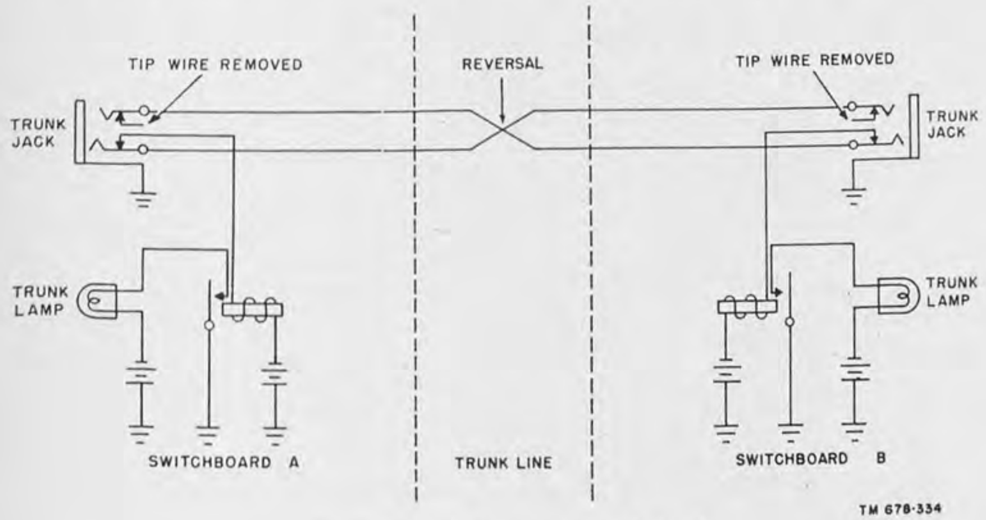


Figure 152. Two-way automatic trunk.

cut-off contact, causing the trunk relay to release. This, in turn, breaks the circuit of the trunk lamp, extinguishing the lamp.

(3) Instead of the series-relay trunk circuits shown in figure 152, cut-off relay trunk circuits (similar to cut-off relay line circuits) could be used. Operation is equally good with any conventional type of trunk circuit.

126. Automatic One-Way, Ring-Down Other-Way Trunk

a. Arrangement of Trunk Circuits. Figure 153 shows the schematic diagram of a trunk in which an *automatic* trunk circuit is used at switchboard A, and a *ring-down* trunk circuit at switchboard B. The automatic trunk circuit is identical with that described in paragraph 125 (fig. 152), and the ring-down trunk circuit resembles that described in paragraph 124 (fig. 151), except that it uses an additional cut-off contact in the trunk jack instead of a separate cut-off relay.

b. Operation of Trunk.

(1) When switchboard A is the calling switchboard, and the operator at A inserts the call plug in his trunk jack, and sends ringing current over the trunk, the operation of the trunk circuit at switchboard B (the called switchboard) is exactly the same as that described in paragraph 124. The ring-down relay is energized, closing the circuit of both the trunk lamp and the holding winding. The lamp lights, and the current through the holding winding keeps the relay in the operated condition after ringing is stopped. When the called operator inserts the answer plug of a cord circuit in his trunk jack, the separation of the jack springs breaks the circuit of the main winding of the trunk relay at the two ordinary cut-off contacts, and also breaks the circuit of both the trunk lamp and the holding winding at the *additional* break contact of the jack, extinguishing the lamps. The called operator then completes the call in the usual manner.

(2) When switchboard B (fig. 152) is the calling switchboard, and the operator at B inserts the call plug in his trunk jack, disconnecting the relay and lamp from the line, the automatic trunk circuit at switchboard A operates in exactly the same manner as that described in paragraph 125.

(3) This type of trunk frequently is used to interconnect a military switchboard with a commercial switchboard. The trunk circuit at the military switchboard is the ring-down type, and that at the commercial switchboard is the automatic type. An advantage of this trunk lies in the fact that it does not require any special equipment at the commercial switchboard, so that calls from the military end are handled in exactly the same manner as calls from any other station.

(4) The trunk transmission line (fig. 153) is reversed to insure proper operation of the supervisory circuits associated with the

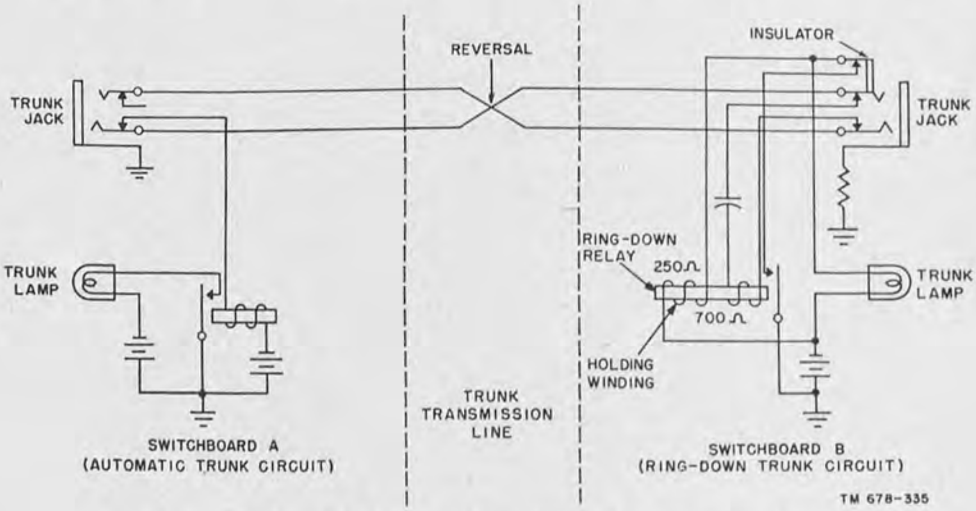


Figure 153. Automatic one-way, ring-down other-way trunk.

cord circuits at the respective switchboards, as mentioned earlier (par. 124*a*(3)). Repeating-coil cord circuits generally are used with this type of trunk. The automatic trunk circuit could be of the cut-off relay type, instead of the series-relay type shown in figure 153, and it would operate just as well.

127. Repeating-Coil Trunk Circuit

In the discussion of the various trunks in the preceding paragraphs, it was explained that a reversal of the trunk line was necessary to insure proper operation of the supervisory circuits in the respective cord circuits, and to permit signaling of the called switchboard over automatic trunks. But this creates a situation where two different grounds appear in a single trunk circuit, causing circuit unbalance, especially in so-called *noisy* areas. This, in turn, may cause the trunk to become unfit for practical operation. A method of preventing this type of interference uses a *repeating-coil trunk circuit*, one type of which is illustrated in figure 154.

a. Structure of Circuit. The repeating-coil trunk circuit (fig. 154) is seen to be more complex than any of the trunk circuits discussed previously. The additional components, however, insure the proper operation of the trunk without necessitating a reversal of the trunk line. The special equipment required, reading from right to left in figure 154, includes the following:

(1) A special trunk jack, J, with one break and one make contact, as shown.
(2) A repeating coil, wired as shown. The 1-μf capacitors are used to make the impedance of the path between the repeating coil windings high to ringing current but relatively low to voice-frequency currents.
(3) A signaling relay, S, to provide supervision at the distant switchboard.
(4) A single winding relay, H, with one make contact, providing a d-c path through the circuit for current from the distant switchboard.
(5) A ring-down relay, R, with a holding winding and a single make contact. The main winding is connected through a 2-μf capacitor to block the flow of direct current through the main winding. This trunk circuit is therefore a *ring-down* circuit, not an automatic one.

b. Operation of Circuit in Trunk. The block diagram of figure 155 shows a telephone system that includes the telephone sets of stations A and B, the line, cord, and trunk circuits at switchboards A and B, and the trunk transmission line between the switchboards. The trunk circuit of switchboard A is an automatic, cut-off relay type, and that of switchboard B is the repeating-coil trunk circuit shown in figure 154. This trunk, therefore, is automatic one way (from switchboard B to switchboard A) and ring-down the other way (from A to B). The schematic dia-

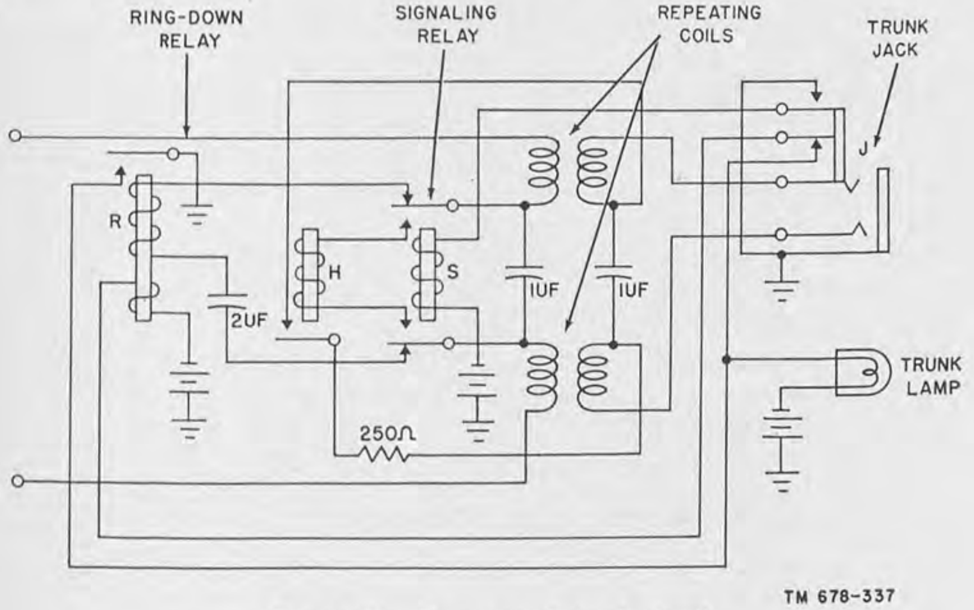


Figure 154. Repeating-coil trunk circuit.

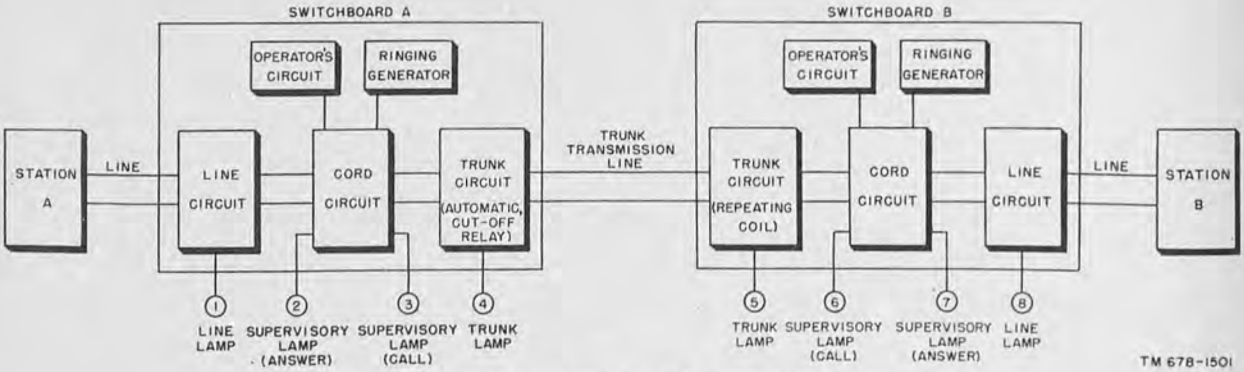


Figure 155. Telephone system with trunk, block diagram.

gram of the same system is shown in its normal condition in figure 156.

c. Call From Station A to Station B.

(1) Assume that someone at telephone station A (fig. 156) wants to talk to a person at station B. The operator at switchboard A receives the line signal (lamp 1) indicating that the handset of the calling station has been lifted from the hook, and he makes connection to the corresponding line circuit by inserting the answer plug of an idle cord circuit in the line jack. Upon receiving the number of the called station in the usual manner, the operator inserts the call plug of the same cord circuit (a repeating-coil cord circuit in this case) in the trunk jack at his switchboard that is connected by the trunk line to switchboard B.

(2) This operation causes supervisory lamp 3 to light (just as if the operator had plugged into the line jack of a called station at the same switchboard), and closes the circuit of cut-off relay E. The operation of relay E opens the circuit of relay F (both windings), and keeps trunk lamp 4 unlighted. Supervisory relay D does not operate because the d-c path through the trunk is open at capacitors C2 and C1. This keeps lamp 3 lighted.

(3) The operator at switchboard A now sends ringing current from the ringing generator over the trunk by the following path: from the generator through the tip contacts of the plug and trunk jack, T1, over the tip side of the trunk line, through contact T2 of flash switch FK (a two-contact lever switch), the upper left winding of the repeating coil in the trunk circuit of switchboard B, the upper, normally made contacts of signaling relay S, the operating winding of ring-down relay R and capacitor C1, through the lower normally made contacts of signaling relay S, the lower left winding of the repeating coil, the normally made contacts R2 of the flash key, returning to the ring side of the trunk line. The larger part of the ringing current flows in this path, rather than through capacitor C2, because the impedance of C2 is very much higher at the 20-cycle ringing frequency than is the combined impedance of capacitor C1 and the main winding of relay R.

(4) Relay R operates, closing the d-c circuit of trunk lamp 5 and the holding winding of relay R. Lamp 5 lights, and the holding winding keeps relay R operated when the ringing is stopped. The subsequent release of relay R now is under control of trunk jack J.

(5) When the operator at switchboard B sees the trunk signal given by lamp 5, he inserts the answer plug of one of his idle cord circuits in trunk jack J. The movement of the tip spring of the jack breaks the circuit of both the holding winding of relay R and lamp 5. Relay R releases and lamp 5 is extinguished. At the same time, the upper make contact of jack J is closed, causing ground to be connected through this contact to the top of the winding of relay S. This completes the circuit of relay S, causing it to operate, and thus completes the d-c circuit through the winding of relay H (from the battery at switchboard A

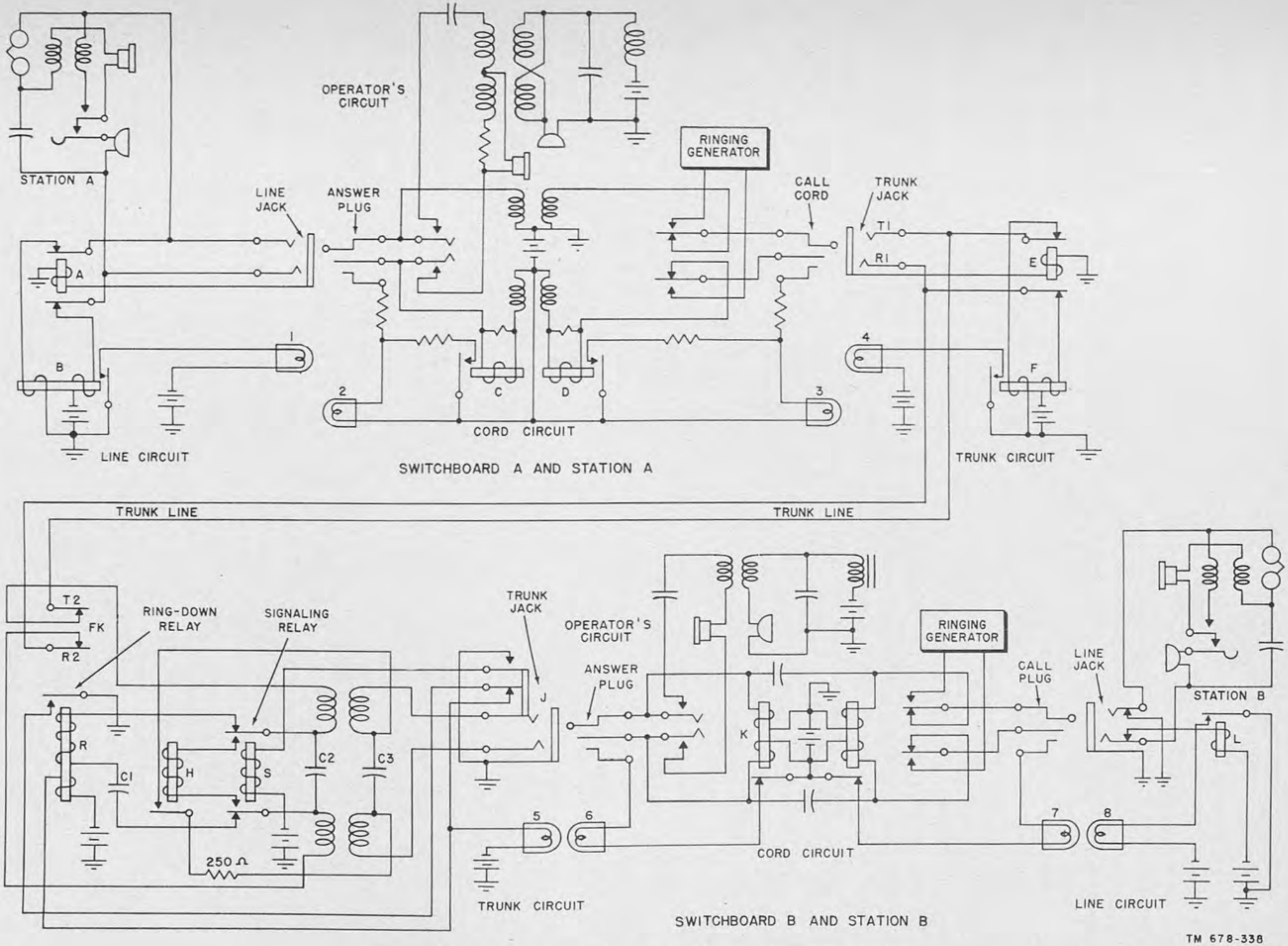


Figure 156. Telephone system with trunk, schematic diagram.

through the call cord circuit of switchboard A and the trunk line).

(6) Since the path of direct current from switchboard A to relay H includes the winding of supervisory relay D, this relay now operates, shunting supervisory lamp 3 with the 40-ohm resistor, thereby extinguishing lamp 3. At the same time, the operation of relay H places the 250-ohm resistor in parallel with capacitor C3 between the two right-hand windings of the repeating coils.

(7) This provides a complete d-c path from the battery at switchboard B through the winding of supervisory relay K over tip and ring of the answer cord and plug and the trunk jack. Relay K operates, breaking the circuit of supervisory lamp 6 (which otherwise would light), and keeping lamp 6 unlighted.

(8) The operator at switchboard B now can obtain the number of the called station connected to his switchboard from the operator at switchboard A. Operator B then can ring station B in the usual manner. Since the talking circuit between the two switchboards has been established, when station B answers, the conversation between station A and station B can take place. When one of the persons hangs up, the operator at the associated switchboard is signaled in the usual manner. He removes plugs from the line and trunk jacks at his switchboard, restoring all circuits to the normal condition.

d. Call from Station B to Station A.

(1) When the call originates at station B (fig. 156), the operation is somewhat different from that described in *c* above. When station B initiates a call by lifting the handset, the operator at switchboard B inserts the answer plug in the line jack and receives the number of the called station. Then the operator inserts the call plug of the cord circuit in trunk jack J. This action causes the upper contact of the jack to be made, closing the circuit of relay S. The operation of relay S closes the d-c path through the windings of relay F at switchboard A as follows: from the negative terminal of the battery connected to the right-hand winding of relay F through this winding and the lower normally made contacts of relay E to the ring side of the trunk line; over the ring of the trunk line through the normally made contacts R2 of the flash switch, the lower left winding of the repeating coil in the trunk circuit of the switchboard B, and the lower operated contacts of relay S; through the winding of *relay H* to the upper operated contacts of relay S; through the upper left winding of the repeating coil, normally made contacts T2 of the flash switch, and the tip side of the trunk line to the upper normally made contacts of relay E; and through the left-hand winding of relay F to ground. Relay F operates, completing the circuit of trunk lamp 4, and lighting the lamp.

(2) Although current flows through the winding of relay H, the additional resistance of the windings of relay F reduces the current to a value too low to operate relay H. This prevents supervisory relay K from operating, and keeps supervisory lamp 6 lighted.

(3) When the operator at switchboard A plugs into the trunk jack (in answer to the signal from trunk lamp 4), cut-off relay E operates and breaks the circuit of relay F. However, the common battery at switchboard A now sends sufficient current through the winding of relay H (over tip and ring of the answer cord and the trunk line from switchboard A) to operate relay H. The operation of relay H, as explained previously, connects the 250-ohm resistor in parallel with capacitor C3, completing the circuit of supervisory relay K at switchboard B. The resulting operation of relay K opens the circuit of supervisory lamp 6, extinguishing it. This signals the operator at switchboard B that the operator at switchboard A has answered.

(4) The call is completed through the cord circuit of switchboard A to station A in the usual manner.

(5) When the operator at switchboard A disconnects from the trunk (in answer to the signal of supervisory lamp 2, which lights when station A hangs up), cut-off relay

E releases, causing the circuit of relay F to be completed again. The additional resistance of the windings of relay F again reduces the current through the winding of relay H, causing it to restore. This breaks the circuit of supervisory relay K (by disconnecting the 250-ohm resistor); hence, relay K restores, completing the circuit of supervisory lamp 6 and relighting it. This signals the operator at switchboard B that switchboard A has disconnected from the trunk, so that he can clear the circuits at his switchboard.

(6) When the operator at switchboard B disconnects first, the circuit of relay S is broken by the removal of the plug from jack J. This breaks the d-c path through supervisory relay D at switchboard A (by restoring the armature of relay S to its normal position and thus breaking the contacts to which the winding of relay H is connected). Relay D restores, opening the path of the 40-ohm resistor, and causing supervisory lamp 3 to light. This informs the operator at switchboard A that switchboard B has disconnected, so that he can clear his switchboard.

128. Summary of Trunk Circuits

a. Common-battery systems, like local-battery systems, employ trunks to interconnect switchboards in the same or in different central offices.

b. A trunk line is terminated at each end by a trunk circuit, one in each of the interconnected switchboards. Trunk jacks and trunk signals are provided on the front panel of the switchboard.

c. Automatic trunks automatically furnish a signal to the called operator. In a ring-down trunk, the calling operator must manipulate a ringing switch to signal the called operator.

d. A one-way trunk is one equipped with a trunk signal at only one end; it can be used only for receiving calls at that end, and only for sending calls at the other end. Two-way trunks are equipped with signals at both ends, and they can be used for initiating or receiving calls at either end.

e. A reversal of the trunk line is necessary when ordinary trunk circuits are used, so that the two office batteries will be connected in series aiding for proper operation of the supervisory relays. A disadvantage of the reversal is the possibility of noise on the line introduced by it. The need for the reversal is eliminated by the repeating-coil trunk circuit.

Section V. MULTIPLE COMMON-BATTERY SWITCHBOARDS

129. Applications of Multiple Switchboards

a. A nonmultiple switchboard is suitable for service involving only a limited number of stations. The number of lines that can be served by such a switchboard is limited by the number of incoming calls that a single operator can handle in a given time, and by the number of line jacks that the operator can reach. This type of switchboard, therefore, is applicable only to small installations, where the total load can be handled by one or two operators.

b. When the number of stations to be connected to a single office is too great for two operators to handle conveniently, a *multiple switchboard* is necessary to accommodate the load. In very large installations, several multiple switchboards may be used in the same office. In such an installation, the various lines and trunks are interconnected between the switchboards, so that each line or trunk coming into the office is connected to a jack in one switchboard, and that jack is connected in *multiple* (parallel) with jacks accessible to a number of other operators. Each line or trunk is said to *appear* at several places on the switchboard. This enables every operator to answer a fairly equal share of the incoming calls, and to complete them on any line or trunk connected to the office.

130. Arrangements of Multiple Switchboards

a. Arrangement of Jacks.

(1) A three-position multiple common-battery switchboard commonly used in military installations is shown in figure 157. Its general appearance is similar to the nonmultiple switchboard shown in figure 113, but there are certain important differences, aside from the obvious fact that the multiple switchboard is larger. There are three general groups of jacks on the front panels of the switchboard. The jacks in the lowest group (closest to the plug-shelf), to which the incoming lines or trunks are connected, have associated signal lamps, as shown. They are

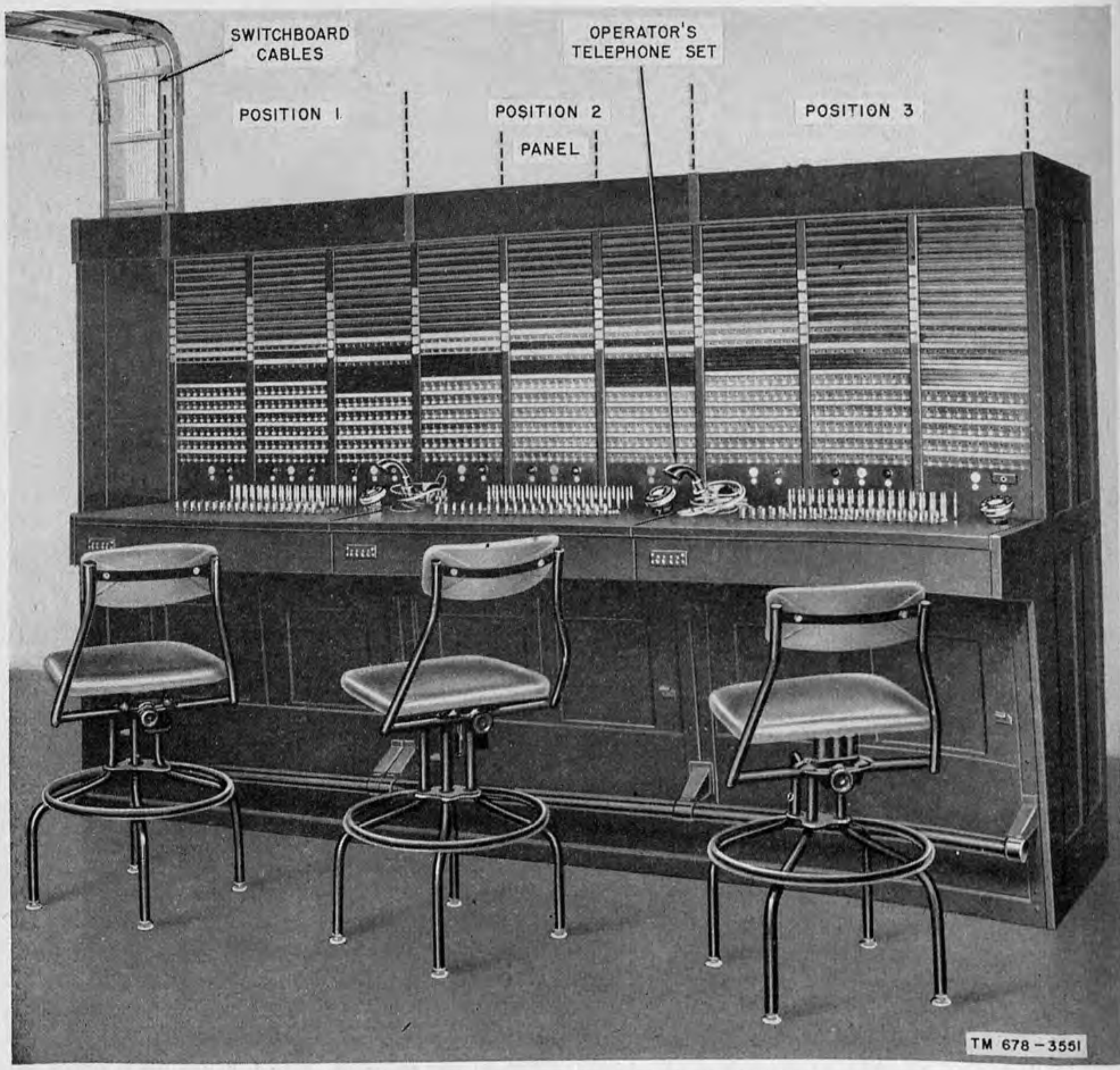


Figure 157. Multiple common-battery switchboard.

called the *answering appearances*, and are distributed over the face of the switchboard so that each operator can handle his share of *incoming* calls.

(2) The jacks in the other two groups, situated above the answering appearances, are called *multiple jacks* or *multiple appearances*. They are used for interconnection between the positions of the same switchboard, or between different multiple switchboards in the same office. The multiple jacks usually do *not* have associated signal lamps. The multiple jacks closest to the answering appearances are called *middle-multiple appearances*, and those nearest the top of the switchboard are called *top multiple appearances*.

(3) The answering jacks usually are arranged in strips of 10, as in a nonmultiple switchboard. An individual removable number plate usually is located beside each jack to identify the jacks. The numbering of the jacks is not consecutive, because the lines are regrouped from time to time to equalize the load among the operators. A line lamp is associated with each answering jack (fig. 155).

(4) The middle multiple appearances gener-

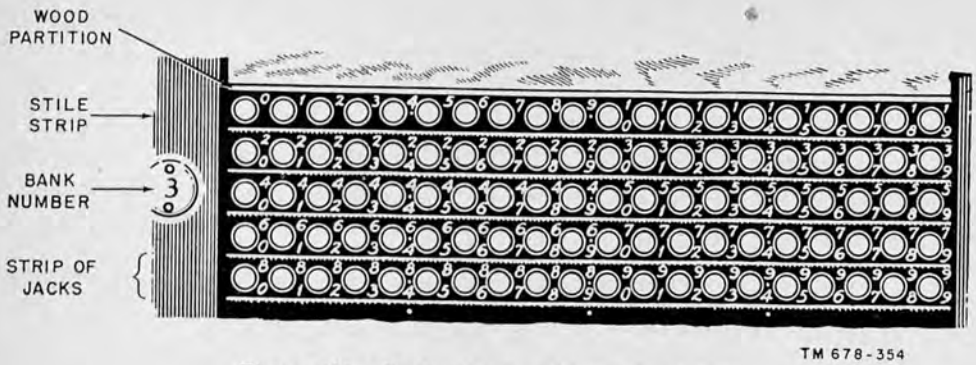


Figure 158. Bank of top multiple appearances.

ally are used for connections to outgoing trunks. They are arranged in strips of either 10 or 20, depending on the particular switchboard, and are numbered consecutively. To the left of each strip of trunk jacks is a number plate, and above the jacks is a strip that is used to indicate the distant exchange to which the corresponding trunk is connected.

(5) The remainder of the face of the switchboard is devoted to the top multiple appearances, which are used for completing calls to stations connected to the same switchboard. They are arranged in horizontal strips of 10 or 20, and grouped in vertical *banks* of five strips, making a total of 50 or 100 jacks in each group. One such bank of 100 jacks is illustrated in figure 158. Each bank has a number plate in the *stile strip* (framework) to its left, to indicate the number of the bank, and is separated from the bank above and below by a narrow strip of wood. The strips of jacks are inserted in the panel from the rear, and are secured in position by disks called *jack fasteners*.

b. Divisions of Multiple Switchboard.

(1) The multiple switchboard can be divided

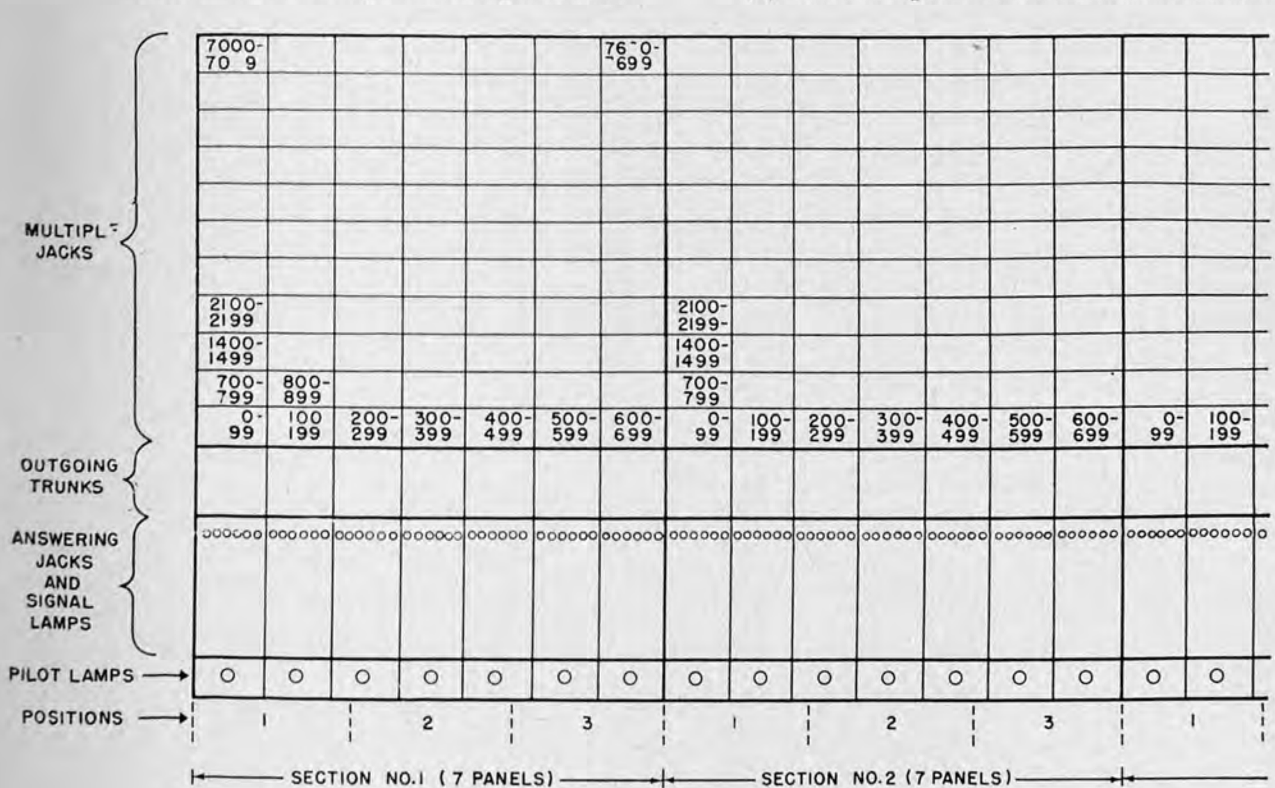


Figure 159. Subdivisions of face of multiple switchboard.

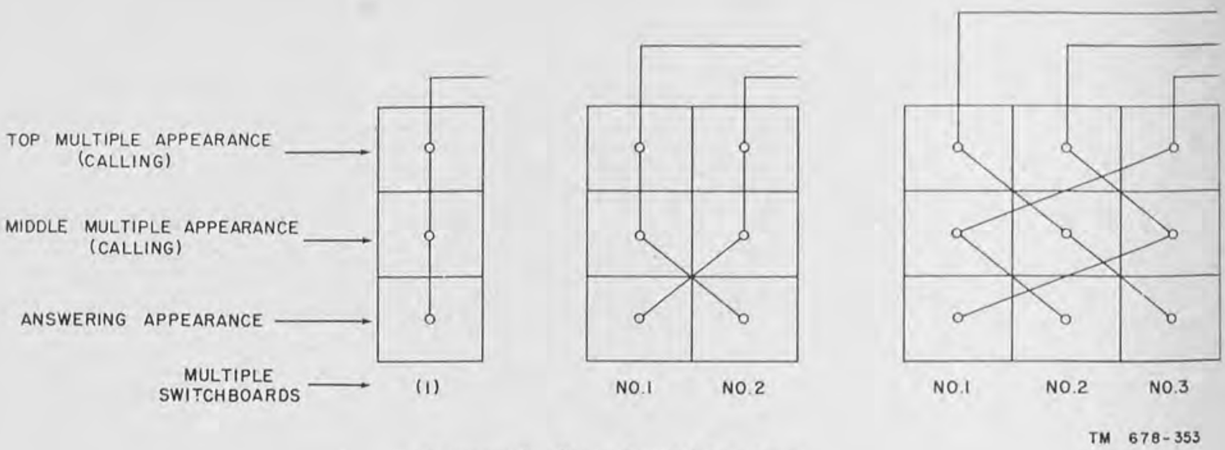


Figure 160. General multiple scheme.

conveniently into *sections*, *positions*, and *panels*. A *panel* is the smallest subdivision of the switchboard equipment, and it has the width of a single strip of answer jacks. A *position* usually includes two or three panels, and it is intended to be handled by one operator A *section* usually includes three positions, and it has one *complete* appearance of the multiple jacks; it is, therefore, the *minimum* initial installation of a multiple switchboard. The multiple switchboard shown in figure 157 has one section with three positions, each position consisting of three panels.

(2) Figure 159 shows the arrangement of the face of a multiple switchboard containing several sections, such as those used in larger installations. Each section contains the top multiple jacks associated with *all* the lines served by the switchboard. The maximum capacity of each section in this arrangement is 7,700 telephone stations (7 times 11 times 100), since each section contains seven panels and there are 11 banks of 100 jacks each in each panel. Each section is divided into three positions to distribute the load of each section among three operators. The answering jacks are distributed among the sections, so that each one appears only *once* on the face of the entire switchboard. Note that one pilot lamp is provided for each *panel* of the switchboard. (The function of the pilot lamps is explained in pars. 137 through 149.) This type of panel arrangement is characteristic of many multiple switchboards in military use.

c. General Multiple Scheme. Figure 160 shows the general scheme followed in the interconnection of the top multiple, middle multiple, and answering appearances on the switchboard, depending on the size of the installation. In an installation using only one multiple switchboard (left diagram), all appearances are connected, as shown. When two switchboards are used (middle diagram), the top and middle multiple appearances of switchboard No. 1 are connected to the answering appearances of switchboard No. 2, and vice versa. In an installation involving three multiple switchboards (right diagram), the top multiple appearances of switchboards No. 1, No. 2, and No. 3 are connected respectively to the middle multiple appearances of switchboards No. 2, No. 3, and No. 1; and the middle multiple appearances of switchboards No. 1, No. 2, and No. 3 are connected respectively to the answering appearances of switchboards No. 2, No. 3, and No. 1. Where more than three multiple switchboards are used in a single installation, they are treated as two sets.

131. Branch Multiple Circuit

a. Equipment of Branch Multiple Circuit.

(1) Since the cord circuits used in multiple switchboards are the same as those used in nonmultiple switchboards, and the process of completing a call from a calling station to a called station, except for the multiple jack arrangement, is also the same, it is not necessary to repeat

the descriptions of the operations of the cord circuits in establishing a talking path between two stations. However, there are differences in the structure of the *line circuits* used in multiple switchboards, and they are discussed here.

(2) A common-battery line circuit using a cut-off relay (par. 101 and fig. 130) may be arranged as a *branch multiple circuit*, as shown in figure 161. The equipment of such a circuit may be divided conveniently into five classes, as shown: terminal equipment, multiple equipment, answering equipment, relay equipment, and auxiliary equipment. The terminal equipment consists of the MDF (main distributing frame), the IDF (intermediate distributing frame), and associated wiring; it is used for the purpose of distributing the incoming lines in an orderly manner to the respective line and auxiliary circuits. These are discussed in more detail in chapter 6.

(3) The multiple equipment consists of the various multiple jacks associated with the incoming line. The tip, ring, and sleeve contacts of the multiple jacks are connected individually in parallel, as shown, and to corresponding terminals on the IDF. Through the IDF, they are connected to the corresponding points on the answering jack and the cut-off relay. The line lamp is connected through an additional terminal of the IDF to the make contact of the line relay. When the

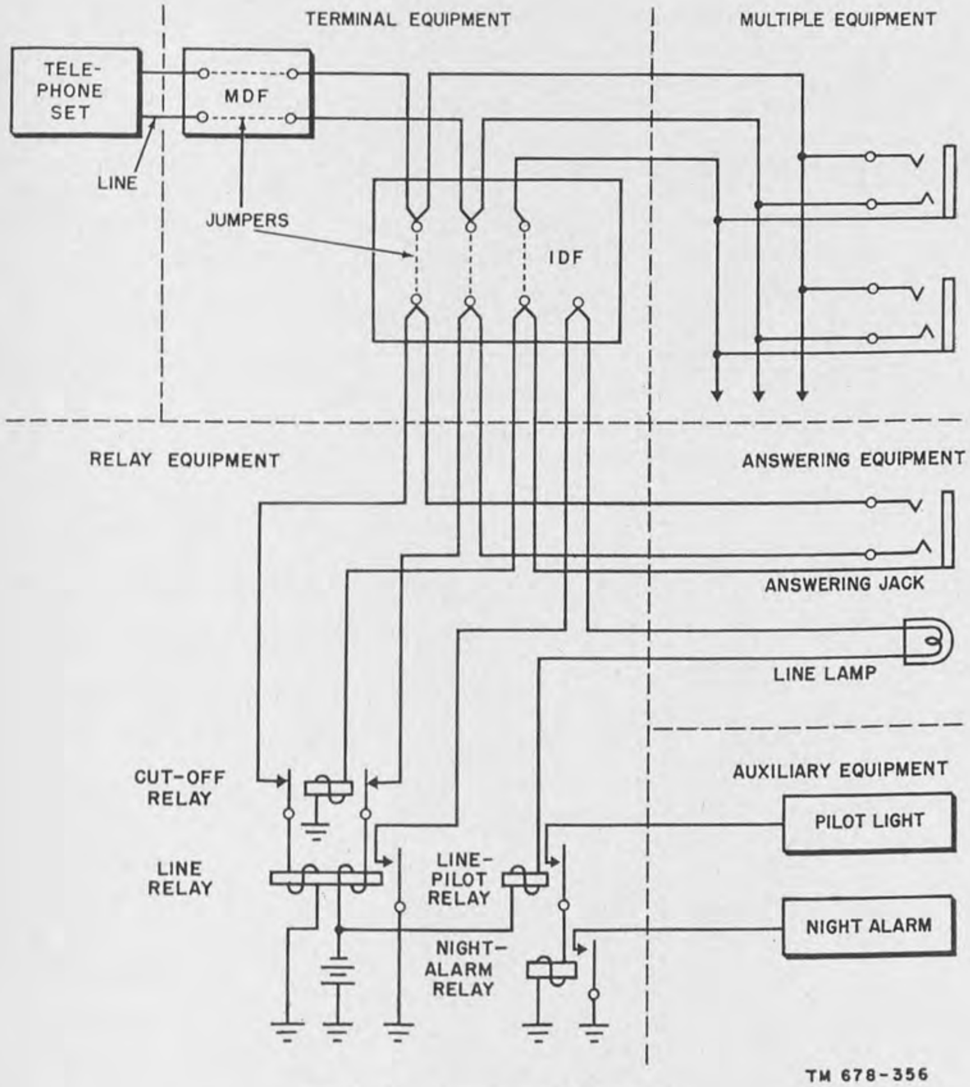


Figure 161. Branch multiple circuit.

call plug of a cord circuit is inserted in *any one* of the multiple jacks, or when the answer plug is inserted in the answering jack, the line circuit operates in the manner as described in paragraph 101.

(4) The auxiliary equipment is common to all the lines appearing on the same panel. It is discussed in paragraphs 137 through 149.

b. Advantages of Branch Multiple Circuit. The branch multiple circuit is characterized by simplicity of design, provision for mounting the relays on a framework outside the switchboard cabinet, and considerable flexibility. The system makes it possible to connect any answering jack and its associated relay equipment to any set of multiple jacks by changing a three-wire jumper on the IDF (ch. 6). This makes it possible to shift the answering jack from one position to another without changing the number of the station associated with the jack, and makes it easy to equalize the switchboard load without changing the directory listings.

132. Lamp-Associated Multiple Circuit

In some multiple arrangements, a line lamp is associated with each multiple jack. Such an arrangement, shown in figure 162, is called a *lamp-associated multiple circuit.* In this circuit, there is no separate answering jack, and when a call comes in from any line connected to the switchboard, all line lamps light simultaneously. The first available operator answers the call by plugging the answer plug of a cord circuit into the multiple, and this extinguishes all the lamps. Thus, the lamp-associated multiple arrangement insures an automatic distribution of traffic load; but it also reduces the capacity of the switchboard, increases battery drain, and is likely to result in two or more operators answering the same call. For these reasons, the use of this arrangement is restricted to small exchanges or offices.

133. Series Multiple Circuit

Another type of multiple-jack arrangement is the *series multiple circuit*, shown in figure 163. In this system the various multiple jacks are connected in *series* with the associated answering appearance through the cut-off springs and contacts of the jacks. Thus, reading from right to left, it can be seen that the tip of the answering jack is connected to the tip auxiliary contact of the mid-

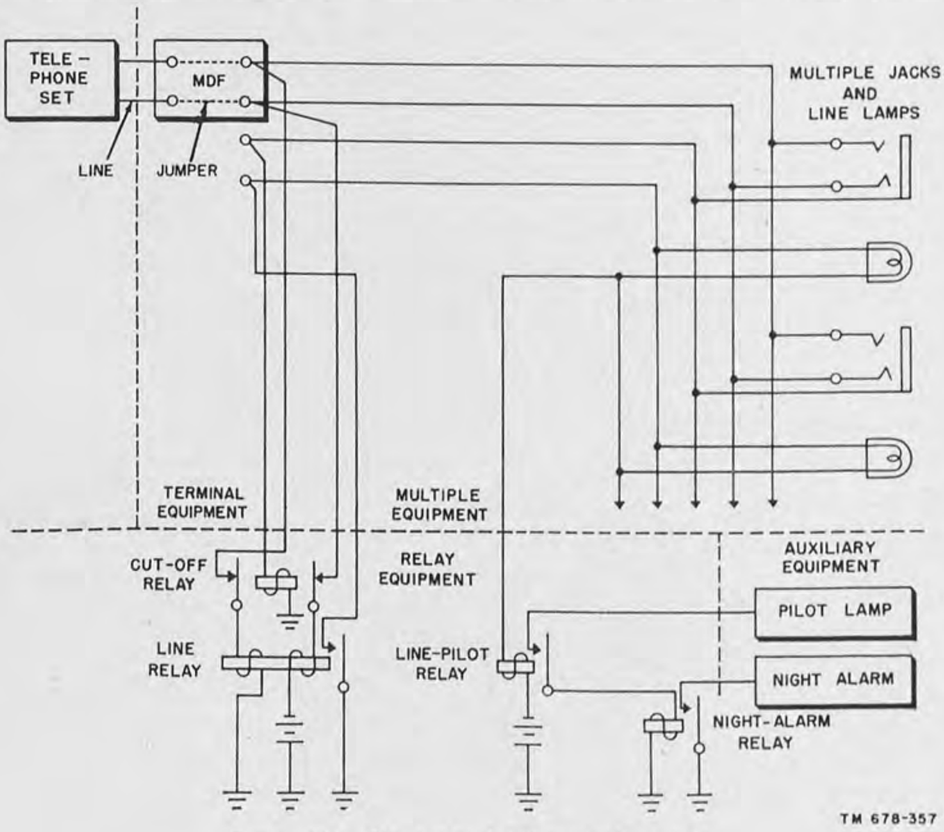


Figure 162. Lamp-associated multiple circuit.

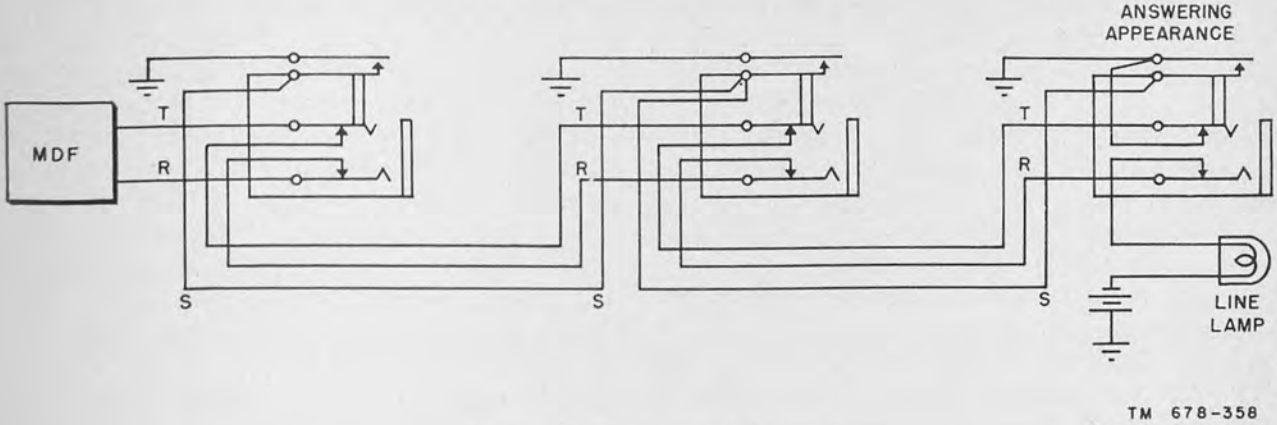


Figure 163. Series multiple circuit.

dle jack, the tip of the middle jack is connected to the tip auxiliary contact of the next jack, and so on. Since cut-off jacks are used (instead of relays), to control the operation of the line lamps, such an arrangement of the multiple jacks is necessary to extinguish the associated line lamp when a plug is inserted in a multiple jack. In switchboards using this type of multiple arrangement, the answering appearance also is used for outgoing calls, because this is the only appearance of the line in that position on the switchboard.

134. Busy-Test Circuit

Although the arrangement of multiple jacks enables every operator to reach all the lines connected to an office for the purpose of *completing* a connection, occasionally it may cause confusion. This

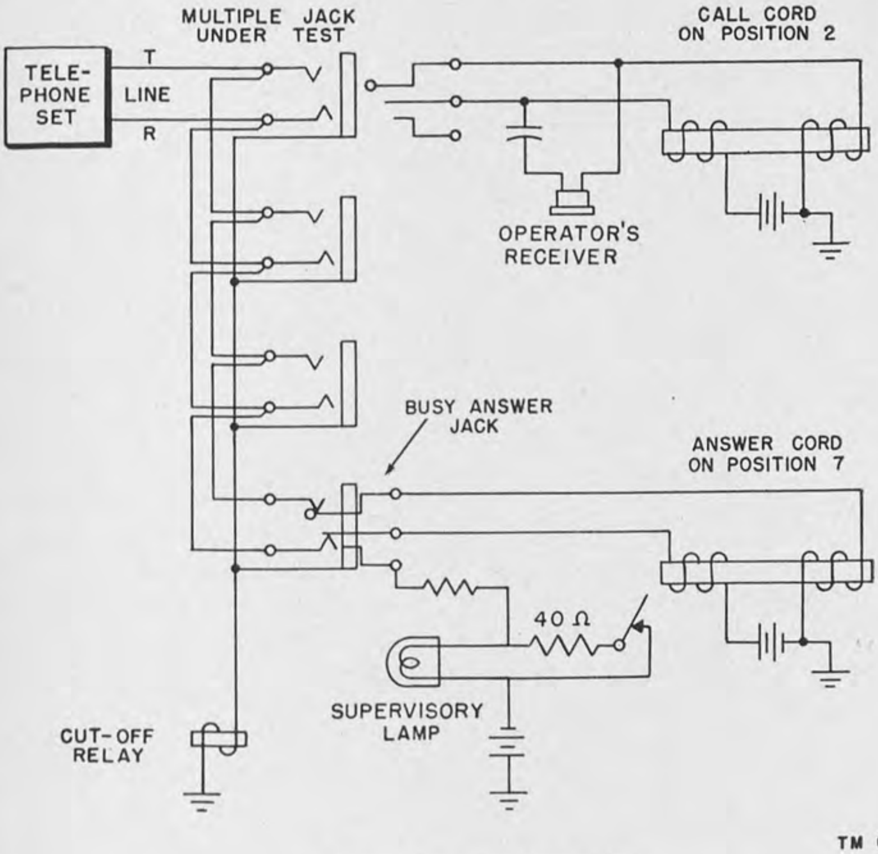


Figure 164. Busy-test circuit.

is because of the possibility of different operators making connection with the same line at the same time, or of an operator plugging into the multiple jack of a line to a station already engaged in a telephone conversation. In order to prevent this, large switchboards incorporate a busy-test circuit for determining quickly whether a particular line is busy. Such a circuit is shown in figure 164. An incoming call from a station already has been answered by an operator at position 7, who has plugged an answer plug into the answering jack. This, of course, has changed the electrical condition of all the multiple jacks associated with the answering jack. Now, if an operator on another position—for example, position 2—is asked to make a connection with this line, he first touches the tip of the plug of his call cord to the sleeve of the multiple jack convenient to his position. If a connection already exists on that line, as shown in the figure, he hears a click in the receiver of his telephone set. This informs the operator that the line is busy, and he does not attempt to complete the connection, but informs the calling station that the line is busy. Note that the operator's telephone set must be connected across his cord circuit to make this test, but this will have been done already in answering the calling station to determine the number of the called station.

135. Designations on Multiple Switchboards

a. Lamp Markings. In all types of common-battery switchboards, and particularly multiple switchboards, various devices are used to assist the operator in giving efficient service. Among these are lamp caps of different colors, and with different markings engraved on the cap and filled with opaque paint. They are used on the line and trunk lamps to distinguish between various classes of service. For example, different colors may be used to indicate that certain lines are to be given priority; that certains lines are denied trunk service; and that certain lines are used only for special services.

b. Signal Plugs. When lines either are disconnected permanently or are temporarily out of service, a *signal plug* is inserted in the appearances associated with the line, to prevent an operator from plugging into the jack. The signal plug can be identified by using different colors, so that the operator will be informed why the line is not in service. If the number of a telephone station has been changed, the new number is marked on the signal plug, and the old number is not used until a new directory is printed.

c. Multiple Jack Markings. There are four small holes around each multiple jack, so that it is possible, by using them in certain combinations, and with certain colors of paint, to mark the jacks to indicate a wide range of service conditions. In order to mark a series of jacks, any one of which is available under the same number, a line of selected color is drawn below the entire series.

136. Summary of Multiple Switchboards

a. Multiple switchboards are used in large common-battery installations to increase the number of lines that may be serviced by a single operator. They are able, therefore, to handle a much greater traffic load than can nonmultiple boards.

b. In multiple switchboards, each line coming into the switchboard is connected to an answering jack, or appearance, and to several multiple jacks. The face of the switchboard is divided into panels, positions, and sections. Each section contains a complete appearance of the multiple jacks, one for each line entering the office.

c. Each operator handles a certain fraction of the incoming calls, since only a fraction of the entire number of answering jacks appears at his position. Since he can reach the multiple jacks of every line entering the office, however, either at his own position or at the positions immediately adjacent to his, he can complete the call to *any* station connected to the switchboard.

d. Multiple switchboards may incorporate one of several types of multiple arrangements, such as branch multiple, lamp-associated multiple, or series multiple arrangements.

e. A busy-test circuit usually is provided on larger switchboards to inform an operator whether a line is busy before he plugs into the multiple jack associated with the line.

Section VI. AUXILIARY CIRCUITS IN COMMON BATTERY SWITCHBOARDS

137. Purpose of Auxiliary Circuits

a. Functions of Auxiliary Circuits. In addition to *major* circuits, such as line, cord, supervisory, trunk, and ringing circuits, common battery switchboards, like local-battery switchboards, are equipped with various *auxiliary* circuits (fig. 165). These circuits assist the operator in handling calls promptly, or in other ways to make the operation of the switchboard more efficient. Some of them provide additional signals, either visible or audible, whenever a line or supervisory lamp lights. Others provide emergency circuits during times when other circuits fail to function. Still others are in the nature of protective devices, and prevent the wires and components of the switchboard from burning out when a short circuit occurs.

b. Types of Auxiliary Circuits. The number and types of auxiliary circuits with which a switchboard is equipped depend on the type, size, and complexity of the switchboard. Practically all common-battery switchboards, both nonmultiple and multiple, include the following types of auxiliary circuits: *line-pilot circuit, supervisory-pilot circuit, night-alarm circuit, generator-switching circuit, position-transfer circuit, and fuse-alarm circuit.* In addition to these circuits, nonmultiple switchboards are equipped with a *battery cut-off circuit.* Multiple switchboards, being more complex, may also be provided with several additional auxiliary circuits, depending

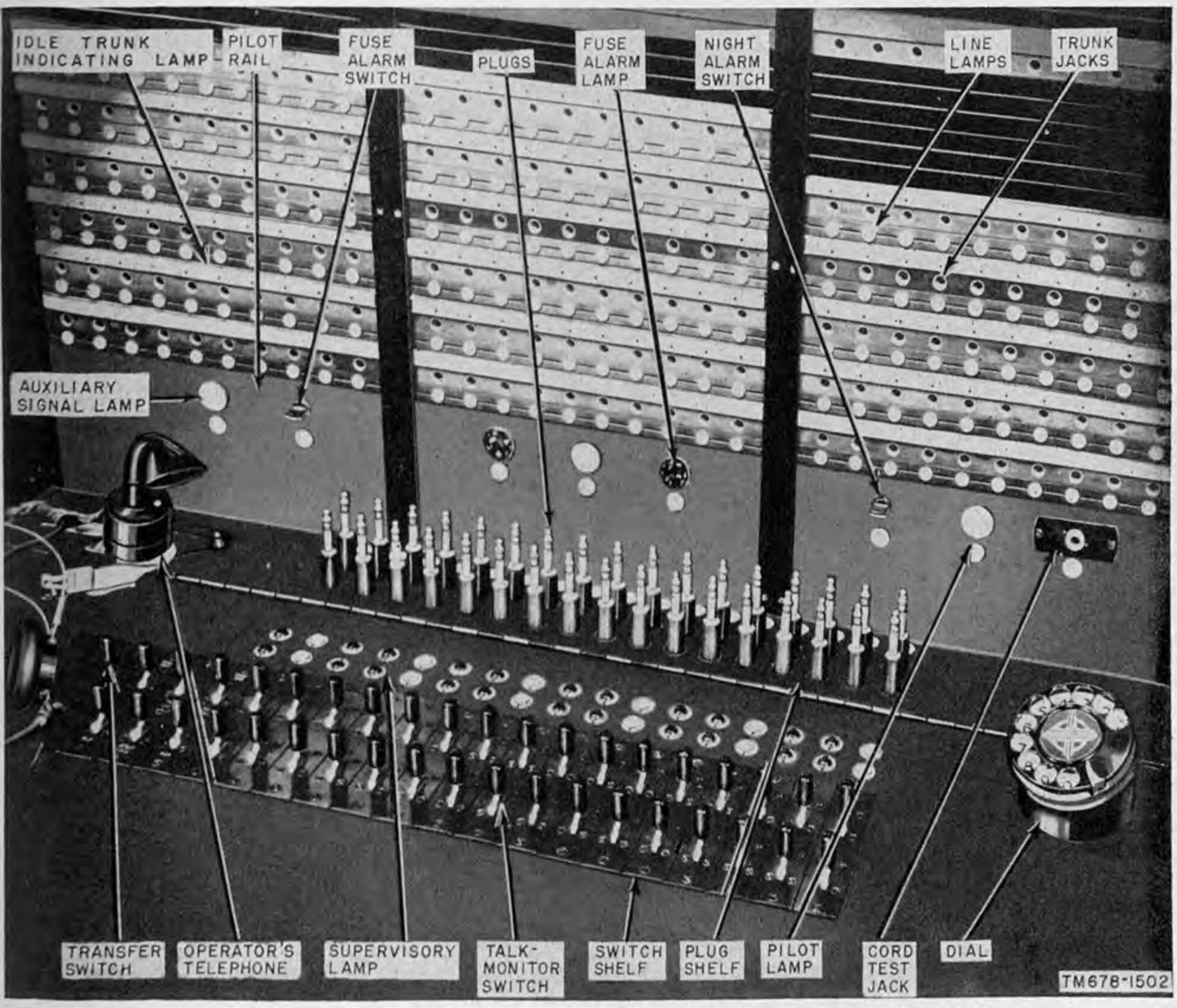


Figure 165. Cordshelf and keyshelf of a typical switchboard set.

on the individual switchboard. The most commonly used auxiliary circuits are explained in the paragraphs following.

138. Line-Pilot Circuit

a. Function of Line-Pilot Circuit. During periods of heavy switchboard traffic, the line lamps of the line circuits often are obscured from the operator's attention by the cords (figs. 157 and 165). Also, during periods of relatively light traffic, when the switchboard does not demand the operator's constant attention, he may not notice a line signal instantly. In order to bring the line signals to the attention of the operator more surely and quickly under all conditions of traffic, a *line-pilot circuit* is included in the switchboard. The operation of this circuit, explained below, causes a *line-pilot lamp* to light whenever *any* of the line lamps on the switchboard panel light. The line-pilot lamp is larger than the line lamps, and it is situated conspicuously on the front panel of the switchboard, usually near the bottom.

b. Operation of Line-Pilot Circuit. Figure 166 shows a typical line-pilot circuit. It contains a *line-pilot relay*, connected between the negative terminal of the battery and a common wire to which one terminal of each line lamp is connected. When any *line* relay operates and closes the make contact, a series circuit is completed through the associated line lamp and the winding of the *line-pilot* relay. The line lamp lights, and the line-pilot relay operates. This, in turn, closes the circuit of the line-pilot lamp in series with the winding of a night-alarm relay (the purpose of which is explained in par. 140), causing the line-pilot lamp to light.

139. Supervisory-Pilot Circuit

a. Function of Supervisory-Pilot Circuit. The *supervisory-pilot circuit* is associated with the supervisory lamps in the cord circuits in the manner in which the line-pilot circuit (fig. 166) is associated with the line lamps. In small switchboards, it usually is associated only with the supervisory lamp in the *answer* cord, whereas in larger switchboards it may be associated with both supervisory lamps. Like the line-pilot circuit, the supervisory-pilot circuit is used to give the operator an additional, more prominent signal during periods when he might not notice the supervisory lamps. The signal used in the supervisory-pilot circuit is also a lamp, but usually of a different color from the line-pilot lamp for easier recognition, and it is situated near the line-pilot lamp.

b. Operation of Supervisory-Pilot Circuit. Figure 167 shows a typical supervisory-pilot circuit associated with the supervisory lamp in the answer cord of a retardation-coil cord circuit. The supervisory lamp, instead of being connected directly to the negative terminal of the office battery (fig. 140), is connected through the winding of a *supervisory-pilot relay*, in a way similar to that in which the line-pilot lamp is connected through the line-pilot relay. Whenever the associated supervisory lamp lights, the supervisory-pilot relay

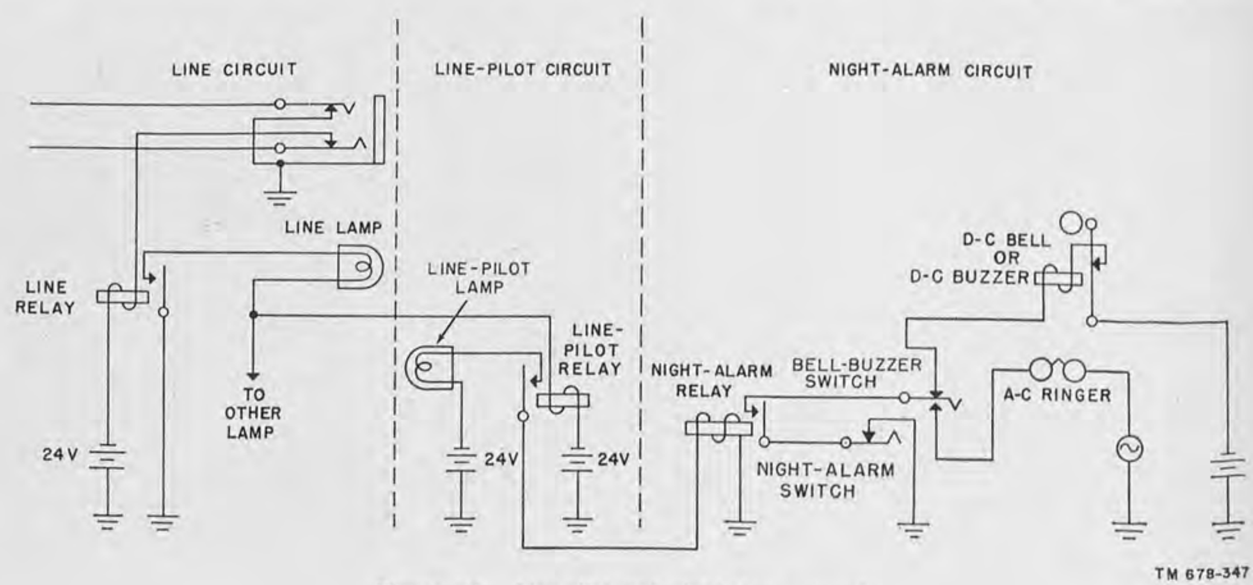


Figure 166. Line-pilot and night-alarm circuits.

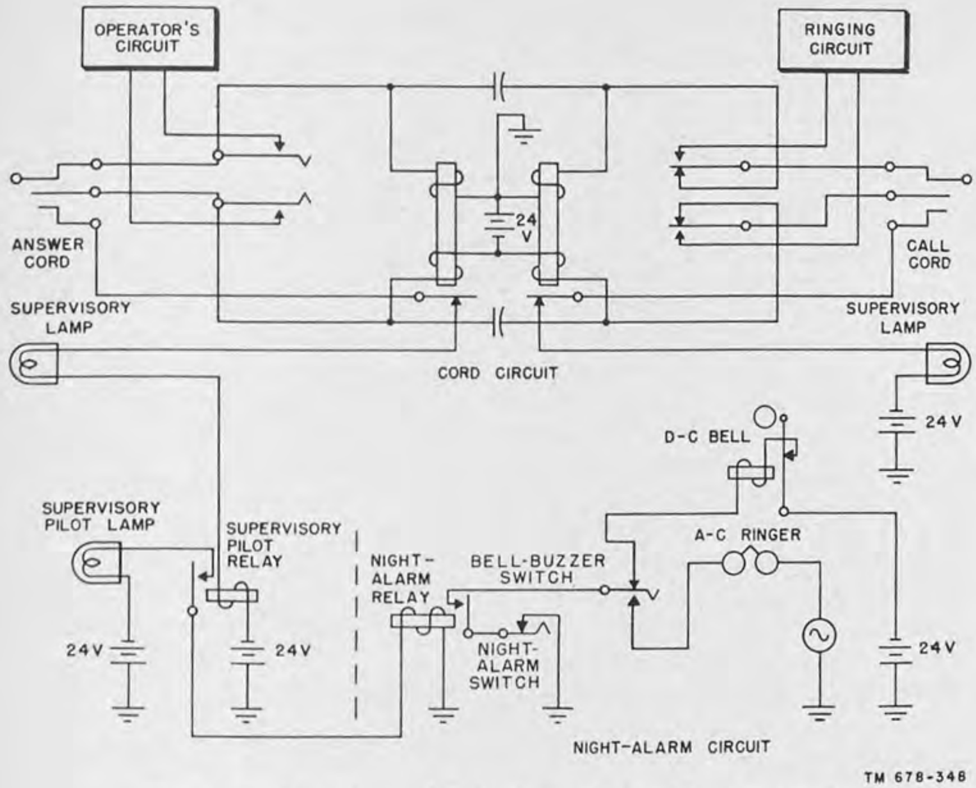


Figure 167. Supervisory-pilot circuit associated with answer cord.

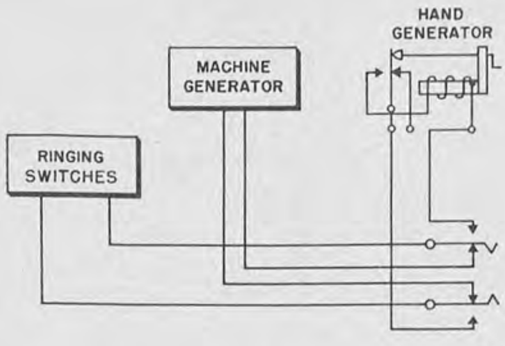
operates. This closes the circuit of the *supervisory-pilot lamp* in series with the winding of the night-alarm relay, and the lamp lights. Actually, as can be seen by comparing figure 167 with figure 166, the armature springs of both the supervisory-pilot relay and the line-pilot relay are wired to one end of the night-alarm relay winding. In this circuit, because the supervisory-pilot circuit is included only in the answer-cord circuit, only one supervisory-pilot lamp is provided for each position on the switchboard. Supervisory-pilot circuits of this type cannot be used in a supervisory circuit in which the supervisory lamp is extinguished by *shunting* it with a 40-ohm resistor (fig. 141), because the path through the winding of the supervisory-pilot relay still would be completed by this operation, causing the supervisory-pilot lamp to be lighted not only when the calling station hangs up, but throughout the entire conversation between the stations.

140. Night-Alarm Circuit

The *night-alarm circuit*, shown in figures 166 and 167, is used to furnish the operator with an *audible* signal in conjunction with both the line-pilot and supervisory-pilot circuits. Besides the night-alarm relay mentioned previously, the circuit includes a *night-alarm switch*, a *d-c bell* connected to the office battery, and an *a-c ringer* connected to a source of alternating current. A two-position switch is used to select either the bell or the buzzer (ringer). When the night-alarm switch is in the make position, as shown, the armature of the night-alarm relay is grounded through the make contact of the switch. When either the line-pilot or the supervisory-pilot lamp lights (figs. 166 and 167), the night-alarm relay operates, completing the circuit of either the bell or the ringer through the make contact of the night-alarm relay. This circuit is used to attract the attention of the operator during intervals when he might be away from his position at the switchboard, but close enough to hear the signal from the bell or ringer. During periods when the operator is attentive at the switchboard, the night-alarm switch can be switched off, making the bell or ringer inoperative.

141. Generator-Switching Circuit

A *generator-switching circuit*, shown in figure 168, is used in a common-battery switchboard to permit a quick change from the ringing machine



TM 678-349

Figure 168. Generator-switching circuit.

generally used for ringing to an emergency hand generator, or vice versa. This is necessary if the power source which usually supplies power to the ringing generator should fail. Generator switching is accomplished by means of a generator-switching lever switch, associated with the ringing switches, as shown. Operation of the hand generator is described in paragraph 50.

142. Battery Cut-Off Circuit

In many cases, it is not necessary to operate a common-battery switchboard throughout the entire day, especially in the case of smaller switchboards. In such switchboards, a *battery cut-off circuit*, shown in figure 169, is provided to disconnect the battery when the switchboard is not in use. This is accomplished by means of a *battery cut-off switch*, which connects the negative terminal of the battery to the negative battery bus in the normal position shown, but disconnects the battery when thrown to the operated position. The negative battery bus is a simple copper bar, to which are wired all the components of the switch-

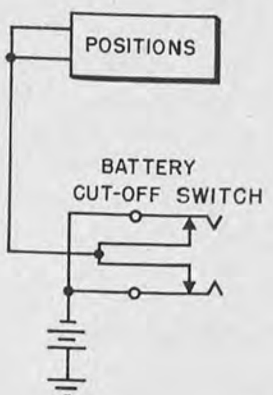


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Figure 169. Battery cut-off circuit.

board that should be connected to the negative terminal of the battery. The grounded terminal of the battery is not affected by the operation of the battery cut-off switch.

143. Fuse-Alarm Circuit

Figure 170 shows a *fuse-alarm circuit* provided in some common-battery switchboards. It is used to inform the operator that a switchboard fuse has blown. It consists of a *fuse-alarm lamp* with one side wired to the fuse-alarm bus and the other side wired through the winding of a *buzzer relay*

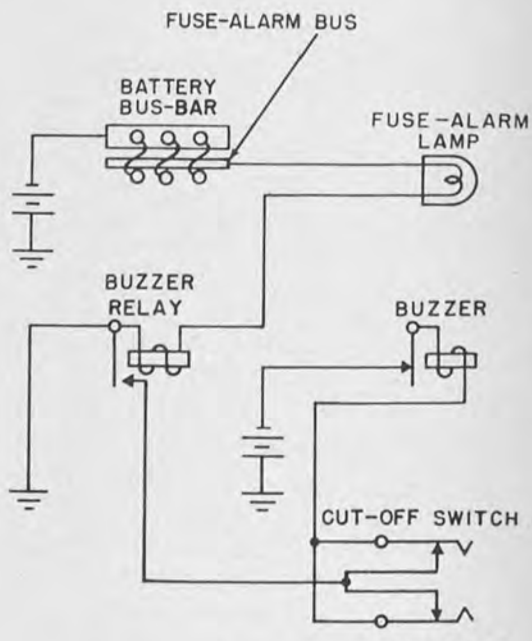

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Figure 170. Fuse-alarm circuit.

to ground. By spring action, as explained in chapter 6, the blowing of a fuse connects the negative terminal of the battery, through the battery bus bar, to the fuse-alarm bus. This completes the circuit of the fuse-alarm lamp and the buzzer relay, causing the lamp to light and the relay to operate. The operation of the buzzer relay closes the circuit of the buzzer through the make contact of the buzzer relay and the normal contacts of the cut-off switch shown. The buzzer therefore sounds at almost the same time that the lamp lights. When the attention of the operator has been attracted by the visible and audible signals, he then can disconnect the buzzer by means of the cut-off switch. The lamp, however, is allowed to remain lighted until the trouble that caused the fuse to blow is corrected. When a new fuse is inserted in the fuseholder, the negative terminal of the battery is disconnected automatically from the fuse-alarm bus, breaking the circuit of the lamp and relay, extinguishing the lamp, and releasing the relay.

144. Conference Circuit

A *conference circuit* is provided in some switchboards to enable a person at one station to converse simultaneously with persons at two or more other stations—that is, to hold a conference by telephone. The circuit, as shown in figure 171, is

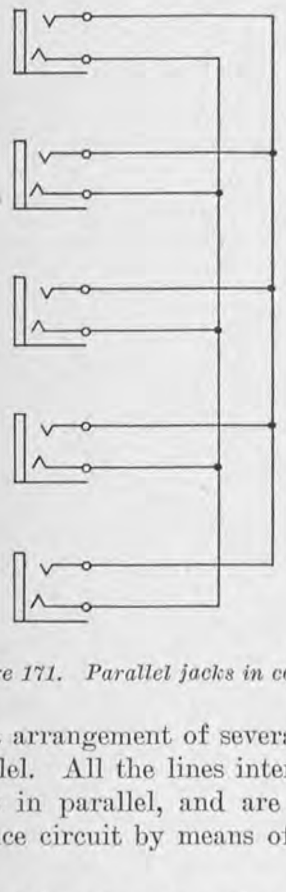


Figure 171. Parallel jacks in conference circuit.

a simple arrangement of several jacks connected in parallel. All the lines interconnected in this way are in parallel, and are connected to the conference circuit by means of cord circuits.

145. Position-Transfer Circuit

A *position-transfer circuit*, also called a grouping circuit, is provided in some common-battery switchboards to interconnect switchboard positions during intervals of light traffic. This enables one operator to handle several positions without moving his telephone set from one position to another. The transfer is made by means of a *grouping switch*, similar to the one used for the same purpose in local-battery switchboards.

146. Additional Auxiliary Circuits of Multiple Switchboards

In addition to the various auxiliary circuits discussed in the preceding paragraphs, multiple common-battery switchboards generally contain several additional auxiliary circuits. Some of these additional circuits are listed below, with brief comments.

a. Order-Wire Circuit. An *order-wire circuit* is used by the operator at a local switchboard in place of a conventional trunk to give the operator at a distant switchboard the number of a called station connected to the switchboard. The circuit simply connects the telephone sets of the two operators by means of an *order-wire switch* at the calling switchboard.

b. Test-Cord Circuit. A telephone office usually has a *test board* for testing local lines and equipment. When this is the case, provision must be made for connecting any line appearing on the switchboard to the test board. This is accomplished by using a *test cord* at one or more of the positions on the switchboard. One end of the test cord terminates at the test board, and the other end terminates in a plug which can be inserted in any line jack for test purposes.

c. Wire Chief's Order Circuit. This is a circuit similar to the order-wire circuit, but it is used for communication between a person at the test board and the switchboard operator. The order-wire switch in this case is at the test board, one switch being provided for each position that has test cords.

d. Peg-Count Circuit. This circuit is used to operate various counters for the purpose of measuring an operator's load.

e. Position-Clock Circuit. The position-clock circuit is used to operate clocks at the positions on the switchboard.

f. Master-Clock Circuit. The master-clock circuit keeps the clocks at the various positions synchronized.

g. Monitoring Circuit. This circuit enables chief operators and others to check the work of the individual switchboard operators.

147. Summary of Auxiliary Circuits

a. Common-battery switchboards incorporate several auxiliary circuits in addition to the major circuits. The purpose of these is to improve the operating efficiency of the switchboard. Practically all switchboards contain line-pilot, supervisory-pilot, night-alarm, generator-switching, and position-transfer circuits. Some also contain fuse-alarm and conference circuits.

b. Nonmultiple switchboards may contain a battery cut-off circuit, to remove the office battery from the battery bus bar during periods when the switchboard is idle.

c. Multiple switchboards provide some or all of the following additional auxiliary circuits: order-wire, test-cord, peg-count, position-clock, master-clock, and monitoring circuits.

148. Summary of Common-Battery Telephony

The following table summarizes the characteristics of common-battery telephony and shows the comparison with local-battery telephony.

Local-battery systems	Common-battery systems
COMPONENTS	

Handset:
    Transmitter.
    Receiver.
    Handswitch.
Induction coil.
Capacitors:
    For antisidetone circuit.
Ringer.
Hand generator.
Battery (dry cells).
	Handset:
	    Transmitter.
	    Receiver.
	    Hookswitch.
	Induction coil.
	Capacitors:
	    For antisidetone circuit.
	Ringer.

CIRCUITS	

Antisidetone:
    Transmitting.
    Receiving.
Signaling:
    Generating.
    Ringing.
	Sidetone (booster).
	Sidetone-reduction.
	Antisidetone.
	Signaling:
	    Automatic, involving hookswitch.

POWER SOURCE	

Transmitting and receiving:
    Dry cells.
Ringing:
    Ringing machine
    or
    Hand generator.
	Transmitting and receiving:
	    Common battery at central office.
	Ringing:
	    Power generator at central office.

COMPONENTS OF LINE CIRCUIT	
Jack: tip, ring. Drop and shutter.	Jack: tip, ring, sleeve. Simple or cut-off type. Line lamp, line relay, cut-off relay.
COMPONENTS OF TRUCK CIRCUIT	
Jack: tip, ring. Drop and shutter.	Jack: tip, ring, sleeve. Trunk line lamp, trunk relay.

Local-battery systems	Common-battery systems
COMPONENTS OF CORD CIRCUIT	
Cord: Answer (two-conductor). Call (two-conductor). Plug: tip and sleeve. Switch (key): Listen. Ring. Ring-back.	Cord: three-conductor. Answer (three-conductor). Call (three-conductor). Plug: tip, ring, sleeve. Switch (key): Listen. Ring.
COMPONENTS OF OPERATOR'S TELEPHONE CIRCUIT	
Induction coil. Capacitors: For antisidetone circuit. For limiting ringing current through operator's telephone receiver. Battery (dry cells).	Special induction coil. Capacitors. Noninductive resistor.
COMPONENTS OF RINGING CIRCUIT	
Ringing machine or Hand generator.	Ringing machine.
COMPONENTS OF SUPERVISION CIRCUIT	
Drop and shutter.	Supervisory lamp and relay.
COMPONENTS OF NIGHT-ALARM CIRCUIT	
Night-alarm buzzer or bell. Night-alarm switch. Night-alarm bus. Drop and shutter. Battery (dry cells).	Night-alarm buzzer or bell. Night-alarm switch. Night-alarm bus.
APPLICATION OR USES	
Field military telephone systems. Forward combat areas. Areas where telephones are scattered and distant from each other.	Larger and more permanent military installations. Commercial telephone systems, except in outlying rural areas.
ADVANTAGES	
Simple in design. Readily assembled and disassembled. Requires less maintenance. Permits longer lines.	Station equipment less bulky. Provides better service. Enables one operator to handle more lines. Avoids periodic replacement of dry cells.

Local-battery systems	Common-battery systems
LIMITATIONS	
Dry cells: Are not economical. Deteriorate rapidly. Must be checked often. Service not uniform. Telephone set bulky. Operator must be signaled manually. Switchboard requires more attention from operator.	Better quality of outside plant construction necessary to minimize leakage. Resistance of loop or line limits distance for transmitter and signaling current. Switchboard more complex. Switchboard requires greater installation time and maintenance.

149. Review Questions

a. State three advantages of common-battery telephone systems over local-battery systems.

b. What are the military applications of common-battery systems?

c. Why does the use of a centrally located storage battery in a common-battery system make the system more efficient?

d. Describe the three basic types of common-battery telephone circuits, and draw a labeled diagram of each one.

e. What is the function of the hookswitch in a common-battery telephone set?

f. What is the function of the induction coil in a common-battery telephone set?

g. Why is it necessary to open the secondary circuit of the sidetone telephone at the hookswitch contacts?

h. In a common-battery telephone set, what is the function of the capacitor in series with the ringer?

i. How does the sidetone-reduction circuit compare with the booster circuit in efficiency of transmitting and receiving?

j. Explain the operation of the balancing network in the antisidetone set.

k. Define nonmultiple switchboard.

l. Describe the arrangement of jacks, plugs, and cords in a nonmultiple switchboard.

m. In the circuit of figure 143, trace a call through the switchboard from station B to station A.

n. Name and describe the three types of common-battery line circuits.

o. State the advantages and disadvantages of each of the three types of line circuits.

p. Describe the common-battery simple jack and cut-off jack.

q. Describe the structure and operating characteristics of a line signal lamp.

r. What are the basic functions of cord circuits in common-battery switchboards?

s. Explain why a simple cord circuit, containing only a battery across the line, will not provide satisfactory transmission between two telephones connected by the cord circuit.

t. What is the function of the retardation coils in a retardation-coil cord circuit?

u. With the aid of a diagram of a retardation-coil cord circuit, trace the path of direct current; of voice-frequency current.

v. What are the limitations of retardation-coil cord circuits?

w. Explain the operation of the improved retardation-coil cord circuit.

x. Describe the operator's telephone set, used in connection with retardation-coil cord circuits.

y. What provisions are made for supervision in retardation-coil cord circuits?

z. What are the limitations of the supervisory circuit in which the lamp is extinguished by opening its circuit?

aa. Referring to figure 143, state the conditions under which each of the following actions occurs: The line lamp associated with station A lights; the supervisory lamp in the answer-cord circuit lights; the lamp associated with station B lights; the supervisory lamp in the call-cord circuit lights; both supervisory lamps light; both supervisory lamps are extinguished.

ab. Describe a typical repeating coil used in connection with repeating-coil cord circuits.

ac. In the repeating-coil cord circuit of figure 137, trace the paths of direct current; of voice-frequency current.

ad. Describe the antisidetone operator's set used with repeating-coil cord circuits.

ae. Why must separate relays be used for supervision in repeating-coil cord circuits?

af. How is supervision provided in repeating-coil cord circuits?

ag. State the function of each of the following: the 40-ohm resistor in the supervisory circuit; the 370-ohm noninductive resistor in the secondary circuit of the operator's telephone; the noninductive winding in parallel with the main winding of the supervisory relay.

ah. Explain the operation of the supervisory circuit in which the lamp is shunted in order to extinguish it.

ai. State the general functions of trunks in common-battery systems.

aj. Why is it necessary to reverse the line on certain types of trunks?

ak. Define automatic trunk; one-way trunk; ring-down trunk.

al. Explain, with the aid of a diagram, the operation of a two-way automatic trunk.

am. In figure 152, what operations cause the trunk lamp at switchboard B to light? To be extinguished?

an. What is a repeating-coil trunk circuit?

ao. What are the chief advantages of a repeating-coil trunk circuit?

ap. What additional components are required for a repeating-coil trunk circuit?

aq. Describe, with the aid of simple diagrams, the five common types of relay windings.

ar. Define marginal relay; differential relay; polarized relay.

as. What is used to make a relay slow-acting? Slow-releasing?

at. What are the disadvantages of code ringing?

au. What is meant by selective ringing?

av. Describe, with the aid of a diagram, the process of two-party ringing to ground.

aw. What alterations are necessary in the mechanical structure of a polarized ringer to enable it to function as a biased ringer?

ax. Describe the process of two-party ringing with pulsating current.

ay. What modifications are necessary to provide pulsating-current ringing on a four-party line?

az. Explain the process of harmonic ringing.

ba. State the function and describe the operation of the following common battery auxiliary circuits: line-pilot circuit, night-alarm circuit, battery cut-off circuit, fuse-alarm circuit, position-transfer circuit.

bb. What are the advantages of a multiple switchboard?

bc. Define answering appearance; multiple appearance.

bd. How are multiple appearances designated?

be. Draw a diagram showing the general scheme for the arrangement of appearances in multiple switchboard.

bf. How are answering jacks and multiple jacks grouped usually?

bg. Define the following terms used in connection with multiple switchboards: section, position, panel.

bh. Why are lamps with caps of different colors or markings used in some multiple systems?

bi. Define branch multiple; lamp-associated multiple; series multiple.

bj. What is the purpose of a busy test on a multiple switchboard?

bk. State the functions of each of the following multiple-switchboard auxiliary circuits: order-wire, test-cord, peg-count, master-clock, monitoring.

CHAPTER 6

AUXILIARY CENTRAL-OFFICE EQUIPMENT

150. Distributing Frames

a. General. The basic principles and switchboard arrangements associated with local-battery and common-battery telephone systems, as presented in chapters 4 and 5, have indicated the large number of components and circuits required to make up a telephone central office. In addition to the switchboards and associated equipment already discussed, a central office is equipped with facilities for arranging the many incoming lines in orderly fashion, and connecting them quickly and properly to their corresponding line jacks on the switchboard. This is accomplished by the use of *distributing frames.*

b. Functions.

(1) Consider a switchboard designed to accommodate 100 users, for which 100 lines, each consisting of a pair of wires, enter the central office. Each line must be connected to its corresponding line jack on the switchboard. The distributing frame provides an effective means for arranging the outside lines at the point where they enter the office, so that they can be identified easily. Each outside line is connected to a pair of terminals on one side of the frame (fig. 172). For each line so connected, a corresponding line is connected to a pair of terminals on the other side of the distributing frame and to the corresponding line jack on the switchboard. For each line in use, the two pairs of terminals then are interconnected by *jumpers,* or cross-connecting wires, shown as heavy broken lines in the figure. Unused lines (as line 5) may be left unconnected until needed.

(2) In addition to providing a means for orderly arrangement of incoming lines, the distributing frame makes possible the rapid changing of the interconnections of the outside and switchboard lines among themselves as may be required

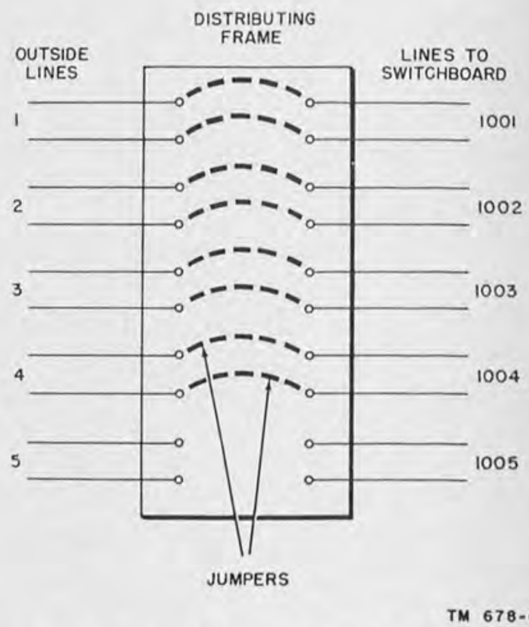


Figure 172. Connection of outside and switchboard lines through distributing frame.

(fig. 173). For example, consider the user whose number is 1001, and whose station is connected to line 1 (fig. 172). Assume that he moves to a new location too remote from line 1 for use of that line, but wishes to retain number 1001. Some means must be provided for changing the connection at the central office so that the switchboard line identified as number 1001 now will be connected to the new line to which the user's station now is connected. Assume that line 5, shown as unused in the figure, serves the user's new location. To make the change it is necessary only to remove the jumper from the terminals of line 1 on the incoming side of the frame and reconnect it to the terminals of line 5 (fig. 173). Thus the system has a flexibility that would not be possible without the use of a distributing frame.

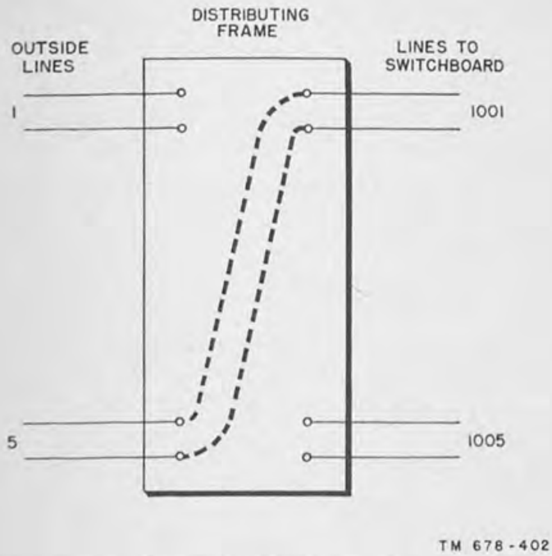


Figure 173. Changing line connections by means of jumpers.

(3) Since the distributing frame is the dividing point between the outside plant and the inside plant, it is the logical place for the location of central-office protective devices. These devices, discussed later in this chapter, protect the inside plant from various hazards originating outside.

(4) The distributing frame, as explained above, makes the outside lines entering the central office easily identifiable and accessible without disturbing any of the switchboard wiring. It thus provides a convenient place from which to test for and locate line faults. Also, the outside line can be disconnected from the switchboard by removing the protective devices on the tip and ring sides of the line in the main frame, thus making unnecessary the removal of the jumpers when making tests on the outside line.

(5) Finally, the use of distributing frames permits the rapid shifting of the switchboard load by changing the number of users connected to the switchboard. This may involve the addition of new users or the removal of lines from one switchboard to another, as required by local conditions. In the operation of large exchanges using multiple switchboards, this is particularly important.

151. Classes of Distributing Frames

a. Wall Frames.

(1) Distributing frames are divided into two

Figure 174. Switchboard side and line side of main distributing frame (portable type).

general classes: wall frames and floor frames. Wall frames generally are used in small offices, depending on such local conditions as amount of space available, type of user served, and probability of expansion. They are built up of units each of which can accommodate 20 pairs or lines. The simplest form of wall frame contains two terminal boards mounted vertically on two horizontal mounting brackets. The outside pairs are fastened to terminals on one board, and the pairs running to the switchboard are fastened to terminals on the other board. Screw-type terminals are used generally to permit easy disconnection and changing of lines. The two boards then are interconnected by jumpers, as explained in paragraph 150.

(2) The jumpers are flexible, and they may be fastened to any desired set of terminals at either end. They are run through rings to facilitate tracing out lines, and to maintain a neat and orderly arrangement.

(3) Protective devices may be mounted on either of the terminal boards, although it is now common practice to install them on the side nearer the outside plant.

b. Floor Frames. In some small military exchanges, floor-type frames are used. These are of three types:

(1) Frames that have two vertical sides (fig. 174), which means that the pairs of terminals are arranged vertically on both

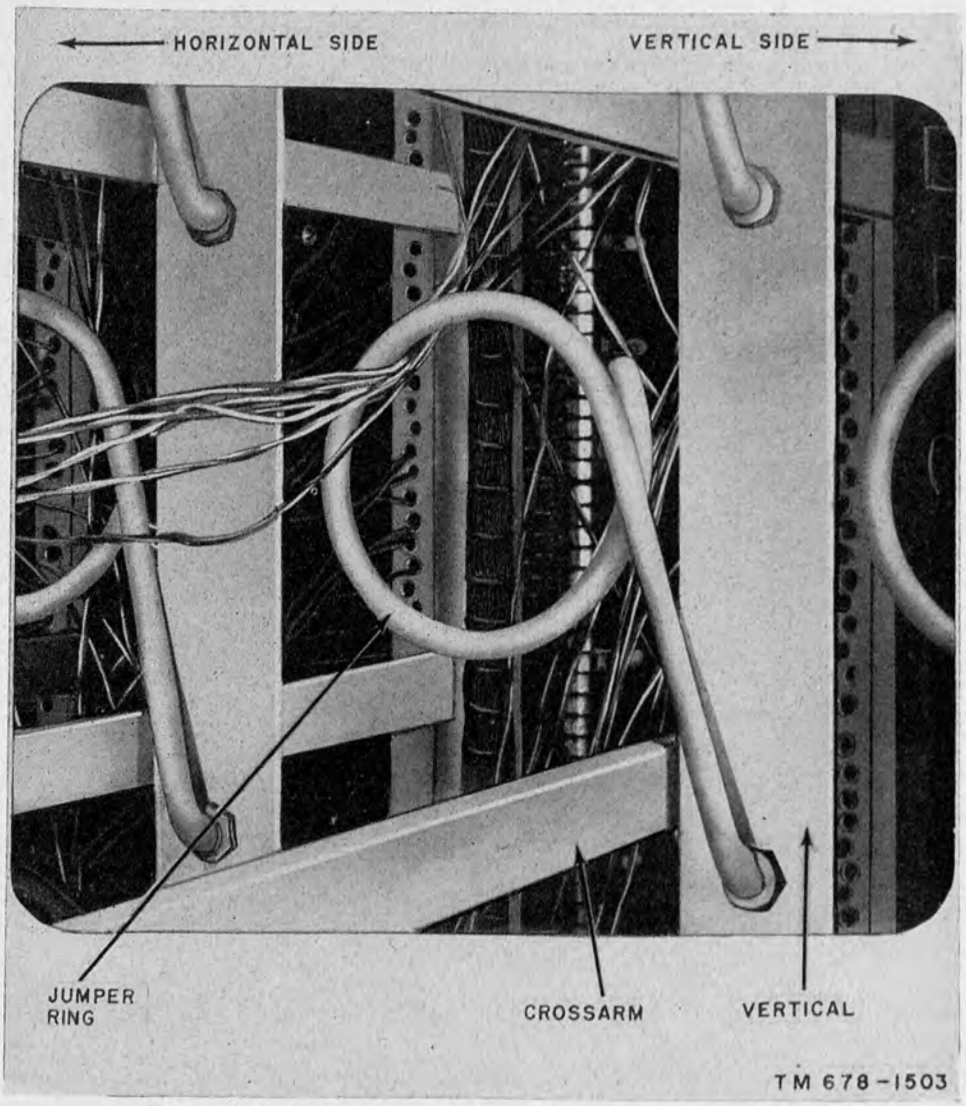


Figure 175. Method of passing jumpers through jumper rings.

sides of the frame. This type of floor frame is used in the smaller military exchanges.

(2) Frames that have one side vertical and the other side a combination of horizontal and vertical. This type is used in larger military exchanges.

(3) Standard floor frames that have one side horizontal and the other vertical.

c. *Structure.*

(1) The main supporting members of a floor frame consist of vertical angle irons (fig. 174). The bottoms of the vertical members are bolted to heavy angle-iron floor plates and the tops are bolted to a continuous angle iron which braces all the vertical members rigidly together. On some floor frames, horizontal cross arms are attached to the upright members. Insulated jumper rings are installed at the junctions of the vertical angle irons and the horizonal cross arms (fig. 175).

(2) On all floor frames the two sets of terminal boards are located on opposite sides of the frame. In the standard type of floor frame section, the terminals are arranged in vertical rows on one side and in horizontal rows on the other, and the sides therefore are referred to as the vertical side and the horizontal side. In figure 176, the protectors are mounted on the vertical side.

(3) When the vertical side of the frame is connected to the switchboard, the frame is called a *type A* frame. When the horizontal side is connected to the switchboard, the frame is called a *type B* frame.

152. Frames for Large Exchanges

a. *Connection of Frames.*

(1) In large exchanges where central-office wiring is more complex because of the greater number of stations accommodated, distribution of lines is facilitated by the use of two distributing frames, the MDF (*main distributing frame*) and the IDF (*intermediate distributing frame*). The vertical side and the horizontal side

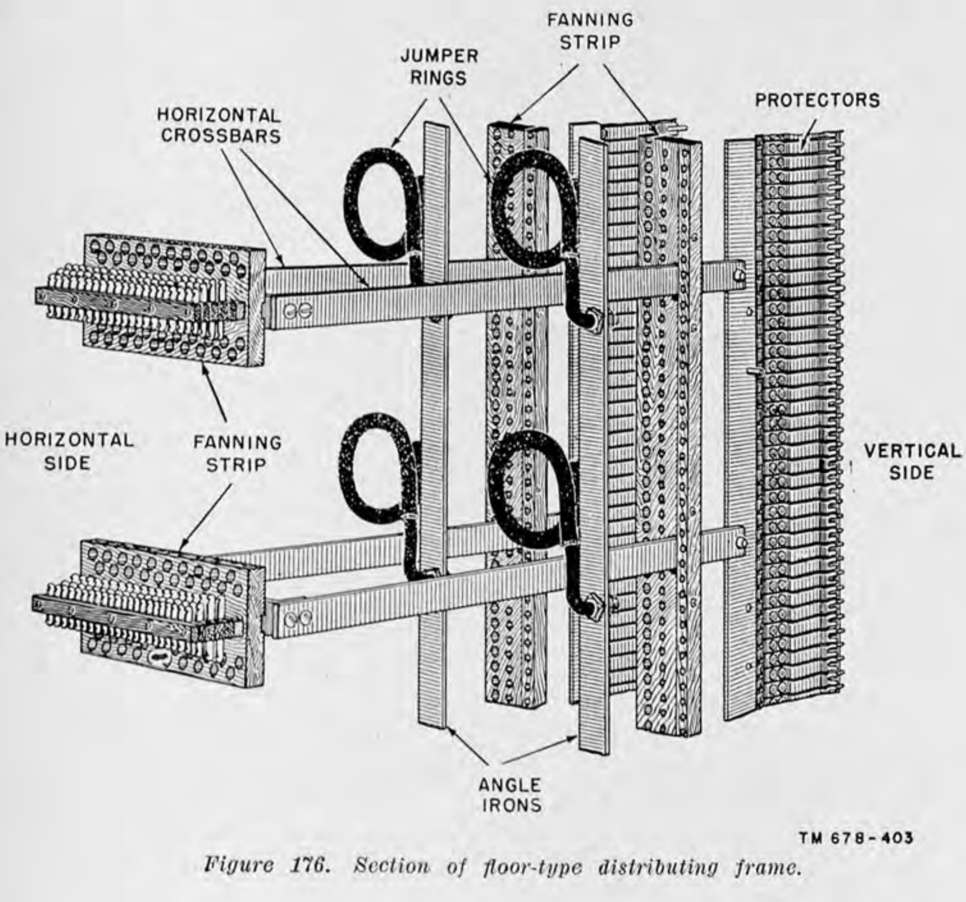


Figure 176. Section of floor-type distributing frame.

of each are called, respectively, the VMDF and HMDF or the VIDF and HIDF.

(2) Figure 177 illustrates the manner in which connections are made through an MDF and an IDF. The outside pairs are brought into the office and are connected to the VMDF of the main frame. The office protectors are mounted at this point.

(3) Two-wire jumpers are used on the main frame (fig. 177) to connect the VMDF to the HMDF. The two conductors of the jumpers correspond with the tip and ring conductors at the switchboard, and are designated as T (tip) and R (ring) in figure 177. The jumpers are *not* themselves connected in the frame by plug and jack connections. A cable is used to connect the tip and ring contacts of the HMDF to the corresponding contacts on the HIDF. The two sides of the IDF (HIDF and VIDF) have *three* contacts for each line (for tip, ring, and sleeve conductors). Three-wire jumpers therefore are used to interconnect the HIDF and VIDF.

(4) Three-wire cables are run from the HIDF terminals to the multiple jacks on the switchboard. A fourth terminal, identified as L in figure 177, is added to the other three terminals on the VIDF. This is used to accomodate supervisory lamp circuits. Four-wire cables then are run from the four terminals on the VIDF to the relays and to the answer jack and lamp.

(5) Since a telephone number is determined by the multiple jack to which the outside line eventually is connected, telephone numbers can be changed in such a distribution system by merely shifting the jumpers on the HMDF. The load on the switchboard, however, can be varied by shifting the jumpers on the VIDF without changing directory listings. This method of distribution is used by all large commercial exchanges.

b. Combined Frames.

(1) In some of the larger military exchanges using multiple switchboards, a single frame, called a *combined frame* (fig. 178) is used instead of a separate MDF and IDF. One side of such a frame is a vertical side, on which the outside pairs are terminated and the protectors are mounted. The other side is a combination side, in that it serves as the horizontal sides of both the MDF and the IDF, and the vertical side of the IDF.

(2) In this type of frame, two sets of jump-

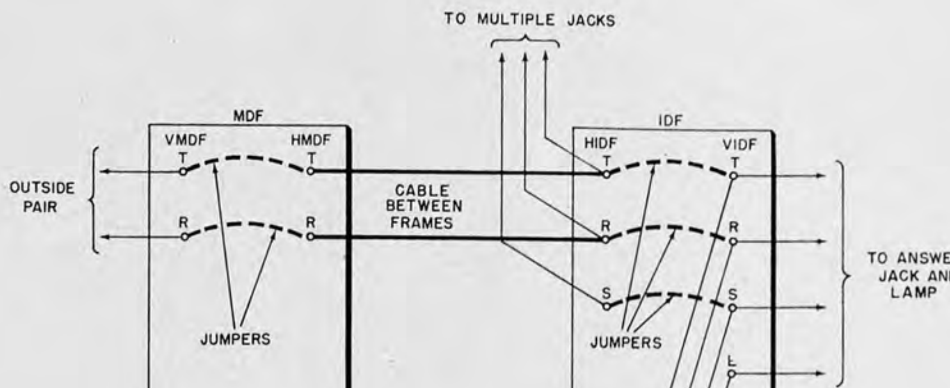


Figure 177. Connections through standard MDF and IDF.

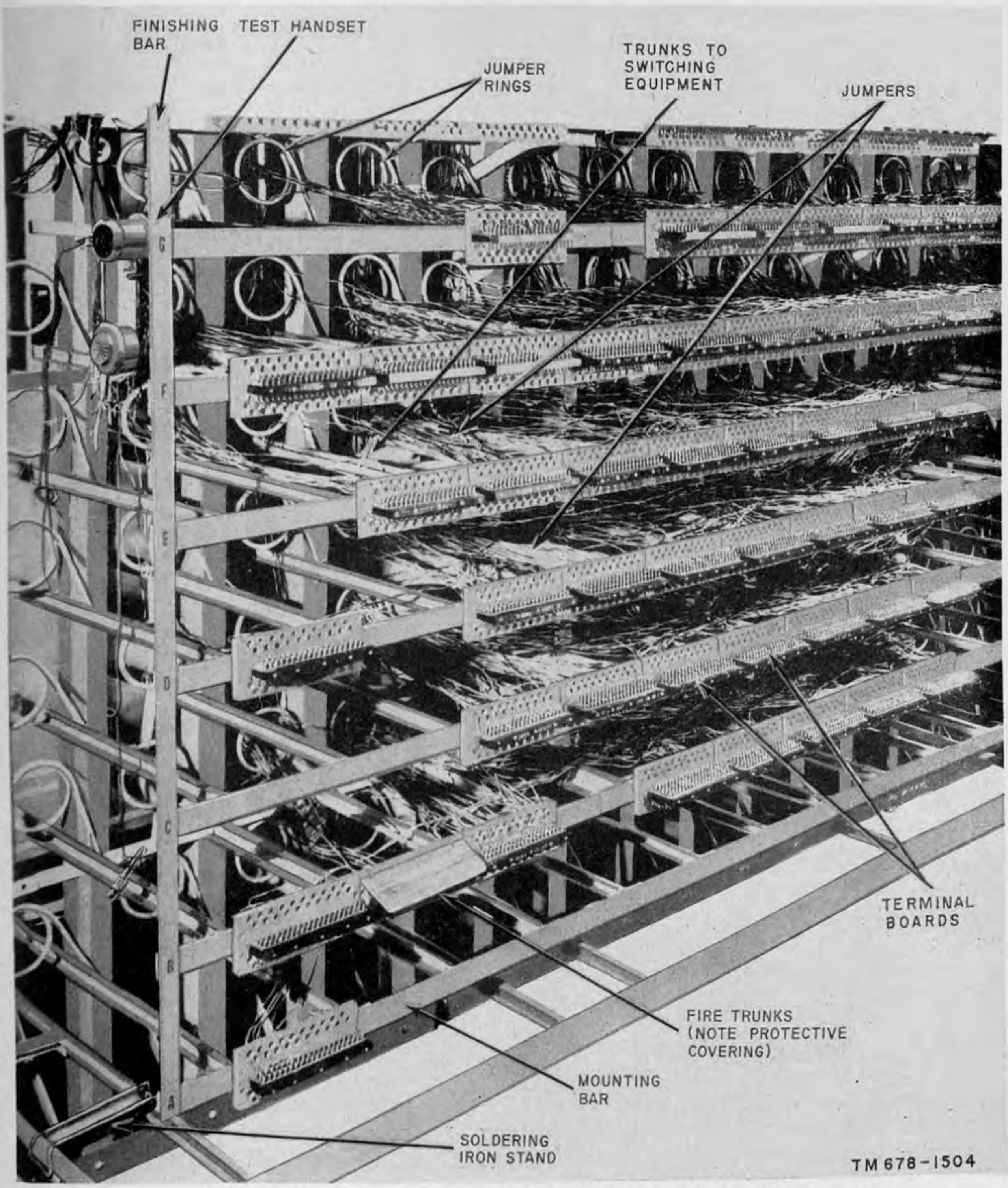


Figure 178. Trunk IDF and combined distributing frame, horizontal side.

ers are used (fig. 179). However, instead of one set on the MDF and the other on the IDF, both sets are on the one frame. This method of distribution is somewhat more economical than that involving the use of a separate MDF and IDF, but some of the flexibility obtained by the use of separate frames is lost.

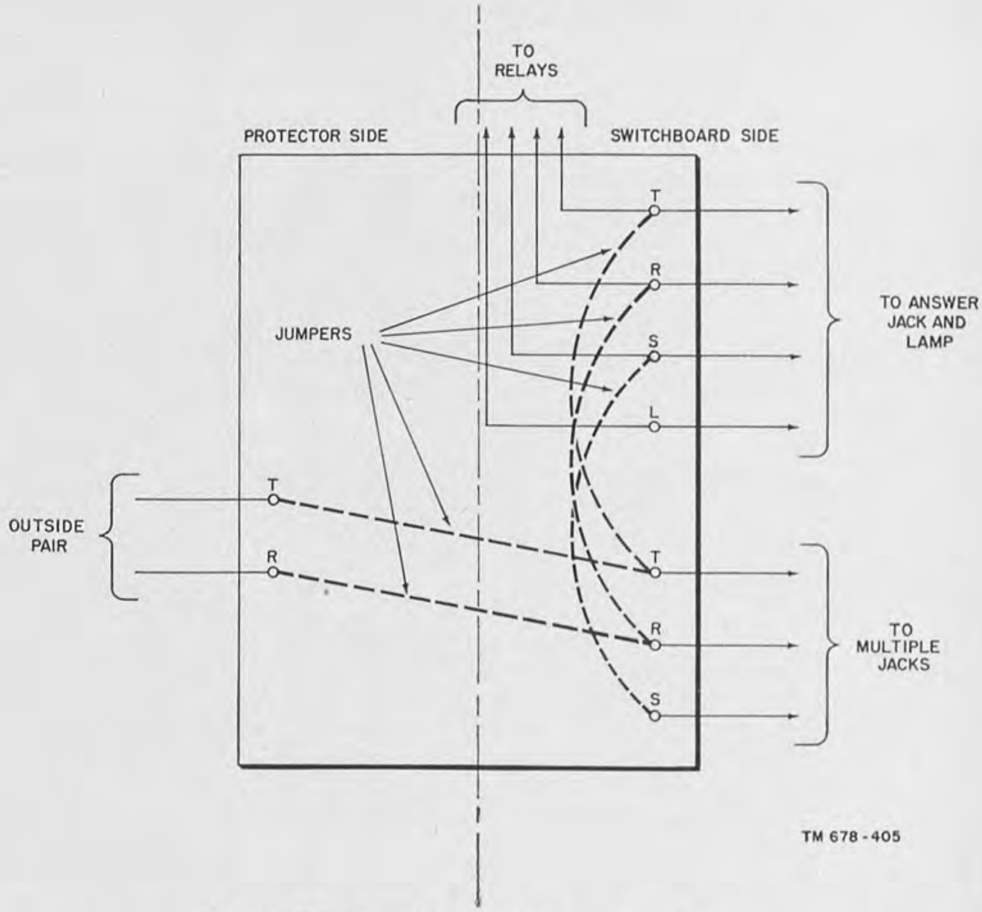


Figure 179. Connections through combined frame.

153. Cables

a. Switchboard Cables. The term *switchboard cables* is used to refer to fabric-covered cables used in telephone wiring. The covering on the conductors which comprise these cables is usually silk and cotton. Switchboard cables vary in size depending on the number and gage of the conductors, and they are made in three different shapes: round, oval, and flat. Switchboard cables are used in a telephone central office to conduct the lines from the distributing frame to the switchboard. On switchboards that accommodate up to 100 lines, a single cable frequently is used to carry all the pairs. On larger switchboards, the cables carry only 20 pairs, and as many cables are used as the the capacity of the switchboard requires. Switchboard cables usually have a flat, oval cross section so that they will pile evenly and maintain their position on the cable rack which is used to support them. The pile of cables is secured by lacing them together and to the cable rack. The conductors of the cables are insulated with silk and cotton threads. They are treated with a covering of special insulating material, such as cellulose acetate, to prevent dampness from entering, and to strengthen the cables.

b. Cables From Outside Plant.

(1) Cables from the outside plant usually are lead-covered for additional protection from moisture and for greater mechanical strength, and the conductors comprising them usually are paper-covered. They may be either underground or aerial. Underground cables enter the central office through a *cable vault*, which is a chamber usually located directly under the distributing frame in the central office.

(2) Lead-covered cables are used also from the incoming side of the MDF to the point at which they are spliced to the outside cables. The lead sheath of the outside cable is removed at the MDF, and the cable pairs are fanned out and connected to the protective devices on the frame.

A minimum number of the conductors should be exposed in this process.

(3) Lead-covered cables are used in the inside plant only when it is necessary to run them where there may be dampness, such as in a basement or through a conduit in a concrete floor.

(4) A detailed treatment of preparing, lacing, and repairing cables is covered in TM 11-471.

154. Central-Office Protection

a. Types of Hazards.

(1) Telephone equipment must be protected against electrical hazards resulting from both natural and artificial causes. The most important natural hazard is lightning. Artificial hazards originating outside the telephone plant include excessive voltages from direct contact or induced in telephone wires from electrical power systems and high-power radio transmitting apparatus in the vicinity of the telephone wires.

(2) Artificial hazards may arise also within the telephone plant. They include accidental currents from the plant power supply in unexpected channels or of abnormally high values.

b. Protective Equipment. To safeguard persons and property against these hazards, special protective equipment is provided. Since protective devices are designed to function *before* any damage occurs, they really are *preventive* devices. At the same time, however, they must not be so sensitive as to cause any unnecessary interruption of service. Practically all outside plant conductors, except those that are completely underground, are exposed to both natural and artificial hazards. Exposed wires always are connected through protective devices before they are led into the central office or into a telephone station. Protective equipment is discussed fully in TM 11-676.

c. Types of Protective Devices. Protective devices are classified, in general, as follows:

(1) The type of device that provides protection against small, accidental currents that become a hazard only when they flow for a considerable length of time. The *heat coil* is an example of this type of protective device.

(2) The device, such as the *fuse*, that protects against *excessive* currents.

(3) The type that provides protection against excessive *voltages*, of which the *open-space cutout*, or *air-gap arrestor*, is an example.

155. Switchboard Fuses

a. Application. In addition to the devices protecting the central office apparatus and equipment from outside hazards, *switchboard fuses* are used to protect the switchboard from its own battery current. In a large central office there may be hundreds of these fuses, distributed over the different groups of circuits.

b. Operation. To avoid serious interruption of service, it is essential for the office maintenance staff to know the instant a switchboard fuse blows and to be able to locate it quickly. For this reason, *indicating fuses* generally are used on the switchboard.

(1) Figure 180 illustrates a typical indicating switchboard fuse, sometimes called a

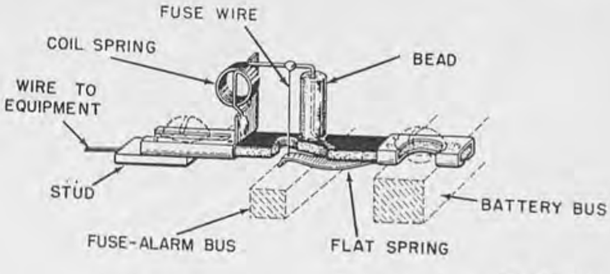


Figure 180. Indicator-alarm fuse.

grasshopper fuse. The fuse is mounted between the battery bus and the stud on which is connected the particular circuit or group of circuits that it protects. Between these mountings is a thin *fuse-alarm bus* which connects to ground through a pilot lamp and alarm bell (not shown), as described in paragraph 143. Normally, the fuse wire holds the flat spring out of contact with the fuse-alarm bus. When the fuse wire melts, both the coil spring and the flat spring are released. The release of the coil spring causes the glass bead to be thrown out of line so that it can be seen more readily. At the same time, the flat spring makes contact with the fuse-alarm bus, com-

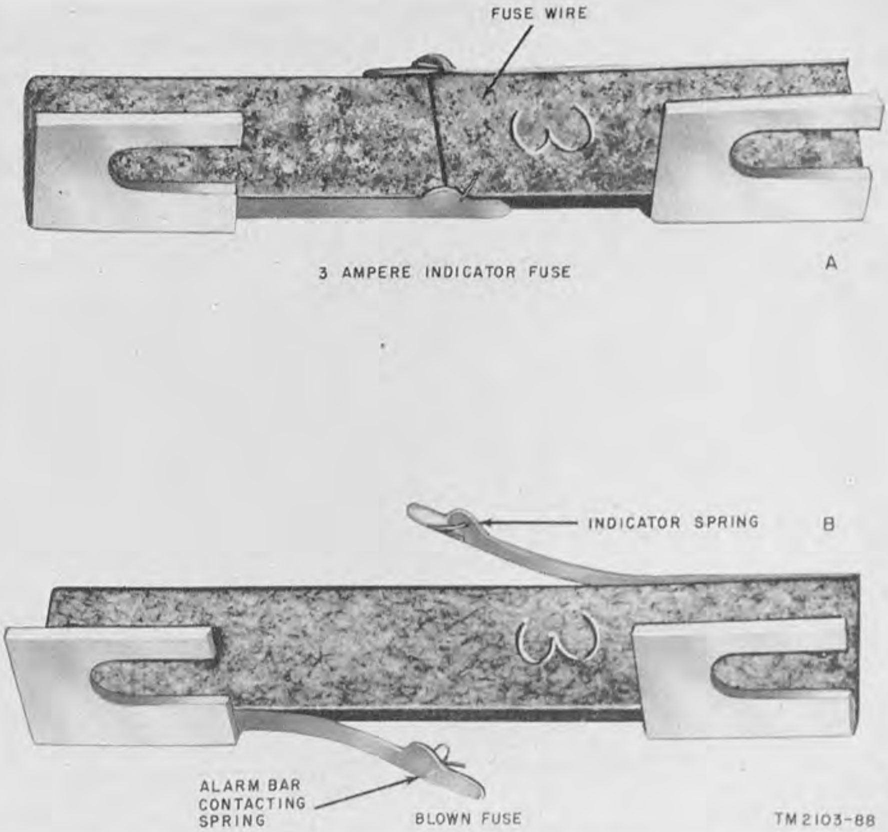


Figure 181. Modern indicator alarm fuse.

pleting the alarm circuit and causing the alarm bell to ring. The blown fuse can be located quickly by inspecting the panel for a fuse with its bead raised out of line.

(2) Another indicator alarm fuse is shown in figure 181. This fuse consists of a fiber body, two metal springs, a fuse element, and two spade terminals. The operation is very similar to that of the fuse shown in figure 180. The two metal springs are held in position by the fuse element. When the fuse element opens, the springs are released and spread apart, indicating that the fuse is blown. The lower spring contacts the fuse-alarm bus and completes the alarm circuit.

c. Sizes. Switchboard fuses are available in various sizes; those most commonly used are of $\frac{1}{2}$-, $1\frac{1}{3}$-, 2-, and 3-ampere capacity. Fuse-circuit prints indicate the size to install in each case, and the capacity of a fuse that is removed will indicate the size to be used for replacement. To aid in the identification of fuses, and to prevent a fuse of the wrong size being used, the glass beads are colored differently for the different sizes. If a fuse of the proper size is not available for a given replacement, a piece of *fuse wire* of the proper rating may be used temporarily, but should be replaced by a fuse at the earliest opportunity. Copper wire *never* should be used in place of a fuse, nor should a blown fuse be replaced by one of larger capacity than is required by the circuit. It is customary to replace one fuse that has blown without investigating the cause of its blowing. If the replacement fuse blows, however, the cause should be determined and the trouble remedied before another fuse is installed.

156. Central-Office Power Equipment

a. Sources of Power.

(1) The primary source of power for operating a telephone central-office exchange usually is furnished by the utility company serving the area in which the central office is located. In most areas of the United States, this power is delivered at 110 or 220 volts at 60 cps, and is purchased by the telephone com-

pany in the same manner that power would be bought by any other power-using customer.

(2) Many central offices have a stand-by power source, to be used in the event of failure of this power supply. This may be a gasoline- or Diesel-engine generator set which can be put in operation to carry the load. These units are located in or near the central-office building in such position that their noise and exhaust will not interfere with the normal operation of the office, and so that floods or gales will not interfere with the operation of the unit.

(3) The Army has a problem in that its central-office equipment may be put in use in any area in the world and under any type of combat condition. Since the voltages and frequencies of power companies in foreign countries vary widely, and since under combat conditions these power companies may not be operating, it has been found impracticable to depend on local power supply for the operation of Army central offices. Each common-battery telephone central-office set used by the Army includes engine-driven generators which are the primary source of power for the central office.

(4) The supply of power to the telephone switchboard and its associated equipment must be absolutely continuous. Even a momentary interruption would de-energize the switchboard relays, and would affect hundreds of calls and important long-distance circuits. For years, storage batteries have been used as the auxiliary power source in telephone exchanges. These batteries are usually of the lead-acid type and supply an emf of 24 volts or 48 volts, depending on the type of office in which they are used. The ampere-hour capacity required of the battery for any given installation depends on the traffic load which the office must handle. Batteries have, however, more than the single function of providing an auxiliary source of power. They provide a supply of essentially constant voltage which offsets the variations in commercial power-line voltage and, in addition, they are

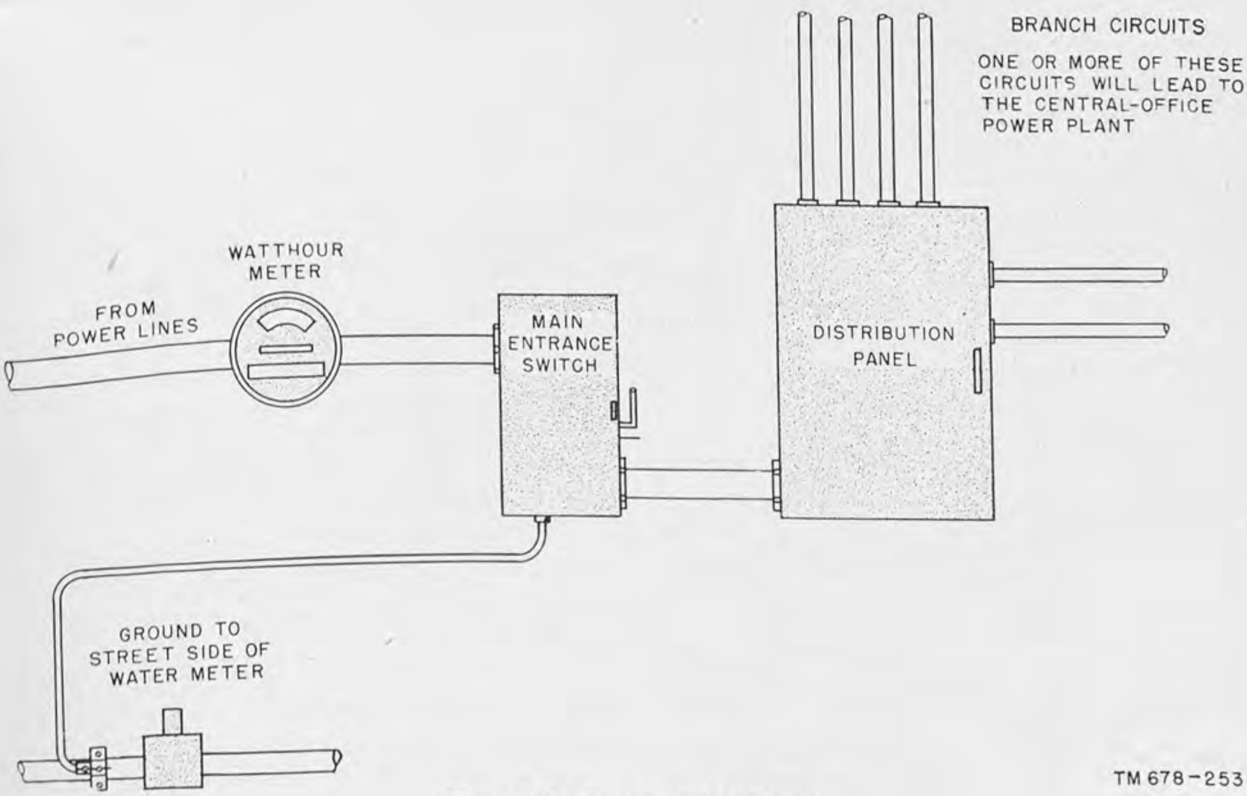


Figure 182. Power service entrance.

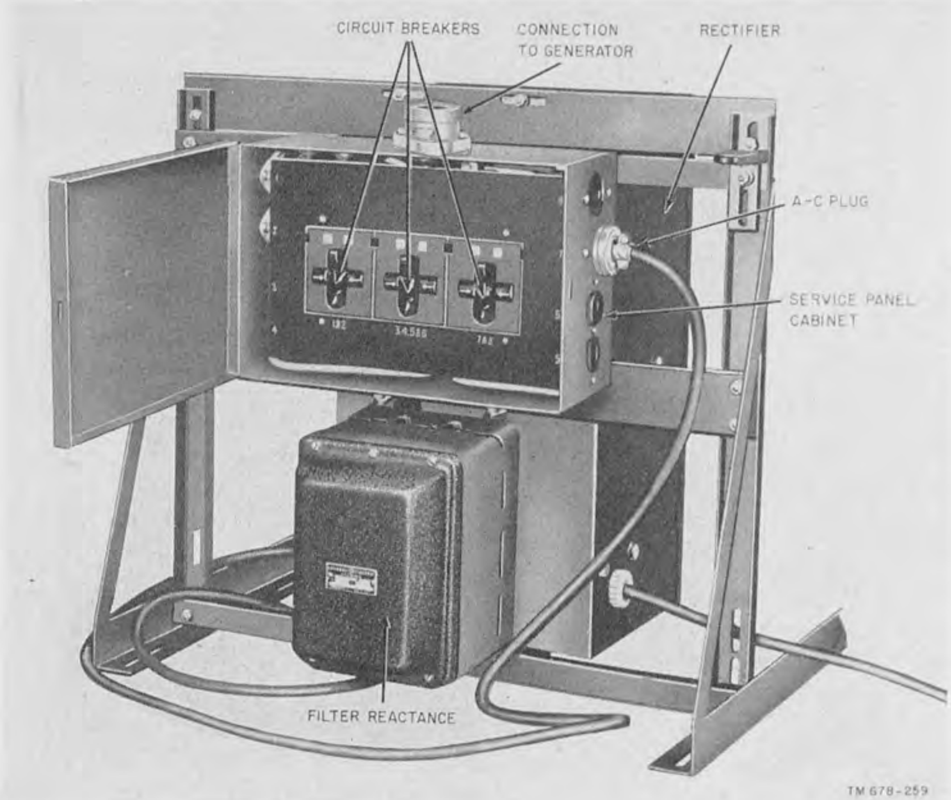


Figure 183. Power service panel.

useful in absorbing the line noises and ripples introduced by the operation of charging equipment.

b. Power Service Panels.

(1) The installation of the power service panel generally is included in the construction contract for the central-office building. This panel is the terminating point of the utility company's supply lines within the central office. It normally consists of a large entrance switch (or switches) controlling the electric power in the entire building, and a sufficient number of distribution panels to protect each electric circuit required in the building. Watt-hour meters (supplied by the utility company) are located near this panel and measure the amount of power used. Figure 182 illustrates a typical power service entrance.

(2) The power supply of Army transportable central-office sets is connected directly from the engine-driven generator set to a small service panel that is mounted on (and forms a part of) the central-office power panel. Figure 183 shows the generator (primary power) connections for a typical Army central-office set.

c. Types of Power Required.

(1) Power is required in several different forms for the operation of a central office. Direct current at 24 or 48 volts (depending on the type of office) is required for voice transmission and for the operation of relays and signals associated with the switchboard. Alternating current and pulsating direct current are used for such functions as signaling telephone stations or other exchanges, and for providing a tone for the busy signal, a dial tone, and other audible indications of circuit conditions. Interrupted signaling currents are provided for machine-ringing facilities found in most large exchanges.

(2) The term *power plant*, or *power equipment*, when applied to telephone work, has reference to that part of the central office which is devoted to the furnishing of current in various forms to operate

the telephone apparatus. The power plant that receives 60-cycle commercial power at 110 or 220 volts converts it to the many forms required by the exchange. To fulfill this function, the central-office power plant is equipped with the necessary rectifiers, motor generators, ringing machines, tone generators, and interrupters. To provide a central point for the protection, control, and distribution of the central-office power circuits, a power panel also is included. Each part of the central-office power plant, including the storage batteries, is connected to the central-office power system through appropriate switches, and circuit breakers or fuses on the power panel.

157. Central-Office Power Circuits

a. Figure 184 shows, in block diagram, a typical central-office power system. The ac from the commercial power lines is led in through the service entrance main switch, and the service entrance distribution panel to the primary power control switch. A-c power from the reserve supply also is fed to this switch. The ac then is converted to dc in the rectifier and motor-generator circuits, and is fed to the power panel, and then through the appropriate meters and switches to the switchboard d-c circuits. The battery is connected directly across this circuit, and in the event of a primary power failure, the battery carries the full load. The output of the motor generator usually is sufficient to carry the full load and also to keep

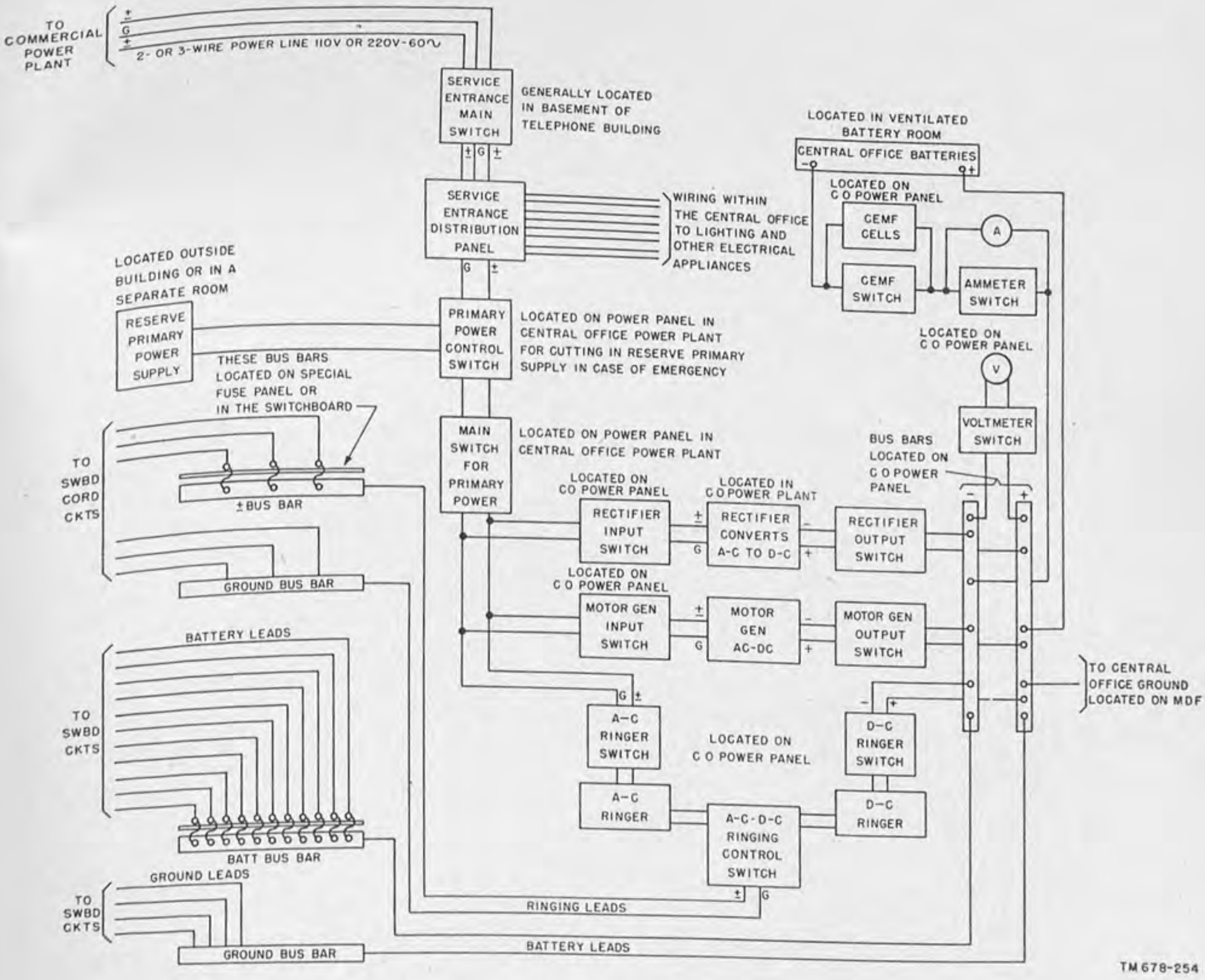


Figure 184. Typical central-office power system.

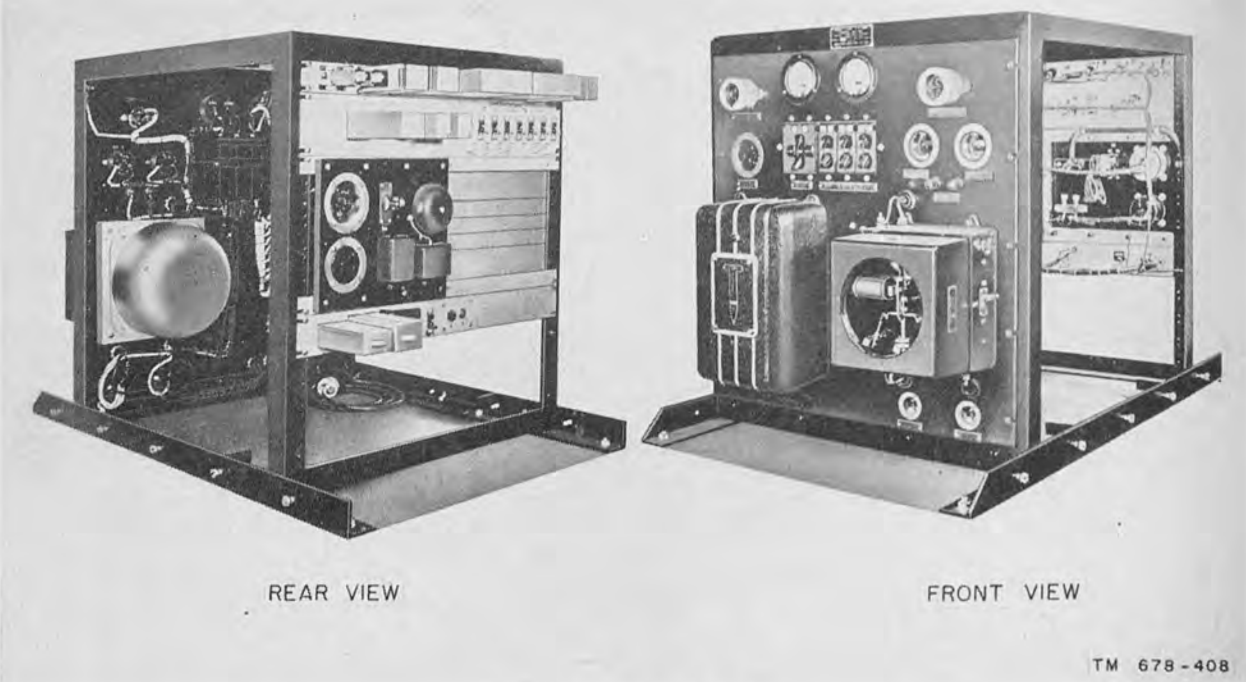


Figure 185. Power panels.

the batteries under slight charge. During periods of heavy traffic, the switchboard load may exceed the output of the charging equipment. Then, both the battery and the charging equipment will supply current to the switchboard, and the battery will recharge when the load returns to normal.

b. The ringing and signaling equipment may operate directly from the primary power source, or it may operate from the central-office battery. Most offices are provided with ac-operated machines for use under normal conditions, and dc-operated machines for use in the event of failure of the primary power source.

c. The functions of the special cells marked CEMF are covered in paragraph 162.

158. Motor-Generator Sets

a. Application.

(1) When the d-c requirements in a telephone central office are 50 amperes or more, the consideration of efficiency in converting power becomes important. Motor-generator sets are the most efficient type of charging equipment, but their use entails constant careful maintenance. The generally accepted practice in telephone plant engineering is to use rectifiers in small central offices and effect a saving in maintenance costs, and to employ motor generators in large central offices where the bulk of the saving will be in increased efficiency of operation. A typical motor-generator set of the type used in large central offices is illustrated in figure 186.

(2) A motor-generator set consists essentially of an electric motor (usually a-c) driving a d-c generator. The motor and generator may be housed separately with their shafts coupled together; or they may be included within a single housing, with the motor and the generator armatures mounted on a common shaft.

(3) The generator used for telephone central-office work may be a shunt-wound type with manual control (found in some older offices) or it may be a compound-wound type (or diverter pole). Some very large offices use high-capacity generators of the shunt type provided with automatic voltage controls. Many modern offices use multiple installations of medium-capacity generators, operating only as many as are necessary to carry the immediate load. Generators designed for central-office charging systems must provide a smooth d-c output with a minimum of commutator ripple.

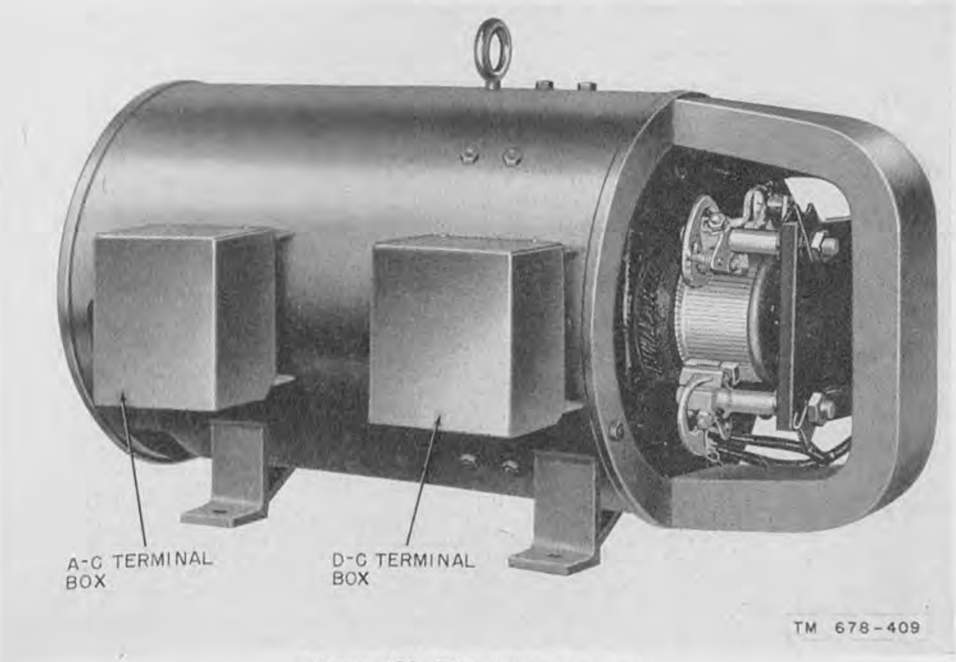


Figure 186. Motor-generator set.

b. Operation.

(1) When a charging set is started, the generator must be brought up to normal speed and then adjusted to the proper voltage output by means of the field rheostat before it is connected to the battery. This precaution is necessary because, if the battery voltage is higher than the output voltage of the generator, the battery will send current through the generator. This will cause the reverse-current circuit breaker, which is provided for this purpose, to operate, opening the circuit to the battery. Larger motors are started by means of special starters, or starting compensators, which limit the starting current while the motor is building up to normal speed.

(2) When the primary power supply fails, the reverse-current circuit breaker automatically disconnects the motor-generator set from the battery. The central-office load then is carried by the battery. Protective devices are provided to disconnect the motor from the primary power source in the event of power failure. These devices prevent the motor from starting when the primary power is restored. It must be started either manually or by means of automatic starting equipment, depending on the type of office.

(3) When primary power is restored after a failure, the batteries, which carried the entire load during the emergency period, must be recharged promptly. The generator voltage therefore is raised to a *charging-voltage* value which is somewhat higher than the voltage used for normal operation.

(4) A more detailed discussion of the operating principles of motors and generators is included in TM 11–681.

159. Rectifiers

A *rectifier* is a device for converting alternating current to direct current without the intermediate processes of transforming electrical to mechanical energy and vice versa. Motor-generator sets are not included in the category of rectifiers because they first convert electrical energy to mechanical energy (motor operation), and then convert the mechanical energy to d-c electrical energy (generator operation).

a. Principle of Operation. The ability of all rectifiers to conduct current in *only one direction* arises from their low resistance (up to several thousand ohms) to current in one direction, and their very high resistance (up to millions of ohms) to current in the opposite direction. The principles of rectification are discussed further in paragraph 160.

b. Types.

(1) Two main classes of rectifiers are used—tube rectifiers and disk rectifiers. Tube rectifiers use any of several vacuum or gas-filled tubes: high-vacuum diodes, mercury-arc tubes, mercury-vapor tubes, and Tungar tubes. The principal disk rectifiers are the selenium and copper-oxide types.

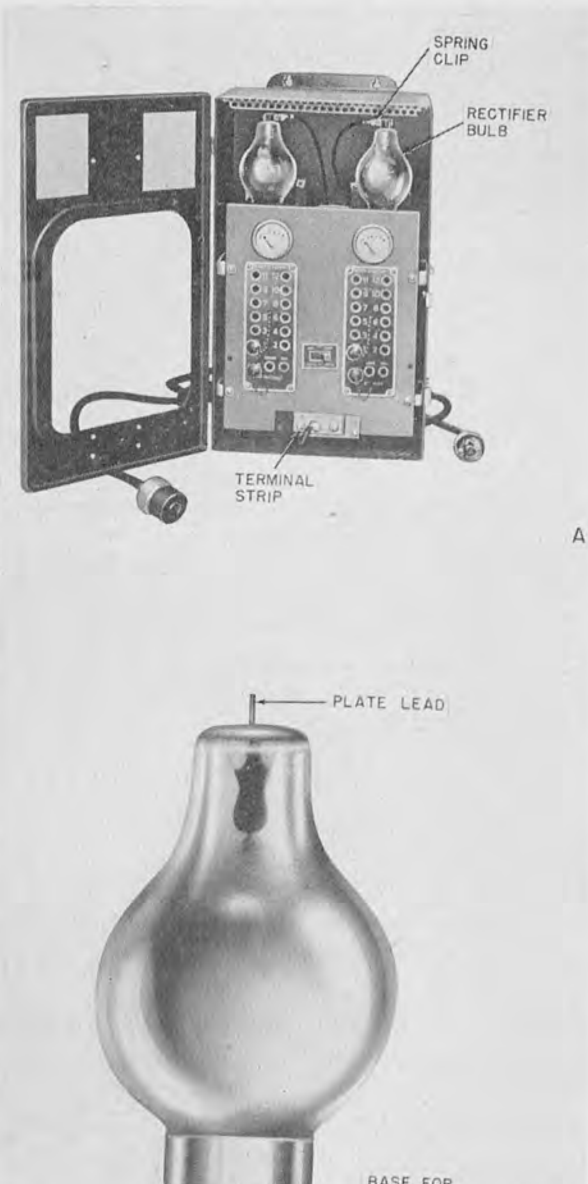


Figure 187. Tungar rectifier and bulb.

(2) Gas tubes are highly efficient rectifiers. They are made by admitting into a vacuum bulb at controlled pressure small amounts of such gases as mercury vapor or argon. Tubes of this type are used commonly where the desired output is less than 50 amperes. The gas tube most widely used by the Army is the Tungar tube, or bulb, which consists of a glass bulb filled with argon gas, a tungsten filament, and a single carbon plate or anode. A, figure 187, illustrates a Tungar rectifier used by the Army, and B shows an individual Tungar bulb.

(3) Selenium-disk rectifiers are used in many military installations instead of gas tubes. They are preferred to copper-oxide rectifiers because they have a better power output-to-weight ratio. A complete selenium rectifier (A, fig. 188) consists of a number of disks bolted together to form a *stack*. The stack is provided with two or more terminals, as determined by its intended use. The rectifier illustrated is designed for use in a full-wave bridge rectifier circuit (par. 161). A cross-sectional diagram (not to scale) of a single selenium disk is shown in B. A base plate of steel or aluminum acts as the support for the disk. Selenium (a metal also used widely in photoelectric cells) is pressed or deposited on one side of the base plate in a thin film. The disk then is heated, causing the selenium to be changed to crystalline form, forming a *natural barrier* layer. This layer is coated with a specially prepared lacquer to form an *artificial barrier* layer. Finally, the *counter electrode* is applied as a sprayed-on layer of an alloy of tin, cadmium, and bismuth. The disk then is *formed* (so that it will conduct current in one direction only) by applying a d-c voltage of opposite polarity to that which will cause the rectifier disk to conduct. A stack is made by mounting several disks on a bolt, which is passed through the *insulating washer* at the center of each disk, as many disks being used as are necessary to withstand the circuit voltage.

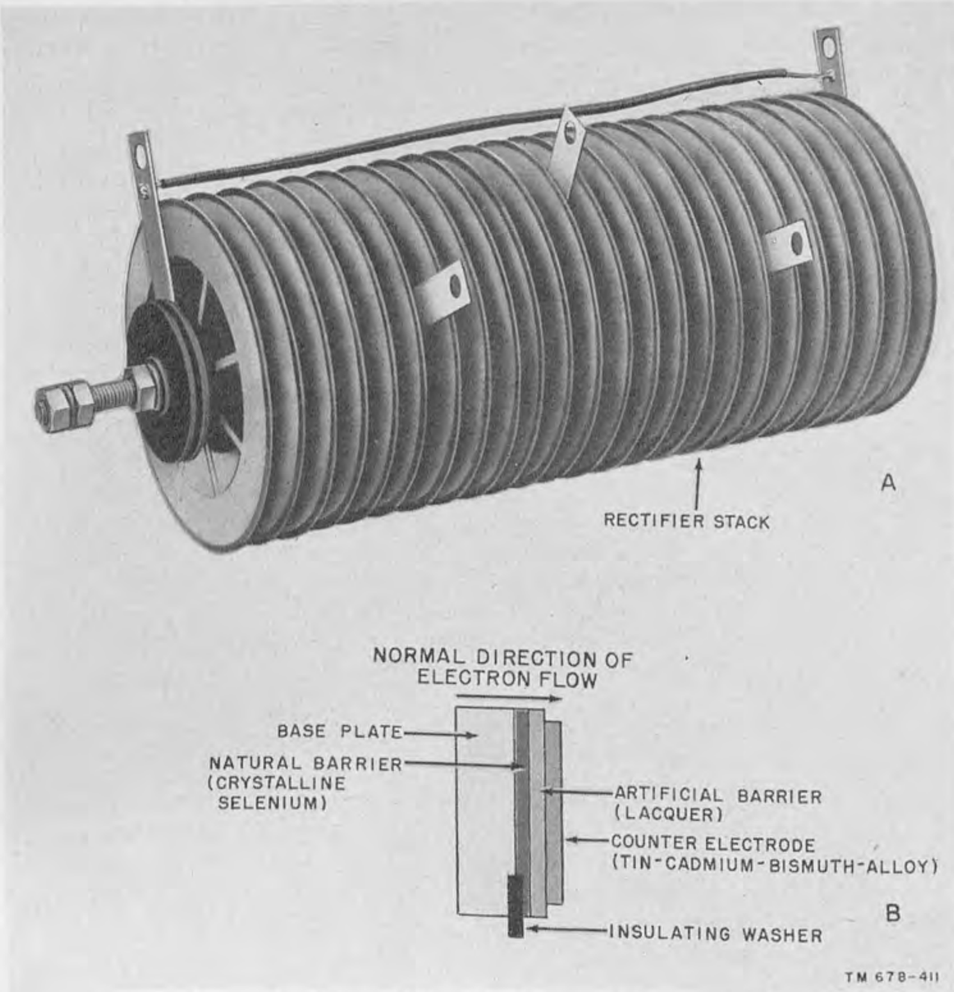


Figure 188. Selenium rectifier.

Selenium disks are rated as to the safe inverse (reverse polarity) voltage they can withstand without breaking down; present disks are rated at 26 volts. Contact between adjacent disks in a stack is made by means of conducting washers or contact buttons.

160. Rectification

a. Half-Wave Rectification.

(1) The circuit of figure 189 is designed to operate as a *half-wave* rectifier.

(2) A source of alternating emf is shown in A connected to a rectifier and a load. Since rectifiers can conduct electrons in only one direction, current flows in this circuit only during alternate half-cycles of the input alternating emf. With the input polarity as shown for the first half-cycle, the rectifier conducts in the direction indicated by the arrow. The waveshapes of the input voltage and load current are as shown in B.

(3) At the end of the first half-cycle, the polarity of the input voltage is reversed as in C. During the second half-cycle, the rectifier does not conduct and only a negligible amount of current flows in the circuit. The resulting waveshapes of input voltage and load current for the entire cycle are shown in D.

(4) The resulting load current is called *pulsating direct* current, since it flows in one direction only but varies in magnitude. This kind of current is not suitable for power supply output in a telephone circuit, because it contains frequency components in the voice-frequency range. In

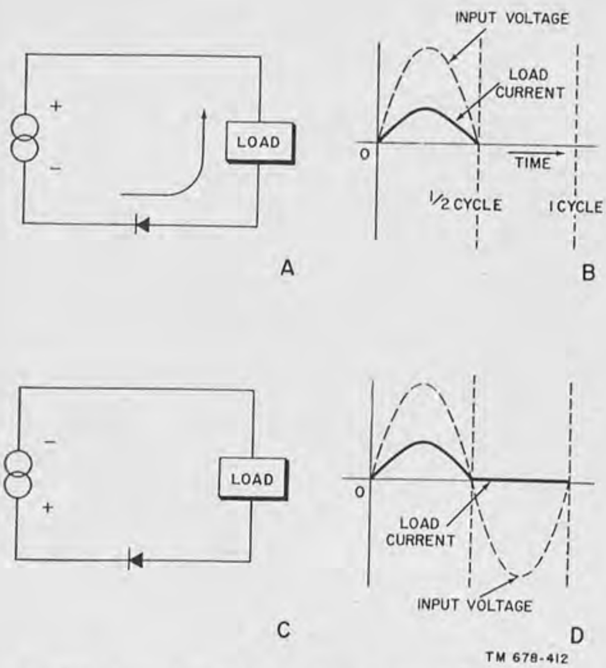


Figure 189. Simplified circuit of half-wave rectifier.

order to make the rectifier system suitable for telephone work, the output current must be well filtered by using smoothing chokes that reduce the variations in the current and make it a practically *steady* direct current. In general practice, it is difficult to obtain adequate filtering of the output of a half-wave rectifier. For this reason, half-wave rectifier circuits generally are not used in the power supply.

(5) Although no particular type of rectifier was mentioned in connection with the foregoing discussion, the theory of operation of a half-wave rectifier is substantially the same for all, disk as well as tube types.

b. Full-Wave Rectification. Figure 190 is a circuit diagram of a *full-wave rectifier*, using Tungar tubes and connected to operate as a battery charger. The anodes of the two Tungar tubes are connected, and the *negative* terminal of the battery (the *load*, in this circuit) is connected to this junction through a filter choke. The alternating emf is applied to the primary of the power transformer. The transformer has three secondary windings, two of which are used to supply heating voltage to the filaments of the Tungar tubes. The third winding is provided with taps on either side of the center point. These taps provide a means of controlling the load current by varying the voltage applied to the rectifier tubes. The filament winding of the upper tube is connected to a tap above the center point, and the filament winding of the lower tube is connected to a symmetrically located tap below the center point. The circuit is completed by connecting the grounded center tap of the secondary winding to the positive terminal of the battery.

(1) Assume that, during the first half-cycle, the filament of the upper Tungar tube (A, fig. 190) is positive in relation to its plate, whereas the filament of the lower tube is negative in relation to its plate. The lower tube therefore conducts current during the first half-cycle, just as though it were a half-wave rectifier (*a* above). If the battery and filter choke were replaced by a resistive load, the load current waveform in B would be identical with that shown in B, figure 189. This waveform is modified slightly by the battery and choke, as explained below.

(2) At the end of the first half-cycle, the polarity of the input voltage is reversed. The filament of the *upper* tube then is negative with respect to its plate. Therefore the upper tube conducts current during the second half-cycle, whereas the lower tube is inoperative. The load current, however, flows through the battery *in the same direction* as during the first half-cycle, as shown by the arrows in A and C. The resulting waveform of the load current (again assuming the battery and choke to be replaced by a resistive load) is illustrated in D.

(3) The fact that the load is a battery, as shown in the figure, instead of a resistance (as assumed in (1) and (2) above) causes the load current to flow for slightly less than a half-cycle at a time. Each tube conducts current only during that part of its conducting half-cycle when the voltage across the secondary winding of the transformer exceeds the battery voltage opposing it. The effect of the battery on the current waveform is shown in E. In telephone applications, this effect is of negligible importance, because the telephone circuit which shunts the battery while it is being charged reduces the

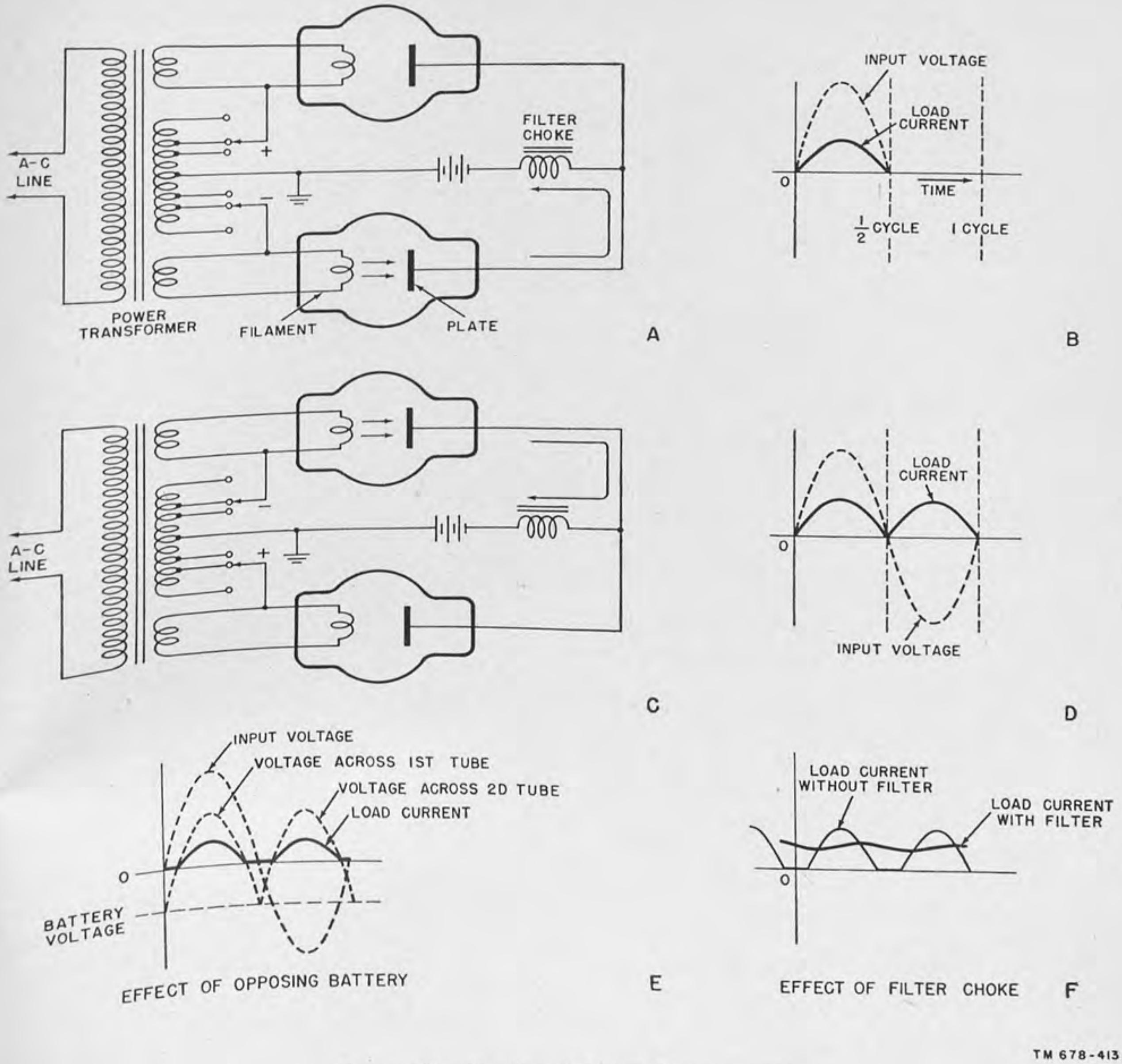


Figure 190. Circuit of full-wave Tungar rectifier.

battery voltage slightly, thereby increasing the conducting time of the tube.

(4) The load current of the full-wave rectifier (still neglecting the effect of the filter choke) is a pulsating direct current, although the variations about its average or d-c value are not so great as in the half-wave circuit, and the zero-current intervals are much shorter. Filtering therefore is accomplished more easily in the full-wave rectifier circuit. Ordinarily, a *filter choke* is connected in series with the battery, as in figure 190, further modifying the load-current waveform, as shown in F. The size of the choke required depends on the current to be taken from the power supply by the load.

161. Full-Wave Bridge Rectifier

a. Structure.

(1) Figure 191 illustrates the circuit of a bridge rectifier using four selenium rectifier stacks, numbered 1, 2, 3, and 4, arranged in the form of a closed loop. The four stacks sometimes are mounted as a

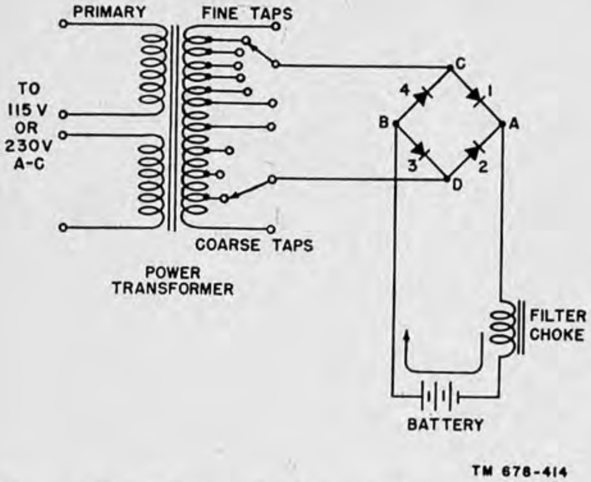


Figure 191. Full-wave bridge rectifier using selenium stacks.

single stack, as in A, figure 188. There are four junction points, A, B, C, and D, respectively. The battery, which is the load in a rectifier circuit used for charging, is connected to points B and A in series with a filter choke, as shown in the diagram.

(2) The power transformer has a primary winding which can be arranged for operation with input voltages of either 115 volts or 230 volts. The secondary is provided with a number of coarse-adjustment taps on one end and a number of fine-adjustment taps on the other, for controlling the voltage applied to the rectifier. The input to the rectifier stacks is connected from one of these taps on each end to junction points C and D.

b. Operation.

(1) Consider the first half-cycle of alternating voltage applied to the rectifier, and assume that point D is negative and point C is positive during this time. If this is true, electron current will flow from point D through rectifier 3, the battery, the filter choke, and rectifier 1. During this first half-cycle, negligible current flows through rectifiers 2 and 4.

(2) At the end of the first half-cycle, the polarity of the secondary emf is reversed, making point D positive and point C negative. The path of electron flow during the second half-cycle is from point C through rectifier 4, the battery, the filter choke, and rectifier 2. A pulse of current therefore flows through the battery in the same direction during both half-cycles. The waveshape of current for the entire cycle is identical with that for the full-wave Tungar rectifier.

162. Central-Office Batteries

Central-office batteries used in large exchanges usually consist of multiple units of individual cells, with a sufficient number of cells connected in series to provide for the needs of the exchange. These cells are contained in sealed glass jars and generally are operated at a specific gravity of 1.210 to 1.220 and an open voltage of 2.05 volts per cell. In 24-volt offices, 11 cells are used and in 48-volt offices, 23 cells are used. Figure 192 shows a typical commercial-type telephone battery cell. Army transportable central offices use a portable or an industrial-type battery. These batteries have a hard-rubber composition case and each battery contains six cells connected in series. Two batteries connected in series are used in Army 24-volt exchanges and four are used in 48-volt exchanges. They are operated at 1.280 specific gravity with an open circuit voltage of 2.2 volts. Figure 193 shows a typical Army central-office battery. Central-office equipment is de-

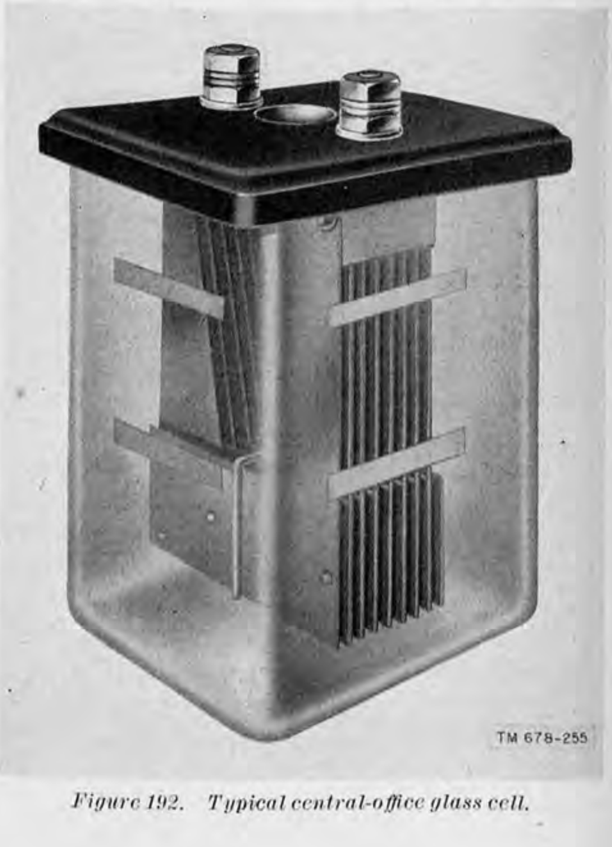


Figure 192. Typical central-office glass cell.

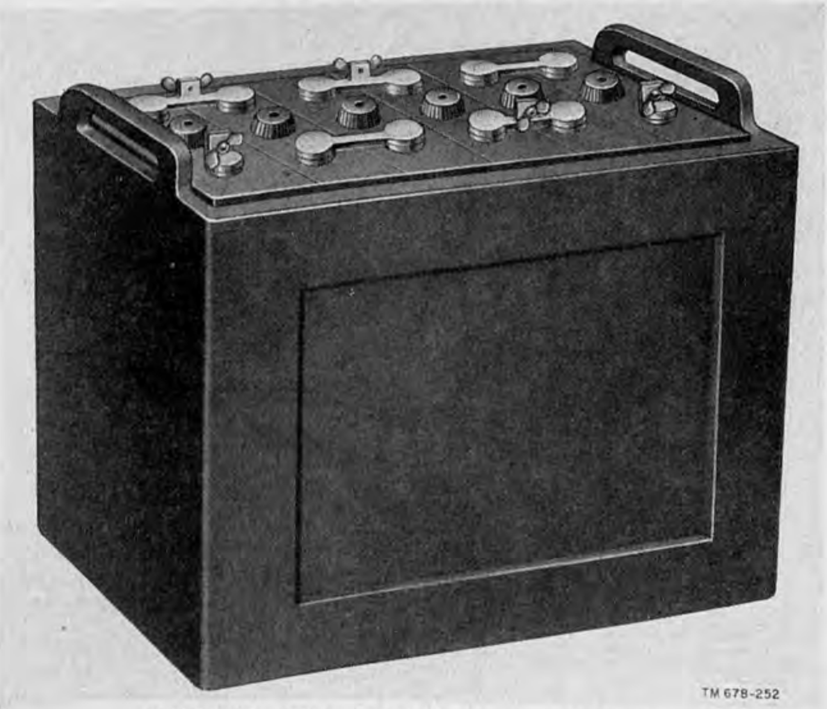


Figure 193. Typical central-office portable battery.

signed to operate within certain voltage limits. In order to function properly, the battery emf must remain substantially constant, regardless of the fluctuations in telephone traffic or operating conditions.

a. End Cells. When the power supply in a central office is operating normally, the charging system is supplying the battery current plus the normal load current and keeps the battery at its normal operating voltage. During a period when the primary power is shut off because of power failure, the battery must carry the entire load alone, and some provision is made for regulating the terminal voltage of the battery. If the terminal voltage falls below the required value, the office equipment will not operate properly, or it may not operate at all. To take care of such emergencies, special cells, called *end cells*, are connected in series with the regular 23 cells during periods when the battery is supplying the load current. They are switched into the circuit only when the terminal voltage falls below the safe minimum value, and are switched out of the circuit when the battery voltage has reached a safe maximum value. The addition of the end cells raises the terminal voltage to a value that will operate the equipment satisfactorily and permits the full discharge capacity of the battery to be used before the equipment fails. End cells are exactly like the other cells of an office battery. Since they are used for very brief intervals only, they require less charging than the regular 23-cell battery. For this reason they usually are kept fully charged by means of a special trickle charger designed for this purpose.

b. Counter Emf Cells.

(1) During an emergency period, such as described in *a* above, the battery discharges appreciably. When the emergency is over, the battery must be recharged more rapidly than during normal operation. The charging voltage therefore is raised somewhat above its normal value. However, since the larger voltage from the charger is directly across the switchboard load as well as across the battery, the load voltage may become too high for safe operation. Consequently, some provision must be made to reduce the load voltage to a safe value, without reducing the charging voltage applied to the battery.

(2) This is accomplished by the use of a group of special cells, called *cemf* (counter emf) *cells* (fig. 194). The typical cemf cell consists of two groups of thin nickel plates suspended from an insulated cover

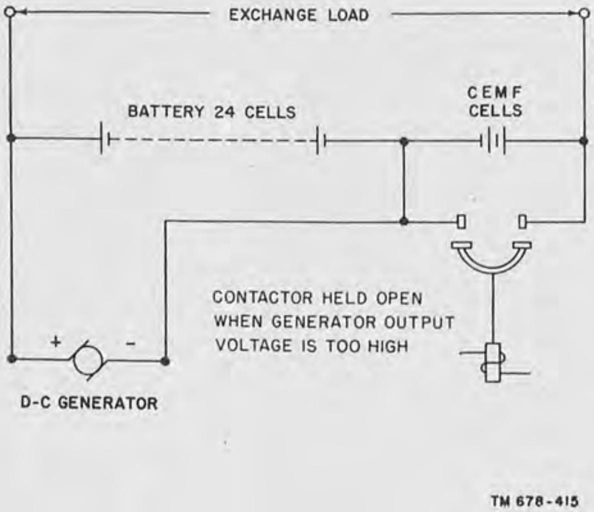


Figure 194. Use of cemf cells.

in an *alkaline* solution known as *NA* solution. The housing for the cell is a Pyrex glass container. The nickel plates are insulated from each other by means of glass insulating beads supported on each plate. A layer of oil, known as *exidol*, is used on the surface of the NA solution to retard evaporation.

(3) Each cell provides a cemf of approximately 2 volts for very small currents, increasing only slightly as the current increases. This cemf has an effect similar to that of introducing additional resistance into the load circuit, except that the cells dissipate much less power and provide a fairly constant cemf. The behavior of these cells is similar to that of a fully charged lead-acid cell except that the plates have practically zero storage capacity and therefore are reversed immediately in polarity when the direction of current changes. The cemf cells are inserted automatically in series with the load circuit when the output voltage of the generator is increased above its normal value.

163. Ringing Machines

A ringing machine is a device that operates from a standard power source to provide ringing current for the switchboard. It is an automatic source, which takes the place of the hand generator. A number of these devices have been designed to meet different requirements. They convert the a-c or d-c voltage of the power source to an a-c voltage which has the required frequency of the ringing current. The machines frequently used are the a-c vibrating-reed interrupter and the d-c vibrating-reed converter, each of which uses a vibrating reed to perform the conversion, and the subcycle static frequency converter which has no moving parts except for a starting relay.

164. A-C Vibrating-Reed Interrupter

The a-c vibrating-reed interrupter produces a 20-cycle ringing current output from a 110-volt, 60-cycle, a-c power-supply input (fig. 195).

a. Operating Principle. Operation of the interrupter depends on a vibrating reed which alternately opens and closes the output circuit at regular intervals. The interruption of the output circuit results in an output voltage consisting of alternate positive and negative half-cycles which, over a 1-second period, add up to the equivalent of a 20-cycle frequency variation. The operating principle can be explained by referring to the simplified circuit of figure 195. The interrupter has a transformer, the primary winding of which is connected to input terminals T1 and T2 of a 110-volt, 60-cycle, a-c generator. A motor coil in series with a vibrating reed and resistance R is connected across the secondary winding. The output circuit includes a lamp and a ringer.

(1) The generator produces a 60-cycle alternating current in the primary winding of the transformer, which induces a 60-cycle a-c voltage in the secondary winding (A, fig. 195). When the vibrating reed is in the position shown, the secondary voltage provides a current in the output circuit to the ringer through the lamp, and also a current through resistance R and the motor coil, which is an electromagnet. The motor coil becomes magnetized and attracts the vibrating reed, opening the output circuit at the secondary winding of the transformer, and stopping the current to the ringer and the motor coil. The motor coil then loses its magnetization and releases the reed. The reed again closes the output circuit to the ringer, current again is supplied to the motor coil, and the cycle is repeated. Thus, the reed is caused to vibrate, the vibra-

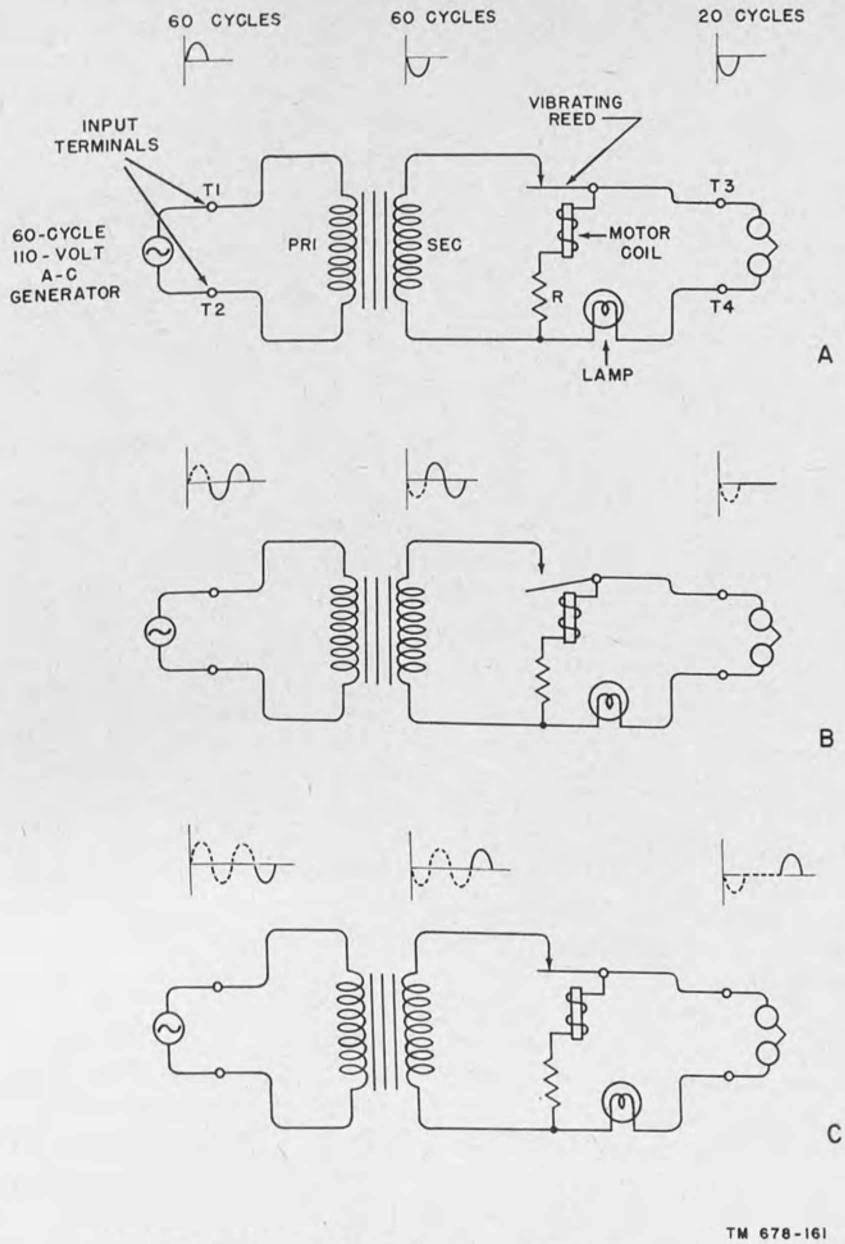
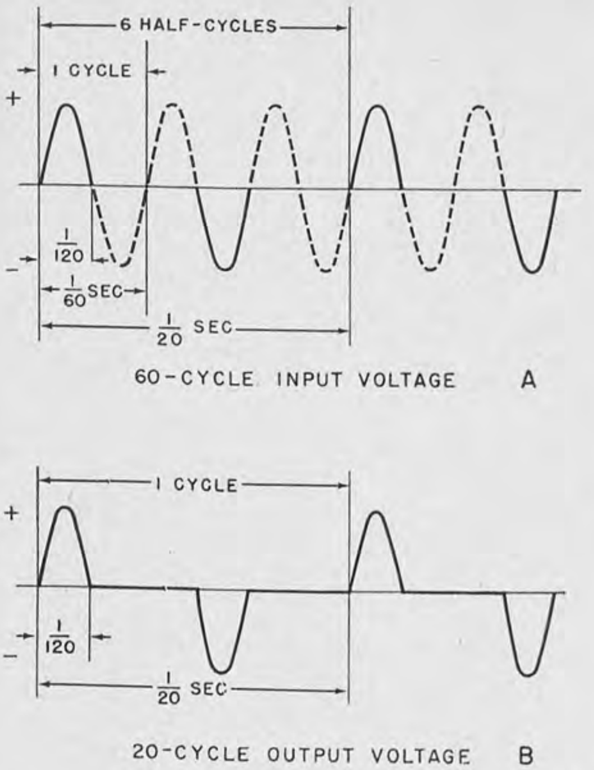


Figure 195. Operation of a-c vibrating-reed interrupter.

tion alternately opening and closing the output circuit to the ringer.

(2) The vibration of the reed is adjusted so that it closes the output circuit for 1 half-cycle of the 60-cycle a-c input and opens the output circuit for 2 half-cycles, or 1 complete cycle. With the output circuit open, the output voltage falls to zero, as shown in the waveform over the ringer in B. When the reed closes the circuit again, as in C, the resultant pulse in the output circuit is of opposite polarity to that of the first pulse. The reed therefore produces an output voltage that consists of half-cycle pulses which alternate in polarity, one being positive and the other negative. These are separated by an interval of zero voltage resulting from the removal of 2 half-cycle pulses between them.

(3) The 60-cycle input voltage has 60 cycles per second; the duration or period of each cycle is $\frac{1}{60}$ second, and for each half-cycle is $\frac{1}{120}$ second (A, fig. 196). The



TM 678-162

Figure 196. Output-voltage waveform of a-c vibrating-reed interrupter.

time interval from one positive half-cycle to the next positive half-cycle, which represents a complete cycle for the output voltage is equivalent to six 60-cycle positive and negative pulses, which amount to $6/120$ second, or $1/20$ second. Because a complete cycle of the output voltage takes $1/20$ second, the frequency is 20 cycles per second.

b. Circuit. Figure 197 shows the actual circuit of an a-c vibrating reed interrupter. A 110-volt, 60-cycle, a-c generator is connected to the input terminals, and the output is connected to the switchboard. The capacitors and the r-f (radio-frequency) chokes, L1 and L2, are used to reduce arcing at the contacts of the vibrating reed and to remove high-frequency peak voltages which could produce radio interference. The ground connections connect to the interrupter chassis, permitting discharge of the capacitors when the unit is shut off. The lamp is provided to prevent damage to the components in case of a short circuit or a heavy load on the machine.

165. D-C Vibrating-Reed Converter

The *d-c vibrating-reed converter* changes a d-c voltage (usually that of a battery) to an a-c voltage of 20 cycles.

a. Operating Principle. The simplified circuit of figure 198 illustrates the operating principle of the d-c vibrating-reed converter. This converter has a transformer which steps up an input of 3 volts to an output of 100 volts. (Other types have inputs of 12 to 48 volts.) There is a center tap on its primary winding. The primary winding is connected to a vibrator unit containing a coil, a center reed, side reeds, and an actuating point. The input voltage is supplied by a battery. The positive terminal of the battery is connected to the center tap of the primary winding through a switch; the negative terminal is connected to the center reed of the vibrator unit. The secondary winding of the transformer is connected to the output terminals of the converter, and the terminals are connected to a ringer. Heavy lines show the momentary circuits during operation.

(1) When the switch is closed, as in A, a complete path for the battery current is provided (in the direction of the arrow)

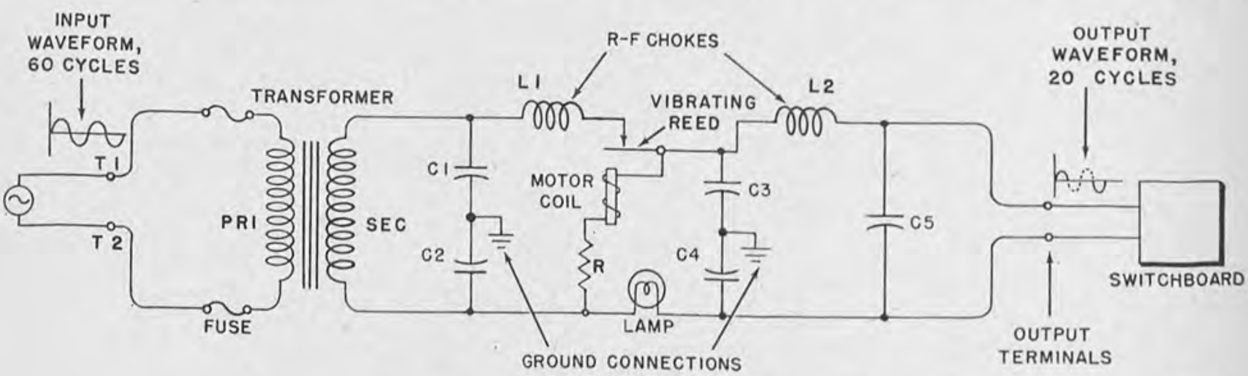


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Figure 197. Circuit of a-c vibrating-reed interrupter.

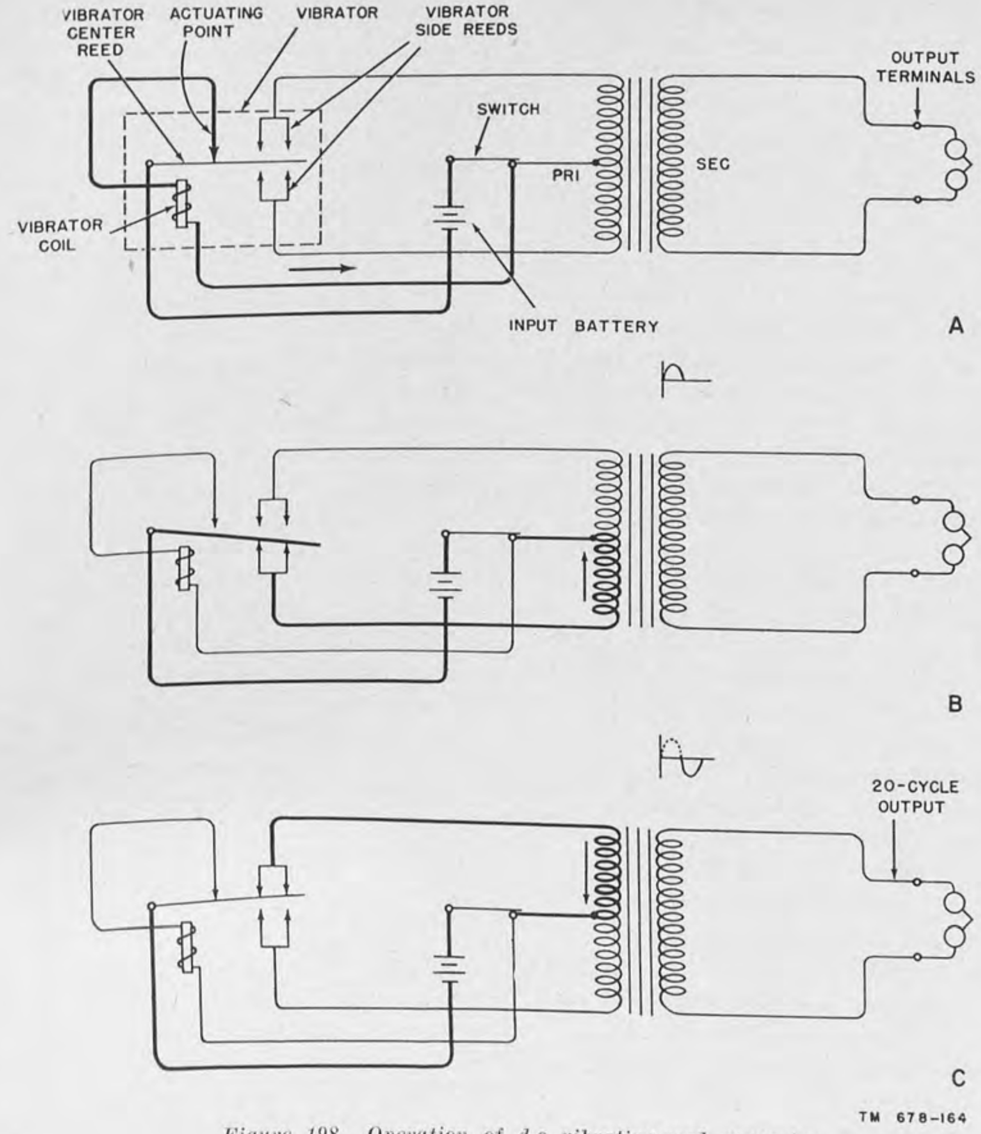


Figure 198. Operation of d-c vibrating-reed converter.

through the vibrator coil, the actuating point, and the center reed. The coil, which is an electromagnet, becomes magnetized by the current and attracts the center reed.

(2) The attraction of the center reed by the coil opens the contact at the actuating point and brings the center reed into contact with the lower set of side reeds, as in B. This provides battery current in the direction of the arrow through the lower half of the primary winding of the transformer. This current is supplied for only an instant, however, since the breaking of the contact to the center reed from the actuating point opens the circuit through the vibrator coil, causing it to demagnetize and release the center reed from the lower side-reed contacts. The make and break of the lower side-reed contacts result in a current rise and fall in the primary winding of the transformer, thus inducing a voltage in the secondary winding, as shown.

(3) When the center reed is released from the lower side reeds, it vibrates and makes contact with the upper side reeds, as in C. As a result, battery current now is supplied to the upper half of the primary winding of the transformer in the direction indicated by the arrow. (Note that this direction is opposite to that of

the current in the lower half of the winding when contact is made with the lower side reeds.) At the same time, the center reed again is brought into contact with the actuating point, and current again is supplied to the vibrator coil. The coil again becomes magnetized and attracts the center reed to the lower side reeds, breaking the contact to the upper side reeds. The make and break of contact with the upper side reeds cause the current to increase and decrease in the upper half of the transformer primary winding, and again a voltage is induced in the secondary winding of the transformer, but in the opposite direction, since the current direction has reversed. Thus, at each make and break of contact between the center reed and the side reeds, a half-cycle alternating current is induced in the secondary winding of the transformer. The center reed is kept in vibration by the vibrator coil, and its rate of vibration is adjusted mechanically to produce the required frequency of 20 cycles for the ringing current for the output.

b. Circuit. Figure 199 shows the actual circuit of a d-c vibrating-reed converter. The input voltage is supplied by a 3-volt battery, and the output is connected to the switchboard. Capacitor C1 reduces the arcing at the contact between the center reed and the actuating point. Capacitor C2 acts as a buffer capacitor, regulating the manner in which the magnetic flux decays in the transformer core during the intervals when the primary circuit is open. The vibrator comes in a single unit containing the coil, the center reed, the side reeds, and the actuating point. The chassis completes the circuit path of the current from the battery, as indicated by the ground connections.

166. Subcycle Static Frequency Converter

The subcycle static frequency converter, or reducer, as its name implies, is a ringing machine without moving parts. Ringing machines using vibrators, vacuum tubes, or rotary parts need frequent adjustment and are expensive to maintain. By comparison, the subcycle converter needs no adjustment or lubrication and will operate continously for many years without attention. It is a subharmonic generator, which furnishes ringing power at either 20 or 30 cycles, subharmonics or submultiples of the standard 60-cycle power frequency. The subcycle converter used in Army central offices is designed for operation from a 115-volt, 60-cycle source. For the operation of subcycle converters at other commercial voltages of the same frequency, a transformer that delivers 115 volts is used between the power line and the converter.

a. Theory. The subcycle converter is essentially a series L-C (inductance-capacitance) circuit containing sufficient amounts of inductance and capacity to resonate at the desired ringing frequency of 20 cycles. A switching action, accomplished electrically by means of a nonlinear inductance called a saturable reactor, allows the 60-cycle current to turn off and on at the proper times to develop the 20-cycle current. The charac-

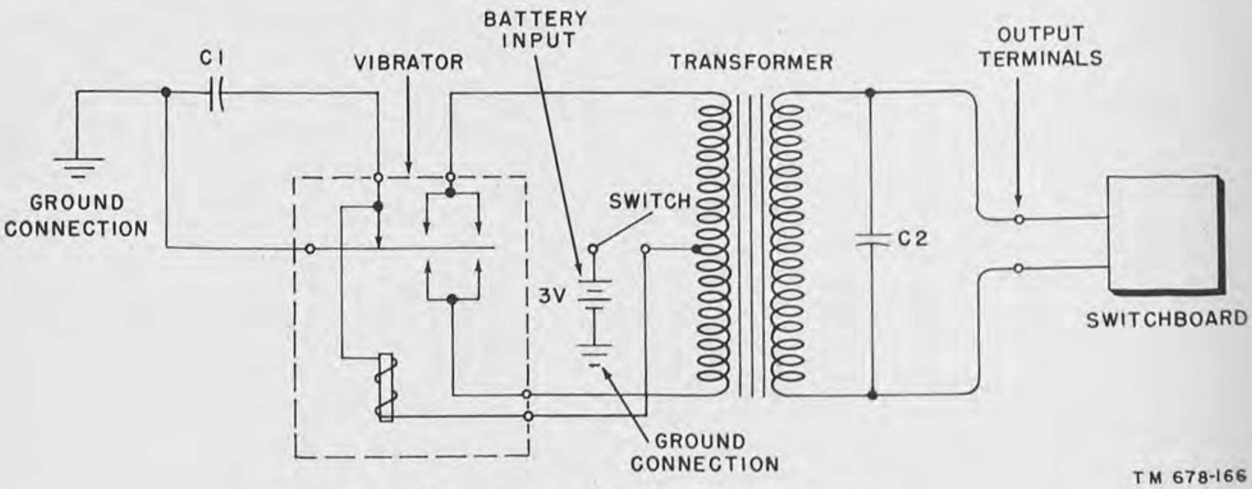
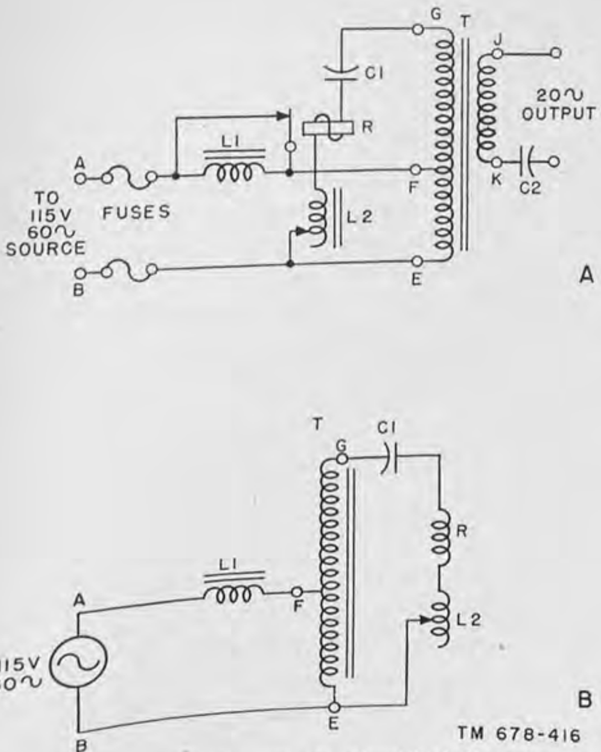


Figure 199. Circuit of d-c vibrating-reed converter.



A. Schematic diagram B. Simplified diagram
Figure 200. Subcycle static frequency converter.

teristics of the saturable reactor are such that its inductance value drops abruptly when a critical rate of change of current through its winding is reached. As a result, the inductor is taken out effectively and placed in the circuit in accordance with the current variations.

b. Starting Operation.

(1) A, figure 200, shows the schematic diagram of a conventional subcycle converter. At the instant of applying the line voltage, the armature of relay R is in the position shown, shorting out the saturable reactor, L1. The total input of 115 volts therefore is applied across winding FE of autotransformer T, which steps up this voltage to approximately 400 volts (peak) across the entire winding, GE. This high voltage appears across the 8-μf capacitor, C1, the winding of the relay, and a small inductance, L2. The peak voltage of 400 volts appearing across this series circuit causes the capacitor to charge through the relay and inductor. The large capacitor charging current flowing through the relay energizes it, causing the armature to be pulled away from the position shown. The operating time of the relay is such that it opens about the time the capacitor has charged to its peak voltage. The relay then remains open during the subsequent operation of the converter, and closes only when overload or power failure stops the charging and discharging of the capacitor.

(2) On the opening of the relay, the saturable reactor, L1, becomes part of the primary circuit of the autotransformer, and the greater part of the input voltage now appears across L1—not across FE, the primary winding of the transformer. (When L1 is not saturated, its inductance value is large.) Since the transformer receives little input voltage, there is little induced voltage across winding GE, and the capacitor is free to begin discharging its stored energy at the natural frequency of its L-C circuit.

(3) B, figure 200, shows the redrawn schematic of the subcycle converter without showing the armature of the relay, since, after starting, the relay remains open during the subsequent operation of the converter, and closes only when overload or power failure stops the charging and discharging of the capacitor. The discharge path of the capacitor is through the relay winding, small inductance L2, the power source, large inductance L1, and winding FG. The discharge path is not primarily through winding EF because, as explained in TM 11–681, the winding common to both primary and secondary circuits of an auto-transformer tends to appear as an open circuit. (Primary and secondary currents 180° out of phase oppose each other directly.) When the discharging capacitor current is in phase with the current from the 60-cycle source, reactor L1 saturates sharply, allowing the input voltage to appear across the primary of the transformer.

c. Normal Operation.

(1) The operation of the subcycle generator now may be considered from a more general point of view. The oscillating series L-C-R (inductance - capacitance - resistance) circuit has small resistance and large values of inductance and capaci-

tance—approximately 8 henrys and 8 μf, respectively. The current in this circuit oscillates at its natural frequency of 20 cps ($fr = .5\pi\sqrt{LC}$). For each half-cycle of oscillation, there is a period during which the 60-cycle current from the power source and the 20-cycle oscillating current are in phase through reactor L1. The combined current saturates L1 so that it no longer offers a high reactance to the 60-cycle source, and therefore the full input voltage appears across the primary winding, and a high voltage again appears across the capacitor, either aiding its charge or its discharge. It should be noted that a discharging current in one direction is also a charging current in the opposite direction.

(2) The 20-cycle output of this generator is taken off by means of inductive coupling from the tertiary winding, JK. Capacitor C2 in series with this winding prevents overloads from damping excessively the 20-cycle oscillations. The generator is designed for a resistive load, or at least for a noninductive load. Any given resistive load is reflected as resistance into winding GE, but the capacitive reactance introduced by C2 is reflected as an inductive reactance (transformer action). This reflected inductive reactance compensates for loss of reactance in the transformer caused by the overload current. If the load on the generator is inductive, the capacitor action of C2 is disadvantageous, since its reactance tends to be canceled by the load, and therefore excessive current will flow in both sides of the transformer.

(3) An additional feature of this generator is that transformer T also has a saturable core, which helps to maintain a constant output voltage with varying input voltages or with varying load conditions. The saturable transformer core also makes winding GF selfadjusting, so far as its inductance is part of the L–C oscillating circuit. Under changing load currents, its reactance remains constant to keep the frequency of the circuit at 20 cycles.

(4) As long as oscillation continues, the current through the relay keeps its contacts open. In normal use, therefore, the only time the relay operates is after an interruption of the 60-cycle supply, such as when a heavy overload causes the 3-ampere line fuses to blow. When the 60-cycle supply is restored, the subcycle converter starts itself again as described above.

(5) The small tapped saturable inductance, L2, is inserted in the circuit to generate harmonics that provide a ring-back, or reverting, tone in the receiver of the calling telephone. Since the 20-cycle frequency of the ringing current is itself inaudible in the usual telephone receiver, this ring-back tone reassures the caller that the called telephone is being rung. Even with the addition of the reverting tone, the 20-cycle output waveform is almost a pure sine wave; this is desirable because it causes a uniform ringing of the telephone bell and induces a minimum of interference in adjacent circuits.

d. Advantages of Subcycle Converter.

(1) Since, during normal operation, the relay contacts are open continuously, the converter normally has no moving parts; this minimizes maintenance and replacement of parts.

(2) The maximum output of the converter is 20 volt-amperes, which is sufficient to operate 25 ringers simultaneously under average line conditions. Under no load, the converter consumes only 20 watts of power and is therefore very economical to operate.

(3) The operation of the subcycle converter is stable and is not affected by relatively wide variations in either line frequency or voltage. This selfregulating characteristic maintains better voltage regulation of the output than could be obtained by using a voltage regulator for the input voltage. From 90 volts no load to 82 volts full load, the output voltage of the converter drops only 8 volts.

167. Summary

a. Distributing frames are used at telephone central offices for the purpose of mounting outside and switchboard lines in a permanent, orderly manner.

b. An IDF may be used, in addition to an MDF, to permit convenient shifting of the operator's load without disturbing the office wiring.

c. Wall frames generally are used in small commercial offices. Floor-type frames are used in small military exchanges.

d. All floor frames have two sets of terminal boards, situated on opposite sides of the frame. Usually, the terminals are arranged in vertical rows on one side and in horizontal rows on the other.

e. A type-A frame is one in which the vertical side is the switchboard side; in a type-B frame, the horizontal side is connected to the switchboard.

f. Two-wire jumpers are used to interconnect the vertical and horizontal sides of the main distributing frame.

g. Cables are used to connect the main frame to the intermediate frame, and three-wire jumpers to interconnect the two sides of the IDF.

h. Some larger military exchanges use a combined frame, instead of a separate MDF and IDF.

i. Lines are conducted from the distributing frame to the switchboard by means of switchboard cables, the number of cables used depending on the size of the board.

j. Protective devices are installed on the main distributing frame to protect the equipment from both natural and artificial hazards.

k. Heat coils are used to guard against the cumulative effects of small currents which might produce excessive heat when they flow for a considerable time.

l. Fuses are used to protect equipment against excessively high currents.

m. Open-space cut-outs, or air-gap arresters, are used to protect against high voltages, such as those produced by lightning discharges.

n. Heat coils and open-space cut-outs usually are combined in central-office protectors.

o. Central-office batteries are usually of the lead-acid type, with an emf of 24 or 48 volts.

p. Provision is made to keep the batteries fully charged by means of a charging system while they are in use.

q. The most commonly used charging methods involve the use of motor-generator sets or rectifiers.

r. Too low battery voltage is overcome by use of end cells; too high voltage during heavy charging is overcome by means of cemf cells.

s. Rectifiers may be either vacuum or gas-filled tubes, such as Tungar tubes, or the metallic disk type, such as selenium or copper-oxide rectifiers.

t. Rectifiers may be designed to operate as half-wave, full-wave, or bridge circuits.

u. Filters, usually consisting of smoothing chokes, are used in conjunction with rectifiers to produce an output direct current relatively free of a-c ripple.

v. The ringing machine is a device used to provide ringing current automatically to the switchboard. It operates from a standard power source, converting the a-c or d-c voltage of the source to alternating current of the required frequency—usually 20 cycles per second.

w. The subcycle static frequency converter is a ringing machine designed to provide 20-cycle ringing power to as many as 25 ringers.

x. The efficiency of the subcycle converter is relatively high, and it possesses the advantage of having no moving parts during normal operation.

168. Review Questions

a. What are the principal functions of distributing frames in central offices?

b. Describe the wall-type frame; the floor-type frame.

c. What is meant by the vertical and horizontal sides of a distributing frame?

d. What are the differences between an MDF and an IDF?

e. When is it necessary to use both an MDF and an IDF?

f. How are the MDF and the IDF interconnected?

g. Where is a combined frame generally used?

h. Draw a diagram tracing a circuit through a combined frame.

i. What is the function of jumpers in connection with distributing frames?

j. Describe the structure of cables used between the distributing frame and the switchboard.

k. How are outside cables usually brought in to the MDF?

l. What types of hazards must be guarded against in telephone offices?

m. Name the three general types of protective devices used to guard against hazards.

n. Describe the operation of the alarm-type switchboard fuse.

o. What two general classes of equipment are used for charging central office batteries?

p. What are the operating requirements of a charging source?

q. What are the sources of primary power usually provided in central offices?

r. Explain, with the aid of a diagram, the operation of a full-wave Tungar rectifier, and a bridge-type selenium rectifier.

s. What is the function of end cells in a central-office battery?

t. Describe the structure of a cemf cell.

u. How are cemf cells used in connection with abnormally heavy charging?

v. What is a ringing machine? What purpose does it serve?

w. With the aid of simplified circuit diagrams, describe the operation of the a-c vibrating-reed interrupter.

x. With the aid of simplified circuit diagrams, describe the operation of the d-c vibrating-reed interrupter.

y. Describe the operation of a subcycle static frequency converter during (1) initial starting, (2) normal operation.

z. What circuit constants determine the oscillating frequency of the subcycle converter?

CHAPTER 7

SOUND-POWERED COMMUNICATIONS

169. Introduction

As previously explained, the carbon-button transmitter and the magnetic-diaphragm receiver involve the use of batteries as the initial source of power, when used as basic components of various telephone systems. Externally supplied power is necessary, because the carbon-button transmitter is not a generating device; it operates on the principle that varying resistance in a chamber of carbon granules causes corresponding variations in a direct current initially produced by a battery in the circuit. For certain applications, it is desirable to communicate by telephone without the use of batteries. A *system* that permits this is called a *sound-powered system* (or *batteryless system*).

170. Sound-Powered Transmitter

a. Structure. The structure of a *sound-powered transmitter* is indicated in the simplified diagram of figure 201. This transmitter has a permanent magnet with double pole pieces N-N and S-S, representing the north and south poles, respectively. In the space between the opposite poles is coil C, wound around a soft-iron armature. The armature is pivoted near its center, P, so that it is free to rotate vertically to a limited extent in either direction. A diaphragm is connected mechanically to the armature by means of coupling rod R. This permits motion of the diaphragm to be transferred to the armature, so that, as the diaphragm moves downward, the armature rotates slightly counterclockwise, and as the diaphragm moves upward, the armature rotates slightly clockwise. Adjusting screw SC limits downward travel of the armature. Terminals 1 and 2 terminate the line.

b. Operating Principle. The operation of the sound-powered transmitter is based on the fundamental principle of electromagnetic induction, as explained in TM 11–681; that is, the value of the induced emf depends on the number of turns linking the flux and the rate of change of flux, according to the formula,

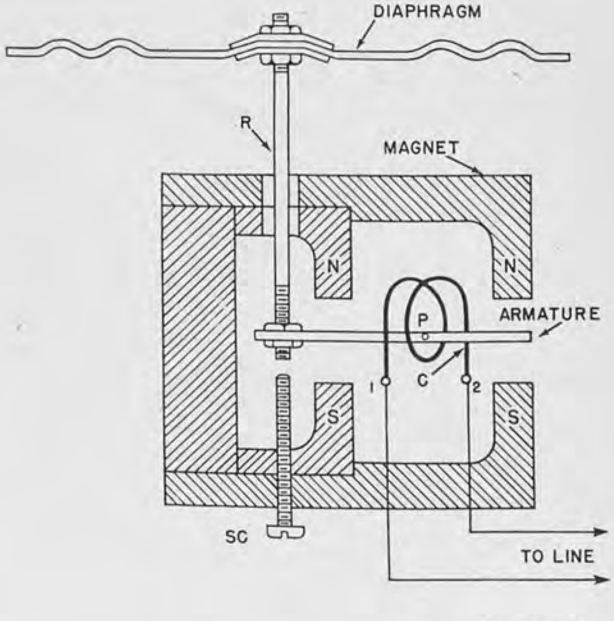


Figure 201. Sound-powered unit.

$$e = -\frac{Nd\emptyset}{dt} \times 10^{-8}.$$

The motion required to change the flux linkages is derived from the acoustical power driving the diaphragm.

171. Operation

a. Assume that the transmitter diaphragm is moving up and down at a rate corresponding to a single-frequency, sine-wave audio note. Figure 202 shows 1 cycle of this action. When the diaphragm is at its maximum downward position, as in A, the induced voltage is zero, since the movement of the armature has stopped momentarily and the rate of change of flux is zero. As the diaphragm then swings upward through its center position, as in B, the rate of change of flux is at a maximum, since it is changing direction; that

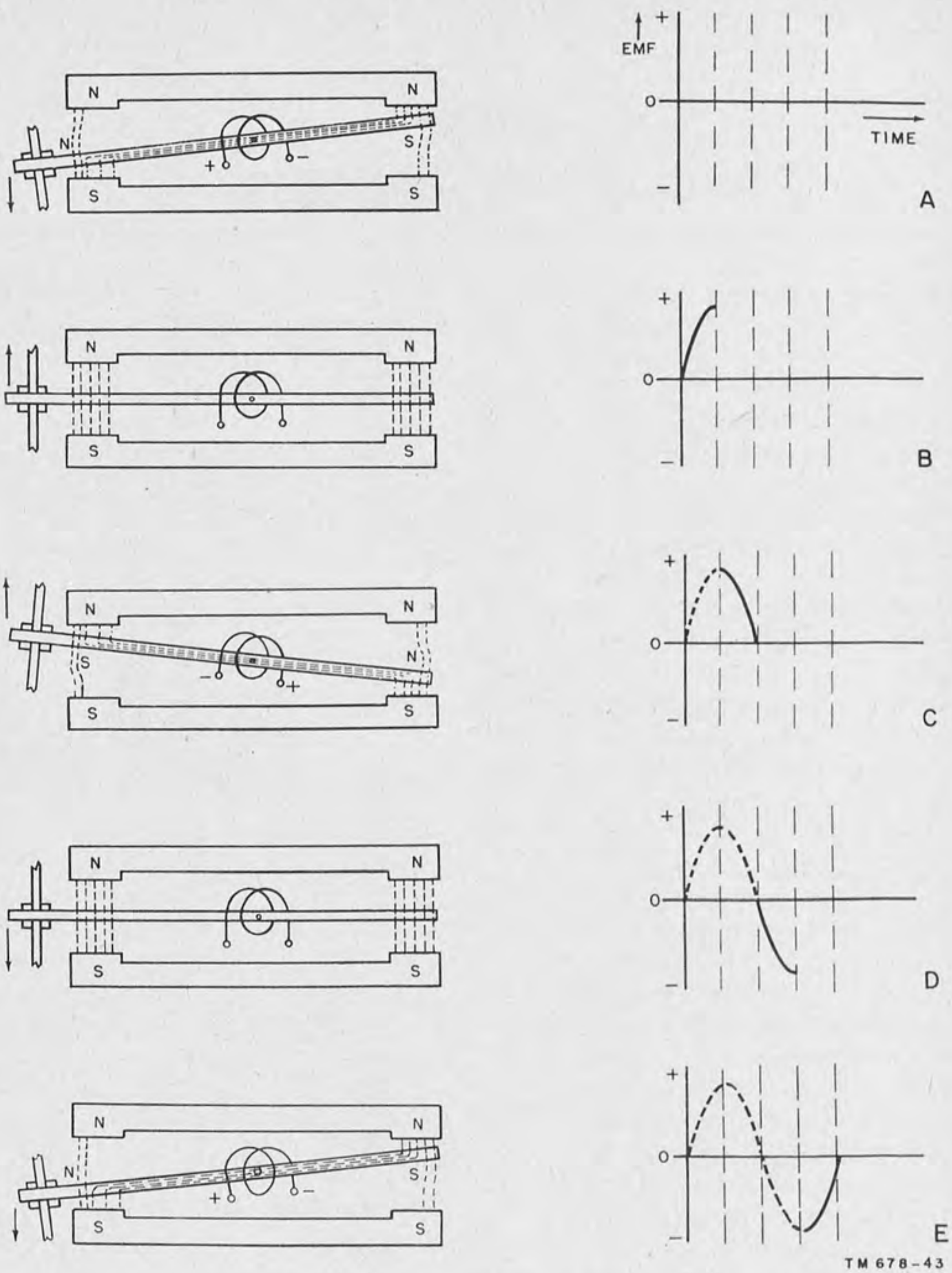


Figure 202. Electromagnetic induction in sound-powered unit.

is, the S pole of the armature becomes N and the N pole becomes S. The induced voltage is, therefore, a maximum. As the diaphragm stops momentarily at its maximum upward position, as in C, the induced voltage again becomes zero, since the rate of change of flux is zero. Continuing through the rest of the cycle, as the diaphragm passes its center position again, as in D, but from the opposite direction, the induced voltage is a maximum in the opposite direction. The induced voltage is zero again as the diaphragm again reaches its maximum downward position, as in E. This action repeats for succeeding cycles of the audio note.

b. The illustrations of figure 202 refer to a simple sound wave of a single frequency. When the sound waves striking the diaphragm are *complex*, as is always the case with speech sounds, the vibrations of the armature also are complex. If the transmitter is designed so that its response to all frequencies in the speech range is essentially the same, the waveshape of the induced emf will be a faithful reproduction of the waveshape of the sound striking the diaphragm. Therefore, the operation described applies to complex waves as well as to simple waves.

c. The alternate counterclockwise and clockwise rotation of the armature results in the induction of a corresponding emf in the coil. This is true whether the ends of the coil are open-circuited (not connected to an external load) or terminated in a load. If the coil is not connected to a load, no current will flow in the coil. However, when a load, such as a transmission line terminated by a receiver, is connected to the coil, the induced emf causes an alternating current of similar waveshape to flow in the coil, in the line, and in the receiver.

172. Sound-Powered Receiver

a. Structure. The structure of the *sound-powered receiver* is identical with that of the transmitter described in the preceding paragraphs. The same unit therefore can be used either as a transmitter or a receiver in a sound-powered system.

b. Operating Principle.

(1) Although the sound-powered receiver is identical in structure with the sound-powered transmitter, the principle on which its operation is based is different. A, figure 203, indicates that when a coil is wound around a soft-iron armature, and current is introduced in the coil, a magnetic field builds up around the coil. The magnetic lines of force through the armature make it an electromagnet. When the north pole of this electromagnet is brought near the south pole of another magnet, a force of attraction is produced and, if the electromagnet is pivoted at its center so that it is free to rotate, the force of attraction causes a counterclockwise rotation of the electromagnet shown in B. If the north pole of the electromagnet is used instead, a force of repulsion will be produced, causing a clockwise rotation of the electromagnet. The sound-powered receiver contains an electromagnet (acting as an armature) moved by forces of both attraction and repulsion.

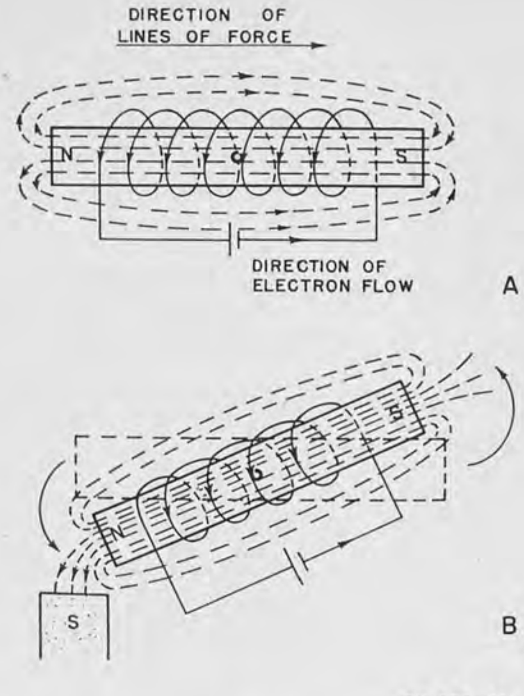


Figure 203. Magnetic field around current-bearing solenoid.

(2) The polarity of an electromagnet can be determined by applying the following rule: When the coil is grasped with the *left hand* so that the fingers encircle it in the direction in which the electrons are moving, the outstretched thumb points in the direction of the north pole.

173. Operation of Sound-Powered Receiver

The application of the electromagnet principle to the sound-powered receiver is shown in figure 204.

a. The single cycle of alternating emf induced in the coil of the transmitter unit, as previously stated, causes an alternating current to flow through the transmission line into the coil of the receiver unit. At the beginning of a cycle, when the current has zero value, as in A, no magnetic field is produced around the armature (electromagnet) and, consequently, it exhibits no polarity. No interaction takes place between the armature and the permanent magnet, and the armature is at its horizontal, *in-between* position of rest. The armature is coupled to the diaphragm in such a manner that it also has its in-between position of rest.

b. The current now begins to increase, as in B.

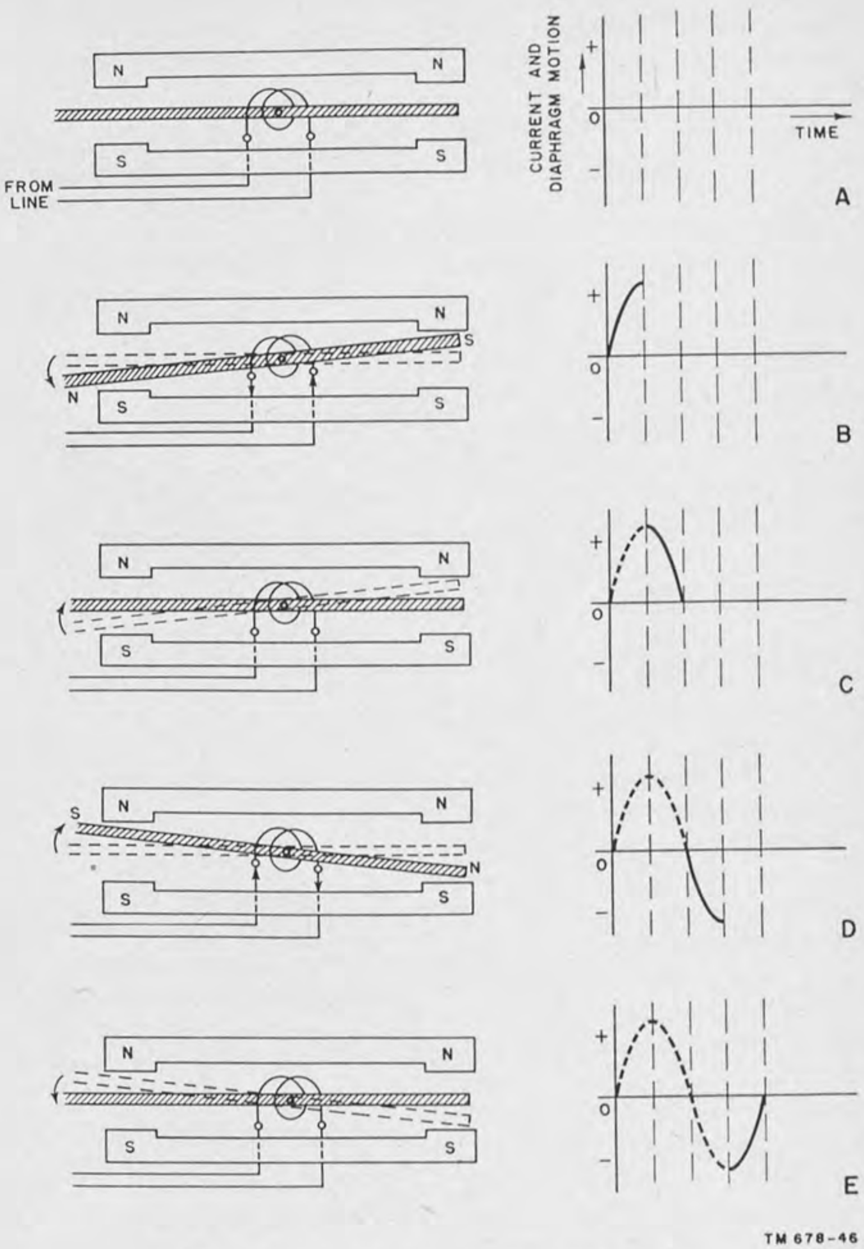


Figure 204. Action of sound-powered receiver.

Assume that the direction of the current is such that the left end of the armature becomes a north pole. The armature rotates counterclockwise, its left end moves downward, being repelled by the left north pole and attracted by the left south pole of the permanent magnet, and, at the same time, the right end of the armature (now a south pole) moves upward because of a similar interaction with the permanent magnet. As the current approaches its maximum value, the downward displacement of the left side of the armature and the diaphragm to which it is coupled mechanically approach maximum.

c. After reaching its maximum value, the current, though still flowing in the same direction, decreases toward zero, as in C. As it does so, the magnetic field around the armature decreases or becomes weaker, and thus the forces acting to rotate the armature are diminished. When the armature is moved from its normal position in either a clockwise or a counterclockwise direction, a force is transmitted from the armature to the diaphragm through the mechanical coupling, E (fig. 201). This force will cause the diaphragm to bend at its center in a direction determined by the direction of the applied force. As the forces diminish between the permanent magnet and the armature, the diaphragm tends to return to its normal position; in doing this, it acts through the mechanical coupling to restore the armature to its normal position.

d. The current now changes direction and begins to increase negatively in magnitude, as in D. The change in direction reverses the polarity of the electromagnet, the armature rotates clockwise, and the left end moves up from its in-between position of rest. When the current becomes maximum in this opposite direction, the diaphragm reaches its maximum upward displacement.

e. After reaching maximum, the current again begins to decrease toward zero, as in E. The strength of the armature field diminishes, allowing the armature to be returned toward its neutral position. The left end of the armature and the diaphragm move downward until, at the instant the current reaches zero, they again reach their in-between position of rest. This instant coincides with the end of a complete cycle of current, armature motion, and diaphragm displacement.

f. Thus, the diaphragm vibrates down and up in accordance with variations of current in the receiver coil. Successive vibrations of the diaphragm produce alternate condensations and rarefactions of the adjacent air particles, and so generate sound waves having variations of amplitude and frequency which correspond to those of the current waves. Since the current waves are of the same form as the voltage waves generated at the transmitter, the sound waves produced by the vibration of the diaphragm of the receiver are essentially of the same waveshape as those introduced at the transmitter.

g. The explanation just given is based on the flow of a simple sine-wave current, but the operation of the sound-powered receiver is essentially the same for the actual complex waves involved in the transmission of speech.

174. Simple Sound-Powered System

An extremely simple sound-powered system suitable for two-way communication may consist of two identical sound-powered units connected by a transmission line (fig. 205). The transmission line is connected to the coils of the two units at stations A and B. Operation requires no battery or other external source of power. For conversation, each person uses his unit as a transmitter when he wishes to speak, and as a receiver

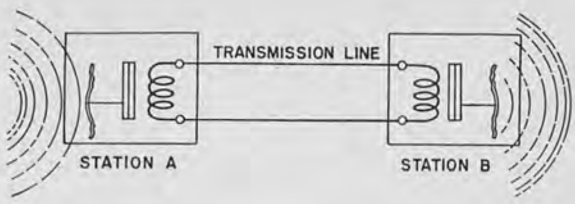


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Figure 205. Simple sound-powered system.

when he wishes to hear the works spoken at the other end of the line. However, an important component of a practical telephone system is missing—a means for signaling or ringing to initiate a conversation. This omission makes the system impractical, except for special applications where signaling is not important. Crews installing tower antennas, for example, may use sound-powered systems for convenient communication between the tower and the point where the set is being adjusted.

175. Practical Sound-Powered System

a. Description. The *practical sound-powered telephone circuit* shown in figure 206 consists of three parallel branches. One branch contains a sound-powered handset in series with the line through capacitor C1; the second branch contains the ringer in series with capacitor C2 and a neon lamp; the third branch contains a hand generator.

(1) The handset is connected permanently across the line in series with capacitor C1, usually of .5-μf capacity. Since the impedance of this capacitor is relatively high at low frequencies, capacitor C1 limits the low-frequency signaling current through the handset and blocks dc. However, at voice frequencies, C1 has a relatively low impedance and does not limit the voice-frequency currents appreciably.

(2) The ringer, capacitor C2, and the neon lamp which constitute the second parallel branch operate on 16- to 20-cycle ac. Screw switch S1 permits the lamp to be shorted out, making possible the use of either lamp or bell for signaling, to suit the tactical situation. When the switch is in the (open) position indicated, the lamp is in series with capacitor C2 and the ringer. Since the lamp offers a rela-

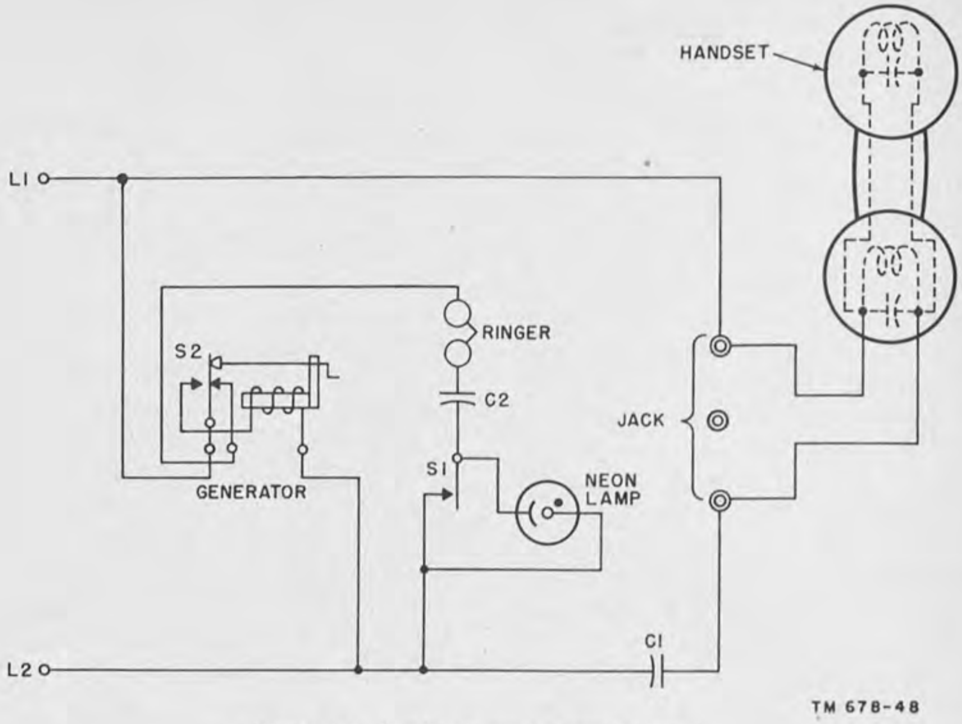

Figure 206. Practical sound-powered circuit.

tively high impedance to the ringing current, the ringer will not operate in this position; however, because the lamp requires only a small current to operate, it will light when ringing current from a distant telephone is applied. When the switch is thrown to the other (closed) position, the lamp is shorted out and the ringer will operate. The inductance of the ringer circuit offers low impedance to the low-frequency ringing current, but high impedance to the voice-frequency currents; consequently, it does not interfere with voice transmission. Capacitor C_2 is usually of 1.9-μf capacity. It is used to prevent dc from magnetizing the ringer coils and interfering with proper operation. It also helps to balance the line impedance.

(3) The third branch contains a generator used to generate the low-frequency ringing current for signaling the distant telephone. The generator switch connects the generator across the line and disconnects the adjoining ringing circuit, so that the ringing current produced by the generator cannot pass through the ringer of the same telephone. The indicated position of the switch shows the generator removed from the line for normal operation of the talking circuit. The generator is of the magneto type previously described.

b. Normal Operation. For normal operation in a practical sound-powered system, two sound-powered handsets are connected to form a complete circuit. When the telephones are used on a two-conductor line (a metallic circuit), the ends of the conductors are connected to binding posts L1 and L2 at each end of the line (only one pair shown in fig. 206). When the telephones are installed on a single-conductor line (a ground-return circuit), the ends of the single conductor are connected to binding post L1 (or L2), and the other binding posts are connected to good grounds.

c. Modern Sound-Powered Handset. Figure 207 is an exploded view of a handset used with one of the commonly used sound-powered telephone systems. The transmitter and receiver units of the handset are not interchangeable. They are designed in such a way that they cannot be inserted in the wrong place, and they differ in the kind of acoustical openings placed over the diaphragm. Each unit is held in place by a plastic cap and retainer ring.

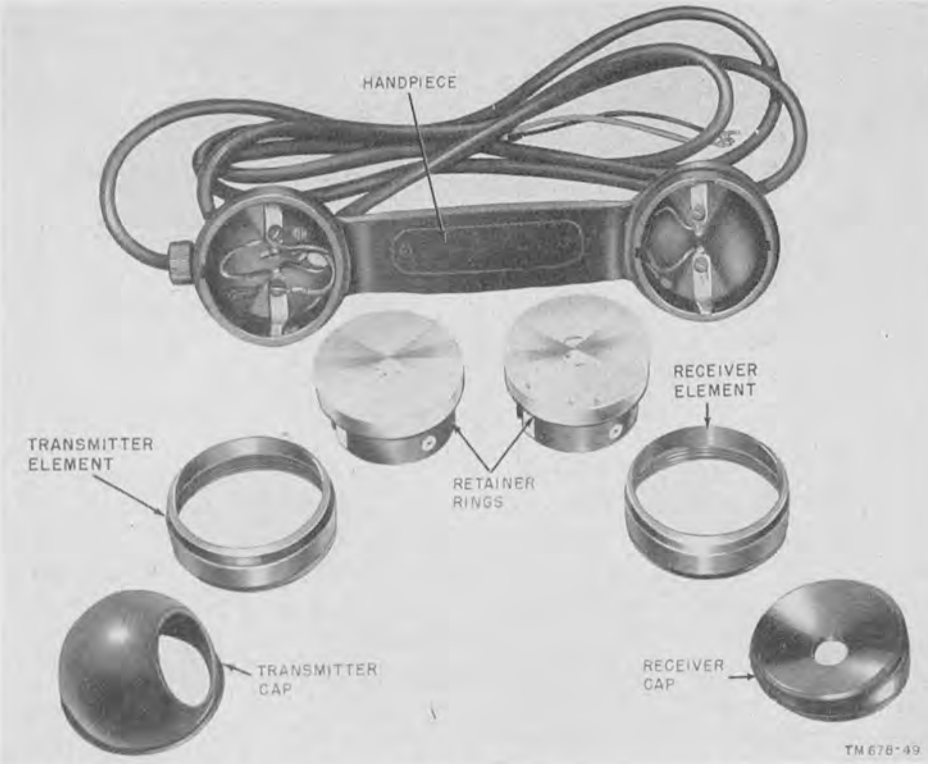

Figure 207. Exploded view of modern sound-powered handset.

176. Comparison of Battery- and Sound-Powered Telephone Systems

a. Advantages of Sound-Powered Telephone Systems. The most obvious advantage of sound-powered over battery-powered telephone systems is the fact that they do not require batteries or similar sources of power. This feature gives them applications which the other types do not have. Sound-powered systems possess other advantages, however. The transmitter and receiver units used in them usually are more rugged. They are less likely to produce distortion of the waveforms of the incident sound, and this makes the sound generated by the receiver a closer reproduction of the sound introduced at the transmitter. They have a better frequency response, which helps to improve the quality of the sound reproduced by the receiver. Finally, they are more compact, which is a decided advantage where portability is an important consideration.

b. Limitations of Sound-Powered Telephone Systems. The greatest limitation of sound-powered systems, and one which may outweigh all their advantages, is the relatively short distance over which they can be used. This limitation arises from the fact that the emf induced in the coil of the sound-powered transmitter is much smaller than the emf induced in the secondary of the induction coil in the carbon transmitter. For incident sounds of normal intensity, the induced emf is approximately 25 millivolts. This means that the current flowing in the transmitter coil is extremely small, and the current reaching the receiver coil is still smaller, because of the losses involved in transmission over wires. In order to reduce these losses to a degree that allows the current in the receiver coil to be sufficiently large to operate the receiver properly, the line length must be held to a minimum. This consideration restricts the use of sound-powered systems to distances of about 4 miles of Army field wire. One method of overcoming this limitation might be to speak more loudly, if possible; but this would overburden the speakers, and would be scientifically impractical, since it would make for greater distortion of the sound. Another method of overcoming the distance restriction would entail the use of amplifiers, but this would add to costs and remove the important advantage of portability. As long as a sound-powered system is operated within its limitations, satisfactory communication can be achieved.

177. Summary

a. Sound-powered telephone systems provide a convenient means of communication, since they do not require batteries or other external sources of power.

b. Sound-powered transmitters operate on the same principle that governs the operation of electric generators. Sound waves, striking the diaphragm of the transmitter, cause it to vibrate. This vibration is transferred to an armature that moves within a magnetic field. When a coil is wound around the armature, the resulting vibration of the coil within the magnetic field causes an alternating emf to be induced in the coil.

c. When the sound-powered transmitter coil is connected to a sound-powered receiver by means of a transmission line, the alternating emf induced in the coil results in the flow of alternating current of similar waveform in the circuit.

d. The sound-powered receiver is an electromagnetic device. The alternating current flowing in the receiver coil sets up a varying magnetic field around the coil. This field interacts with the field of a permanent magnet and produces vibration of a soft-iron armature within the field. The vibration is transferred to a diaphragm, resulting in the reproduction of sound waves of similar waveform to the current in the coil.

e. Simple sound-powered systems consist of two identical units, one serving as the transmitter and the other as the receiver.

f. The more practical systems include provisions for signaling from one station to the other. They contain generators for producing the ringing current, and ringers for alerting personnel.

g. Besides the obvious advantage of not requiring external sources of power for their operation, sound-powered systems possess the additional advantage of more rugged components, better frequency response, and portability.

h. The chief limitation of sound-powered systems is the relatively small distance over which they may be operated. This is because the alternating emf induced in the transmitter coil is very small, resulting in correspondingly small currents in the coil of the receiver at the distant station.

178. Review Questions

a. What is meant by the term *sound-powered?*

b. Discuss briefly, with the aid of a diagram, the operating principle of the sound-powered transmitter.

c. On what factors does the magnitude of the emf induced in the coil of this type of transmitter depend?

d. Why is a soft-iron armature used in the sound-powered unit?

e. Under what condition will the emf induced in the coil of the transmitter cause a corresponding flow of current?

f. Discuss briefly, with the aid of a diagram, the operating principle of the sound-powered receiver.

g. Is the diaphragm used in the sound-powered receiver constructed of a magnetic material? Explain.

h. Explain why the same unit may be used as either transmitter or receiver in a sound-powered system.

i. Referring to figure 206, explain briefly the function of the following components: capacitor C1, screw switch S1, the generator switch, and capacitor C2.

j. Does the path containing the ringer offer a relatively high or low impedance to (1) voice currents, (2) ringing current? Explain.

k. Draw a block diagram of a simple sound-powered system.

l. What are some possible applications of sound-powered systems?

m. List some of the advantages of sound-powered systems over battery-powered systems.

n. What is the major limitation of sound-powered systems?

o. What are the objections to attempting to increase the distance over which sound-powered telephones can be used effectively by (1) speaking more loudly, (2) using amplifiers along the line?

CHAPTER 8

TRANSMISSION LINES

179. Introduction

The preceding chapters have discussed all the basic elements of the local- and common-battery telephone systems except one—the transmission line. Telephone sets, switchboards, and their components were explained in detail, but the transmission line was considered only as a metallic conductor for signals traveling between the individual telephone sets and the interconnecting switchboard. The transmission line is a major element in all telephone systems, however, for it presents problems which vitally affect practical operation. Chief among these problems are the power losses along the lines, and the distortion and interference which result from interaction between adjacent lines. This chapter explains these problems and their solutions.

180. Types of Transmission Lines

Before considering the electrical characteristics of transmission lines, this paragraph describes the physical characteristics of some of the types of lines in common use. Three main classes of transmission lines are used in military telephone installations: open-wire lines, cables, and field wires.

a. Open-Wire Lines.

(1) Open-wire lines are parallel bare conductors strung on electrical insulators mounted on the cross arms of telephone poles, as shown in figure 208. The wires may be made of hard-drawn copper, steel, copper-galvanized steel, or iron. Two wires constitute a line. The two wires of a line are spaced a standard distance apart, usually 8 inches. When more than one pair of wires are strung on the same poles, the spacing between wires usually is 10 or 12 inches, depending on the type of cross arm in use.

(2) The wire diameters most frequently used for open-wire lines range from 80 mils to 165 mils (1 mil is equivalent to 1/1,000 inch).

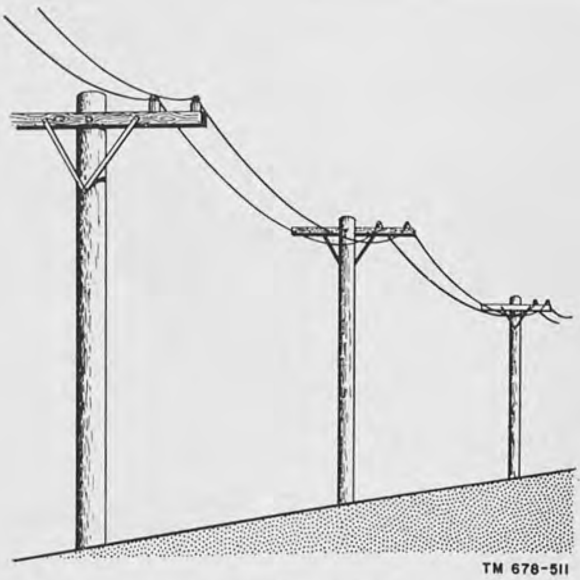

Figure 208. Open-wire line.

b. Cables. Cables may be described as consisting of one or more pairs of wires, each wire individually insulated; the wires of a pair are twisted together, the pairs usually are twisted together, and the entire group is covered with an outer covering. Two types of cable frequently used in military installations are illustrated in figure 209.

(1) *Spiral-four cable* contains four conductors, in two pairs (fig. 209). Each conductor is made up of seven strands of copper, and is covered with a polyethylene insulation. The insulation on one pair of conductors is light colored, and that on the other pair is dark, to facilitate identification of circuits. The insulated conductors are spiraled around a polyethylene core. A polyethylene *belt* surrounds the spiraled conductors, and is in turn surrounded by black carbon tape. Around the tape is a stainless-steel braid, to provide mechanical strength for the cable. This is covered by an outer jacket of vinyl.

(2) *Five-pair rubber cable* contains ten conductors, arranged in five pairs, as shown.

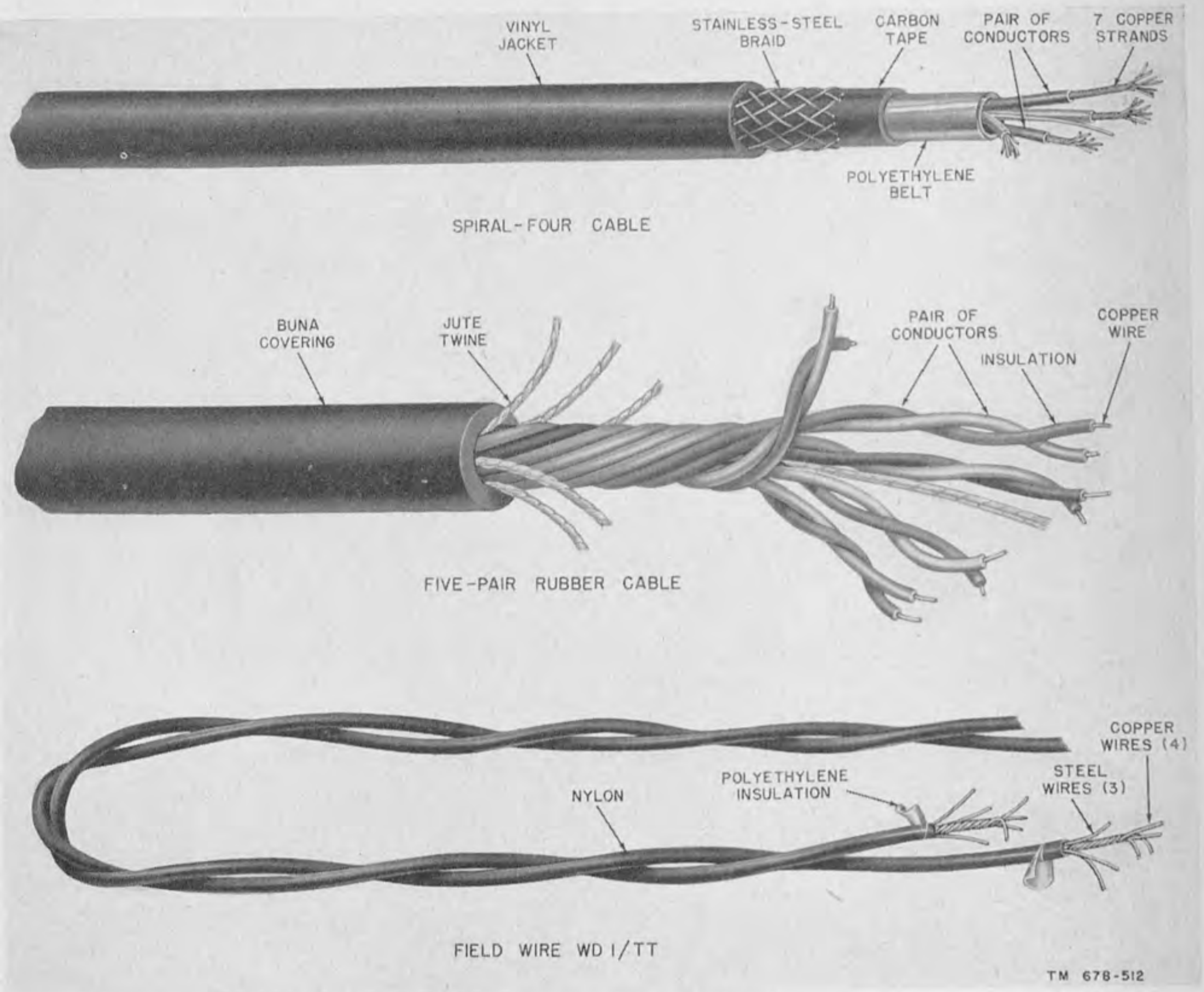

Figure 209. Types of cables.

Each conductor is a tinned solid-copper wire, covered with rubber or latex insulation. The insulation on one wire of each pair is white and the insulation on the other wires is color-coded for identification, a different color insulation being used for each wire—red, yellow, green, blue, and black. The outer covering is made of buna (a synthetic rubber), which incloses, in addition to the ten conductors, five strands of jute twine, inserted as filler and for mechanical strength.

(3) *Toll cable* (not illustrated) differs from the two types just described primarily in that its outermost covering is made of lead. In general, it is used in permanent installations for long-distance transmission, and either may be strung overhead on poles, or installed underground. The conductors usually are twisted pairs of annealed copper wire, insulated either by spirally wound paper tape or by a covering formed on the wires from paper pulp. The wire sizes customarily used are #19 and #16 AWG, although smaller wires sometimes are used for short distances.

c. Field-Wire Lines. Field wires consist of simple pairs of insulated wire twisted together. Field-wire lines are used in military applications for emergency and temporary installations. They are used primarily for short lines, because of their high transmission loss. The military designations for the field wires most commonly used are W–110–B, WD–14/TT, and WD–1/TT (the latter type illustrated in fig. 209). Each of the two conductors has seven strands, of which four are copper and three are steel. Each seven strand conductor is covered with polyethylene insulation and an outer protective covering of nylon.

d. Talking Range of Lines. Although field

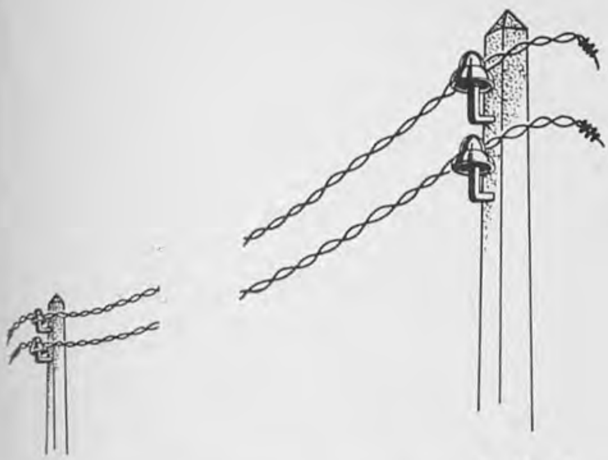

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Figure 210. Arrangement of twin pair.

wires as a rule are used as single pairs, two pairs occasionally are used in order to extend the talking range (fig. 210). The two wires of one pair are connected to form one conductor of the line, and the two wires of the other pair are connected to form the other conductor of the line. In this way, the resistance of the line is cut in half, thus extending its useful range. The talking ranges under various operating conditions of a single pair and of a twin pair (of wires) are shown in the table below. The range for wire laid on the ground is lower than the range for the same wire strung above the ground. Wetness (rain or, sometimes, heavy dew) greatly reduces the range of all the wires when they are used without insulators.

Wire	Single pair (in miles)		Twin pair (in miles)					
	Conditions		Strung on poles with insulators (8-inch spacing)		Strung on trees without insulators (8- to 24-inch spacing)		Laid on ground (8- to 24-inch spacing)	
	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry
W-110-B	11	18	65	65	25	65	15	65
WD-14/TT	12	20	70	70	27	70	17	70
WD-1/TT	12	20	70	70	27	70	17	70

181. Characteristics of Transmission Line

a. Electrical Length of Line. An important characteristic of a transmission line, significant in determining its behavior, is its *electrical length.* The electrical length expresses the relationship between the length of a line and the wavelength of the signal being transmitted over the line. The wavelength of an electrical wave is defined as the velocity with which the wave is traveling along the conductor divided by the frequency of the signal, or

$$\text{wavelength} = \frac{\text{velocity}}{\text{frequency}}$$

The velocity of propagation at 1,000 cycles per second on open-wire lines varies from 176,000 to 180,000 miles per second, approximately; on nonloaded toll cables, it varies from 47,600 to 65,300 miles per second, approximately, for the sizes customarily used.

(1) *Short lines.* A *short line* may be defined as one in which the length of the line is considerably shorter than the wavelength of the transmitted signal. A, figure 211, represents a line that is *electrically short.* This line is 1 loop mile in length. The signal applied to the sending end of the line has a frequency of 1,000 cycles; therefore, if the velocity is assumed to be 180,000 miles per second, the wavelength of the signal is 180 miles, or the 1-mile line is 1/180 of a wavelength electrically. A line 1 mile long having a velocity of propagation of 60,000 miles per second is 1/60 of a wavelength electrically. Although both lines, or pairs, are 1 mile in physical length, the slower circuit is electrically three times as long as the faster circuit. Note that electrical length as defined here is based on phase change per unit length, in contrast to electrical length based on attenuation per unit length.

(2) *Long lines.* A *long line* may be defined as one in which the length of the line is approximately equal to, or longer than, the wavelength of the transmitted signal. B, figure 211, represents a line that is electrically long, for the line is 360 miles in length and it carries a 1,000-cycle signal having a wavelength of 180 miles. As the wave travels along this line, *two complete* voltage and current waves exist on it at any single instant of time. Under different circumstances, the same line may behave either as an electrically short or an electrically long line. For example, if the line shown in A, figure 211, is ener-

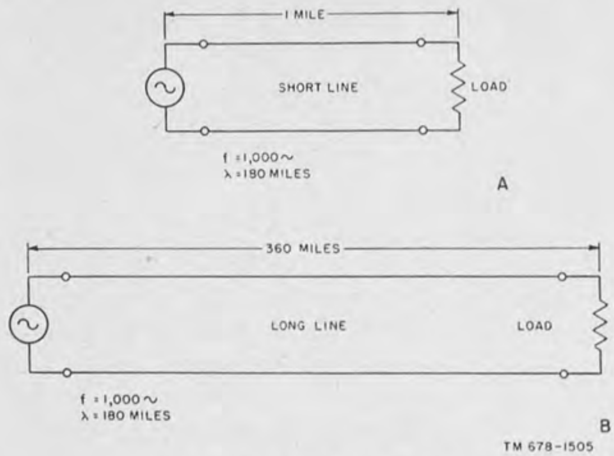

Figure 211. Short and long lines.

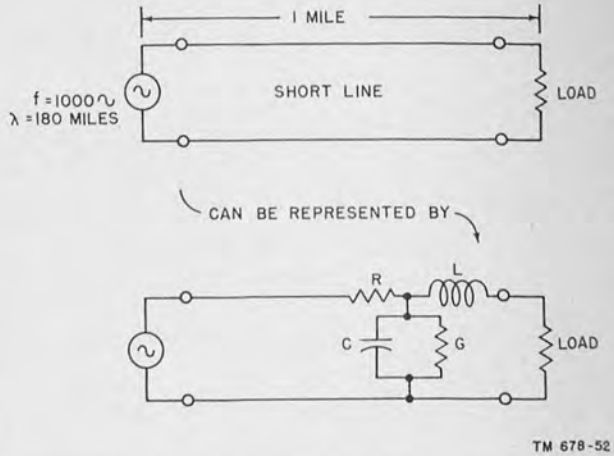

Figure 212. Short line and its equivalent circuit (lumped constants).

gized by a signal having a frequency of 200,000 cycles, corresponding to a wavelength of .9 mile, it is considered (and behaves like) a long line; or, if the line shown in B is energized by a signal having a frequency of 60 cycles, corresponding to a wavelength of 3,000 miles, it is considered (and behaves like) a short line.

b. Line Parameters. Transmission lines, because of their basic structure, possess certain *line parameters.* These parameters, commonly called *constants*, comprise series resistance, R, series inductance, L, shunt capacitance, C, and shunt-leakage conductance, G—all these with respect to a unit length, usually a mile. The numerical values of these constants not only depend on the size of the conductors, their spacing, and insulation, but also vary with the frequency of the transmitted signal and the weather conditions.

(1) *Constants.* The four line parameters mentioned above are distributed along the entire length of the line and for this reason are called *distributed constants.* If the parameters had been concentrated in one place, for example, the way a resistor concentrates resistance, they would have been called *lumped constants.* In the study of transmission lines, a transmission line is shown in the form of an equivalent circuit in which the distrib-

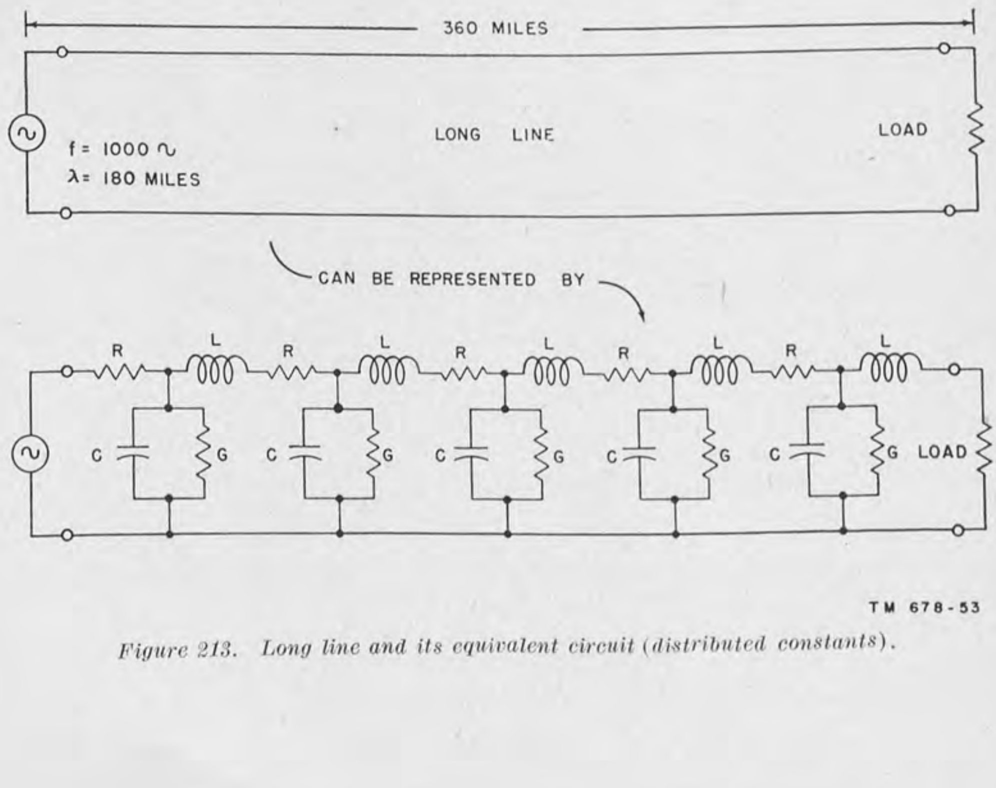

Figure 213. Long line and its equivalent circuit (distributed constants).

uted constants for a given length are shown in the form of lumped constants (fig. 212). The series resistance, R, series inductance, L, shunt capacitance, C, and shunt conductance, G, for a unit length of 1 mile, are shown as lumped constants. A long transmission line can be considered to be made up of a series of unit sections (fig. 213). In this case, five sections are used to represent the 360-mile line so that each section represents a 72-mile length of the line. Any convenient length can be used as the unit length, but 1 mile is the preferred length. By using this method to represent transmission lines, the study of their behavior is simplified greatly.

(2) *Values for distributed constants.* Values for distributed constants of commonly used open-wire lines and nonloaded cables are given in the table below. Note that as the wire diameter of an open-wire line increases, the series resistance decreases appreciably and the series inductance decreases only slightly; the shunt capacitance increases slightly and the shunt conductance does not change. This is because the shunt conductance is actually leakage conductance, and depends only on the nature of the insulating material separating the wires. In the case of cables, only the series resistance decreases as the wire size increases (lower gage number), the other constants remaining essentially constant.

Type of line	Size of wire and spacing	Distributed constants per loop mile			
		R (ohms)	L (henrys)	C (microfarads)	G (micrhighs)
Open-wire	104 mils = 8 inches.	10. 36	. 00340	. 00905	. 29
	128 mils = 8 inches.	6. 87	. 00327	. 00944	. 29
	165 mils = 8 inches.	4. 19	. 00310	. 00996	. 29
Nonloaded cable.	#19 AWG	86. 0	. 001	. 062	1. 4
	#16 AWG	42. 0	. 001	. 062	1. 4

182. Characteristic Impedance

The *characteristic impedance*, Z_O, of a network is the value of *load* impedance which makes the impedance at the *input* terminals of the network equal to the load impedance. The tee and pi sections of figure 214 help to explain this. For example, in the tee section of A, the load impedance, Z_R, is 600 ohms. This resistor is in series with the right-hand 200-ohm resistor of the section, making a combined resistance of 800 ohms. Combining this resistance with the 800-ohm shunt resistor of the section gives 400 ohms. Finally, by adding the left-hand 200-ohms resistor to 400 ohms, the input resistance, Z_S, is found to be 600 ohms. Since this is the same value as the terminating or load resistance, the characteristic impedance of this tee section is said to be 600 ohms. A similar calculation can be made for the pi section shown in B, the characteristic impedance of which is also 600 ohms. Since a change in the values of the elements of the network changes its characteristic impedance, the characteristic impedance of a network is a property which depends on the elements or constants of the network.

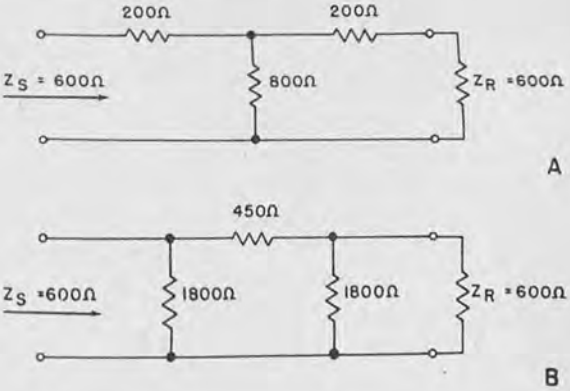

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Figure 214. Tee and pi sections terminated in Zo.

a. Long Lines. The characteristic impedance of a long line is determined by its distributed constants. Depending on the type of line, the characteristic impedance may be nearly a pure resistance, as in the case of low-loss open-wire lines, or may consist of both resistance and capacitive reactance, as in the case of cables. For example, the characteristic impedance of a 165-mil, two-wire, open-wire line at a frequency of 1,000 cycles comprises a resistance of 562 ohms and a capacitive reactance of 58 ohms. Note that the resistance is nearly 10 times the capacitive reactance. On the other hand, the characteristic impedance of a 19-gage cable at the same frequency comprises a resistance of 340 ohms and a capacitive reactance of 314 ohms. It is this quality of cables that accounts for the low wave-propagation velocity of signals transmitted over them.

b. Characteristic Impedance. Figure 215 aids in understanding the development of the characteristic impedance of a long line. In order to simplify the calculations, the basic section of the line is represented as a tee section containing only resistance. If the single section shown in A is open-circuited, the sending end, or input impedance, E_S, is 200 ohms in series with 800 ohms, or 1,000 ohms. If a second section now is connected to the input terminals of the first section, as in B, the right-hand 200-ohm resistance of this second section adds to the 1,000-ohm input resistance of the first section, giving a combined resistance of 1,200 ohms. This is combined in parallel with the shunt resistance of 800 ohms, making the equivalent resistance 480 ohms. Finally, adding this in series with the left-hand 200-ohm resistance, the input resistance for the two sections is found to be 680 ohms. Using a similar sequence of calculations, the input impedance for three sections can be shown to be 620 ohms, as in C. As more sections are added, the input impedance decreases slowly, approaching a steady value of 600 ohms in D. This value is the *characteristic impedance* of the long line.

c. Impedance Measurements. The characteris-

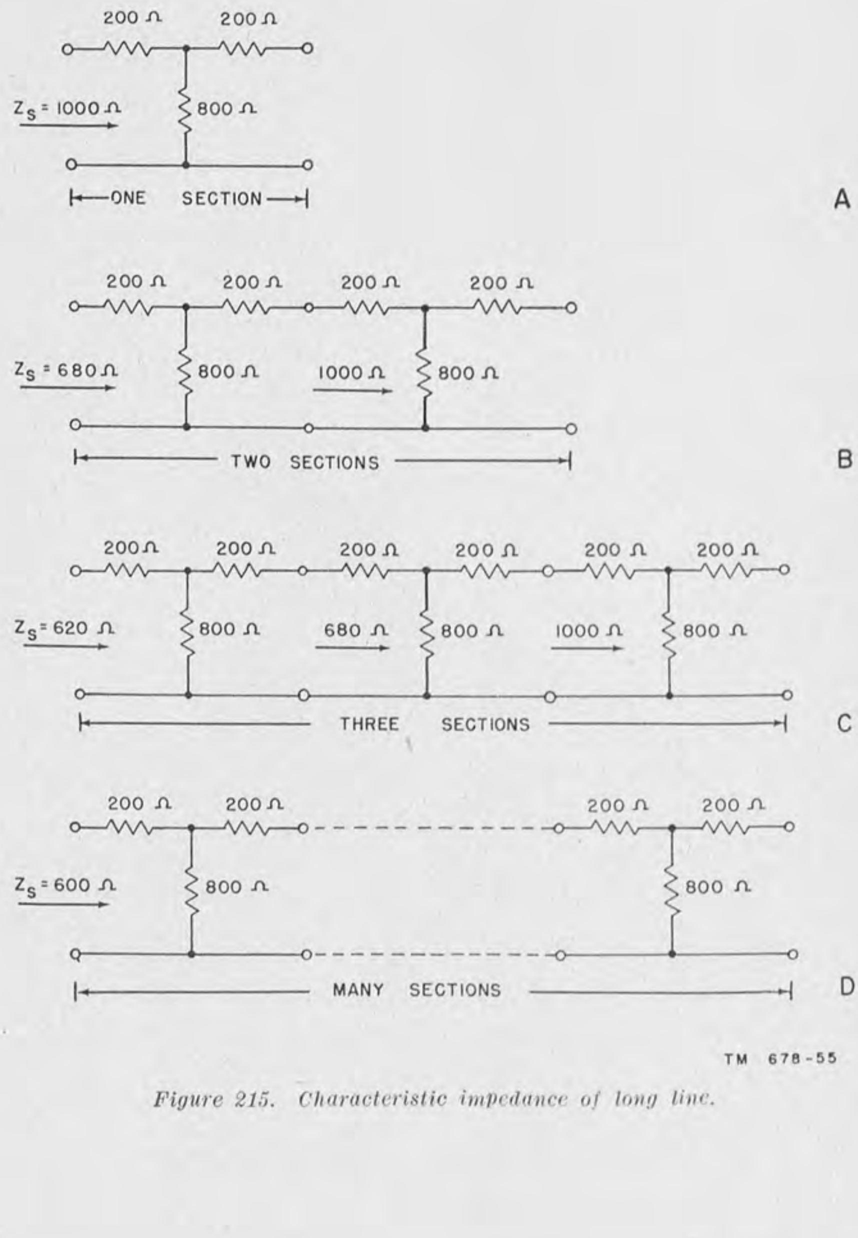


Figure 215. Characteristic impedance of long line.

tic impedance of an open-wire line or cable can be determined by making two impedance measurements. First, the impedance at the sending (near) end is measured with the receiving (distant) end open-circuited. This gives the *open-circuit impedance*, Z_{OC}. Then the imepdance at the sending end is measured with the distant end short-circuited. This gives the *short-circuited impedance*, Z_{SC}. The characteristic impedance can be calculated from these two measured impedances by using the following formula:

$$Z_O = \sqrt{Z_{OC} Z_{SC}}$$

In A, Z_{OC} for the single section is 1,000 ohms, and Z_{SC} is 200 ohms in series with the combined resistance of 200 ohms and 800 ohms in parallel, or 360 ohms. Substituting these two values in the formula, Z_O is found to be $\sqrt{1{,}000 \text{ times } 360}$, or 600 ohms. In other words, for a uniform line, the characteristic impedance of the entire line is the same as that of a single section of the line.

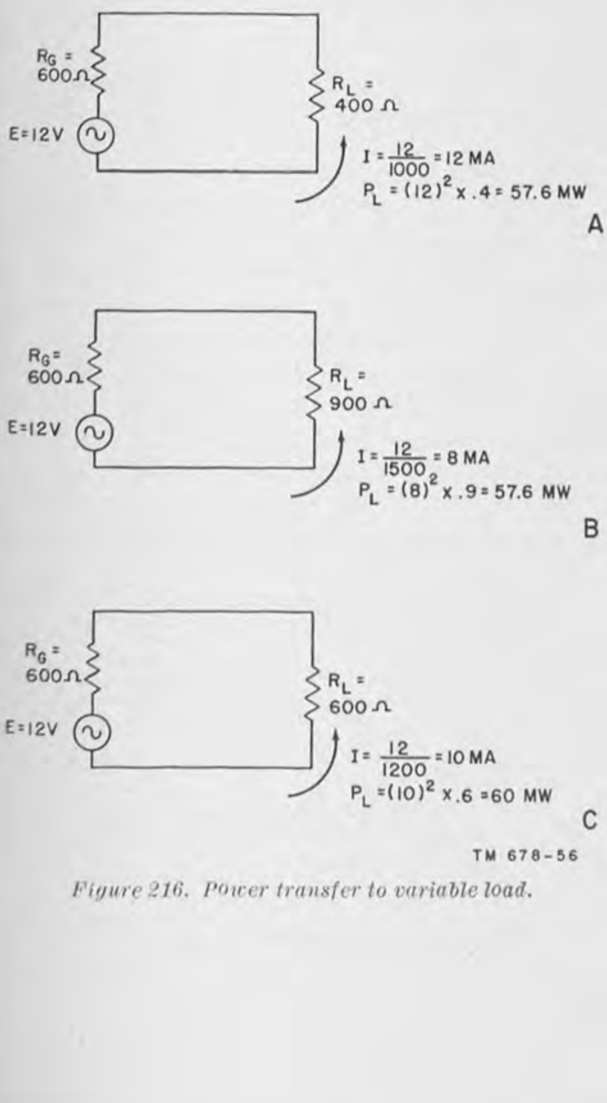


Figure 216. Power transfer to variable load.

183. Transfer of Power to Transmission Line

Since a transmission line may cause considerable power loss, it is important in telephone communications that lines be designed in such a way that maximum power is transferred from the transmitter to the receiver.

a. Maximum Power Transfer.

(1) The condition for maximum power transfer from a source to a load can be developed with the aid of figure 216. In A, a 12-volt generator with an internal resistance, R_G, of 600 ohms is connected to a load resistance, R_L, of 400 ohms. Applying Ohm's law, current I is 12/1,000 ampere, or 12 ma. The power delivered to the load is found by using the relation I^2R_L, where I is in ma, R_L is in kilohms, and P is in mw (milliwatts). The power delivered to the 400-ohm (.4 kilohm) load is 57.6 mw.

(2) B shows the same circuit with the load resistance changed to 900 ohms. The current is now 12/1,500 ampere, or 8 ma. The power delivered to the load is therefore $(8)^2$ times .9, or 57.6 mw. Note that this is the same load power as that produced for the conditions given in A.

(3) In C, the load is changed to 600 ohms, the same value as R_G. The current becomes 12/1,200 ampere, or 10 ma, and the load power is now $(10)^2$ times .6, or 60 mw. This is larger than the load power obtained under the conditions shown in A and B.

(4) If the load resistance is changed to values above and below 600 ohms, the corresponding values of power delivered to the load can be calculated by the method used in the previous examples. The results of such calculations are shown in the table below. From these data may be plotted a power-transfer curve, such as that of figure 217. It can be seen from the tabulation of load power versus load resistance that maximum power is transferred from a generator to a load *when the resistance of the load equals the internal resistance of the generator*. This relationship is called the *maximum power transfer theorem* for resistive networks.

Load resistance R_L (kilohms)	Load current (ma)	Load power (mw)
0.0	20. 0	0. 0
.1	17. 14	29. 5
.2	15. 0	45. 0
.3	13. 33	53. 5
.4	12. 0	57. 6
.5	10. 9	59. 5
.6	10. 0	60. 0 (max)
.7	9. 25	59. 8
.8	8. 6	59. 0
.9	8. 0	57. 6
1.0	7. 5	56. 2
1.1	7. 08	55. 0
1.2	6. 67	53. 3
1.3	6. 32	52. 0
1.4	6. 00	50. 4
1.5	5. 71	48. 9
1.6	5. 45	47. 7

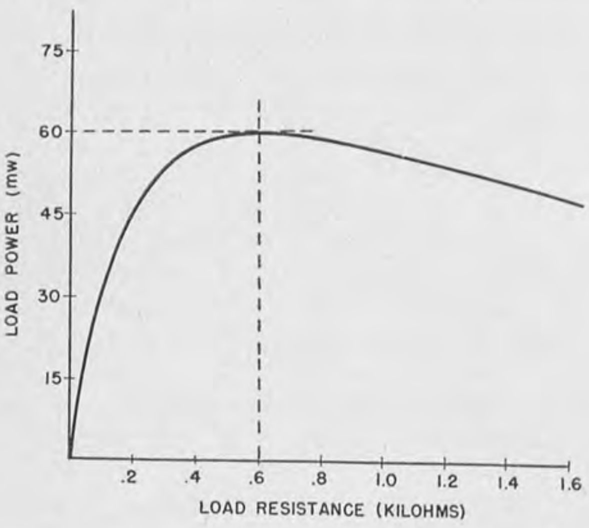


Figure 217. Variation of power transfer.

b. Application of Maximum Power Transfer Theorem to Transmission Line. Figure 218 illustrates the application of the maximum power transfer theorem to transmission lines. For simplicity, the transmission line under consideration is assumed to be replaced by a tee section composed of pure resistances. The characteristic impedance of such a section has been shown to be a pure resistance of 600 ohms (fig. 214).

(1) In A, figure 218, the line is shown to be terminated in a resistance of 66.7 ohms. By using the methods previously discussed for combining series-parallel resistances, the resistance at the input terminals of the line, Z_I, is found to be 400 ohms. From the table in *a*(4) above, the current and power in a 400-ohm resistance connected to a 12-volt generator in series with an internal resistance of 600 ohms are 12 ma and 57.6 mw, respectively. However, these are values for current and power at the *input* terminals of the circuit. By applying the laws of division of current in parallel circuits, the line current of 12 ma divides so that 3 ma flow through the shunt 800-ohm resistance of the tee section, and 9 ma flow through the actual load of 66.7 ohms. The power delivered to this load is therefore *5.4 mw.*

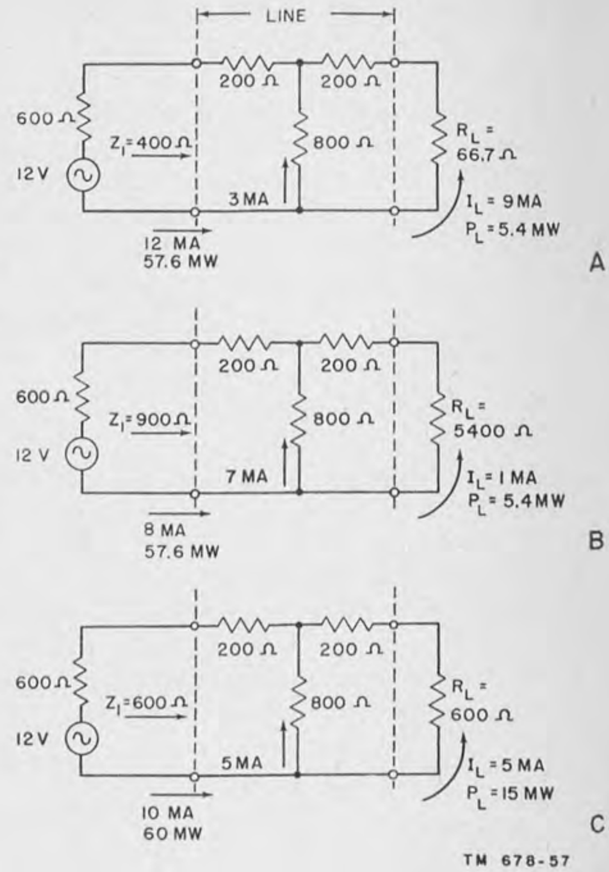


Figure 218. Power transfer from transmission line to load.

(2) In B, the load resistance is changed to 5,400 ohms. This value makes the resistance at the input terminals of the line 900 ohms. Therefore, the line current is 8 ma, and the power delivered to the input terminals of the line is 57.6 mw. Again,

applying the laws of division of current in parallel circuits, the current through the shunt 800-ohms resistance is found to be 7 ma, so that the load current is 1 ma. The load power again is shown to be 5.4 mw.

(3) Finally, in C, the line is terminated in 600 ohms, the characteristic resistance of the line. Therefore, the input resistance of the line is 600 ohms (by the definition of characteristic resistance). Referring to C, figure 218, the line current and the power delivered to the input terminals of the line are now 10 ma and 60 mw, respectively. Since the two parallel branches are equal in resistance (800 ohms), the load current is one-half of the line current, or 5 ma. This makes the load power $(5)^2$ times .6, or 15 mw. This is only one-fourth of the input power because of the attenuation of the line, but it is considerably greater than the load power obtained for the values of load impedance shown in A and B.

(4) The power delivered to a load resistance varied on either side of 600 ohms in such a circuit is tabulated in the table below. The tabulation shows that maximum power is transferred to the load by the transmission line when the line is terminated in its characteristic resistance (600 ohms, in this example). Note that, although the input power varies only slightly when the termination is not Z_o, the load power varies considerably from its maximum value. In order to reduce the line loss to a minimum, therefore, the line must be terminated in its characteristic impedance.

R_L (kilohms)	Input resistance (kilohms)	Line current (ma)	Load current (ma)	Input power (mw)	Load power (mw)	Line loss (mw)
0.0	0. 36	12. 5	10. 0	56. 1	0. 0	56. 1
.0667	. 4	12. 0	9. 0	57. 6	5. 4	52. 2
.28	. 5	10. 9	6. 81	59. 5	13. 0	46. 5
.6	. 6	10. 0	5. 0	60. 0	15. 0 (max)	45. 0 (min)
1.133	. 7	9. 25	3. 47	59. 8	13. 65	46. 15
2.2	. 8	8. 6	2. 15	59. 0	10. 2	48. 8
5.4	. 9	8. 0	1. 0	57. 6	5. 4	52. 2
	[1] 1. 0	7. 5	. 0	56. 2	. 0	56. 2

[1] Open circuit.

184. Attenuation

Attenuation is the term used to express the loss of power that occurs in a network or transmission line. This loss is attributable to the line parameters, especially the series resistance and shunt conductance. These constants, whether distributed or lumped, dissipate power in the line and therefore cause the output power of the line to be less than its input power. This is illustrated in figure 218, and in the table (par. 183*b*(4)). For example, in C, the power delivered to the line is 60 mw, whereas the load power is only 15 mw. The difference in power, 45 mw, is dissipated in the three resistances of the tee section. By noting the currents in these resistances, it will be seen that the left-hand 200-ohm resistance dissipates $(10)^2$ times .2, or 20 mw; the right-hand 200-ohm resistance dissipates $(5)^2$ times .2, or 5 mw; and the shunt 800-ohm resistance dissipates $(5)^2$ times .8, or 20 mw. Thus, the total dissipation is 45 mw.

a. Decibel. Ordinarily, the attenuation of a line is expressed as a ratio of input to output power. To simplify such calculations, the *db* (*decibel*) has been adopted as a measure of attenuation. A decibel is defined as the attenuation which occurs on a line when the ratio of input to output power is 1.25. The total attenuation in decibels of a transmission line can be calculated by using the following formula:

$$\text{Attenuation in db} = 10 \log. \frac{\text{input power}}{\text{output power}}.$$

In C, figure 218, the ratio of input to output power is 60/15, or 4. The attenuation in db therefore is 10 log 4, or 6 db. Similarly, in A and B, the power ratio is 57.6/5.4, or 10.67; the attenuation is therefore 10 log 10.67, or 10.28 db.

b. DB Table. In order to facilitate calculation of line loss, the attenuations in db and the power ratios to which they correspond are tabulated in the table below. When the power ratio is an exact power of 10, such as 100 or 1,000, the attenuation is 10 times the number of zeros in the ratio. For example, when the ratio is 100 (two zeros), the attenuation is 10 times 2, or 20 db. Similarly, when the ratio is 10,000 (four zeros) the attenuation is 10 times 4, or 40 db. The attenuation corresponding to a power ratio which is found to be a multiple of a power of 10, such as 5,000, can be found by *adding* the attenuations corresponding to the multiple to the power of 10. For example, when the power ratio is 5,000, the attenuation is found to be 7 (corresponding to the multiple 5 in the table) plus 30 (corresponding to 1,000), or 37 db. By using this method, the reader can verify the fact that the attenuation corresponding to a power ratio of 200 is 23 db, and that the attenuation corresponding to a power ratio of 400 is 26 db. When the value of the power ratio is doubled, the attenuation is increased by 3 db, so that if the ratio is 800, or twice 400, the attenuation is 3 db higher than 26 db, or 29 db. These fundamental relations are useful in determining the attenuations of lines and networks.

Power ratio	Attenuation (db)
1	0
1.25	1
2	3
4	6
5	7
10	10
100	20
1,000	30
10,000	40

c. Factors Influencing Attenuation. The attenuation of a pair usually is expressed in db per loop mile of line. One loop mile is 1 mile of two-wire line—that is, 2 miles of wire. The attenuation per loop mile of an open-wire pair depends on the size, spacing, and material of the conductors, and on the kind and number of insulators and their condition (wet or dry). Ice has a large effect on attenuation, particularly at high frequencies. The frequency of the current has an important effect on attenuation. Under average conditions, an open-wire pair has less attenuation per mile than either cable or field wires. For example, the dry weather attenuation at 1,000 cycles for 8-inch spaced wires of 165-mil, 128-mil, and 104-mil copper is, respectively, .032, .049, and .070 db per loop mile at 68° F. An approximate expression for this attenuation is as follows:

$$\text{Attenuation} \simeq \left(\frac{R}{2}\sqrt{\frac{C}{L}}+\frac{G}{2}\sqrt{\frac{L}{C}}\right)\times \underset{\text{per loop mile.}}{8.686 \text{ db}}$$

185. Loading of Transmission Line

Loading, as applied to a transmission line, is the method of increasing the series inductance of a line by the addition of external inductance. Its purpose is to improve the performance of the line by reducing attenuation and distortion. Loading may be either: *lumped loading* or *continuous loading*.

a. Lumped loading is effected by the addition of *loading coils* (which have relatively high inductance) at regular intervals along the line. The loading coils used at present consist of two windings on a molybdenum permalloy dust core (C, fig. 219). With this core material, high inductance is obtained with a rather small coil. Before the molybdenum permalloy dust core was perfected, loading coils had iron dust or permalloy dust cores illustrated in A and B. For the same inductance value, these coils are physically larger.

b. The insertion of heavy loading coils in submarine telephone and telegraph cables would subject them to excessive strain at the points of insertion. For this reason, a different method of increasing series inductance, called *continuous loading*, is used. Continuous loading is effected

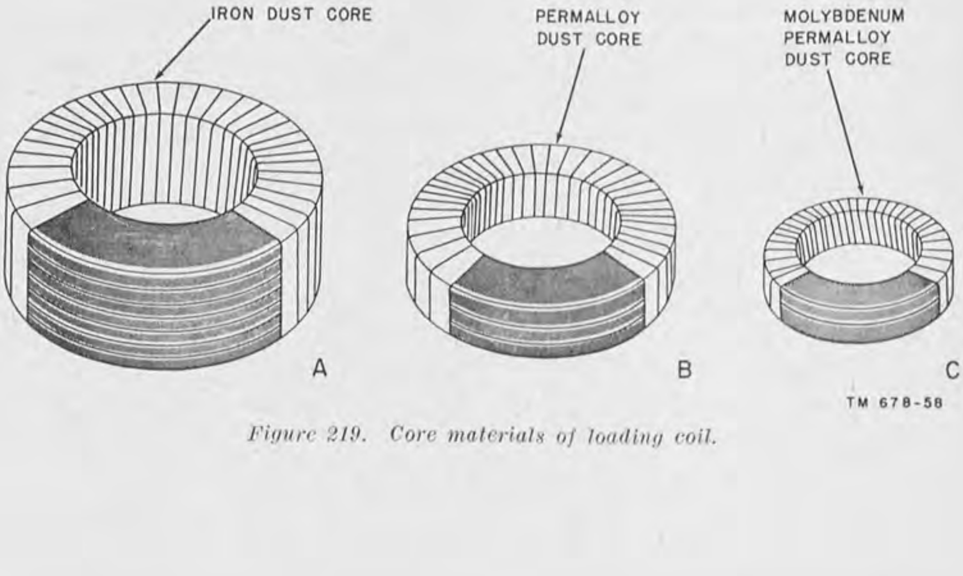
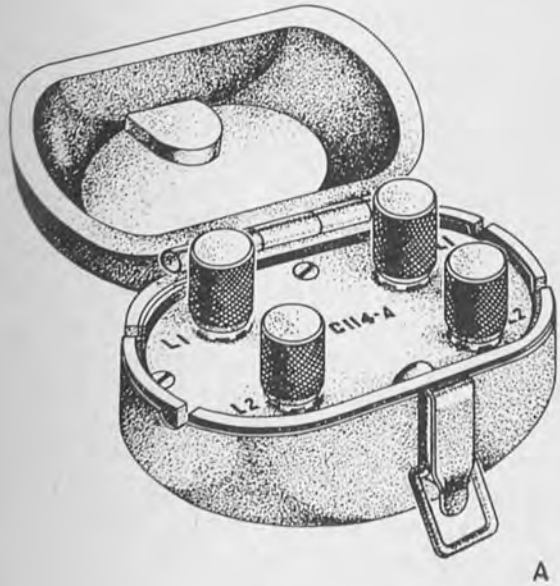


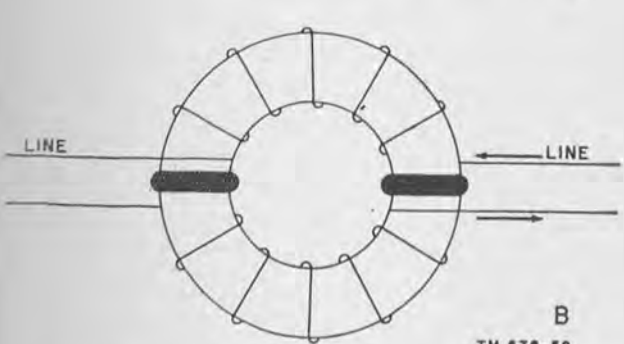
Figure 219. Core materials of loading coil.

by wrapping the cable conductor with a tape or wire of magnetic material, such as iron or permalloy. Because such loading distributes the inductance continuously along the line, it causes the line to behave like one with distributed constants.

c. Commercially, at the present time, only land cables are loaded in the United States. For open-wire lines, excessive distortion is overcome by the use of compensating or corrective networks, and excessive line losses are compensated for by means of repeaters or amplifiers. For military purposes, however, both cables and field wire lines are loaded to increase the talking range. Figure 220 shows one of the loading coils used in military applications. This coil has an inductance of 88 millihenrys. It is inserted at approximately 1-mil intervals on field wire. In order for loading to be effective in increasing the talking range, the insulation between wires, or between wires and ground, must be good, and the loading coils must be installed carefully. For example, when the



A



B

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Figure 220. Typical loading coil and symbol.

three field-wire lines listed in the table in paragraph 180*d* are loaded, as recommended, with loading coil as shown in A, figure 220, the talking ranges of a single pair (wet) are increased from the values given in the table to 19, 22, and 90 miles, respectively. The talking ranges of a single pair (dry) are increased to 35, 40, and 90 miles, respectively. The symbol used in schematic diagrams to represent loading coils is shown in B.

d. The formula:

$$\text{attenuation} \simeq \frac{R}{2}\sqrt{\frac{C}{L}} + \frac{G}{2}\sqrt{\frac{L}{C}} \times 8.686 \text{ db per loop}$$

mile, given in paragraph 184*e* is useful in showing how loading reduces attenuation. In this expression, the term $R/2\sqrt{C/L}$ often is called the series loss, and the term $C/2\sqrt{L/C}$ is called the shunt loss. On most lines, the series loss is many times larger than the shunt loss. With this fact in mind, the effect on attenuation of increasing the inductance may be examined. Practice confirms that increasing the series inductance decreases the series loss and increases the shunt loss. However, as long as the latter is the much smaller loss, the over-all effect will be a reduction in attenuation. If the shunt loss were not much smaller than the series loss, the inductance could not be increased much before the attenuation would be increased by a further addition of inductance. This brings out the importance of good insulation in loaded lines. Inductive loading in the presence of poor insulation actually may *increase* the attenuation over its nonloaded value. Loading also gives a more uniform attenuation-versus-frequency characteristic over the useful frequency band and therefore reduces distortion caused by nonuniformity.

186. Interference on Transmission Lines

Interference on telephone lines is a serious problem. It may be the result of lightning or other natural disturbances of the atmosphere, or of artificial sources, such as power lines, railway communication facilities, or other communication circuits. Interference from other communication circuits may result when several telephone lines are operating in parallel with each other, and interference from power lines may result when telephone lines are run parallel to power lines for considerable distances. Such interference—which results from the transfer of electric energy from one telephone line to another, or from a power line to a telephone line—is called *inductive interference*. Inductive interference may be either *crosstalk* or *noise*.

a. Crosstalk. Crosstalk is interference which results when two or more telephone talking circuits exist side by side, and the conversation on one circuit may be heard on the others. Obviously, this is objectionable. It not only may reduce intelligibility, but it may destroy secrecy. Crosstalk can result from any or all of the following causes:

(1) *Conduction through leakage paths.* Current in one line may be transferred to another line if the insulation between lines is faulty, or if branches of trees or brush come in contact with the wires. This is a problem of proper maintenance, and crosstalk from this cause can be eliminated by keeping the lines in good mechanical condition.

(2) *Inductive coupling.* One of the basic principles of electricity is that a magnetic field exists around a wire through which current is flowing. The magnetic field consists of concentric circular lines of force at right angles to the wire in space. The strength of the magnetic field varies inversely with the distance from the wire; that is, the greater the distance, the weaker the magnetic field. The magnetic field has the same waveform as the current that produces it. If the current is constant in magnitude and direction, the magnetic field is constant in strength and direction. If the current is alternating, as it is in the case of voice frequencies, the magnetic field varies instantaneously in magnitude, and changes direction every half-cycle. If such a varying magnetic field cuts an adjacent conductor, it induces an alternating emf in the conductor, in accordance with the generator principle. The magnitude of this emf varies inversely with the distance between the center of the magnetic field and the conductor. The conductor is said to be *inductively coupled* to the original wire which produces the magnetic field. A, figure 221, illustrates how inductive coupling between adjacent telephone circuits can cause crosstalk. Assume that an alternating voice-frequency current is flowing in circuit 1–2, which consists of a telephone line connecting two telephone sets, T1 and T2 (represented by generators). At some instant of time, the current is flowing in the direction indicated by the arrows. A magnetic field exists around both wires, causing the production of a resultant magnetic field. When another telephone circuit, consisting of a line connecting telephone sets T3 and T4, is located near the first circuit, as shown, the magnetic field of the first circuit links wires 3 and 4 of the second circuit (field not indicated). Because the magnetic field is varying instantaneously in intensity, an emf is induced in each wire of circuit 3–4. The polarity of the induced emf is the same for both wires. Assume the polarity to be as shown. Wire 3, however, is closer to the center of the magnetic field than wire 4, and, consequently, the emf induced in wire 3 is greater than the emf induced in wire 4. An unbalanced emf (E3–E4) therefore exists in circuit 3–4, and produces a corresponding current through sets T3 and T4. This current, having the same frequency variations as the current in circuit 1–2, causes the conversation in circuit 1–2 to be heard in sets 3 and 4.

(3) *Capacitive coupling.* Capacitive coupling produces an unbalanced emf in a circuit because of the capacities between the wires of an adjacent circuit and ground and the associated *electric* fields. This type of coupling between two adjacent telephone lines is illustrated in B, figure 221, which shows a telephone circuit consisting of telephone sets T1 and T2 connected by wires 1–2. The capacities of these wires to ground are represented by C_{G1} and C_{G2}, respectively. Since the two capacities are in series between the two wires, a voltage exists across each capacitance. If the capacitances are assumed to be equal, the voltages across them are equal in magnitude but opposite in polarity, as indicated. This causes an *electric field* to appear between each wire and ground, with the respective directions indicated by the arrows. If a second telephone

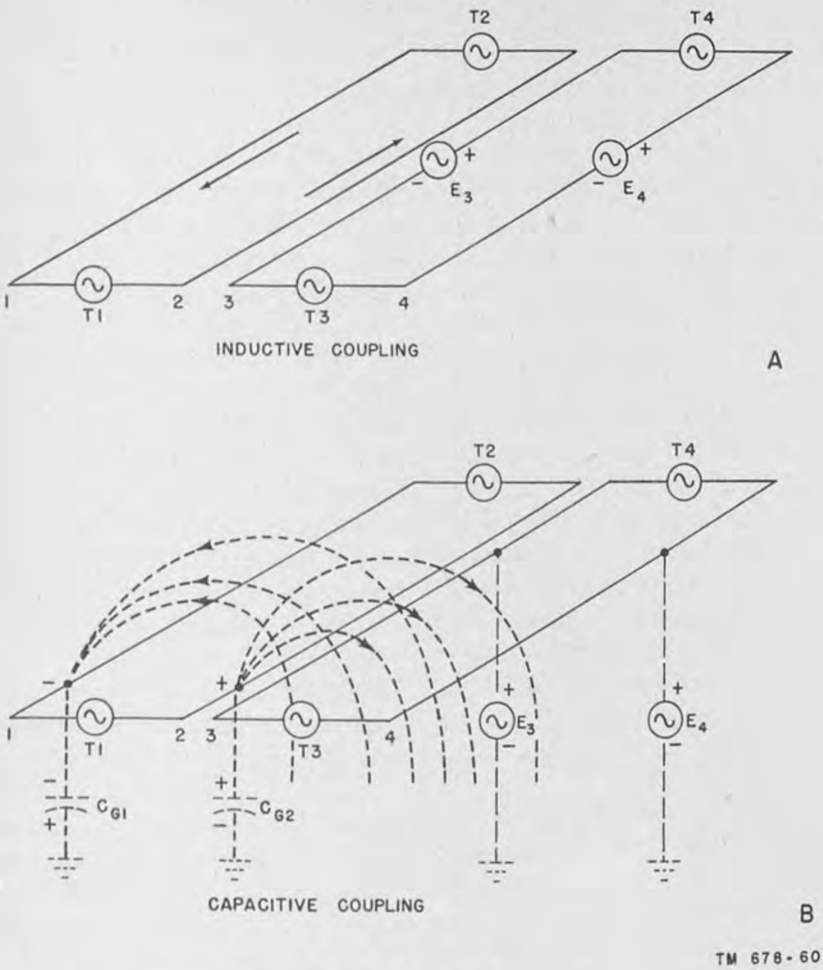


Figure 221. Causes of crosstalk.

circuit, consisting of sets T3 and T4 connected by wires 3–4, lies near the first circuit, each of its wires is linked by the field existing at that point. Since the strength of the field diminishes with increasing distance from the source, wire 3 is linked by a stronger electric field than that which links wire 4. This causes wire 3 to be raised to a higher potential above ground than wire 4, so that a difference of potential exists between wires 3 and 4. This potential difference, or unbalanced emf, causes a current having the same frequency variations as the current in circuit 1–2 to flow in circuit 3–4, and produces crosstalk in circuit 3–4. The closer the two circuits are to each other, the greater is their susceptibility to this type of interference.

b. Noise. Interference in telephone lines caused by such sources as adjacent power lines, electric motors and generators, and railway communication facilities, is classified as *noise*. Electric noise results from the fact that the voltages in electric power lines and electric machines and such sources are not pure 60-cycle sine waves, but also contain many other frequencies. Some of these frequencies lie in the transmitted voice-frequency range, between 200 and 2,700 cycles. When power lines and telephone circuits exist side by side, voltages at these frequencies may be induced in the telephone lines by exactly the same processes discussed in *a* above. These voltages cause corresponding currents to flow in the lines, and result in the production of noise in the receivers. Noise produced in this manner usually takes the form of a hum of varying pitch. It can be as objectionable and disturbing to the listener as crosstalk.

187. Reduction of Interference on Transmission Lines

Various methods have been developed to reduce interference on telephone lines.

a. Maintenance of Lines. One obvious way of minimizing interference is by keeping telephone lines in good repair. This requires periodic inspection of splices and joints, as well as insulators and other equipment. Careful initial installation of lines also helps to prevent causes of interference.

b. Transposition of Wires. Transposition of the wires of a telephone line, as shown in figure 222, is an effective method of reducing crosstalk or noise produced by inductive coupling between lines. Note that the wires of circuit 3–4 have been *transposed*, or made to cross over. As explained previously, the closer the wire is to the center of the magnetic field of the adjacent circuit, the greater is the emf induced in it. By transposition of the wires, however, a greater emf is induced in parts of wires E_{3A} and E_{4B}. Similarly, a smaller emf is induced in the other parts of wires E_{3B} and E_{4A}. This makes the resultant induced emf in wires 3 and 4 nearly equal. Since very little unbalanced emf now exists between the wires, the crosstalk current produced in circuit 3–4 is at a minimum. The same effect can be obtained by transposing the wires of circuit 1–2.

c. Capacity Balance. Cables, since they often contain hundreds of pairs of wires, are particularly susceptible to crosstalk caused by capacity coupling between adjacent pairs. An important reason for this is the fact that the various wires exhibit different capacities to ground, making the system *unbalanced* to ground. One method of overcoming this is to equalize the capacities by transposing the various wires in the cable at points where one length of cable is spliced to an adjacent length of cable. Another method consists of equalizing the capacities by adding capacity to those pairs of wires that show less capacity to ground than do other pairs. This capacity is added by connecting the wires on one end of a short length of a twisted pair to the cable pair and leaving the wires on the other end of the short length unconnected.

d. Use of Repeating Coils. In remote or rural areas, or in emergency installations for military uses, one-wire ground-return telephone circuits (par. 191) often are used. Since transposition is impossible on such circuits, they are much more susceptible to inductive interference from adjacent circuits. Even when connected directly to full metallic two-wire circuits, there is usually an objectionable amount of noise interference, since one side of the two-wire line must be grounded, creating an unbalance to ground. However, if the one-wire line is connected to the two-wire line through a *repeating coil* which isolates the two circuits, the two-wire line need not be grounded, and it operates as a balanced line. Ground-return circuits usually are replaced by two-wire circuits as soon as possible in order to avoid excessive interference.

e. Noise Filters. Battery chargers and similar apparatus used to maintain batteries in common-battery systems are often the cause of hum, because the output voltage from these devices contains large amounts of energy at random frequencies. Filtering the output voltage by means of low-pass filters, which consist of series choke coils and shunt electrolytic condensers of fairly large capacity, removes the higher frequencies that lie in the voice-frequency range and, therefore, prevents noise interference from this source.

188. Summary

a. Telephone lines may be constructed in the form of cables, open wire, or field wire. Cables or field wire may be supported on poles similar to openwire lines, or may be laid on the ground. Cables may also be laid underground.

b. Transmission lines are considered *electrically*

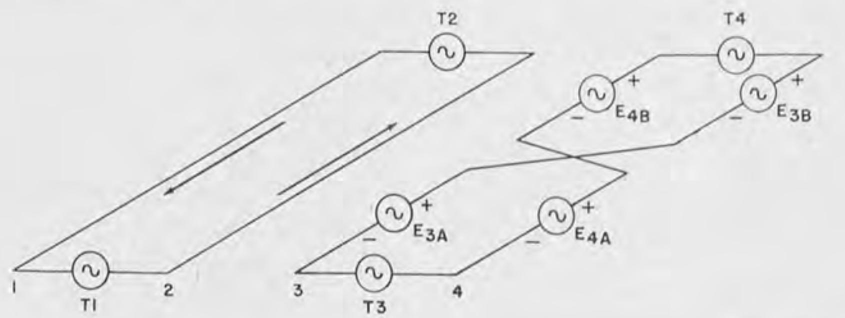


Figure 222. Reduction of crosstalk by transposition.

short if their length is shorter than the wavelength of the transmitted signal; they are considered *electrically long* if their length is approximately equal to or longer than the wavelength of the transmitted signal.

c. The electrical properties of a pair depend on its parameters, R, L, G, and C, all expressed in values per unit length (commonly 1 loop mile) and on the frequency of the transmitted current. For an electrically short pair, the parameters may be treated as lumped. For electrically long pairs, the parameters may be treated as distributed.

d. The characteristic impedance, Z_o, of a line is equal to the impedance that must terminate the line in order to make the input impedance equal to the terminating impedance. On a pair that is extremely long, the input impedance will equal the characteristic impedance of the line irrespective of the terminating impedance.

e. The characteristic impedance of a pair depends on the parameters of the pair and on the frequency, but it is independent of the length of the pair. The resistive component of the characteristic impedance is generally high at low frequencies and falls off with increasing frequency, approaching a value equal to $\sqrt{L/C}$ at high frequencies. The reactive component also starts out high at low frequencies and decreases at the higher frequencies. The characteristic impedance of a pair may be obtained from the measured open-circuit and short-circuit impedances by the formula,

$$Z_o = \sqrt{Z_o C Z_{sc}}$$

f. Maximum power is transferred from a source to a load over a transmission line when the line is terminated in its characteristic impedance.

g. Attenuation is the term used to express the power loss in a line. The attenuation of a line is measured in db and can be calculated by using the relationship,

$$\text{attenuation in db} = 10 \log \frac{\text{input power}}{\text{output power}}.$$

h. The attenuation of any pair depends on the parameters R, L, G, and C of the line and on the frequency. Sometimes G or L, or both, are small enough to be neglected.

i. The loading of a transmission pair improves its response by increasing its series inductance. This may be accomplished by use of loading coils (lumped loading), or by wrapping the conductors with a tape or wire of magnetic material (continuous loading).

j. Cables and field wires are loaded by means of loading coils for military applications.

k. Interference in telephone circuits is of several kinds. Among natural causes may be listed lightning and other natural atmospheric disturbances. Among other causes may be listed interference from adjacent telephone circuits, possibly in the form of intelligible crosstalk or noise, and interference from nearby power or electric railway lines usually in the form of noise.

l. Crosstalk and noise may be produced by magnetic, conductive, and capacitive coupling between adjacent circuits.

m. Interference may be minimized by careful installation of the line, by transpositions of the wires of the line, by balancing the line capacities, and by proper maintenance of equipment.

189. Review Questions

a. Why is an understanding of the behavior of transmission lines important in the study of telephony?

b. What types and sizes of lines are used most commonly in telephony?

c. Define an electrically short line; an electrically long line. Give examples.

d. What are the line constants of a transmission line? How are they measured?

e. State the difference between lumped and distributed constants.

f. Define characteristic impedance.

g. How may the characteristic impedance of a line be determined?

h. A transmission line is found to have a short-circuit impedance of 100 ohms, and an open-circuit impedance of 400 ohms. What is its characteristic impedance?

i. State the condition for maximum power transfer from a generator to a load.

j. Why is it important to terminate a line in its characteristic impedance?

k. What kind of characteristic impedance usually is found on open-wire lines? On cables?

l. Define attenuation. How is it measured?

m. What is the attenuation of a line if the input power is 10 watts and the output power is 5 watts?

n. What factors determine the attenuation of open-wire lines? Of cables?

o. What is meant by lumped loading? By continuous loading?

p. What is the effect produced by loading a transmission line?

q. Define: crosstalk, electric noise.

r. Explain briefly how crosstalk and noise may be produced on a line by inductive coupling; by capacitive coupling.

s. Explain briefly how transposition of the wires of an affected circuit can reduce interference caused by inductive coupling.

t. Mention some other methods by which interference on telephone lines may be overcome.

u. How should grounded circuits and full metallic circuits be interconnected?

CHAPTER 9

SPECIAL CIRCUITS

190. Introduction

This chapter covers single-line telephony and some of the elementary methods of obtaining an extra voice channel over a telephone line as used in early long distance telephony. These methods, referred to as multiplexing, are in use today in commercial and military systems, although they gradually are being replaced by more advanced techniques.

191. Single-Line Telephony

Single-line telephone circuits may be full-metallic circuits or ground-return circuits, depending on the type of physical connection provided between the two telephone sets.

a. Full-Metallic Telephone Circuit. This circuit is one in which two conductors are used to interconnect the telephone sets (chs. 4 and 5). It has the advantage of permitting transposition of wires as a means of overcoming inductive interference. For this reason, full-metallic circuits are used almost exclusively in military applications.

b. Ground-Return Telephone Circuit. Figure 223 shows a ground-return telephone circuit.

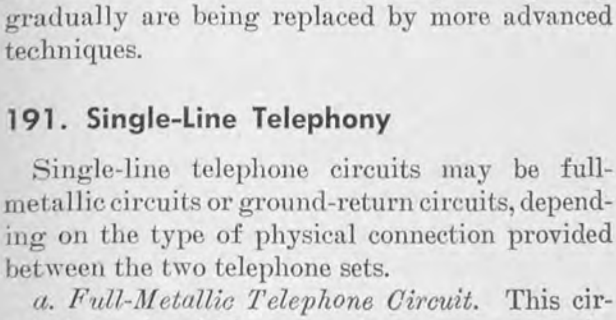


Figure 223. Ground-return telephone circuit.

Only one wire is used to connect telephone sets T1 and T2; the other terminal of each set is returned to ground.

(1) One advantage of this type of circuit is that it is more economical to construct than a full-metallic circuit, since it requires only half as much wire. Other advantages are the relative ease with which the circuit may be installed, and its lower line resistance (if the ground connections are made carefully). Lower line resistance means lower attenuation and more efficient transmission. Because of these advantages, ground-return telephone circuits still are used in rural areas, especially those where interference from power lines is not an important factor. For emergency operation, the two conductors of an ordinary field wire can be connected and used as a single wire in order to extend the talking range of a telephone circuit.

(2) The disadvantages of ground-return circuits include their susceptibility to inductive interference from power lines, variations in operation which may result from differences in ground potential at different points, and the possibility of additional noise produced by faulty ground connections. Although ground-return circuits are not suited particularly to telephone communication, they have considerable application in military telegraphy, and also may be used for ringing circuits in telephony.

192. Simplex Circuit

A *simplex circuit* is one in which a ground-return telephone or telegraph circuit is superimposed on a full-metallic circuit in order to obtain an extra channel. Of course, provision must be made for preventing interaction or interference between the two circuits. The principle of operation of a simplex circuit is explained later in this paragraph.

a. Repeating Coils. In order to obtain the required isolation of the simplex and metallic circuits, repeating coils are used. A, figure 224, illustrates one type of coil used in switchboards of newer types because it is small, light, and efficient. The two upper terminals on the frame, marked SWITCHBOARD, are connected to the switch-

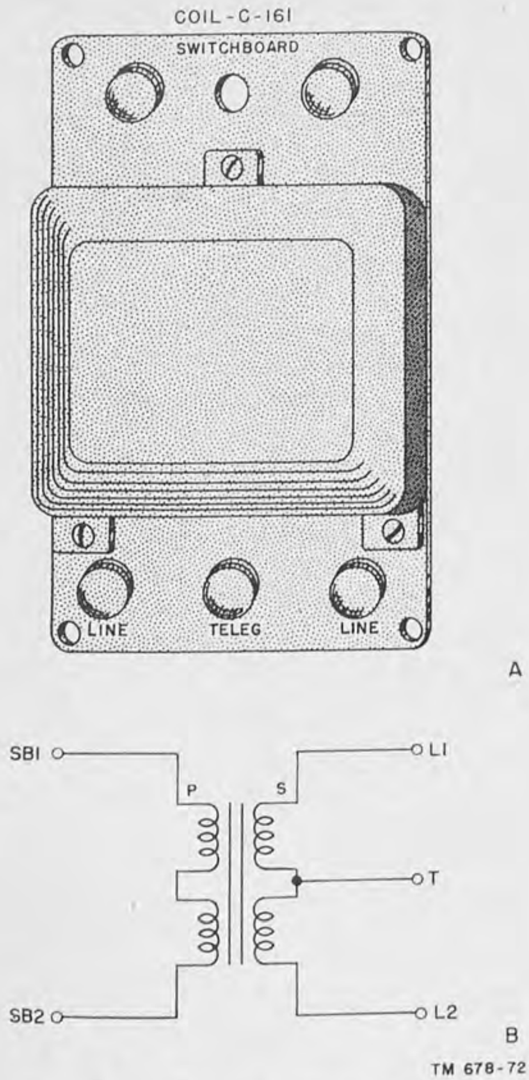


Figure 224. Typical repeating coil and symbol.

board line terminals. The two outside bottom terminals, marked LINE, are connected to the incoming trunk line. The center bottom terminal, marked TELEG, is connected to one terminal of the telephone or telegraph set that is being operated on a simplex circuit. The symbol used to represent this type of repeating coil in schematic diagrams is shown in B. In this symbol, the switchboard terminals are designated by SB1 and SB2, the line terminals by L1 and L2, and the center terminal by T. Repeating coils used with simplex circuits are highly efficient transformers of 1-to-1 ratio. The primary is identical with the secondary, each consisting of two balanced windings in series. The resistance of each of these four windings is 21 ohms. The only physical difference between them is that the secondary has a center terminal, T, connected to the junction of its two windings. Repeating coils installed at a switchboard are mounted either above or below the terminal strip. They are mounted so that they are accessible for maintenance, but they are protected from moisture or accidental injury. Figure 225 shows the position of a repeating coil in a line terminating and simplex panel. The coil has the 1-to-1 turns ratio used in simplex circuits. Input to the unit is by way of the protectors, which are open-space cutouts used to protect the unit against excessive voltages induced in the connected line by lightning and other extraneous disturbances.

b. Operation. Figure 226 is a schematic diagram of a simplex telephone circuit superimposed on a metallic telephone circuit. Telephone sets T1 and T2 are connected to the metallic two-wire line by means of repeating coils RC1 and RC2, respectively. These two sets operate as a two-way full-metallic telephone system. By means of the repeating coils, an additional telephone circuit, or branch, is provided. This branch consists of telephone sets T3 and T4, and one terminal of each is connected to the center terminal on the secondary of its associated repeating coil. The other terminal is connected to a good ground, to furnish the return path for the current in this branch. The additional circuit thus provided is called a *simplex circuit*, and the metallic circuit

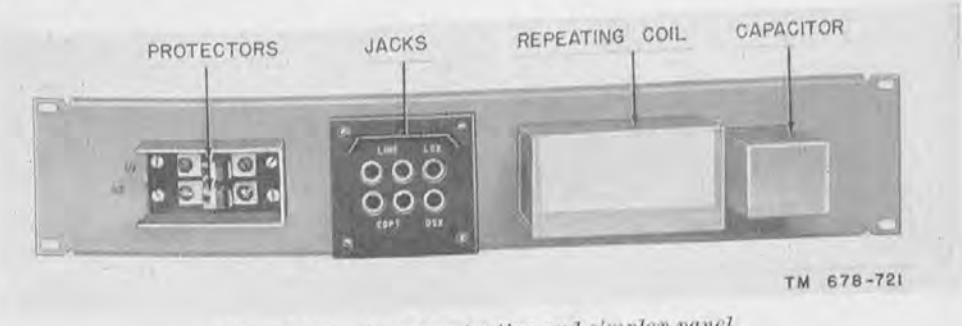


Figure 225. Line terminating and simplex panel.

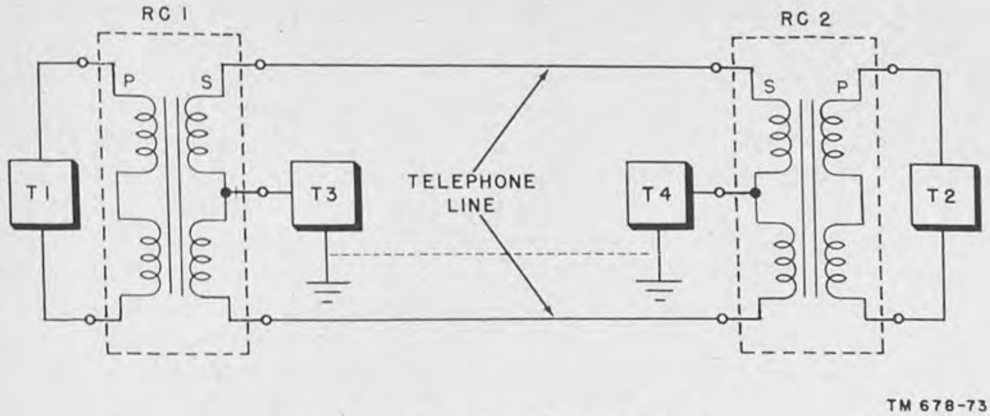


Figure 226. Simplex telephone circuit.

on which it is superimposed is said to be *simplexed* by the ground-return circuit.

193. Current Paths in Simplex Circuit

The function of the repeating coils which permit a metallic circuit to be simplexed without interference between the two circuits can be explained by reference to figure 227, in which the paths of the metallic-line currents, or *side-circuit currents*, are indicated by solid-line arrows and those of the simplex circuit by broken-line arrows.

a. Path of Side-Circuit Current. Assume that a conversation is taking place between telephones T1 and T2 (fig. 227). Also assume an instant of time when the pulsating current in the primary of the induction coil of transmitter T1 flows in the direction indicated by the solid-line arrows. This current induces an emf in the secondary of RC1 and causes a corresponding current to flow in the secondary of repeating coils RC1 and RC2, as shown by the solid-line arrow. Note that the secondary windings of the two repeating coils are connected by the two wires of the metallic line, thus furnishing a closed current path. The current flowing through the secondary winding of RC2 induces a corresponding emf in the primary which produces a current in the primary winding. Since telephone T2 is connected to the primary of RC2, this current flows through the receiver of T2, and results in the reproduction of the sound which originated in the transmitter of T1.

b. Path of Simplex-Circuit Current.

(1) At the same time that this conversation

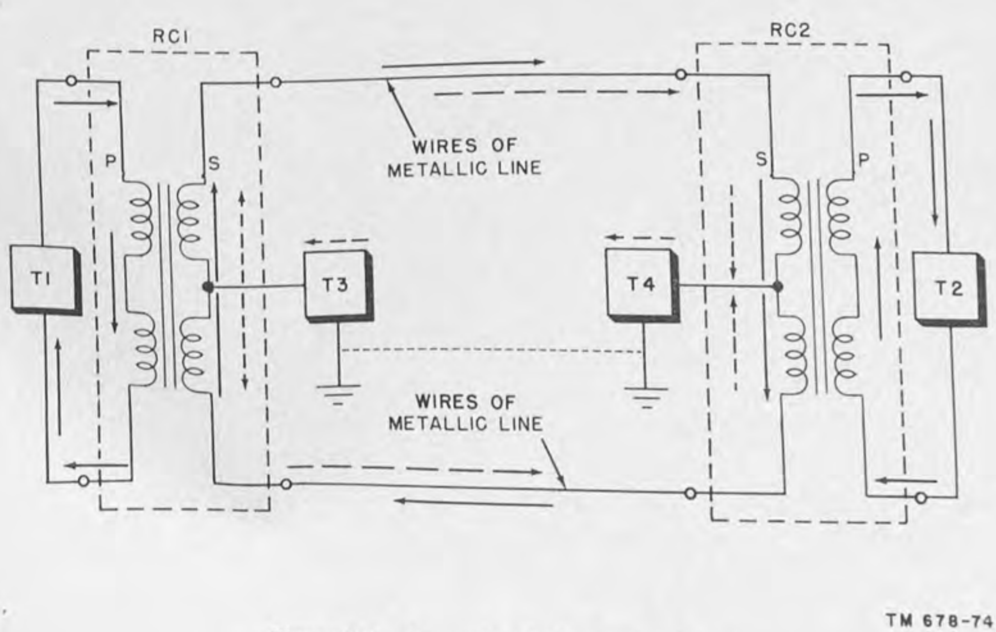


Figure 227. Current paths in simplex circuit.

is taking place, a person at telephone T3 may communicate with telephone T4 (fig. 227). The voice current at the center terminal of the secondary of RC1 divides equally into the two windings of the secondary of RC1, as shown by the broken-line arrows. Since equal currents flow in opposite directions through the two windings, no emf is induced in the primary of RC1, and no voice current flows in the receiver of T1. The conversation originating in T3 therefore is not heard in T1.

(2) The voice current flows through both wires of the metallic line, however, as indicated by the broken arrows. The current flowing up through the top winding of the secondary of RC1 flows through the upper line and through the top winding of the secondary of RC2. Similarly, the current flowing down through the bottom winding of the secondary of RC1 flows through the lower line and through the bottom winding of the secondary of RC2. These two currents join at the center terminal of RC2 and flow through the receiver of telephone T4. The path is completed through ground, as indicated by the dashed line. Just as the two equal and opposite currents in the two windings of the secondary of RC1 induce neutralizing (canceling) emf's in the primary of RC1, the two currents in the windings of the secondary of RC2 induce neutralizing emf's in the primary of RC2. Since the resultant emf induced in the primary of RC2 is zero, no current resulting from the conversation between T3 and T4 flows in the receiver of T2. Consequently, a means is provided of carrying on two independent conversations without mutual interference on a single metallic circuit.

c. Line Balancing With Simplex Circuit.

(1) The operation of a simplex circuit takes place without mutual interference only if the repeating coils have identical windings, and if the wires of the metallic line have the same impedance. It may be assumed that proper design and manufacture of the repeating coils eliminates any unbalance resulting from the coils. However, interference caused by different impedances in the two wires of the metallic circuit may be troublesome. The main cause of unbalance in the lines of field-wire circuits is caused by poor splices, which may introduce a high resistance into one side of the circuit. Another cause of unbalance is improperly taped splices and worn and damaged insulation, which may result in excessive leakage from one side of the circuit to ground, particularly when the wires are wet.

(2) Interference resulting from a poor splice may be reduced to a tolerance level by

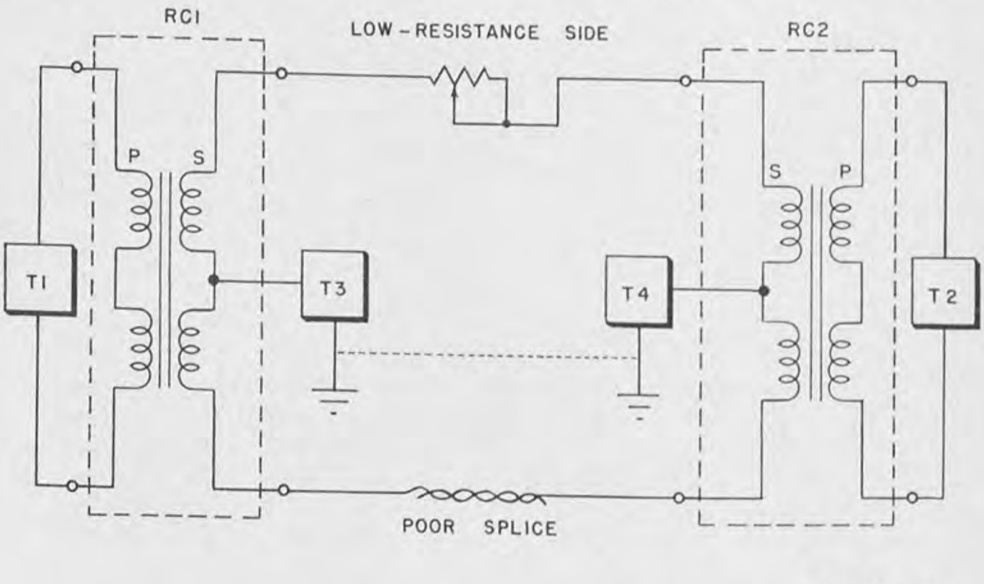


Figure 228. Balancing simplexed line.

introducing an additional loss in the circuit; this is accomplished by using a rheostat in the low-resistance side of the line (fig. 228). The low-resistance side is ascertained by trial; that is, the rheostat is inserted first in one side of the line, and then in the other. When placed in the low-resistance side, adjustment of the rheostat markedly equalizes the loss on each side of the line. When these losses are equal, interference drops to a minimum.

194. Advantages and Limitations of Simplex Circuit

a. Advantages. One of the obvious advantages of the simplex circuit which make it useful in military applications where time is an important factor is that it adds telephone or telegraph channel to a two-wire line without interference, thus effecting a considerable saving of material and maintenance. Another advantage is the comparative ease of installation.

b. Limitations. In spite of the considerable saving in time, material, and personnel obtained with simplex circuits, they usually are not used to provide an additional telephone channel. The ground-return makes the line susceptible to interference from noise and crosstalk. Also, the ground-return circuit signal is more susceptible to interception by an enemy. *Telegraph* circuits, however, operate effectively on a ground-return system, and simplex circuits frequently are used to provide an additional telegraph channel on a two-wire metallic line.

195. Phantom Telephone Circuit

a. A *phantom circuit* provides an additional telephone channel on two 2-wire metallic circuits. Side circuit Nos. 1 and 2 in figure 229 are the two 2-wire metallic circuits of such an arrangement. These two circuits, together with the phantom circuits, constitute a *phantom group.*

b. The phantom group contains *six* repeating coils located at the central office. These coils are similar to those used in simplex circuits. Repeating coils RC1 and RC2 are connected in circuit No. 1 at the *line* terminals of the switchboard. Telephone sets T1 and T2 are connected at the switchboard to the *switchboard* terminals of RC1 and RC2, respectively. Similarly, repeating coils RC3 and RC4 are connected inside circuit No. 2, and telephone sets T3 and T4 are connected at the switchboard to the respective switchboard terminals of these repeating coils. The phantom circuit uses two additional repeating coils, RC5 and RC6. One line terminal of RC5 is connected to the center terminal of RC1, and the other terminal is connected to the center terminal of RC3. Similarly, the two line terminals of RC6 are connected, respectively, to the center terminals of RC2 and RC4. The center terminals of RC5 and RC6 are not connected to any other point. Telephone set T5 is connected at the switchboard to the switchboard terminals of RC5, and telephone set T6 is connected in a similar manner to the switchboard terminals of RC6. T5 and T6 also may represent telegraph sets instead of telephones, so that phantom operation provides either additional telephone or telegraph channels. It is also possible to construct a phantom group without the use of repeating coils RC5 and RC6 by connecting set T5 *directly* to the center terminals of RC1 and RC3, and connecting set T6 to the center terminals of RC2 and RC4. This arrangement affords economics in initial cost and maintenance, since it eliminates two repeating coils, but it is more susceptible to inductive interference.

196. Analysis of Phantom Circuit

a. Path of Phantom-Circuit Current.

(1) As in the simplex circuit, the center-tapped iron-core repeating coil used in a phantom group prevents the voice currents of the phantom circuit from interfering with those of the side circuits. Assume that at a given instant the phantom circuit in figure 229 is operating from left to right; that is, a person at telephone set T5 is talking to someone at telephone set T6. If the voice current in the primary winding of RC5 is assumed to flow *down* at this instant, the emf induced in the secondary will cause a corresponding current to flow *up* through the secondary (broken arrows). This current flows up to the center terminal of the secondary of RC1, where it divides equally into the two branches, since the branch resistances of a perfectly balanced line are equal. Since the current in the upper winding of the secondary of RC1 is flowing *up*, and an equal current in the

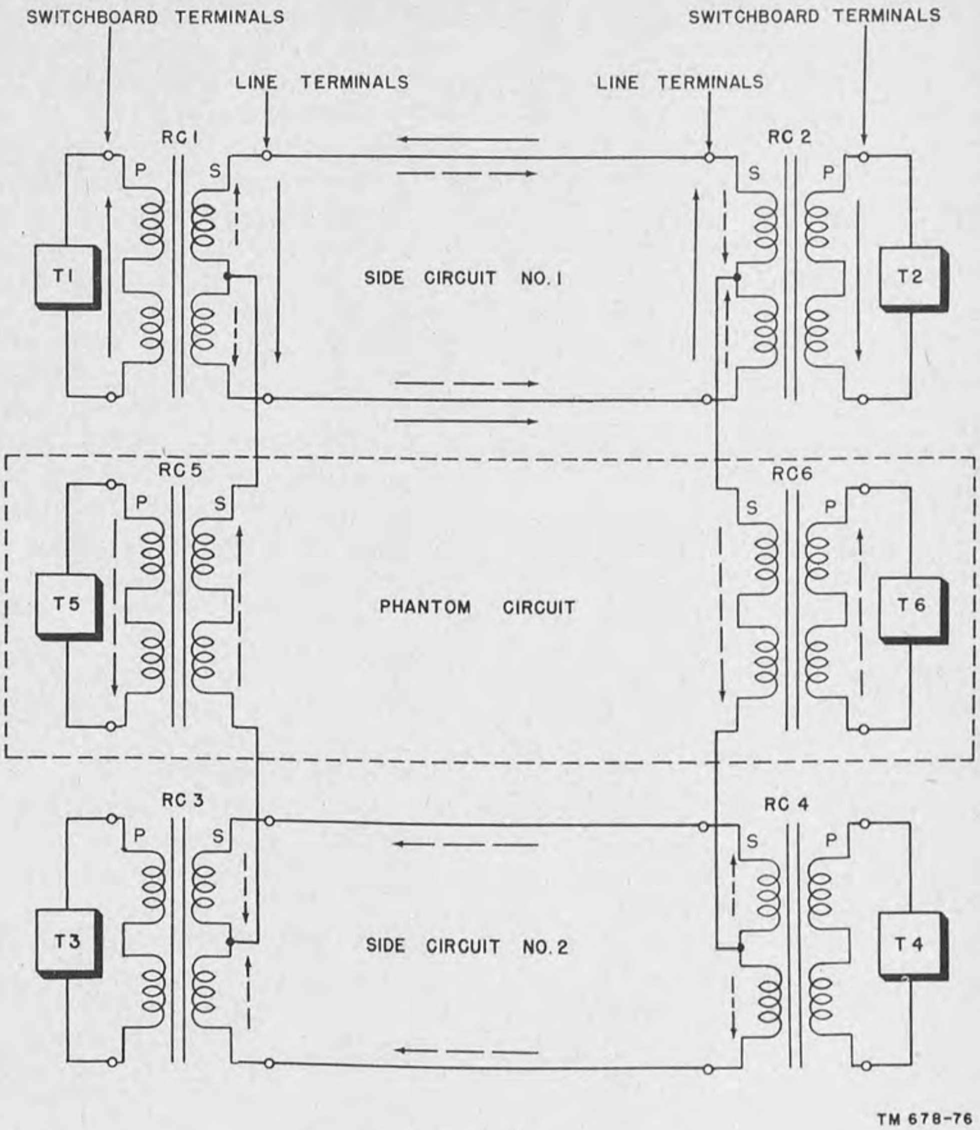


Figure 229. Phantom telephone circuit.

lower half is flowing *down* (broken arrows), the resultant voltage across the secondary is zero. Therefore, no corresponding emf is induced in the primary of RC1, and no corresponding current flows in the receiver of set T1.

(2) The currents continue to the right in the metallic wires of the line of side circuit No. 1 and join at the center terminal of the secondary of RC2 (broken arrows). Since the current in the top wire flows *down* through the upper winding, however, while an equal current in the bottom wire flows *up* through the lower winding of the secondary, the same canceling effect occurs as in RC1. Therefore, no corresponding current flows in the primary of RC2 or in the receiver of T2.

(3) The combined current flows out of the center terminal of RC2 and down through the secondary of RC6 (broken arrow). This is the same total current that flows up through the secondary of RC5. A corresponding current therefore flows in the primary of RC6 and through the receiver of set T6, reproducing the sound originally introduced at the transmitter of T5.

(4) By a similar analysis, the path of current can be traced through the secondary of RC4, the wires of the line of side circuit No. 2, and the secondary of RC3.

Since the same canceling occurs in these repeating coils, no phantom circuit current flows in the primaries of these coils or in sets T4 and T3.

b. Path of Side-Circuit Current.

(1) The use of repeating coils in a phantom group also prevents the *side-circuit* currents from interfering with those of the phantom circuit. This can be seen by following the *solid-line* arrows from set T1 through side circuit No. 1 and set T2, and back again, to T1 (fig. 229). Assume an instant of time when a voice current originating in the transmitter of T1 flows up through the primary of RC1. An emf is induced in the secondary, causing a corresponding current to flow *down* through the *entire* secondary. *None* of this current flows out through the center terminal of RC1, and consequently no part of the current flows through the secondary of RC5 or RC3. No interference exists, therefore, between set T1 and sets T5 and T3.

(2) The current flows to the right through the bottom wire of side circuit No. 1 and up through the secondary of RC2, the path being completed through the top wire. Again, no part of this current flows out of the center terminal of RC2 or through the secondaries of RC6 and RC4. Therefore, no corresponding current flows through the receivers of sets T6 and T4, and there is no interference in these sets.

(3) The current in the secondary of RC2, however, induces an emf in the primary. A corresponding current therefore flows down through the primary of RC2 and through the receiver of T2, reproducing the sound introduced at the transmitter of T1.

(4) Similar analysis can be made for conversations originating in T2, T3, and T4. They will show that the operation of a phantom group prevents interference between the side circuits and the phantom circuit. Of course, perfect operation requires perfect balance of the lines of the side circuits, and well balanced repeating coils.

197. Advantages and Limitations of Phantom Circuits

a. Advantages.

(1) The most important advantage of the phantom circuit over the simplex circuit is the elimination of the ground return. This gives an additional telephone channel with freedom from the inductive interference to which ground-return circuits are susceptible. Phantom circuits are used to obtain an additional telegraph channel when good ground connections—always necessary for its operation in a simplex circuit—are difficult to obtain. Phantom circuits often are used in teletypewriter communications.

(2) When the side circuits of a phantom group are composed of cables instead of open-wire lines, it is possible to reduce attenuation and obtain distortionless operation by using loading coils. These coils are arranged so that the currents in the phantom circuit produce *aiding* magnetic fluxes in the core of the phantom loading coil, but *opposing* fluxes in the cores of the loading coils in the side circuits. In this way, the phantom currents do not affect the side circuits, nor do the side-circuit currents affect the phantom circuit. Of course, the loading coils must be designed, constructed, and installed carefully, to maintain a perfect balance and prevent crosstalk between the phantom and side circuits.

b. Limitations. For the circuits of a phantom group to operate without interference, the two metallic circuits upon which the phantom circuit is superimposed must be well balanced. The method of balancing a line by the use of a rheostat in the low-resistance side of an unbalanced line can be used also in the side circuits of a phantom group. Also, for operation without interference, the repeating coils must be identical and installed properly. When these conditions are satisfied, a phantom-group operation has advantages that outweigh its limitations, so that it occupies an important place in military communications.

198. Simplexed-Phantom Circuit

a. Description. A circuit that combines the principles of both simplex circuits and phantom groups is called a *simplexed-phantom* circuit (fig.

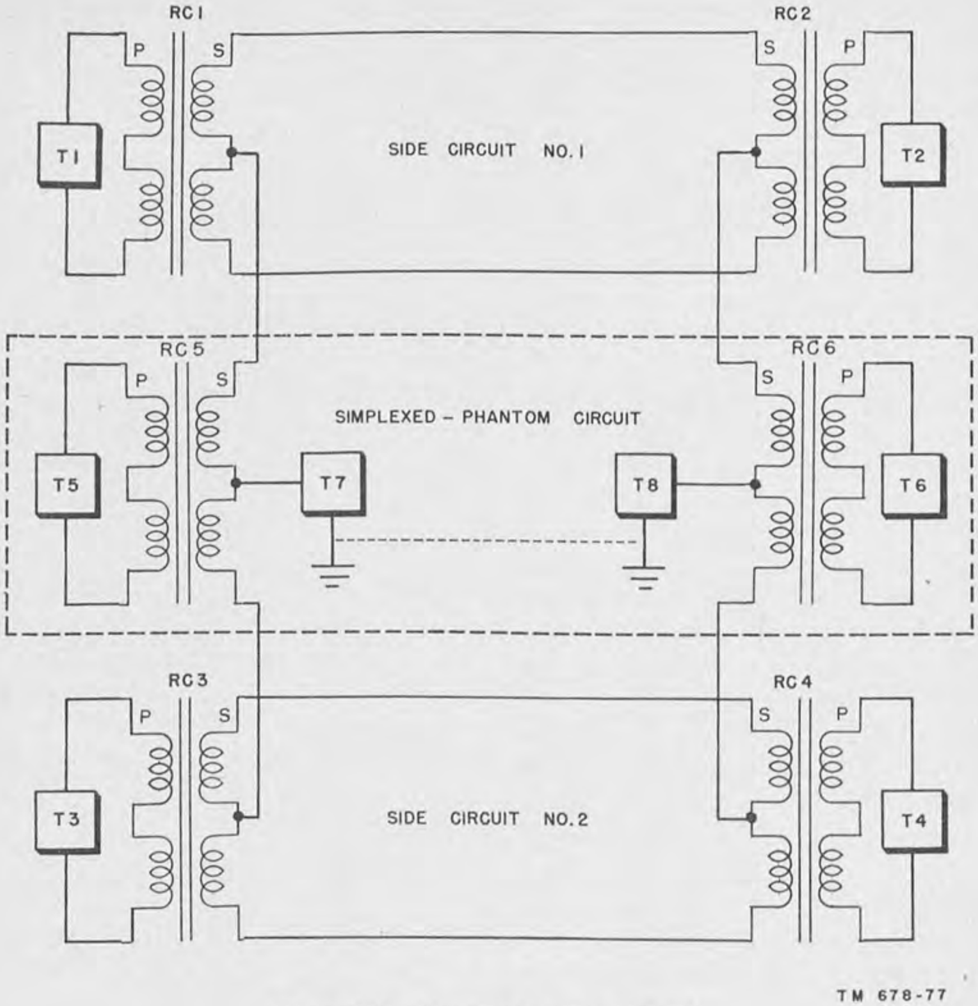


Figure 230. Simplexed-phantom circuit.

230). It consists of two side circuits and a phantom circuit, comprising a phantom group, with the addition of a simplex circuit accommodating the operation of telegraph sets T7 and T8.

b. Operation. The simplexed leg of the simplexed-phantom circuit contains a ground-return circuit which permits transmission of telegraph signals between telegraph instruments T7 and T8. The connections of these instruments are similar to those of the simplex circuit. One terminal of set T7 is connected to the center terminal of the secondary of repeating-coil RC5, and one terminal of set T8 to the center terminal of secondary RC6. The other terminal of each set is grounded as effectively as possible, to furnish the return path. By using an analysis similar to that given in the discussion of simplex and phantom circuits, the currents of the simplex leg, the phantom circuit, and the side circuits can be traced. Such an analysis will show that a signal originating in T1 is reproduced only in T2, one originating in T3 is reproduced only in T4, one originating in T5 is reproduced only in T6, and a telegraph impulse originating in T7 is reproduced only in T8. In the usual operation of a simplexed-phantom circuit, the side circuits and the phantom circuit are used to obtain three *telephone* channels, since these circuits involve full metallic-line operation. The simplex leg provides a telegraph channel.

c. Limitations. The same general limitations discussed in connection with simplex and phantom circuits, and concerned primarily with the maintenance of perfect balance in the metallic lines and the repeating coils, apply to simplexed-phantom circuits. The existence of *four* channels in a simplexed-phantom circuit makes perfect balance even more critical than in the other types. For this reason, and because they are more difficult to maintain in the field, simplexed-phantom circuits often are not used in forward areas of operation.

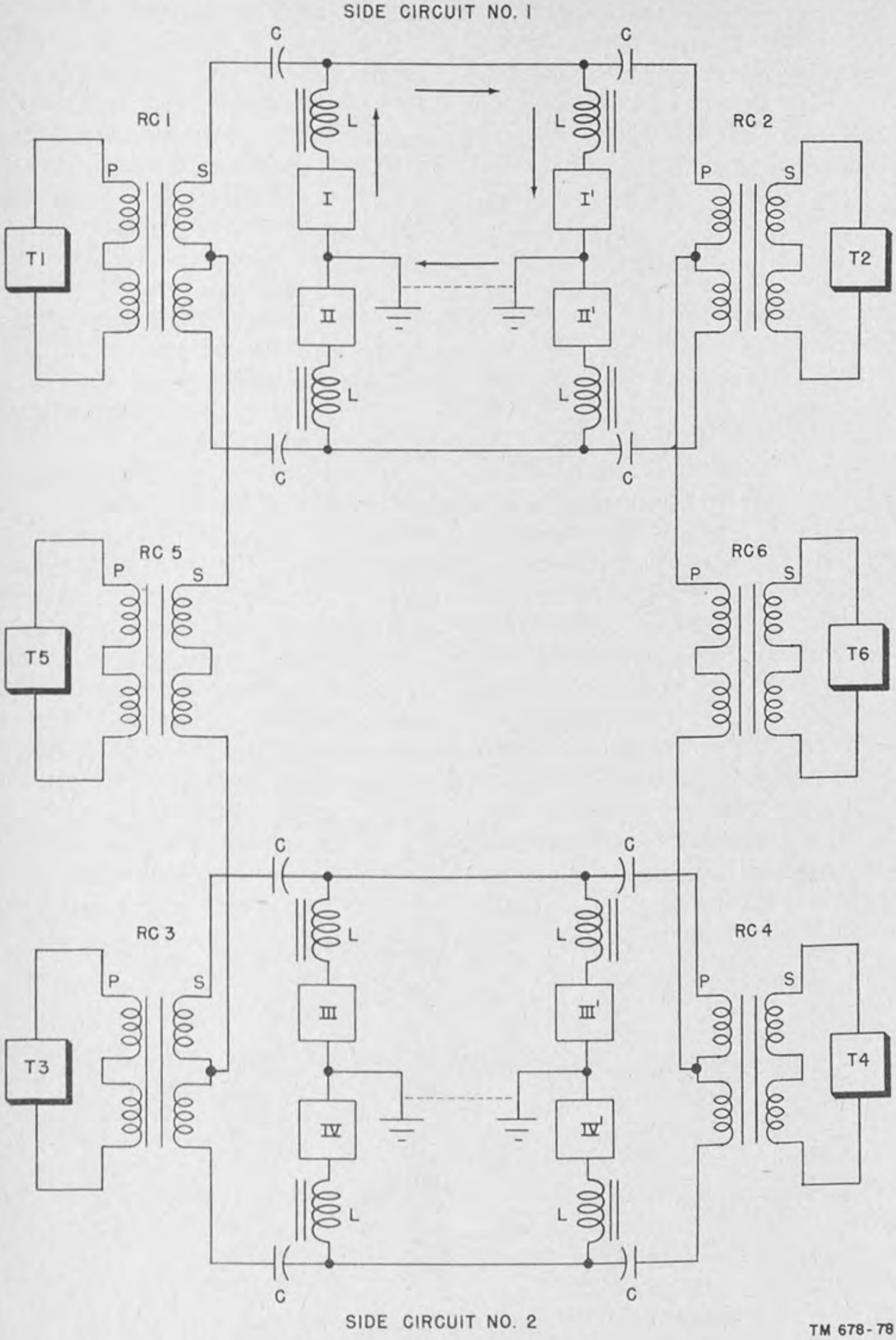


Figure 231. Composite circuit.

The attenuation of the telegraph impulses is lower than in the case of the simplex circuit, since the wires of the two side circuits are effectively in parallel and thus offer less resistance to current flow. (An interesting feature of the operation of a simplexed-phantom circuit is the fact that the telegraph channel operates even if three of the four line wires are broken, since only one wire is needed to provide a complete path in a ground-return circuit.)

199. Composite Circuit

a. Description. Another type of circuit that provides simultaneous telephone and telegraph service is the *composite circuit* shown in figure 231. This circuit permits the simultaneous operation of three telephone channels over a phantom group, and four additional telegraph channels, two in each side circuit. The telegraph channels operate as ground-return circuits. They are indicated on the left side of the circuit by the designations I, II, III, and IV.

b. Operation. In addition to the two metallic lines and the six repeating coils required for phantom-group operation, the composite circuit requires eight capacitors and eight coils, indicated by C and L. These elements act as high-pass and low-pass filters, respectively. The turns ratio of the six repeating coils is not always 1-to-1.

(1) In order to comprehend the need for these capacitors and coils, it must be understood that a telegraph channel can operate over a path that passes frequencies *up to* 100 cycles, whereas a telephone channel can operate over a band of from 200 to 3,000 cycles, approximately. It must be remembered, also, that a capacitor offers low impedance to *high* frequencies, but relatively high impedance to low frequencies, and that a coil, inversely, offers low impedance to *low* frequencies, but relatively high impedance to *high* frequencies. Because of this, telegraph impulses originating in the telegraph set on the left side of telegraph channel I pass through coil L, through the central portion of the upper wire of side circuit No. 1, through the second coil and the set on the right-hand side of channel I, and back to its origin through the ground-return path. This telegraph current is blocked by the four capacitors in the line of side circuit No. 1, and thus is prevented from reaching any of the six telephone sets. Operation is similar in each of the other three telegraph channels.

(2) Similarly, a telephone conversation originating in telephone set T1 is *passed* by the capacitors in the line of side circuit No. 1, and, by the transformer action of the repeating coils, is heard in set T2 (fig. 231). Since these currents are blocked by the coils in series with the telegraph sets in channels I and II, however, they are prevented from reaching the sets. For example, if the condensers are assumed to have capacities of 2 μf each, and the coils to have inductances of .5 henry each, the capacitive reactance of each capacitor at a frequency of 200 cycles is approximately 400 ohms, and the inductive reactance of each coil at this frequency is approximately 628 ohms. At

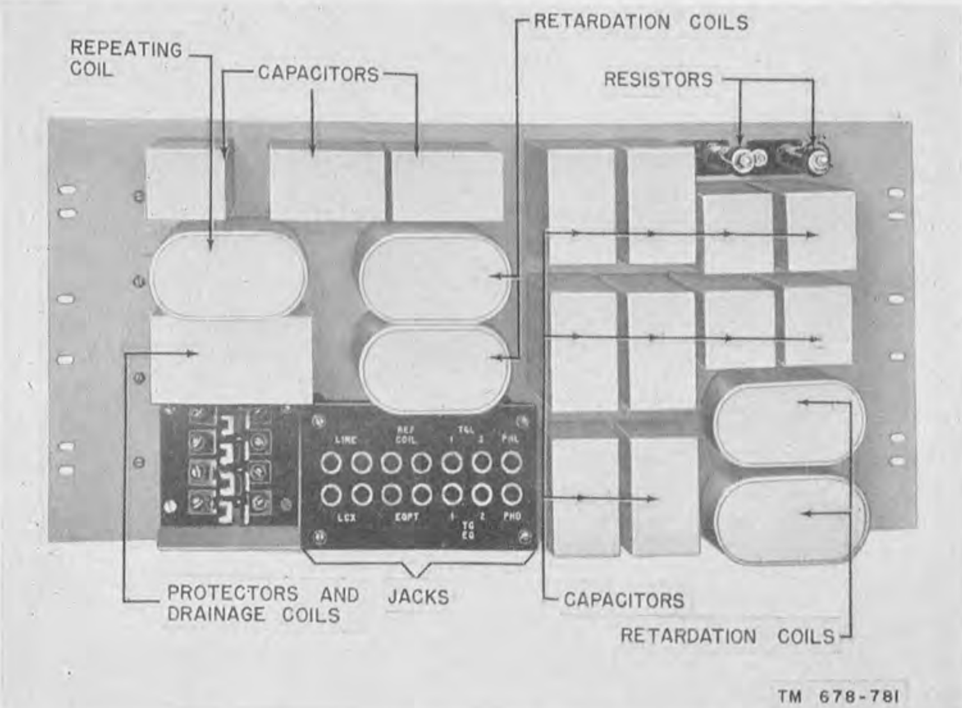


Figure 232. Line terminating and composite panel.

1,000 cycles, the capacitive reactance is only 80 ohms, and the inductive reactance is 3,140 ohms. At 50 cycles, however, the capacitive reactance is 1,600 ohms, and the inductive reactance is only 157 ohms. Because of the basic operation of these filters, therefore, the three telephone channels and four telegraph channels may be operated simultaneously without mutual interference. Low-frequency ringing cannot be used on the telephone channels because of the attenuation that occurs below 200 cycles. Instead, interrupted 1,000-cycle ringing is used.

(3) Figure 232 shows a line terminating and composite panel which contains a composite circuit and its associated components.

c. Limitations of Composite Circuit. The operation of the composite circuit is subject to the same limitations as the simplex and phantom circuits. The repeating coils and lines must be balanced perfectly to prevent interference among the various channels. Furthermore, the capacitors and coils comprising the filters must be selected carefully and installed in order to insure proper separation of low and high frequencies in the telegraph and telephone channels.

200. Summary

a. Single-line telephony is a system of telephone communication in which two telephone sets are connected by a single transmission line.

b. Single-line telephone circuits may be full-metallic, involving a two-wire line, or they may be ground-return, in which only one wire is used, the circuit being completed through the ground.

c. Full-metallic circuits are less susceptible to inductive interference than ground-return circuits, and therefore they are preferred for telephone communication.

d. Ground-return circuits operate well for telegraph communication, and for signaling (ringing) circuits in telephone communication.

e. A simplex circuit is a ground-return circuit superimposed on a full-metallic circuit. It permits the addition of either one telephone or one telegraph channel on an existing two-wire telephone channel. It is used frequently to provide an additional telegraph channel.

f. Operation of the simplex circuit involves the use of repeating coils at each end of the metallic line. These coils are efficient 1-to-1 iron-core transformers, consisting of two equal primary windings in series and two equal secondary windings in series. The usual resistance of each of the four windings is 21 ohms.

g. Perfect balancing of the repeating coils and the line of the metallic circuit insures efficient operation of a simplex circuit, without mutual interference between the simplex leg and metallic circuit.

h. If faults on the line make one wire of greater resistance than the other, balance can be obtained by inserting a rheostat in the low-resistance side, and varying it until the resistances of both sides are equal.

i. A phantom circuit provides a means for obtaining an extra channel over two full-metallic circuits. The additional channel thus obtained is called the phantom circuit. It may be used either for telephone or telegraph. The two full-metallic channels are called side circuits, and the entire combination is called a phantom group.

j. Efficient operation of a phantom group depends on the use of six repeating coils which must be perfectly balanced. This prevents interference between the current in the phantom circuit and the currents in the side circuits.

k. Cables used in the construction of phantom circuits may be loaded by the use of specially designed loading coils. These reduce attenuation and improve the performance of the phantom group.

l. A simplexed-phantom circuit extends the application of a phantom group by providing an additional telegraph channel. This channel is a simplex circuit superimposed on the phantom circuit of the group.

m. Perfect balance in the repeating coils and the lines of the side circuits is required also in a simplexed-phantom circuit.

n. Simultaneous telephone and telegraph communication also is provided in the composite circuit. This circuit permits four additional telegraph channels to be superimposed on a phantom group without mutual interference. Its operation is based on the use of capacitors in series with the lines of the side circuits, and coils in series with the telegraph instruments that are bridged across the lines of the side circuits. The condensers and coils behave like high-pass and low-pass filters, respectively.

201. Review Questions

a. Define single-line telephony.

b. State the two general types of single-line circuits, and give the relative advantages of each.

c. Draw a schematic diagram of a repeating coil used in connection with simplex and phantom circuits.

d. What is a simplex circuit? For what purpose is a simplex circuit customarily used?

e. How is the current in the simplex leg of a simplexed circuit prevented from interfering with the current in the side circuit?

f. What is a phantom circuit? For what purpose is a phantom circuit customarily used?

g. What is a phantom group?

h. In figure 229, trace the path of current originating in the transmitter of T4.

i. State the advantages of phantom circuits over simplex circuits.

j. What is a simplexed-phantom circuit?

k. In figure 230, trace the path of current originating in telegraph set T7.

l. What is a composite circuit? How many channels does it accommodate?

m. What is the function of the capacitors and coils used in composite circuits?

n. In figure 231, trace the path of current originating in the transmitter of T5; in the telegraph set on the right of channel III.

CHAPTER 10

DIAL TELEPHONE SYSTEMS

202. Introduction

a. When the field of communications by telephone first was opened by Alexander Graham Bell, there began a search for ways and means by which the services this instrument would provide could be improved in quality and extended in scope. This search has been a continuing enterprise ever since and is expanding year by year.

b. One important segment of the over-all search has been directed toward improving the methods by which telephones can be interconnected with a minimum degree of error and with a maximum of dispatch. The earliest aims along these lines were limited in scope and possibly could have been satisfied by the simple switching device shown in figure 30.

c. As the number of telephones in service increased, the capacity of the associated switching device (switchboard) had to be increased to meet the greater interconnection requirements; in addition, facilities had to be provided by which the operator at the switchboard could determine the particular line seeking a connection with another line, signal the desired line, and be signaled when a connection might be discontinued. All of these facilities gradually were incorporated in the switchboard, with corresponding improvement in the service provided. Because connections and disconnections were completed by manual effort, this method of interconnection became known as the *manual system*.

d. Long before the advent of the first telephone, man had directed his energies along lines that had the objective of replacing human effort with machine effort. This idea soon was projected into the field of telephone communications, and as early as the year 1889 a mechanically operated switchboard made its appearance; however, since it neither did nor could provide the degree of dependability and accuracy of the operator, it failed to find a place in its intended field.

e. The general idea behind the original mechanical switching device was recognized as having some merit. That it had potentialities not uncovered in the original design became apparent. Explorations began which were aimed at overcoming the shortcomings of the original machine. Gradually, improvements were developed and applied until finally a mechanical switching device was constructed that would provide dependable, fast, and accurate interconnection service. A system using such a device became known as a machine-switching system, or simply a dial system.

f. Comparisons between manual telephone systems and dial telephone systems point up the fact that their differences are changing constantly. In the matter of initial costs, improvements in manufacturing methods and in installation methods tend toward reducing this cost difference. Preventive maintenance methods have been improved and maintenance personnel training has been so expanded that maintenance costs between the two systems now are reasonably comparable. The matter of mobility, so important to the armed forces, and which, in the past, definitely favored the manual system, is shifting gradually to favor the dial system. This shift is the result of concentrated, continuing research. The necessity for operating personnel is dispensed with, disconnections are completed faster and with greater accuracy, and unusual traffic loads at unexpected times are disposed of more efficiently where a dial system is in use.

g. Both systems present advantages and disadvantages which, when properly evaluated, will aid in the determination of the system most suitable to requirements. Cost and economy, although not bearing directly on the quality of the service furnished, nevertheless are considered in selecting the type of system to use. At more extensive manual installations, it would not be economical to retain the same personnel forces at the switchboard during times of known minimum traffic load as are required to handle maximum load. If, at a time when the switchboard is manned for minimum load, an emergency should occur which suddenly would increase the traffic load appreciably, then the system could not meet that demand in a satisfactory manner until operating personnel were

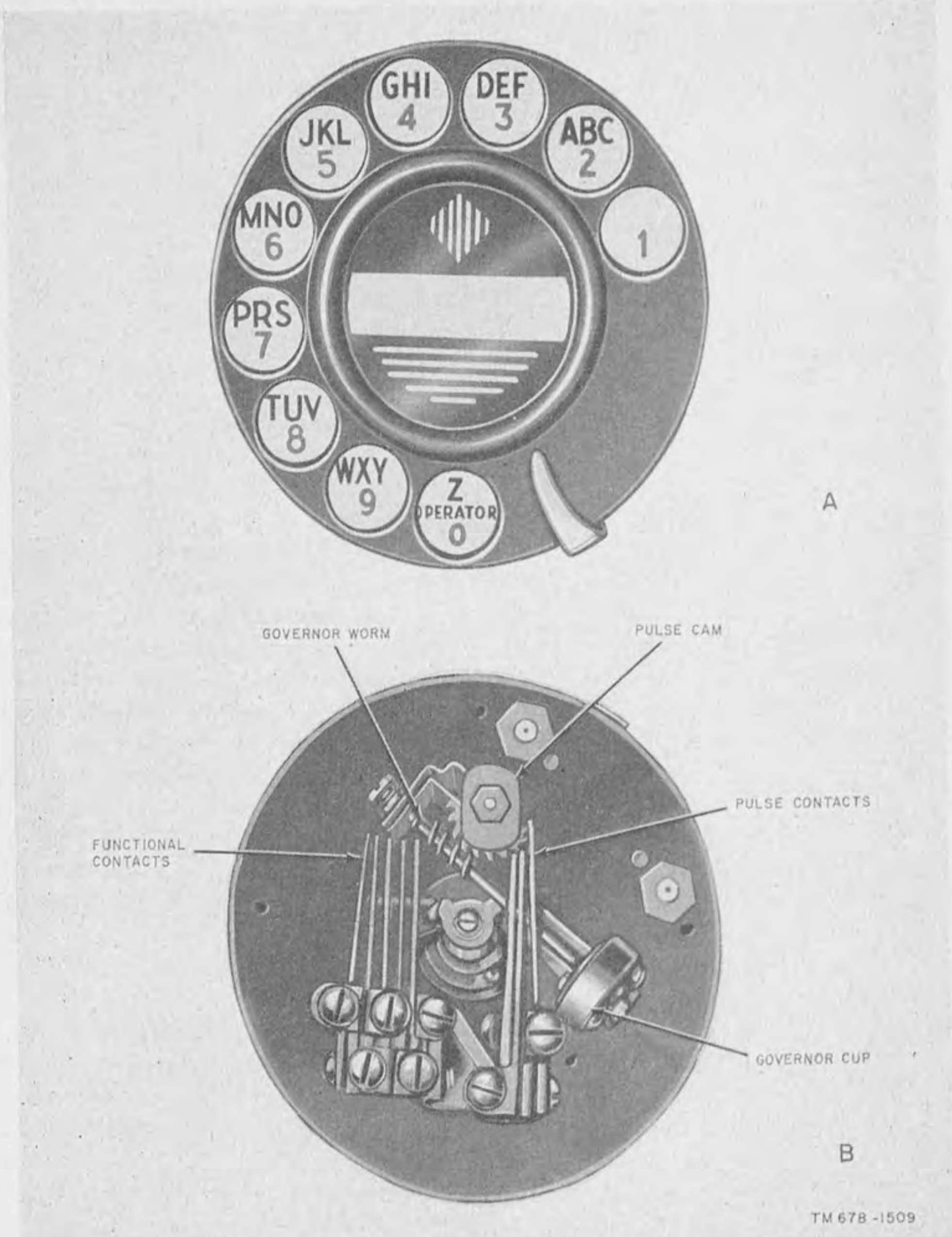


Figure 233. Telephone dial, front and rear views.

brought to the switchboard. Maximum connecting facilities of a dial telephone system are available at all hours.

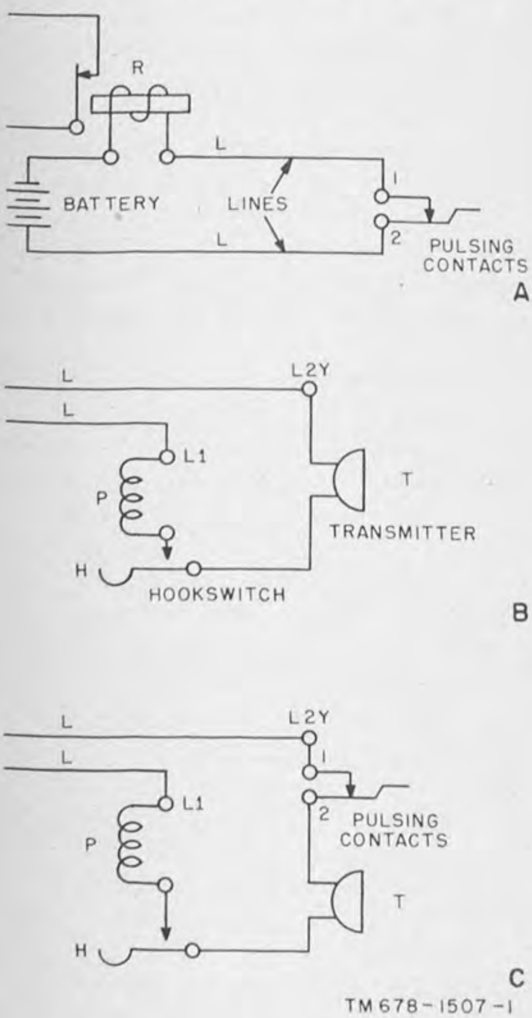
h. Automatic switching systems vary over a wide field in relation to the apparatus, wiring, and arrangements for a specific installation. The type of equipment selected to equip a central office is determined generally by the latest development coming out of the laboratories, where continuing research is producing continuing improvements. As a result, many types of automatic switching systems, including step-by-step, cross-bar, rotary, all-relay, and panel systems, have been built and placed in use. An explanation of all these types is, of course, beyond the scope of this manual and, for this reason, coverage is limited to one representative type called the Strowger step-by-step system. The term *step-by-step* system comes from the fact that, as each digit of a called number is dialed, the central-office apparatus responds by completing one of the several operations, or steps, necessary to complete the connection.

203. Dial Telephone

At manual central offices, the operator completes the connection at the spoken request of the calling person. At the *dial telephone central office*, such connections are made automatically in response to impulses introduced into an electric circuit by the action of a pair of contacts wired in series with the circuit. These contacts are part of the telephone set dial and are called the *pulse contacts* (fig. 233).

a. A, figure 234, shows a simplified schematic diagram of such a circuit. A mechanism within the dial can be made to open and close these pulse contacts in trains of opens and closures from 1 to 10. From the sketch, it will be seen that when the circuit is closed, the contacts of the central-office R relay are closed and when the circuit is opened, the relay contacts are open. These relay contacts control the operation of more complex circuits within the central office or switching-center equipment which ultimately completes the connection to the called telephone. (The R relay mentioned above is used here only as a symbol.)

b. The intercommunication service provided by a dial telephone set is substantially the same as that obtained from a manual telephone set. It differs only in the manner by which two telephones which are part of a common system are interconnected and disconnected. B shows a simplified schematic diagram of the manual sidetone telephone set transmitter circuit. C shows the circuit in B with the pulse contacts (1–2) added. If the pulse contacts are made to open and close a number of times, the effect of such action will be reflected



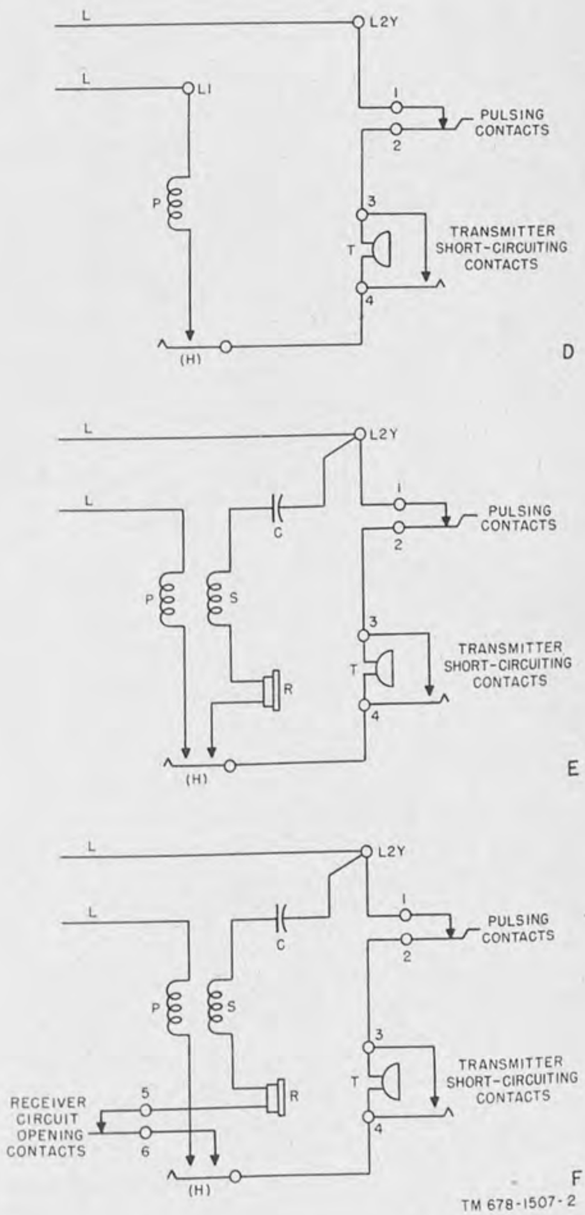


Figure 234. Dial telephone, functional diagrams.

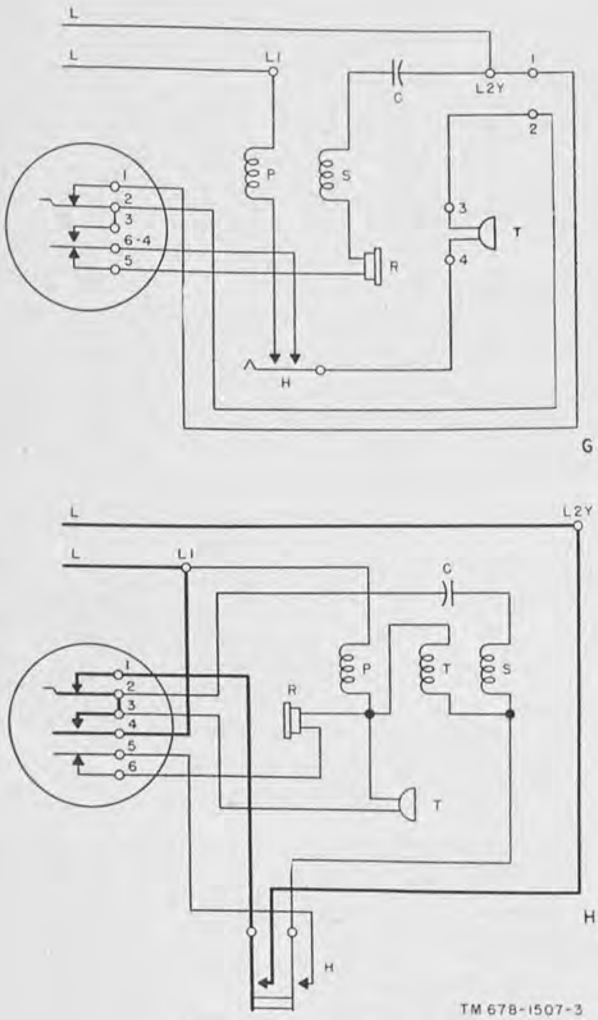


Figure 234. Continued.

at the R relay in the central office, as it releases and operates in step with the pulsing.

c. The central-office equipment response efficiency to the current impulses produced by the operation of the dial pulse contacts is affected by the circuit resistance. It is desirable, therefore, to reduce this resistance where this is practicable. Contacts 3–4, in D, connect a short circuit around the transmitter carbon granules throughout the duration of each pulse train. This removes the resistance of the transmitter from the dialing circuit and thus extends the length of the line over which dialing can be accomplished. These short-circuiting contacts provide other desirable and necessary features. Opening and closing the line circuit causes relatively high voltages to be induced in inductively wound apparatus normally found in the circuit. If disregarded, these voltages would act on the carbon granules and ultimately impair the transmitter efficiency. Older types of transmitters, when held in certain positions by the user, so arranged the carbon granules that momentary open-circuit conditions were introduced, and thus dialing was affected adversely. The transmitter short-circuiting contacts overcome this condition.

d. E introduces the receiver circuit to those of the line and transmitter circuit shown on the previous sketches. The circuit in E shows that, as the pulse contacts open and close, the line current alternately will be connected to and cut off from primary winding P of the station induction coil. The alternate current flow and current cut-off will cause an alternating voltage to be induced in the associated secondary winding, S. This voltage will act to establish an alternating current that will oscillate in the circuit made up of the secondary winding, receiver R, hookswitch contacts, transmitter short-circuiting contacts, and capacitor C. Each passage of current in the receiver winding will actuate the receiver diaphragm, and each such actuation will produce a so-called bang-in-the-ear. Since the pulse contacts of a properly adjusted telephone-set dial open and close at a frequency between 8 and 11 times per second, it will be obvious that such an undesirable condition cannot be tolerated long. Prevention is provided by one of two methods, depending on the design of the telephone set. One method—the one most commonly in use—is to provide means for opening the receiver circuit for the duration of the dialing period. The other is to provide means for short-circuiting the receiver winding throughout the dialing period. The former method will be discussed here.

e. F shows the receiver circuit-opening contacts (5–6) added to the components shown in E. These contacts also are component parts of the dial. When the dial is moved a few degrees from its normal position (off normal), the receiver circuit is opened automatically; it remains opened until the dial returns to its normal position, at which time the circuit is closed automatically.

f. Reference to F, figure 234, shows that a total of three pairs of contacts has been added to a manual sidetone telephone set. These additions make the set suitable for use in a dial area. In order that these contacts can be controlled by a single mechanism, it is necessary only to assemble them at a common point and in a manner such that controlling dial components can reach them. G, figure 234, shows the contacts assembled at a common point. These contacts, with their controlling mechanism, are called a station dial. The numerals, 1 to 6, shown on the sketches are not present on the dial; they are used here only for purposes of association among the sketches. Comparing G with C shows that the pulse contacts are wired alike in both sketches so far as circuit conditions are considered. D, E, and F show that contacts 3 and 4, on closure, connect a short circuit around transmitter T, and F shows that contacts 5–6, when open, will open the receiver circuit. G shows that contact 6, in addition to its normal function, takes over the function of contact 4; that is, when contact 6 moves away from contact 5, it moves far enough to make contact with 3. This places a short circuit around the transmitter and eliminates the necessity for a contact 4.

g. Dials used in dial common-battery telephone sets may include some refinements not present in the dial described herein; but, regardless of refinements, all such dials perform the same functions in operation; that is, the receiver circuit is opened or short-circuited, the transmitter is short-circuited, and the line battery circuit is opened and closed as many times as is indicated by the digit dialed. H is added for comparative purposes. This schematic shows an antisidetone common-battery, dial telephone set. The heavy line outlines the path of the dial pulses. Comparison of H with G will show that the dial in H has one contact more than that in G; also, that dial contacts 3–4 not only short-circuit the transmitter, but also short-circuit the primary, P, winding of the station induction coil. Short-circuiting the primary winding reduces interference between the telephone set and nearby radio equipment during dialing periods, and reduces also the dialing circuit resistance.

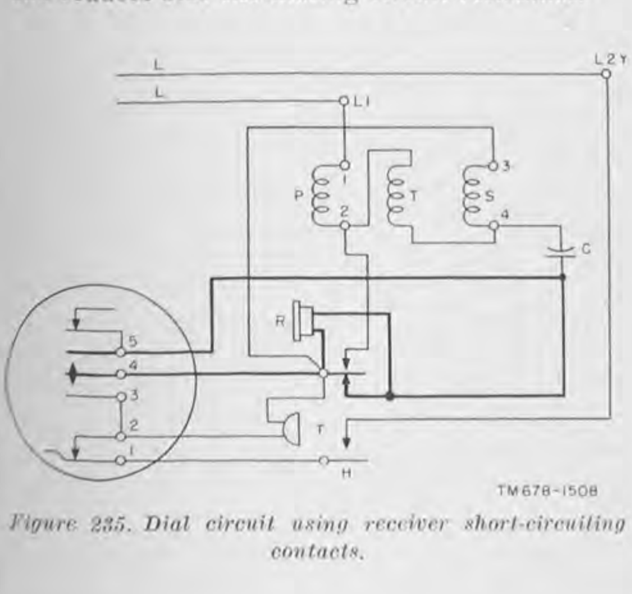


Figure 235. Dial circuit using receiver short-circuiting contacts.

h. Figure 235 is a schematic drawing of a typical telephone set. When operating, the dial in this telephone set does not short-circuit the primary winding of the induction coil, but does short-circuit the transmitter. The receiver circuit is not opened, as is the circuit previously discussed, but the receiver is short-circuited. This short-circuit is shown by heavy lines. The ringer circuit is not included, because it has no bearing on the involved points.

204. Numbering Systems

a. The numbering systems used to identify particular lines terminating at a manual-type telephone switchboard generally start with line No. 1 and continue in numerical sequence up to the capacity of the particular switchboard involved.

b. In step-by-step dial telephone systems, the number of digits per line number is based on the capacity of the system. Where the capacity is less than 100 lines, a 2-digit system is used generally; when capacity exceeds 100 lines, a 3-digit or a 4-digit numbering system must be used. The reasons that dial numbering systems vary according to the system capacities will be understood as the progress of calls in such systems is discussed in paragraphs 205 through 211.

205. Interconnections Between Two Telephones (Manual)

a. In the broader sense, the manual and the dial systems provide similar service features; they differ only in the manner by which interconnection between telephones is accomplished. By comparing the methods, the similarity will become more obvious. For example, the drawing in figure 236 shows two pairs of cords in use at a manual-type switchboard to connect two talking channels having a telephone at each end of each channel. Each cord contains three conductors, identified as the *ring* conductor, the *tip* conductor, and the *sleeve* conductor. The ring and the tip conductors are used to provide talking channels; the sleeve conductor is used to provide supervisory signals at the switchboard. Only the ring and the tip conductors will be considered at this time.

b. Each cord of a pair is identified according to its position at the switchboard. The cord farthest away from the attending operator is known as the A (answering) cord. It is used by the operator to answer a calling line (extension station).

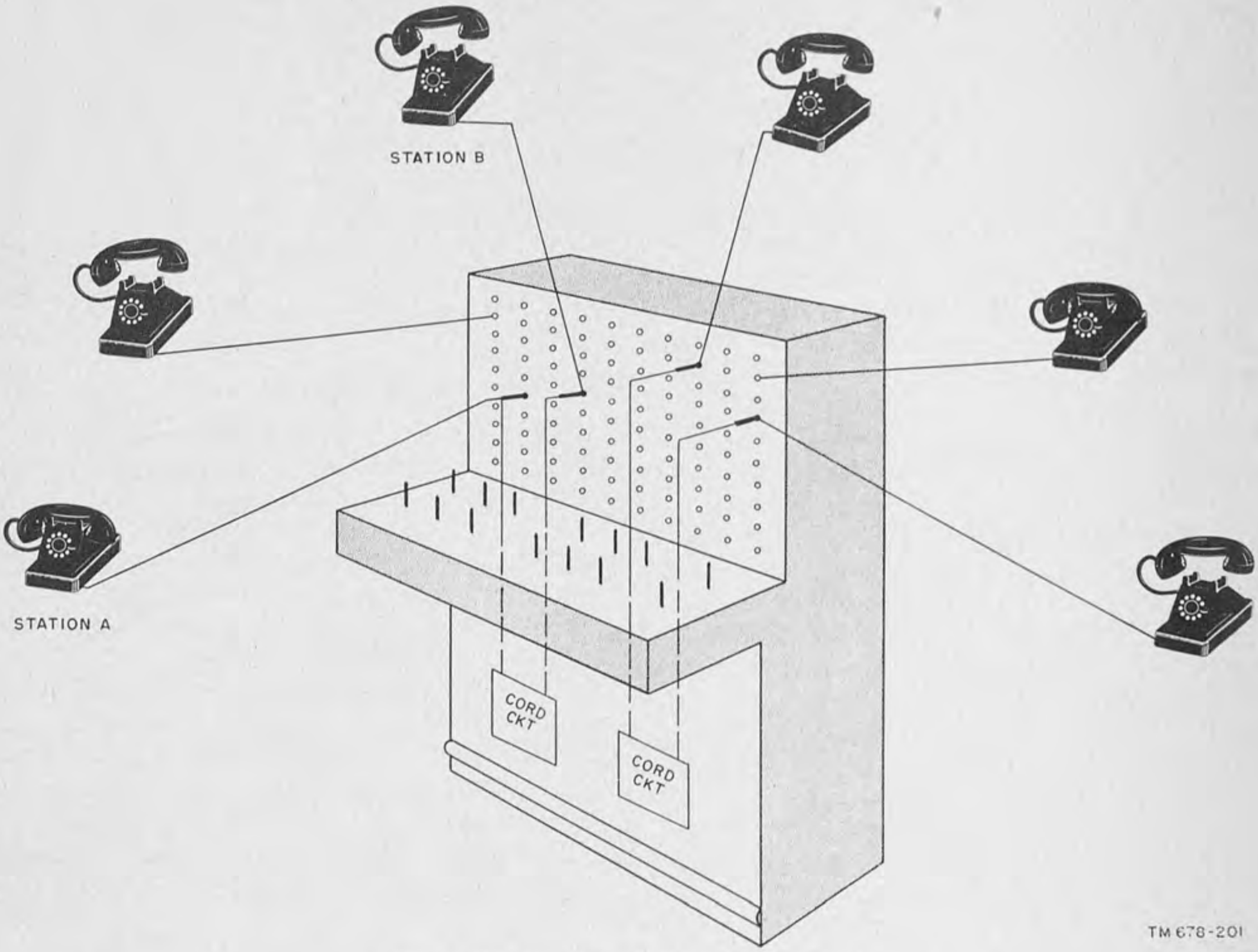


Figure 236. Manual switchboard cord circuits.

The other cord of the pair, the one near the operator, is known as the C (calling) cord. This cord is used to extend the calling line to the called line. Where commercial company central-office lines terminate at a switchboard, the C cord *always* is used, whether for incoming or outgoing service on these lines. This procedure is necessary for correct signal supervision.

c. Other features are provided by the standard manual switchboard, such as visual line and supervisory signals, audible signals, ringing switches, listening switches, and a dial; however, discussion of these items properly may be deferred at this time.

206. Connecting Two 2-Digit Line Number Telephones (Dial)

a. In the course of discussing this topic, the progress of a connection through the automatic switching equipment will be compared with similar progress at a manual switchboard. When the receiver is removed from the hookswitch in the manual system, the operator responds by connecting an A cord to the calling line and then asking for the number of the desired line. One can just as well say that the operator *finds the calling line* with the A cord. In the dial system, when the receiver is removed at a station, a *linefinder* automatically *finds the calling line* and extends that line to the *connector*. The connector connects a tone (dial tone) to the line. This dial tone has the same significance in a dial system as the operator's "Number please" in the manual system, and the calling party, instead of enunciating the desired line number as in the manual system, will dial each digit of the desired line number (dial the number). It should be understood that, in the dial system, the call extends automatically to the connector at the instant that the receiver is removed from the hookswitch. This compares with the fact that in the manual system when the A cord is connected to the line, the line circuit is extended automatically to the ring and tip of the C cord.

b. When the two digits of the desired line are dialed, the connector completes the connection and automatically applies ringing current to the called line. In the manual system, on learning the number of the desired line, the operator connects the *C* cord to that line and connects ringing current. In both instances, removing the receiver from the hookswitch requires that a supplying talking battery be supplied to the called line. This occurs automatically in the manual system when the operator releases the manually operated ringing switch; the necessary connection is automatic in the dial system.

c. To review the progress of the call in the dial system, refer to figure 237. When the receiver is removed from the hookswitch at the calling station (extension 11), circuit conditions are established automatically which cause an idle linefinder shaft to move vertically as many steps as are indicated by the first digit of the calling line number which, in this case, is 1. Having reached this level, the switch shaft automatically will take as many steps in a horizontal direction as are indicated by the second digit of the calling line—in this case 1. At this point, the switch will come to rest with its line wipers on terminal No. 11 of the line bank. Line bank terminal No. 11, like all similar terminals, is made up of two segments each insulated from the other (fig. 238). The ring and the tip leads from the calling line are terminated at these segments. The line wipers are an assembly of two spring contacts, each insulated from the other; the line wipers thus extend the ring and the tip leads from the calling line through a connecting trunk to the connector.

d. When the extension to the connector has been completed, the dial tone is connected automatically to the calling line, and is the signal to proceed with dialing. Response to the dial pulses will take place at the connector only. Unlike the linefinder, which operates automatically when the receiver is removed from the hookswitch, the connector switch will move only in response to dial pulses.

e. Since the number of the called telephone in this case is 00, the first digit dialed will be 0 (zero). Dialing 0 produces 10 impulses at the connector switch; this causes the switch shaft to move 10 steps vertically. Arriving at the tenth level of the line bank, it will remain at rest until the second digit is dialed. Dialing the second 0 (10 impulses) causes the switch shaft to move horizontally 10 steps and come to rest with the connector switch wipers on terminal 00. Reference to the drawing will show that the leads (ring and tip) from the called line terminate at this point; the calling line thus is connected to the called line. Ringing current is connected automatically to the called line and a ringing induction signal is returned to the calling line until the called station answers, at which time the ringing current is disconnected and the talking battery automatically is connected to both stations.

f. Should the called line be busy, the connection will not be completed; instead, the switch will

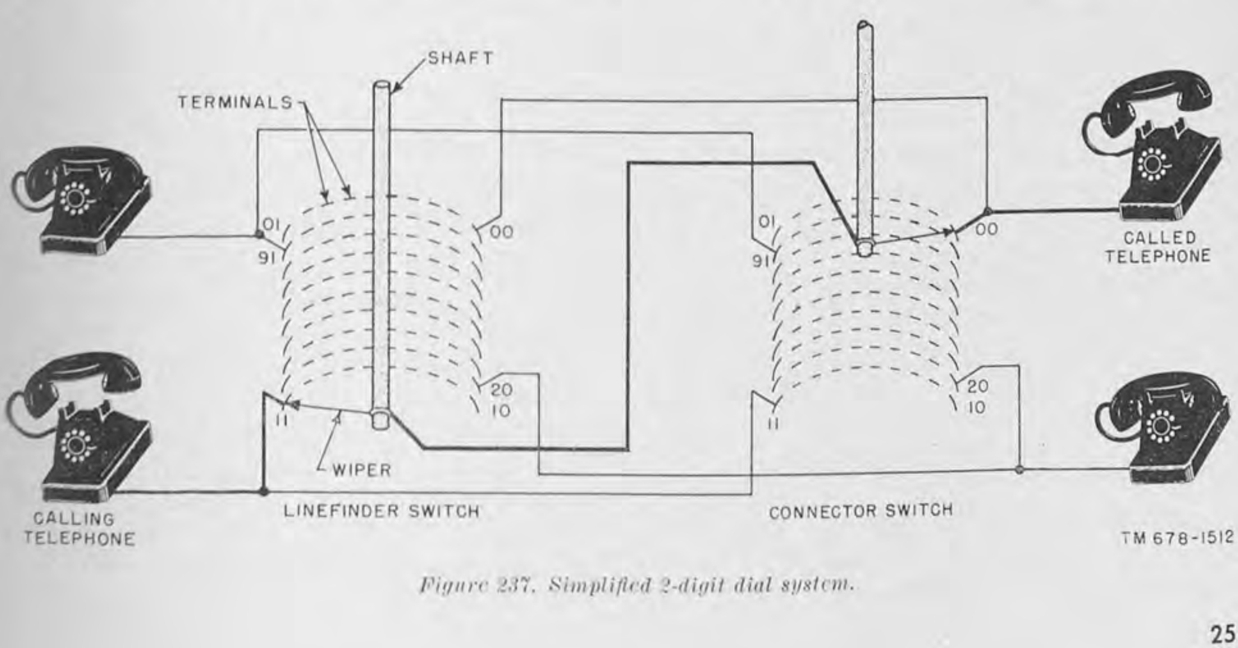


Figure 237. Simplified 2-digit dial system.

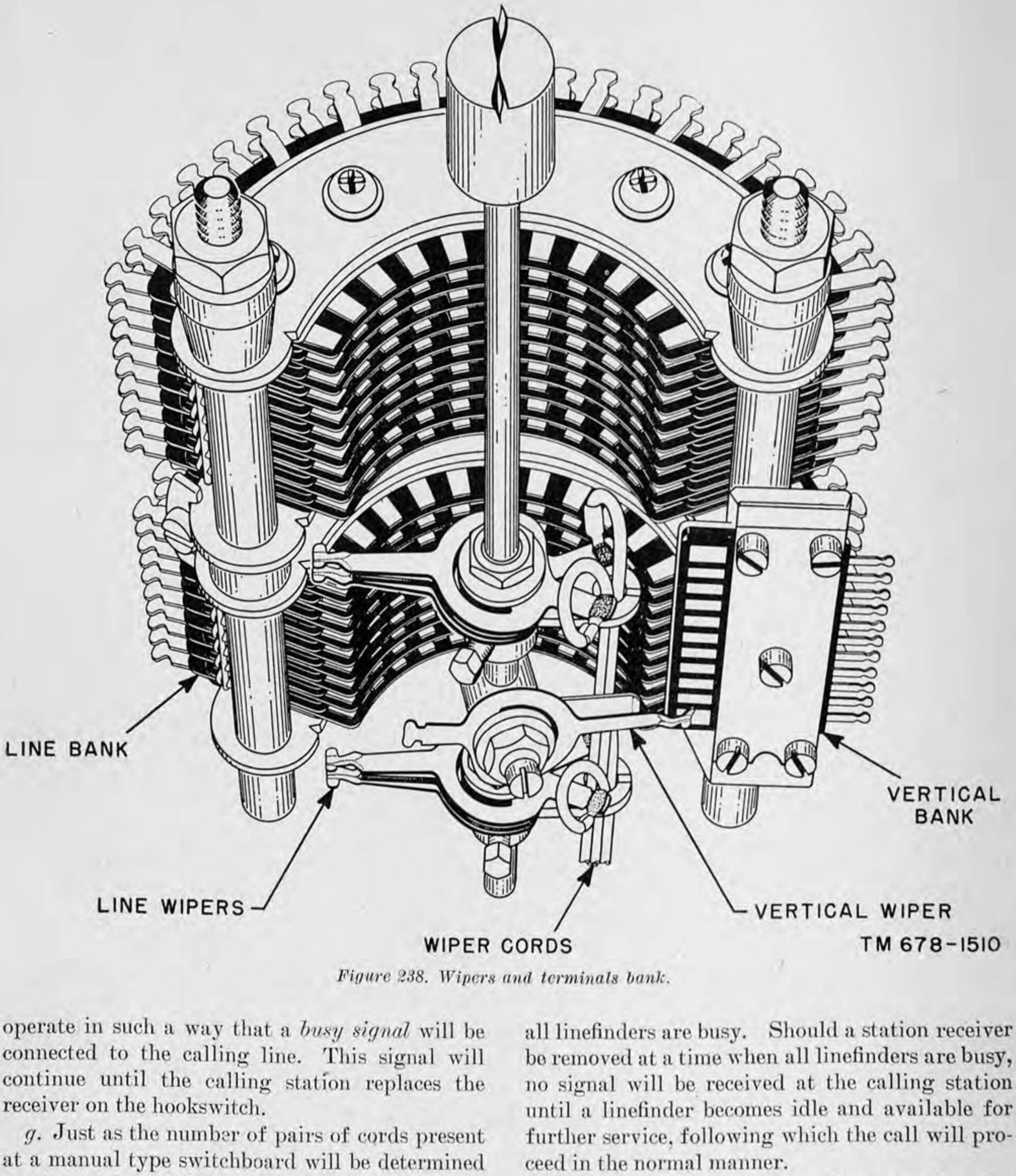


Figure 238. Wipers and terminals bank.

operate in such a way that a *busy signal* will be connected to the calling line. This signal will continue until the calling station replaces the receiver on the hookswitch.

g. Just as the number of pairs of cords present at a manual type switchboard will be determined by the number of lines terminating at the switchboard and the amount of traffic handled, so also do similar conditions at dial central office determine the number of linefinder-connector combinations present in the system. Just as no further service, requiring cords, can be provided until idle cords are available, neither can further service of a similar nature be provided in a dial system when all linefinders are busy. Should a station receiver be removed at a time when all linefinders are busy, no signal will be received at the calling station until a linefinder becomes idle and available for further service, following which the call will proceed in the normal manner.

h. Reference to the drawing shows that the ring and the tip leads from the various lines terminate at similar positions at both the linefinder and the connector line bank. This is necessary, since any line may be either a calling or a called line. When a line is a calling line, it must be accessible to a linefinder, and as a called line it must be accessible at a connector.

i. Most step-by-step systems, particularly those of larger capacity, provide a medium by which connections to points outside the immediate system may be controlled. Control is accomplished generally through an attended switchboard and an operator. Where this condition exists, the highest bank of terminals on the bank (zero bank) of the first selector (par. 208) is reserved for trunks to the operator; thus, to dial this operator, the station will dial the numeral 0. Then the first selector switch, in response, will move vertically 10 steps and move horizontally automatically until the wipers come in contact with the line terminals of an idle trunk to the switchboard, at which point the switch will remain at rest and a signal will appear at the switchboard. A system so arranged obviously would not have a line the number of which began with 0.

207. Line Bank Numbering System

The positions of the numbers on the line banks shown in figure 237 may be confusing on first sight. They appear to have violated all the rules of numerical sequence, and, in some respects, this is true; however, if the various terminals are considered with respect to the position of the wipers in response to two trains of dial pulses, the positions of the numbers then will be justified. Consider the connector shown on the drawing (fig. 237) and, on the basis of the discussion in paragraph 206, assume that a station dials line No. 19. Since the first digit dialed is 1, then the connector switch shaft will move vertically 1 step and there come to rest. The second digit dialed would be 9. In response to the 9 dial pulses, the switch will move 9 steps horizontally and come to rest on the ninth terminal, counting from the left of the terminal row. Assume, now, that the dialed number is 10 instead of 19. In such a case, the last digit dialed will be 0 and, of course, dialing the digit 0 sends 10 pulses to the connector. In response, the switch wipers will move 10 steps horizontally and come to rest on the tenth terminal. Similar reasoning will approve the relative positions of line numbers 29 and 20, 39 and 30, and so on.

208. Connecting Two 4-Digit Line Number Telephones at a Dial Telephone Central Office

a. The dial system discussed in paragraph 207 deals with a system where the extension stations have 2-digit numbers. Such systems are limited in scope to as many stations as can be accommodated with such numbers; the limitation lies between the numbers 11 and 00 for a maximum total of 100 stations. But dial systems sometimes require a much wider range in capacity, some as many as 10,000 lines (extension stations). This requirement is met by using 4-digit numbers ranging between 1111 and 0000.

b. Figure 239 shows a simplified block diagram of a 4-digit system. The diagram shows that a total of four switches is required in establishing a connection between two lines. These switches and the order in which they operate are as follows: linefinder, first selector, second selector, and connector.

c. Assuming that an extension station, other than the called station, removes the receiver from the hookswitch with the intention of dialing telephone No. 4658. Removing the receiver causes a linefinder automatically to find the calling line in exactly the same manner as that outlined for the 2-digit system. At this point, a variation occurs in the maner in which the connection is extended. When the linefinder finds the line, that line is extended automatically to the first selector, and dial tone originating at the first selector is connected to the calling station. On hearing the dial tone, the calling party dials the first digit—4.

d. In response to the four impulses sent by the dial, the first selector switch will travel upward to the fourth level of the line bank and, on reaching that level, the switch *automatically* will move horizontally toward the right until the associated wipers come into contact with the terminals of an idle trunk. This trunk will be one of several such trunks wired permanently between the first and the second selectors. The calling station line now is extended to the second selector. The second selector switch, assumed to be idle at the moment, will be in its normal position.

e. The calling station now will dial the next digit of the called station number; this is digit 6. The six impulses sent by the dial will cause the second selector switch to move upward to the sixth level. On arriving at this level, the switch will move horizontally *automatically* toward the right until its wipers are in contact with the terminals of an idle trunk connecting the second selector with the connector. This operation is similar to that of the first selector.

f. The calling station line now is extended to the connector. The action of the connector dif-

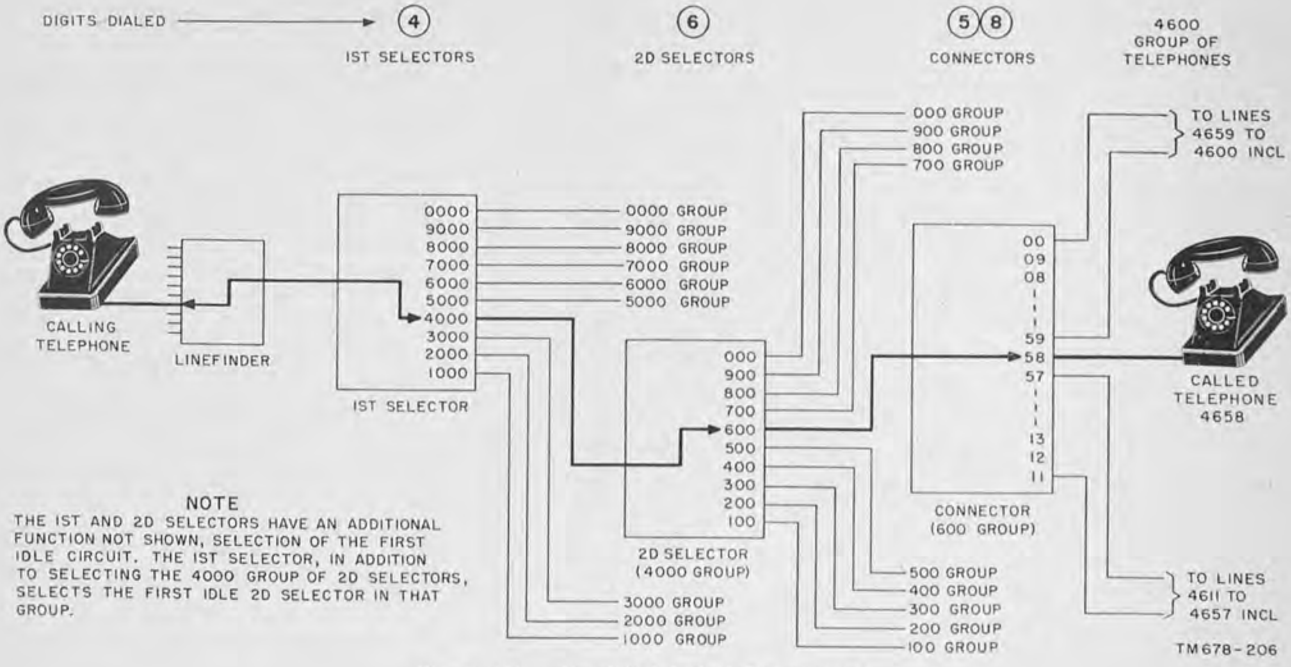


Figure 239. Simplified 4-digit dial system.

fers slightly from that of the selectors in that the horizontal movement of the selectors takes place automatically, whereas, in the connector, the horizontal motion is in response to dial pulses. As the calling station dials the next digit of the number, 5, the connector switch will move vertically to the fifth level of the line terminals and *come to rest* at that point; then, as the final digit, 8, is dialed, the wipers will move across the seven terminals of the row and come to rest on the eighth terminal, provided the called station is idle.

g. Ringing power now is connected automatically to the line of the called station. This power will be applied continuously until the called station answers, or, in the event of no answer, until the calling station replaces the receiver on the hookswitch. Should the called station answer, the ringing power will be disconnected and the talking battery will be connected to both stations automatically. (For supervisory purposes, this battery to the calling line is reversed.)

h. The heavy lines on the diagram outline the connecting path between the connected lines.

i. When the connected stations replace their receivers, the switching equipment releases and returns to its normal positions.

j. In considering the progress of the connection between the calling and the called stations, it may be well to consider the possibilities of insufficient idle equipment being available to complete a connection. In the 4-digit system, and considering the called line to have been No. 4658 and an idle linefinder to have been available, removing the receiver at the calling line automatically will extend the line to the first selector. When the first digit, 4, is dialed, this selector switch will move vertically to the fourth level and then automatically will move horizontally (hunt) across that level until an idle trunk to the second selector is found. Should all the trunks on the level be busy, an overflow busy tone will be heard at the calling station. If all of the trunks connecting the first selector with the second selector are not busy, the calling line will be extended into the second selector. Digit 6 now will be dialed. This train of pulses will elevate the second selector switch to the sixth level, and trunk hunting on that level will begin automatically. Should no idle trunk be available between this selector and the connector, an overflow busy tone will be heard at the calling station. If an idle trunk is available, the call will be extended into the connector, and from that point will proceed in the manner outlined for the 2-digit system.

209. Discussion Limitations

The fact will be obvious that the discussion on this particular subject has been limited in scope and restricted to the most simple fundamentals. This is necessary, since a thorough understanding of the circuits, apparatus, wiring, and arrangements involved in dial telephone systems requires extended technical training.

210. Summary

a. After many years of experimentation, a dependable machine-switching, or dial, system of telephony was developed.

b. Advantages of the dial system include its speed of operation, accuracy, and response to peak loads at all hours; disadvantages include its higher initial cost and higher costs of training maintenance personnel.

c. Many types of automatic switching systems have been developed, one of which is the Strowger step-by-step system.

d. All automatic switching systems respond to circuit changes produced by action of the dial pulse contacts.

e. Functional, or off-normal, contacts in the dial set perform the following functions during the dialing period:

(1) Short-circuiting of the transmitter.
(2) Opening (or short-circuiting) of the receiver circuit.
(3) Short-circuiting of the primary of induction coil (some telephone sets).

f. Manual and dial systems provide similar service features; they differ in the manner by which interconnection between telephones is accomplished.

g. The dial tone has the same significance in a dial system as the operator's "Number, please," in a manual system.

h. One automatic switching system uses a digital arrangement of linefinders, selectors, and connectors to perform the central-office switching operations.

i. The number of lines terminating at a dial central office and the amount of traffic handled determine the requirements for the machine-switching equipment.

j. Numerical sequence is modified in the switching sections, or banks, to compensate for the use of the digit 0 as number 10.

k. A Strowger switching bank contains 100 sets of terminals arranged in pairs and 10 single terminals. During operation, the terminals are connected electrically to the appropriate circuits through wipers.

l. All operations normally performed by the operator of a manual switchboard are performed automatically at the central office of a dial system.

211. Review Questions

a. What are the advantages and disadvantages of a dial system?

b. What is the function of the telephone set pulse contacts?

c. What other circuit changes occur in the telephone set as a result of dial operation?

d. How do dial and manual telephone systems differ?

e. What information does dial tone convey to the calling party?

f. Name the switches involved in a 2-digit system connection? In a 4-digit system connection?

g. In a station-to-station connection, what switch operates first? What switch operates last?

h. In a 4-digit system, what switch responds to the first digit dialed? To the second digit dialed? To the third digit dialed? To the fourth digit dialed?

i. How does the calling party learn that the called station is being rung? Called station is busy?

j. What signal advises the calling party that an idle linefinder was available to take the call?

k. What action is taken by the calling party when a busy tone is heard?

l. On the line bank, what terminals are located immediately to the *left* of terminals 10? 40? 70? 00? What terminals are to the immediate *right* of terminals 11? 31? 61? 01?

m. On what levels are the following terminals located: 01? 00? 99? 59? 19?

n. Why is the transmitter shorted during a dialing period?

o. Why is the receiver circuit either open- or short-circuited during the dialing operation?

p. Compare the switching operations of a manual and a dial system.

q. What factors determine equipment requirements in a dial system?

APPENDIX

CIRCUIT SYMBOLS

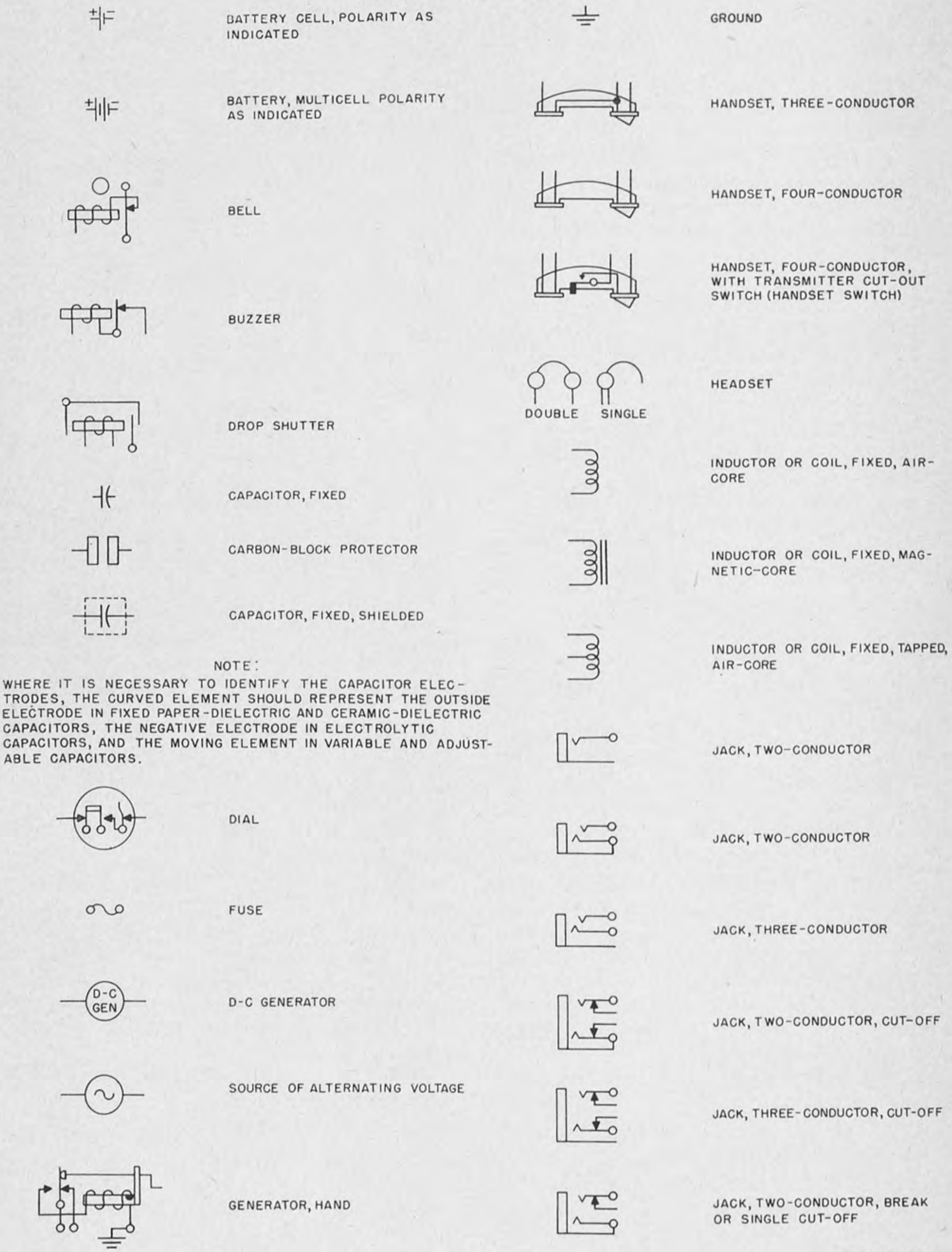


Figure 240. Circuit symbols.

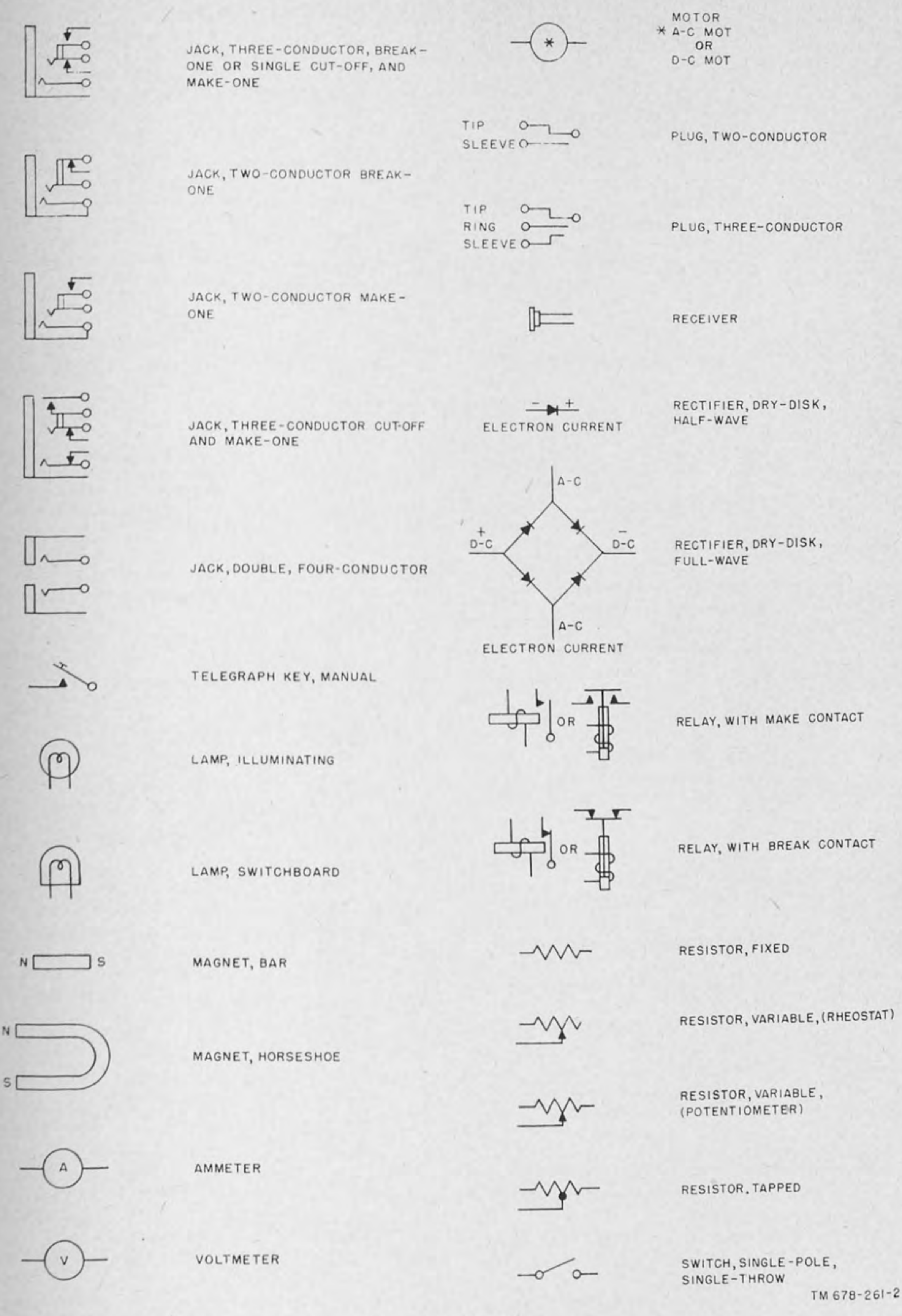


Figure 240. Continued.

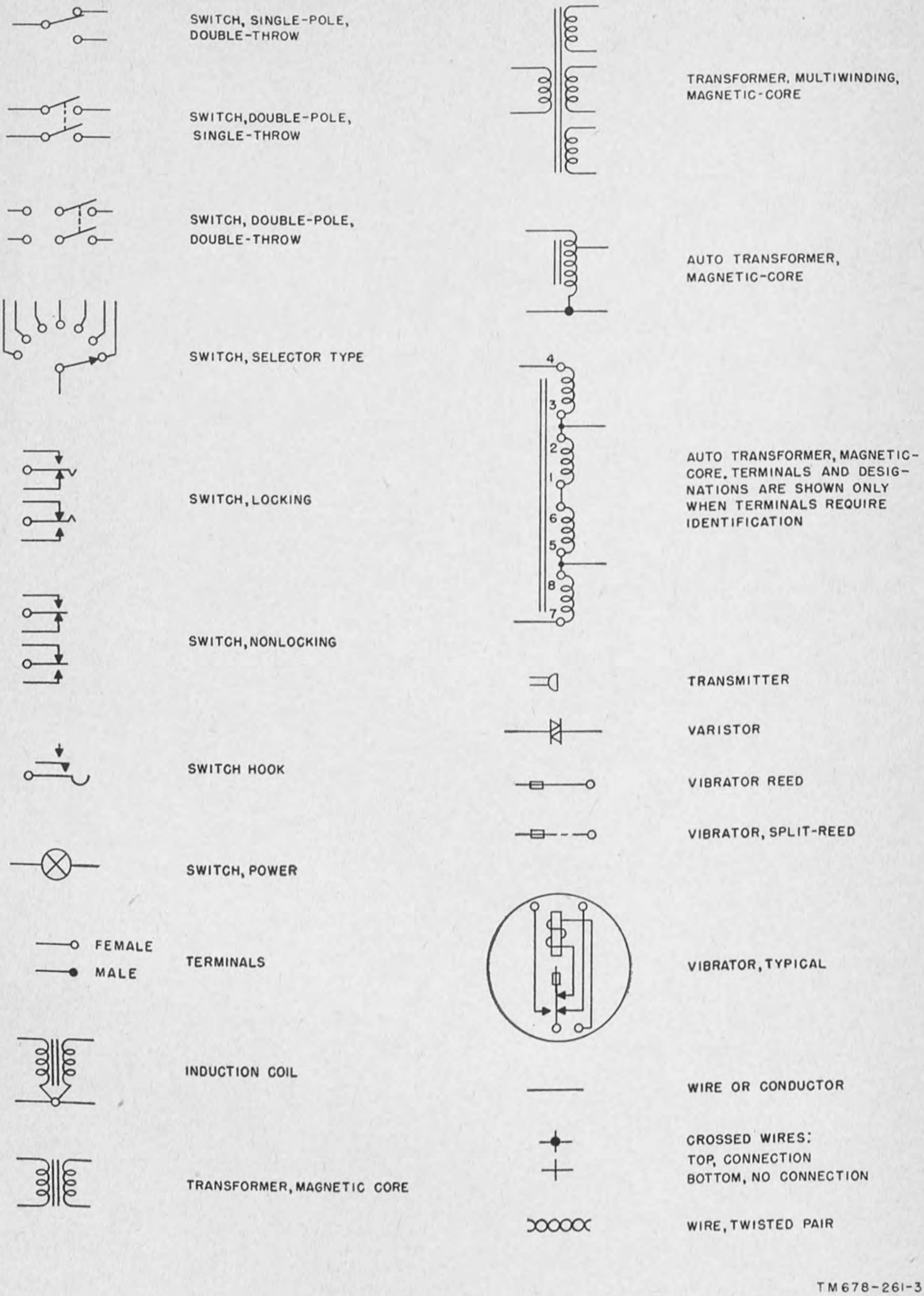


Figure 240. Continued.

INDEX